VARNA SCIENTIFIC AND TECHNICAL UNIONS

INSTITUTE OF OCEANOLOGY - VARNA

**FOURTEENTH INTERNATIONAL CONFERENCE
ON MARINE SCIENCES AND TECHNOLOGIES**

PROCEEDINGS

ISSN 1314 – 0957

October 10th - 12th, 2018

Festival and Congress Centre - Varna, Bulgaria

COPYRIGHT-2018 by the Varna Scientific and Technical Unions

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission by the Varna Scientific and Technical Unions.

The author's materials are published without any editing, correction, etc. Therefore, the authors carry full responsibility for the information presented

VARNA SCIENTIFIC AND TECHNICA UNIONS

**BULGARIA
9000 VARNA
25, „TCAR SIMEON I” Str.**

**Phone: +35952 630532
e-mail: nts@nts.varna.net
URL: nts.varna-bg.org
DOI: <https://doi.org/10.7546/IO.BAS.2018.3>**

ISSN 1314-0957

**FOURTEENTH INTERNATIONAL CONFERENCE
ON MARINE SCIENCES AND TECHNOLOGIES**

**Dedicated to the 110th Anniversary of
VARNA SCIENTIFIC AND TECHNICAL UNIONS
and 45th Anniversary of the
INSTITUTE OF OCEANOLOGY – VARNA**

PROCEEDINGS

ISSN 1314 – 0957

**October 10th - 12th, 2018
Festival and Congress Centre - Varna, Bulgaria**

Organized by:

**VARNA SCIENTIFIC AND TECHNICAL UNIONS
INSTITUTE OF OCEANOLOGY (VARNA) - BULGARIAN ACADEMY OF
SCIENCES**

With the Co-operation of:

**TECHNICAL UNIVERSITY OF VARNA
BULGARIAN NATIONAL ASSOCIATION OF SHIPBUILDING
AND SHIPREPAIR (BULNAS)
BULGARIAN SHIP HYDRODYNAMICS CENTRE (VARNA) -
BULGARIAN ACADEMY OF SCIENCES
“N. VAPTSAROV” NAVAL ACADEMY - VARNA**

* * *

Main Topics of the Conference:

- (1) Shipbuilding and Ship Repair**
- (2) Ship Hydrodynamics**
- (3) Machinery and Propulsion Systems**
- (4) Maritime Transportation and Port Operations**
- (5) Oceanology**
- (6) Marine Education**

INTERNATIONAL ADVISORY COMMITTEE

Prof. Carlos Guedes Soares

University of Lisbon, PORTUGAL

Prof. Mathias PASCHEN

University of Rostock, GERMANY

Prof. Leonard DOMNISORU

Dunarea de Jos University of Galati, ROMANIA

Prof. Ionel CHIRICA

Dunarea de Jos University of Galati, ROMANIA

Prof. Gennadiy V. EGOROV

Marine Engineering Bureau ,Odessa, UKRAINE,

Prof. Yordan GARBATOV

Technical University of Lisbon, PORTUGAL

Prof. Pentsho PENTSCHEW

University of Rostock, GERMANY

EXECUTIVE COMMITTEE

Honorary Chairman :

Prof. Petar KOLEV

Technical University of Varna, BULGARIA

Chairman:

Prof. Stefan VACHKOV

Chairman of the Varna Scientific and Technical Unions

Co-Chairperson

Prof. Snejanka MONCHEVA

Director of Institute of Oceanology-BAS Varna

Scientific Secretary:

Assoc. Prof. Stefan KYULEVCHELIEV

Bulgarian Ship Hydrodynamics Centre-BAS Varna

Organization Secretary:

Eng. Nedelcho VICHEV

Varna Scientific and Technical Unions

Members:**Prof. Rosen VASILEV**

Rector of Varna Technical University

Flotilla admiral Prof. Boyan MEDNIKAROV

Rector of “N. Vaptsarov” Naval Academy - Varna

Eng. Svetlin STOYANOV

Chairman of the Bulgarian National Association of Shipbuilding and Shiprepair (BULNAS)

Prof. Rumen KISHEV

Head of Bulgarian Ship Hydrodynamics Centre-BAS Varna

Prof. Atanas PALAZOV

Deputy Director of Institute of Oceanology-BAS Varna

Assoc. Prof. Ivan V. IVANOV

Technical University of Varna

Assoc. Prof. Petar GEORGIEV

Technical University of Varna

Dr.-Eng. Nikola DUKOV

Gas Flow Control, J. S. Co, Manager

Eng. Dimitar TODOROV

ODESSOS Ship repair Yard, J. S. Co – Varna, Executive Director

Dr.-Eng. Kiril PALAVEEV

ULA Ltd. – Varna, Manager

Eng. Elena VELIKOVA

Bulgarian National Association of Shipbuilding and Ship repair (BULNAS), Executive Secretary

* * *

E D I T O R S

Prof. Dr. Eng. Rumen KISHEV**Prof. Dr. Eng. Atanas PALAZOV****Assoc. Prof. Dr. Eng. Petar GEORGIEV**

CONTENTS

(1) Shipbuilding and Ship Repair:

<i>About design of LNG fuel vessels</i> Gennadiy V. EGOROV	15
<i>Backgrounds of creation of river passenger vessels for socially important routes</i> Gennadiy V. EGOROV, Alexander G. EGOROV	21
<i>Analysis of applicability of river passenger and cargo-passenger concepts for linear services</i> Gennadiy V. EGOROV, Alexander G. EGOROV	27
<i>Forecast of river-sea vessels' fleet structure till 2025 with definition of the most demanded types of vessels</i> Gennadiy V. EGOROV, Alexander G. EGOROV	33
<i>Design features of diving vessels for Caspian region</i> Gennadiy V. EGOROV, V.O. MUSTAFAYEV, Oyrad M. ABDULLAEV	39
<i>Research of influence of restricted area navigation classes on metal consumption of river-sea vessel</i> Olga G. EGOVA	45
<i>Application of unified dimensionless factors for estimation of residual overall strength of river-sea vessel's hull</i> Vladimir A. NILVA	50
<i>Oil-chemical tankers of "Volga-Don max" class with enhanced sea function</i> Gennadiy V. EGOROV, Valery I. TONYUK	56
<i>Realization of requirements of the International Convention for the Control and Management of Ships' Ballast Water and Sediments on the design stage</i> Gennadiy V. EGOROV, Alexander E. NILVA, Dmitriy V. KOLESNIK	62
<i>PV300 concept of river cruise passenger vessel for replacement of main part of existing fleet</i> Gennadiy V. EGOROV, Igor A. ILNYTSKII, Yaroslav V. KALUGIN	68
<i>About approaches to design of one-day trip vessels for pleasure cruises for the Black and Caspian Seas</i> Gennadiy V. EGOROV, Igor A. ILNYTSKII, Nickolay V. AVTUTOV	74

(2) Ship Hydrodynamics:

Special considerations in model tests of high speed vessels 83
Marta Pedišić BUČA

On the forebody shape effect on ship resistance in still water and seaway 89
Ihor P. DAVYDOV, Andriy V. PECHENYUK

Systematic investigation of the ship geometry characteristics influence on the average loss of speed in waves 95
Silvia KIRILOVA

Numerical investigation of the free surface effects on underwater vehicle resistance 100
Aleksandrina VASILEVA, Stefan KYULEVCHELIEV

(3) Machinery and Propulsion System:

Improvement of models for automated design of engine room arrangement on a transport ship 107
Vladimir YORDANOV, Alexey DANILOVSKIY, Htet Paing AUNG

(4) Maritime Transportation and Port Operations:

On improvement of radar observation capabilities of the Bulgarian vessel tracking management and information system 117
Chavdar ALEXANDROV, Miroslav TSVETKOV, Milen TODOROV, Iliyan ILIEV and Yordan SIVKOV

(5) Oceanology:

Use of macroalgae to assess ecological status of Bulgarian coastal waters for the aims of european water framework directive 127
Kristina DENCHEVA

Mapping and assessment of the ecosystem services to fisheries in the Black Sea 136
Marina PANAYOTOVA, Georgi DASKALOV, Valentina TODOROVA, Ioana GEORGIEVA, Radoslava BEKOVA, Stefania KLAYN and Valko BISERKOV

Distribution of marine biotoxins on south Bulgarian coast of the Black Sea 141
Zlatina PETEVA, Stanislava GEORGIEVA, Mona STANCHEVA, Lubomir MAKEDONSKI

<i>Setting threshold values of the zooplankton abundance indicator</i>	150
Kremena STEFANOVA, Valentina DONCHEVA, Elitsa STEFANOVA	
<i>Identification of black mussel (<i>m. galloprovincialis</i>, lamark, 1819) populations in two zones in northern Bulgarian Black Sea part based on esterases polymorphism</i>	155
Petya IVANOVA and Elitsa PETROVA	
<i>Taxonomic diversity of marine sediments from the Black Sea: next-generation sequencing survey</i>	162
Nina DZHEMBEKOVA, Petya IVANOVA, Snejana MONCHEVA, Satoshi NAGAI	
<i>Age-size structure and growth rate of the Golden grey mullet and Leaping mullet (<i>Chelon auratus</i> and <i>Chelon saliens</i>) in Bulgarian Black Sea coast</i>	168
Radoslava BEKOVA, Galerida RAIKOVA-PETROVA, Marina PANAYOTOVA, Bogdan PRODANOV	
<i>Age and growth of Flathead grey mullet (<i>Mugil cephalus</i>, Linnaeus 1758) in Bulgarian Black Sea coast</i>	174
Radoslava BEKOVA, Galerida RAIKOVA-PETROVA, Bogdan PRODANOV, Marina PANAYOTOVA	
<i>The influence of environmental condition of Varna and Burgas bays on population-biological parameters of Mullet species (<i>Mugil cephalus</i>, <i>Chelon auratus</i> and <i>Chelon saliens</i>)</i>	180
Radoslava BEKOVA, Bogdan PRODANOV, Marina PANAYOTOVA, and Todor LAMBEV	
<i>Organic enrichment in the Bulgarian Black Sea coastal sediments based on geochemical indicators</i>	186
Valentina DONCHEVA, Ognyana HRISTOVA, Boryana DJUROVA, Ekaterina TRIFONOVA, Valentina TODOROVA	
<i>Geoarchaeology of submerged landscapes in the western Black Sea</i>	194
Preslav PEEV, Raina HRISTOVA	
<i>Impact of the mesoscale circulation on the dispersion of oil pollution in the western Black Sea basin</i>	199
Irina GANCHEVA, Elisaveta PENEVA	
<i>Interannual variability of the mixed layer summer sea water temperature in the western Black Sea</i>	204
Nadezhda VALCHEVA	

<i>Evaluation and spatial variability of theoretical wave power along the Bulgarian Black Sea coast</i> Nikolay VALCHEV	211
<i>Coastal flooding hazard assessment at vulnerable locations along Varna regional coast</i> Petya EFTIMOVA, Nikolay VALCHEV, Nataliya ANDREEVA, Bogdan PRODANOV, Lyubomir DIMITROV	217
<i>Assessment of flood-driven direct impacts on coastal receptors along Varna municipality seaside</i> Nataliya ANDREEVA, Petya EFTIMOVA, Nikolay VALCHEV and Bogdan PRODANOV	224
<i>Comparative study of numerical simulation of coastal flooding in urban & estuarine areas</i> J.N. PAN, V. PENCHEV, J.S. ZHANG, F. PENCHEV, M.J. XIONG, D. DRAGANCHEVA, S. SHUKRIEVA, D.T. WANG, J.H. WANG	232
<i>Mapping seabed habitats in emodnet - the Black Sea case</i> Valentina DONCHEVA, Valentina TODOROVA, Nikolay VALCHEV, Adrian TEACA, Mihaela MURESAN, Jacques POPULUS, Mickaël VASQUEZ, Eleonora MANCA	239
<i>Appropriateness and availability of the Mnemiopsis leidyi and Beroe ovata data on the Black sea</i> Elitsa STEFANOVA, Violeta SLABAKOVA, Kremena STEFANOVA, Volodymyr MYROSHNYCHENKO, Ahmet KIDEYS, Tamara SHIGANOVA	245
<i>SatWebMare products and services in support of the sustainable management of the Bulgarian coastal zone</i> O. KOUNCHEV, L. PASHOVA, L.FILCHEV, D. KALAGLARSKI, V. CRACIUNESCU, V. GALABOV, E.PENEVA, M. ILIEVA, B. SREBROV, Z. BIBOV	251
<i>Applying semantic approach in search of oceanographic data</i> Nurhan HASSANOV, Vasil DONEV, Atanas PALAZOV	256
<i>One-way short baseline underwater positioning system</i> Konstantin CHTEREV	261

(6) Marine Education:

Establishment of a blue career centre as an important link in the blue economy in Bulgaria 269

Ilze ATANASOVA, Rumen KISHEV, Petar GEORGIEV

Profile of the innovation needs of sme's from maritime sector in the region from the Adriatic-Ionian seas to the Black Sea 275

Petar GEORGIEV, Ilze ATANASOVA, Martina ROSSI, Carlo KRASKOVIC, Angelos KTORIS

* * *

Black Sea S2018

SHIPBUILDING AND SHIP REPAIR

ABOUT DESIGN OF LNG FUEL VESSELS

Gennadiy V. EGOROV

Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

Abstract. In paper it is shown that usage of natural gas as main ship fuel on river-sea vessels and sea train-ferries (on the example of Marine Engineering Bureau vessels of RST27 and CNF19M projects) has basic advantages in comparison with usage of low-sulphur diesel fuel or heavy fuel with scrubber purification systems of exhaust gases from sulphur oxides, as allows to exclude completely sulphur emissions, essentially reduce emissions of nitrogen oxides, carbon and also solid particles. Therewith the level of emissions of nitrogen oxides conforms to requirements of Tier III MARPOL without usage of additional purification systems of gases.

Technical feature of developed CNF19M ferry project for Baltic Sea is compliance to the most modern requirements for safety, including requirements for ecological safety.

The following options of LNG filling stations are offered: from road-train LNG-carriers, LNG bunkering vessel, port LNG bunkering station, LNG tank-containers.

Keywords: design, ecology, efficiency, fuel type, LNG filling technologies.

INITIAL PROBLEM

Majority of UN system organizations as well as IMO included in own activity essential ecological component oriented on transition to sustainable development of mankind. Example is step-by-step toughening of requirements to air pollutants contained in vessels' exhaust gas including sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matters according to Annex VI of MARPOL.

The hardest restrictions are specified for emission control areas (ECA): Baltic and Northern seas, coast waters of the USA and Canada. Now IMO discusses ECA extension on Mediterranean Sea, Japan coast etc.

Native river-sea vessels (RSVs) including "super-full" RST27, RST27M tankers and RST54 combined vessels [1] (54 vessels were built) and also new train ferries for Kaliningrad region of CNF19M project [2] can be operated within ECA. In case of inclusion of Mediterranean Sea in ECA list question of compliance to requirements of Annex VI of MARPOL becomes sharper for RSVs Shipowners.

Questions of implementation of requirements of Annex VI of MARPOL on different types' vessels were considered by specialists of classification societies [3-5] and researchers [6-10] however RSVs owing to their dimensional restrictions and features of operation require improvement of received earlier theoretical and practical decisions.

AIM OF THE PAPER

Search of such technical solutions which will allow to solve problem with emissions from engines for perspective series of RSVs on the example of RST27 tanker and CNF19M train ferry.

MAIN TEXT

There are some ways of solution of problem of compliance to requirements of Annex VI of MARPOL to air pollutants contained in vessels' exhaust gas including SO_x and NO_x as usage of low-sulphur marine diesel oil (MDO), heavy fuel oil (HFO) with scrubbers installation (purification system of exhaust gases from sulphur oxides), liquid natural gas (LNG).

Usage of low-sulphur MDO is unreasonable because of its high price in comparison with HFO and LNG. Usage of scrubbers, for example, on RST27 tankers is inexpedient as installation of scrubbers which are offered for delivery by different companies (complete unit dimensions about 5400x2700x1700 mm) will require cardinal changes in constructions of superstructure, engine room (ER) case and arrangement of ER mechanisms. Therewith, independently of applied fuel type, to fulfill Tier III NO_x standards which came into force since 01.01.16 installation of additional purification systems of exhaust gases from nitrogen oxides are required.

Therefore usage of LNG as primary ship fuel for RST27 tankers and CNF19M train ferries for solution of problem of compliance to requirements for emissions in atmosphere has basic advantages:

1. Allows to exclude completely sulphur emissions, to reduce significantly emissions of nitrogen oxides (by 85%) and carbon (by 25%) and also particulate matters [11].

2. Level of NO_x emissions will fulfill Tier III requirements of MARPOL without installation of additional purification systems of gases [11].

Steady tendency of increase in number of LNG fuel vessels is observed for some time past. On LNG carriers gas is quite successfully applied as main fuel since 60th years of the last century. Number of LNG fuel ferries, supply vessels, special purpose ships, tankers, pleasure crafts, etc. grows [12]. LNG fuel vessels with direct diesel drive on screw start appearing.

The most important factor defining possibility of usage LNG as fuel on vessels which are operated in domestic ports is provision of supply of vessels with gas fuel in necessary volume.

Many organizations and structures in Europe are involved in this process. The report "North European LNG Infrastructure Project: a feasibility study for an LNG filling station infrastructure and test of recommendations" is one of the detailed documents on this subject (full report for Danish Maritime Authority [13]). In the report possible ways of bunkering of LNG fuel vessels are described: from refueling truck to vessel, from terminal to vessel, from vessel to vessel. Data of existing and planned for building LNG bunkering stations is provided, main risks while gas bunkering and ways of their reduction are analyzed, forecasts for LNG bunker prices are given.

Now let analyze possibility of usage of LNG as fuel on river-sea RST27 tanker designed by Marine Engineering Bureau [1] (see Fig. 1).

Main questions which need to be solved are follows: - choice of LNG fuel main engines with saving of concept of direct drive of torsion torque on screw; - choice and placement of auxiliary equipment necessary for work of LNG fuel main engines; - check of possibility of LNG application for steam boilers and diesel-generators; - choice of way of LNG storage, choice of tanks for storage and their placement on the vessel; - securing of safe operation of tanker with LNG fuel onboard.

Figure 1. General view of RST27 river-sea LNG fuel tanker

While design and operation of LNG fuel vessels special attention should be paid to safety. There are following characteristic types of dangers caused by LNG and its vapours availability on the vessel: volume gas explosion appears from its leak in gaseous state in closed volume with presence of ignition source; explosion of gas tanks because of overpressure; fire as a result of burning of spread gas or jet fire as a result of burning of gas under pressure; gas cloud in which fire can be appeared; fast phase transformation when liquefied gas contacts water which is similar to explosion without ignition; "rollover" – rapid significant increase of pressure in cryogenic tank; suffocation as a result of man's contact with gas cloud; injuries from low temperatures because of influence of liquefied gas on man's skin; atmosphere pollution as a result of gas leaking [3].

Following characteristic dangers connected with usage of LNG in internal combustion engines should be kept in mind: volume gas explosion because of gas leaking in crankcase, exhaust case, air collector and ER; possibility of gas dissolution in circulating oil with subsequent detachment in lube oil tank and formation of explosive concentration and finally explosion.

At the moment native rules for LNG fuel vessels (not gas carriers) are not developed. Thence DNV Rules requirements [5], IMO recommendations [9] and requirements of RMRS Rules of classification and building for gas carriers [4] (in volume they are applicable to this project) have been taken into account at study of complex of actions which provide increase of safety of RST27 project.

On RST27 tanker main propulsion plant which consists of two WARTSILA 6L20 diesel engines working on 2 SCHOTTEL SRP1012 FP full revolving steerable propellers with fixed pitch propellers in propulsive nozzles is foreseen. As main fuel IFO 380 with viscosity of 380 cSt at 50°C or MDO are used.

WARTSILA presented line of LNG fuel L20DF engines. The project of L20DF engines line is based on well-known L20 series which is presented on market since the beginning of 90th years of last century and was tested in different conditions. WARTSILA L20DF engines represent medium-speed dual fuel engines which can work on LNG, HFO and MDO. Switching between different types of fuel happens at working engines without falling of power. During L20DF engines work in gas mode mix of gas and air ignites by means of giving in cylinders of pilot MDO in volume of 1% from necessary for full load. The most important feature of these engines is that they can be used as for generators' drive and adjustable pitch propellers at constant rotating speed, and for drive of fixed pitch propellers at variable rotating speed. It is obvious that the most logical decision in this situation is replacement of 6L20 engines on 6L20DF. Such decision will allow to build new vessels of the series without considerable changes in the project. Also without big problems it is possible to make re-equipment of main engines on built RST27 vessels for work on LNG with minimum changes in systems servicing main engines. However power of 6L20DF is smaller than 6L20 engines.

On the basis of results of calculation of required power depending on vessel's operational speed WARTSILA 6L20DF dual fuel engines with continuous maximum rating of 1056 kW with frequency of 1200 min⁻¹ can be accepted for LNG fuel RST27 project. Chosen engines at loading of 85% provide vessel's operational speed about 10.7 kn on clear water. The necessary gear ratio for the screw will be provided with rudder-propeller reduction gearbox.

Main technical characteristics of WARTSILA 6L20, 6L20DF main engines are given in Table 1.

As for use of HFO on tankers equipped for use of LNG there is no sense for dismounting HFO systems in re-equipment process of already built tankers. In case of building of new vessels final decision will be made by Shipowner and will depend on expected area of operation of vessels and also on prices of liquid and gaseous fuels.

Auxiliary equipment which needs to be provided in the project for use of natural gas follows: gas valve units (one on each engine); tanks for storage; fuel gas heater and gas evaporator units; special gas receiving stations from each side.

On the basis of analysis of information provided by WARTSILA complex of main actions which need to be considered at re-equipment of RST27 project for LNG usage is specified: fuel-delivery system of primary liquid fuel to engines remains the same as on initial RST27 project; for delivery of pilot fuel to engines it is necessary to foreseen additional system with separate pumps and pipelines; gas delivery to gas valve units and then and to engines near ER is carried out by means of pipes with double-layer walls.

Table 1. Main characteristics of WARTSILA 6L20 and 6L20DF engines

Main characteristics of main engine:	6L20	6L20DF
Continuous maximum rating, kW	1200	1056
Rotation speed, min-1	1000	1200
Cylinder's number	6	6
Cylinder's diameter, mm	200	200
Piston stroke, mm	280	280
Mean effective pressure, MPa	2.73	2.0
Mean piston speed, m/s	9.3	11.2
Specific fuel consumption, g/(kW·h) (100% loading)	192	213
Lubrication oil consumption, g/(kW·h)	0.5	0.5
Weight of engine, t	9.33	9.5

Start-up and stop of WARTSILA dual fuel engines in operation are made on MDO, at short stops of engines it is allowed to make start-up and stop on HFO. Transition to gas is carried out while engine is working. Herewith it is necessary to consider that if engine works on HFO, firstly transition to MDO and then transition to gas are carried out. Transition scheme from gas to HFO is the same (LNG-MDO-HFO). From mentioned above auxiliary gas equipment of main engines only gas valve units have to be located in closed spaces. Cryogenic tanks, fuel gas heater and gas evaporator units, special gas receiving stations can be placed on open deck of tanker in cargo zone.

Scheme of arrangement of gas valve units and pipelines with double-layer walls for gas supply is shown on Fig. 2.

Hermetic construction of WARTSILA gas valve units allows to place units directly in ER compartment and does not require additional compartments. Herewith it is necessary to provide autonomous pipelines of ventilation on open deck from internal spaces of gas valve units.

Figure 2. Arrangement of gas valve units

Arrangement of equipment at initial RST27 tanker ER allows to place gas valve units and pipelines without replacement of any equipment.

NG can be stored on vessels in two ways: compressed and liquefied. Compressed natural gas (CNG) is stored and transported in compression tanks without liquefaction. The main advantage of CNG is that for its transportation and subsequent gasification LNG plants are not required. Nonetheless usage of CNG on vessels has not found extensive application for the following reasons: efficiency of compressed gas transportation is in at least 3 times lower than liquefied gas transportation; required volume of tanks for CNG storage on vessel is in 2.5 times more than for LNG; because of high storage pressure (20-25 MPas) of CNG weights of tanks also are bigger [8].

For reasons of increase of the vessel's navigation autonomy and reduction of weight of gas storage tanks LNG fuel is offered as the most suitable for existing conditions. The main difficulty when using LNG on vessels is rather big required space for cryogenic tanks. In comparison with fuel oil equal amount of LNG requires approximately by 1.9 times of bigger volume. With taking into account thermal isolation of tanks required volume increases approximately by 2.3 times. In case of installation of LNG storage tanks in vessel's hull required volume can be increased by 4 times. On tankers this problem can be solved by placement of cryogenic tanks on cargo deck.

On the basis of preliminary calculations of gas consumption for operation of mechanisms of machinery plant required volumes of cryogenic tanks depending on the vessel's navigation autonomy are defined (see Table 2).

At preliminary calculations following input data has been accepted: percent of cryogenic tanks filling – 98%; net calorific value of LNG – 49620 kJ/kg; LNG density – 422 m³/kg. The main difficulty in calculations of NG expenses is that at the moment there are no international standards on ship gas fuel. Therefore it is necessary to consider that gas consumption will depend on net calorific value of LNG which depends on gas field.

Table 2. Volumes of cryogenic tanks depending on the vessel's navigation autonomy, m³

Combined work of mechanisms	Autonomy, days			
	5	10	15	20
All mechanisms	133.06	266.12	399.18	532.24
Only main engines	89.35	178.70	268.06	357.41
Main engines and diesel-generators	100.73	201.45	302.18	402.90
Main engines and boilers	121.69	243.37	365.06	486.74

In conformity to RST27 project two possible variants of applied cryogenic tanks are analyzed: WARTSILA LNG-Pak cryogenic tanks and container-cryogenic tanks.

LNG-Pak cryogenic tank is complex construction consists of: cryogenic tank with isolation and external protection cover; fuel gas heater and gas evaporator units with armature and pipelines; necessary sensors and control-measuring devices; attachments to external pipelines and exchange of information interfaces with ship integral control system.

Preliminary study of arrangement has shown that two WARTSILA 308 LNG-Pak cryogenic tanks with capacity of 277 m³ of LNG each can provide 20 days autonomy of RST27 tanker with main engines, boilers and diesel-generators working on LNG. Specified cryogenic tanks can be placed in aft part of tanker's cargo zone (see Fig. 3).

Figure 3. Arrangement of LNG-Pak cryogenic tanks

The second variant is usage of container-cryogenic tanks. This variant will allow to make LNG delivery to the vessel by means of railway or motor transport without classic bunkering operations. Replacement of tanks will be required only. One of the main suppliers of container-cryogenic tanks in Russia OJSC "URALKRIOMASH" offers container-cryogenic tank of KTSM-35/0.6 model in dimensions of standard FEU which is assigned for reception, storage and LNG delivery and can be used as container for its transportation by railway, sea, river and motor transport providing full safety of product under different weather conditions.

Top variant of LNG loading and discharge is applied. Discharge is executed by the effect of creation of pressure in cryogenic tank by outside pressurization.

If to use container-cryogenic tanks following circumstances must be kept in mind: effective volume of container-cryogenic tanks will require their significant amount, for example, for providing 5 days autonomy with main engines, boilers and diesel-generators working on LNG 4 containers will be required, for 10 days autonomy – 8 containers; in addition onboard the vessel stationary units of evaporators and gas heaters with armature and pipelines will also be required; for pressure monitoring of gas supply to gas valve units and replacement of containers in ports appropriate load-lifting means have to be foreseen. Container-cryogenic tanks can be placed in aft and bow parts of tanker's cargo zone.

For securing safe usage of LNG fuel in addition to already provided for classic tankers following main constructive features are applied: gas supply system located within ER has to be put into gastight envelope, i.e. has to be with double-layer walls; for each engine near ER separate line of gas supply with possibility of remote automatic shutdown in case of detection of leaks has to be provided; possibility of instant automatic transition from gas fuel to liquid in case of shutdown of gas supply; sensors of NG leakages' control in places of the most probable leaks (ER, interpipe space of doubled gas supply pipelines etc.); gas leak signal generation in ship's warning protection system (20% of explosive concentration); automatic shutdown of NG supply to equipment with signal generation in ship's warning protection system (60% of explosive concentration); induced ventilation of interpipe space of pipelines with double-layer walls and internal spaces of gas valve units; ventilation of ER gas outlet circuits while engines are stopped; supply of inert gas, for example nitrogen, for blowing off gas supply pipelines to engines; preliminary ventilation of boiler furnaces before their ignition.

New train ferries for connection of Kaliningrad region with rest part of the Russian Federation are indispensable as main freight traffic now follows by railway through Lithuania and Belarus. Therewith alternative variants of delivery of specific cargoes including military ones (ferry communication is the only way to deliver cargo without transportation through neighbouring states) are almost absent.

There are no active train ferries with maximal possible overall dimensions and characteristics for Ust-Luga – Baltiysk line. Vessels which can effectively work in ice conditions of Ust-Luga port are necessary.

The Baltic Sea – special NO_x (NECA) and SO_x emission control area (SECA). Since 1st January 2015 the maximum sulphur content of marine fuels used in SECAs has been reduced to 0.1%. Standard liquid fuel with such content of sulphur becomes extremely expensive and significantly increases expenses on sea cargo transportations. Gas fuel allows completely to exclude SO_x emissions and particulate matters, to reduce NO_x emissions by 90% and CO₂ emissions by 30%.

Therefore urgent need of LNG fuel new generation ferries which meet the most modern requirements to safety has appeared. The new concept of CNF19M train ferry for Baltic (see Fig. 4 and Fig. 5) is LNG fuel steel self-propelled vessel with Arc4 ice category, with bulbous stem, with one cargo deck providing placement of 80 railway cars in one plane without usage of cargo lifts, aft located ER, with diesel propulsion plant, aft auxiliary thruster and two bow thrusters.

Figure 4. General view of LNG fuel CNF19M train ferry

Figure 5. General arrangement of LNG fuel CNF19M train ferry

Technical feature of the developed project of new generation ferry is compliance to the most modern requirements to safety including requirements to ecological safety. This is the modern, safe and economic vessel which will allow to make 135 round trips per year, to transport 8910 railway cars or 534 600 tons of cargo per year. Round trip duration is 2.7 days if bunkering will be in time of cargo operations. CNF19M ferry requires about 1500 m³ of gas while autonomy is 10 days. So full bunkering is supposed once in three round trips or partial – at each calling at Baltiysk (or Ust-Luga). Options of filling stations: from road-train LNG-carriers, LNG bunkering vessel, port LNG bunkering station, LNG tank-containers.

Examples of all decisions of gas filling stations already exist in the world.

CONCLUSIONS

1. Usage of LNG as primary ship fuel for river-sea tankers and train ferries has basic advantages in comparison with usage of low-sulphur MDO or HFO with scrubbers as allows to exclude completely sulphur emissions, to reduce significantly emissions of nitrogen oxides, carbon and also particulate matters. Level of NO_x emissions fulfills Tier III requirements of MARPOL which came into force since 01.01.16 without installation of additional purification systems of gases.

2. As for use of HFO on tankers equipped for use of LNG there is no sense for dismounting HFO systems in re-equipment process of already built tankers. In case of building of new vessels final decision will be made by Shipowner and will depend on expected area of operation of vessels and also on prices of liquid and gaseous fuels.

REFERENCES

- [1] G.V. Egorov, V.I. Tonyuk. RST27 river-sea tanker of "VF-Tanker" type with deadweight in river/sea 5427/7030 tons with extremely full hull contours // Shipbuilding and shiprepair. - 2013. - №57-58. - pp. 22-35 (in Russian).
- [2] G.V. Egorov, I.A. Ilnytskiy, D.V. Chernikov. Features of design of hull of train ferry for Ust-Luga – Baltiysk – Sassnitz – Mukran line // Proceedings of Ship structural design science-technical conference named for prof. P.Ph. Papkovich. - SPb: Krylov state research center, 2015. - pp. 24-25 (in Russian).
- [3] A.N. Blinkov, A.A. Vlasov, V.K. Shurpyak. Analysis of methods of gas fuel usage in ship power plants // Science-technical collected book. - SPb: RMRS, 2011. - Vol. 34. - pp. 177-197 (in Russian).
- [4] *Rules of classification and building of gas-carries.* - SPb: RMRS, 2016. - 109 p (in Russian).
- [5] Det Norske Veritas. *Rules for classification of ships. Newbuildings. Special equipment and systems additional class.* Part 6, chapter 13. Gas fuelled engine installations, 2001.
- [6] V.S. Epifanov. *Operation of LNG fuel ship power plants.* - M.: TransLit, 2010. - 216 p (in Russian).
- [7] G.V. Egorov, E.A. Osadchiy. Research of possibility of usage of LNG as gas fuel on RST27 river-sea tanker // Maritime Market. - 2012. - №1 (39). - pp. 20-29 (in Russian).
- [8] Usage of gas on water transport. – National gas-engine association website. URL.: http://www.ngvru.ru/story_04.shtml.
- [9] International Maritime Organization. Resolution MSC.285(86). *Interim Guidelines on safety for natural gas-fuelled engine installations in ships.*
- [10] R. McArthur. Gas-fuelled mechanical propulsion solutions offer major emissions reductions // Twentyfour7, 2011. - Vol. 1. - pp. 66-68.
- [11] Wartsila Engines. Wartsila 20DF. - Wärtsilä Corporation Bock's Office, 2009. - 2 p.
- [12] E.N. Pronin. Green light to "Blue corridor". - National gas-engine association website. URL.: http://www.ngvru.ru/st6_1.shtml.
- [13] North European LNG Infrastructure Project: A feasibility study for an LNG filling station infrastructure and test of recommendations. Draft Feasibility Report/ URL.: http://www.lngbunkering.org/sites/default/files/2012%20DMA%20North%20European%20LNG%20Infrastructure%20Project_0.pdf.

BACKGROUNDS OF CREATION OF RIVER PASSENGER VESSELS FOR SOCIALLY IM-PORTANT ROUTES

Gennadiy V. EGOROV*, Alexander G. EGOROV**

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – Marine Engineering Bureau (Odessa, Ukraine), chief researcher, Dr, RINA member

Abstract. Necessity of creation and building of modern economic vessels for liner services providing is shown. Experience of such transportations on the example of Arkhangelsk, Yakutia and Leningrad region is analyzed.

In general the situation is characterised by burning need in development of short local and interregional passenger traffic. First of all it is connected with the solution of the problem of their economic efficiency. Operation of passenger fleet is carried out on the directions subsidized by local budgets (social transportations) or for the tourist purposes (St. Petersburg, Moscow, Seliger, Valdai, Ilmen, etc.). The sizes of required subventions so much the more than vessels are less adapted for operating conditions.

Therefore new modern and attractive passenger and ferry fleet having minimum of need for subventions is necessary for saving and in long term for growth of liner passenger traffic.

Keywords: design, economic efficiency, main characteristics, social task, way conditions.

INITIAL PROBLEM

The problem of water passenger transportations with account of outage of existing vessels (toughening of requirements of regulatory authorities after tragedy of "Bulgaria" and "Ivolga", sharp increase of volumes of repairs, lack of spare parts on old equipment) becomes more and more sharp.

Therefore the problem of creation of new generation passenger and cargo-passenger vessels for local and interregional lines is represented actual and important for water transport industry.

AIM OF THE PAPER

Grounding of necessity of new generation vessels' building on basis of analysis of condition of passenger transportations (for example in Arkhangelsk region in the delta of the Northern Dvina River, Yakutia), existing fleet of passenger and cargo-passenger vessels which are operated on local and interregional lines, and also way conditions.

MAIN TEXT

In 2015 internal passenger transportations have increased by 6.8 % in comparison with 2014 and have made 13.6 million people. The increase is connected with growth of passenger traffic in transport connection, on excursion and tourist routes volumes of passenger transportations have been reduced. In 2017 passenger transportations have made 12.7 million people. In general in last five years passenger transportations are on stable level.

The considerable part in transport connection was provided by following shipping companies: OJSC "Tatflot", LLC "Volgograd passenger port", OJSC "Arkhangelsk river port", OJSC "Zhilkomservice" (Syktyvkar), OJSC "Tobolsk river port", OJSC "Severrechflot", OJSC "Passazhirrechtrans", CJSC "Amur passenger transportations", OJSC "Yaroslavl river port". OJSC "Arkhangelsk river port" carried out socially important transportations of passengers on island parts of the Arkhangelsk region (864 225 passengers) [1].

In 2017 passenger turnover has grown by 2.2% and has made 562.4 mln pass-km (in 2016 passenger turnover – 550.5 mln pass-km). Main part of passenger traffic compiles in Volga and North regions, Siberia and the Far East. Intensity of river passenger fleet services usage (ratio of passenger traffic to population in the region) according to Federal State Statistics Service is reached by 80% (Arkhangelsk region) and even 87% (Amur region).

Therefore dynamics of passenger traffic is non-uniform. In Leningrad region, Republic of Komi, Amur region and Nenets Autonomous Area it was noted more than 20 percent growth of passenger traffic. In Khanty-Mansi Autonomous Area, Republic of Sakha – Yakutia, Ulyanovsk and Nizhny Novgorod regions passenger traffic is steadily high. In Republic of Udmurtia, Kirov, Ivanovo and Astrakhan regions falling of passenger traffic on 20% and more is noted.

The basis of transport passenger traffic (96%) is reached by transportations on short (50 km and less) routes: - cargo-passenger vessels (ferries) between cities located on two sides of river; - routes between cities and suburbs; - routes between Russian and Chinese cities at the Far East including ferries (Amur River). Transportations on long-haul (over 50 km) distances make 4%. Such transportations are carried out mainly in North regions, Siberia and the Far East, especially in Yakutia. Because of low population density building of automobile roads and railways far from the main transport nodes in North regions, Siberia and the Far East is, as a rule, inexpedient.

Striking example is the Republic of Sakha – Yakutia. With population density in different areas of the Republic is from 0.1 to 2.8 man on sq.km building of automobile roads and railways in some areas is extremely inefficient from the point of view of economy. Inland water transport during navigation is backbone for passenger traffic: every third inhabitant of Yakutia uses inland water transport per year.

Therefore presence of steady summer routes of inland water transport and reserve of vessels during season of floods is important component of life support of regions in which automobile roads and railways are insufficiently developed. At the same time such regions are located generally in Siberia, at the Far East and in the North of European part, their quantity and population are not too big.

As development of roads in these regions is inefficient passenger traffic on inland water transport cannot switch to other means of transport and, most likely, will remain at stable level.

Arkhangelsk region is the most important representative in sense of liner local routes. There is about 50 river crossings and about 20 transport operators. Only in Arkhangelsk up to 1.2 million passengers is transported every year.

Transportations in Arkhangelsk. 90% of passengers are carried by OJSC "Arkhangelsk river port" transports [2].

It is necessary to pay attention to the conception "Intercity Island Passenger River Lines" as there is a special role of water transport in transportations of Arkhangelsk inhabitants to numerous islands on the Northern Dvina.

More than 20 thousand inhabitants of Arkhangelsk and Primorskiy municipal district living on islands of delta of the Northern Dvina River need stable river intercity and suburban transportations.

River transportations in Arkhangelsk are top requested by inhabitants as with some island parts of the city it is the only way of connection in summer time [3].

According to Arkhangelsk region Transport Agency annual volume of transportations of passengers on Maymaksanskiy Timber Port – Timber Yard No.14 route makes about 260 thousand people per year.

Because of need of transportation of many people passenger capacity of ferry for this line has to be about 200 people plus possibility of transportation of two "Kamaz" cargo vehicles (RPF14 project of Marine Engineering Bureau as for example [6]).

Annual volume of passenger transportations on Arkhangelsk – Kego Island route makes also about 260 thousand people. More than 2300 people are living now on Kego Island. During the day vessel carries out 12 round voyages. Herewith the first 3 voyages from Kego Island and the last 3 voyages from Arkhangelsk have 100% loading. In the afternoon loading of vessel in both directions does not exceed 30-40%.

Because of need of transportation of many people passenger capacity of vessel for this line has to be about 250 people (PV16 project of Marine Engineering Bureau as for example [6]).

During ice formation and ice drift (month – three months in autumn and three – four weeks in spring) situation becomes simply catastrophic as passenger transportations from 1970s are provided with classic tugs (there are no passenger vessels with required ice class at all) with sufficient for operation in ice conditions ice class, icebreaking capability and hull strength. Tugs transport inhabitants until complete freezing.

Such transportations are carried out with violation of "Rules of provision of services of transportation of passengers, luggage and cargoes for personal (household) needs on inland water transport" and requirements of Russian River Register (RRR) [4].

As it is noted in [3] in "rush hour" tugs make additional voyages if there are passengers on berths. Except passenger transportations, tugs carry out functions of stand-by vessel remaining at night on islands for fast delivery of ill persons, solutions of tasks of Ministry of Internal Affairs and Ministry of Emergency Situations providing express delivery of products and medicines for the population of islands.

During ice drift and ice formation citizens are transported free of charge (for example, in 2011 tugs transported 170 thousand people – more than 5 thousand per day) [3].

Problems are even then when ice drift has stopped. On one side pedestrian and transport ice crossings are created every winter, but on other side cargo vessels calling at the port destroy ice cover on the Northern Dvina River, create ice channels and hummocks and detain placing of pedestrian crossings across the river.

Passenger transportations on the Northern Dvina are carried out on morally and physically outdated vessels which are poorly adapted (or even not adapted at all) for such transportations including but not limited absence of reinforcements for operation in conditions of the river freezing.

That is why creation of passenger (for 250 passengers, PV16 project) and cargo-passenger (for 200 passengers and two cargo vehicles, RPF14 project) vessels possible to work in such conditions (with Ice 40 category and rather deep draughts up to 2.40 m) is extremely important and actual task for the region.

River crossings in Arkhangelsk region in upper part of the Northern Dvina. In total there are about 50 active river crossings in headwaters. Vessels operated at crossings are physically and morally outdated. This problem sometimes leads to violations or lack of communications at all.

Analysis has shown that for local crossings of Arkhangelsk region it is recommended to use new shallow draught cargo-passenger vessel of Marine Engineering Bureau RPF15 project (instead of existing and parametrically close vessels of 774, M-105, DO-57 projects). This ferry is fitted for transportation of 50 passengers and one cargo vehicle [6].

River crossings in Leningrad region. River crossing across Svir River in Voznesenye is the part of Petrozavodsk – Oshta regional highway. Its functioning is provided by three vessels: "Svir-1" non-self-propelled ferry (1984 building year) and "RT-328" river tug-pusher (1980 building year) during summer time and "SP-28" self-propelled cargo-passenger vessel (1969 building year) during winter time. Maintenance of this crossing is carried out by State Enterprise "Lodeynopolsk Road Maintenance and Construction Department".

Because of technical conditions RRR implemented restrictions on operation of "RT-328" and "Svir-1" outdated vessels. Maximal passenger capacity was reduced to 20 people and problem with passenger transportation has appeared (big queues waiting for vessel). To solve the problem in 2015 Nevskiy shipbuilding and ship repair yard built new cargo-passenger vessel "Arkadiy Filatov".

River passenger transportations in The Republic of Sakha – Yakutia. According to opinion of S.V. Sokolov general director of LLC "Passenger District Management" (one of the main republican carriers), such transportations are characterised by insufficient number of existing fleet and its physical and moral aging; considerable length of routes; availability of numerous generally private carriers in the market that is not characteristic for such services; market forming of fare, especially on top requested lines with serious passenger traffic; lack of moorings that leads to landing/disembarkation including on non-equipped coast; transportation of passenger cars and cargoes.

In 2014 navigation LLC "Passenger District Management" worked on 6 routes, LLC "Lenaturflot" – on 5; Belgorod district of OJSC "LURS" – on 2, Kondratiev private entrepreneur – on 2, OJSC "Vilyuy Shipping company", Aldan part of FBE "Lena basin Administration", Prokopiev private entrepreneur, Vysotskiy private entrepreneur – all one-by-one. There are 19 lines with total length is of 9200 km and 79 stops overall.

The most extended is Yakutsk – Tiksi route (1664 km) and also Yakutsk – Zhigansk (771 km), Ust'-Kut – Peledui (765 km), Ust'-Kut – Maya – Tommot (764 km) and Olekminsk – Yakutsk (627 km). Herewith the biggest number of passengers used Olekminsk – Yakutsk route (13300 people) and on the most extended Yakutsk – Tiksi route there were 2136 people. Certainly the most demanded (420 thousand passengers per year) is the shortest 24 km route between Yakutsk and Nizhny Bestyakh – end railway station of Amur-Yakutsk railway.

As S.V. Sokolov notes 85-95% of passengers move between start and end stops of the route thence it is offered to build vessels which will be able to carry out landing (disembarkation) to non-equipped coast. For example on LLC "Passenger District Management" routes only 5 (Yakutsk, Sangar, Zhigansk, Batamai, Olekminsk) from 23 stations have pontoon wharfs.

General problems of local passenger transportations. Analysis of general external factors (and not only in Arkhangelsk region) which produce an effect on passenger and cargo transportations on river local routes has shown that main problem of this type of transport is its dependence on subsidies and local budgets. Without relevant financing such transportations will simply disappear. Need of such transportations is that for many routes there are no alternatives and it is possible to reach from point A to point B only by the river (or in some cases by road going round the bigger distance and spending much more time).

It should be noted that countrywide river passenger transport for local routes does not sustain competition to other means of transport especially with automobile because of sharp growth of private cars and also appearance of numerous intercity and long-haul bus routes.

Meanwhile need of river short transportations remains and in many places even grows because of rather natural restrictions in development of road infrastructure (that is characteristic for East and North basins of the country), congestion of roads (Moscow and Moscow region) and high cost of local aviation connection. In some regions of the country there is significant amount of territories where alternative to water transport is only expensive and low-capacious helicopter.

Main form of organisation of passenger fleet operation is linear. Grounding of routes' scheme is carried out at stage of preparation of operation plan of shipping company for the forthcoming navigation. The matter of task is on the basis of sizes of passenger traffics in certain directions and structure of passenger fleet to select specific operational routes for each vessel's type with accounting of full satisfaction of passenger traffic needs and minimal transportation costs.

Crucial importance in organisation of transportations and for type of operational model of passenger or cargo-passenger vessel has average vessel waiting time value acceptable for passengers. Organisation of service in the mode of accidental call (with accumulation of passengers on berths) with presence of mobile and GPS communication can be used in places of sporadic appearance of passengers but such decision is not suitable for domestic conditions (theoretically it can be used in megalopolises in "river taxi" form).

The main problems of river passenger transportations are: - unprofitability of passenger transportations (high operational costs, usage of not fully adapted for operating conditions vessels, in some cases lack of wide effective demand for transportations etc.); - seasonality of work of enterprises operating fleet of passenger vessels for local routes; - lack of illumination on internal water ways during dark nights twice reducing fleet usage; - outdated fleet of passenger vessels for local routes; - technical obsolescence and unpracticalness of vessels to operating conditions (lack of necessary modern vessels, their impracticality for internal routes, their insufficient comfort and unattractiveness for tourism, incomplete compliance to shore infrastructure etc.); - specificity of operating conditions (farness and non-equipment of port stations, seasonality, imbalance of passenger and cargo traffics etc.); - destroyed mooring berths and (or) lack of pontoon wharfs (impossibility of mooring of passenger vessels for local routes); - limited budget financing of passenger transportation losses which stops carrying out of full repairs and development of infrastructure which can be used for executing of local routes passenger transportations; - rather high cost of building and operation of new passenger vessels, lack of funds for purchasing of modern fleet, considerable need for means for building and operation of shore infrastructure etc.

New modern and attractive passenger and ferry fleet having minimum of need for subventions is necessary for growth of liner passenger traffic. Need for passenger and cargo-passenger vessels for local and interregional routes is possible (at initial stage) to define as the number of vessels necessary for stepwise updating of fleet into operation.

Existing passenger fleet for local transportations. According to RRR data (on October, 2016) age structure of river passenger vessels is characterised by following parameters (see Table 1).

In the belief that the age of vessels in each group is normally distributed about average value it is possible to estimate mean age of passenger vessels with using data from Table 2. On the basis of stated above mean age of passenger vessels of all types according to RRR can be estimated in 33 years.

Table 1. Age of passenger vessels of all types according to RRR (except small crafts suited for passenger transportations)

Fleet type	Age groups							Total number of vessels
	< 10 yrs.	10-20 yrs.	21-30 yrs.	31-40 yrs.	41-50 yrs.	51-60 yrs.	> 60 yrs.	
Age groups' passenger vessels' distribution								
Passenger, un.	191	93	220	352	134	263	81	1334
Age fleet structure								
Passenger, %	14.32	6.97	16.49	26.39	10.04	19.72	6.07	100.00

Source: Russian River Register

For the analysis of condition of passenger fleet for local and interregional routes 25-50 m long vessels were selected. Choice of such dimensions is determined by allowances that vessels less than 25 m long can be referred to excursion and pleasure category and vessels more than 50 m as rule belong to cruise category.

Structure of fleet of river passenger and cargo-passenger vessels for local routes is shown in Table 2.

Thus 972 passenger vessels for local and interregional routes are registered in RRR.

Table 2. Structure of fleet of river passenger and cargo-passenger vessels for local routes

Project	Quantity	Mean age
River passenger vessels for local routes		
R-51, R51E, R-51EK, R-51EA "Moskva"	232	29.10

Project	Quantity	Mean age
River passenger vessels for local routes		
544, 544SH, 544P "Moskvich"	183	55.66
780, 780-03 "OM"	125	49.53
81080, 81080A "Moskovskiy"	34	22.84
839, 839A "MO"	85	49.05
331	12	49.50
R-35 "Neva"	6	38.21
2646/P-51EK	6	28.87
NVS-496 (China)	6	4.50
623	10	51.80
R-83	95	30.13
M-105	7	53.01
KS-104-01	31	10.75
T-101, T-101P, T-101PM	31	43.20
1430	7	36.42
Other projects (T-129, 075, 939)	4	23.44
Passenger vessels in all	874	36.00
River cargo-passenger vessels for local routes		
603	12	40.33
R-144	6	24.65
M-105	3	52.69
PR-70	8	17.66
SPBA-100	6	29.51
133B	14	37.58
6258	5	23.50
183B, 183BM, 183V	3	35.38
774	7	40.38
81210, 81210L	4	17.60
81212, 81212R	4	14.92
R-66	5	38.98
R-146AM, R-146M, R-146P	3	20.68
Other projects (SM-241, 65, 661, 780/331, 81080, 81219, 944, JH-401, B/212, DO-57, PN-97-60, PN-99.50, P-92A, 52)	18	28.94
Cargo-passenger vessels in all	98	30.20
ALTOGETHER	972	33.10

Source: Russian River Register

According to foregoing data the biggest number of vessels belongs to "Moskva", "Moskvich" and "OM" types (about 70% of all investigated fleet). These vessels were created long time ago. Nowadays they are morally and physically outdated.

B.M. Sakhnovskiy noted that on small and side rivers in operation there is significant amount of displacement passenger and auxiliary vessels (running boats, buoy-laying vessels and others) which transport passengers [5]. Older vessels are modernized to fulfill new requirements of RRR, new functionality and with taking into account modern architectural decisions.

Serially built from 1965 to 1984 semiplaning passenger motorships of 946, 946A and R83 projects of "Zarya" type are removed now from majority of operation routes on small and side rivers because of increased requirements for environmental protection. By having high power and speed "Zarya" type motorships make

significantly influence on ecological condition of small rivers. They have been replaced with sidewall surface-effect ships of "Zarnitsa", "Orion", "Luch" types, bottom air layer planning vessels of "Linda" type, amphibious hovercrafts of "Irbis" type. Results of special researches have shown that such vessels make smaller negative impact on ecological condition of small rivers.

Search of new technical decisions is necessary for creation of fleet of economic effective passenger vessels and as B.M. Sakhnovskiy has shown for river passenger vessel the most significant factors of influence are shallow water and constraint of fairway dimensions.

Shipping companies in all regions carry out modernizations of operating vessels in particular by replacement of main engines and refurbishment of interior. It allows to transport passengers in more comfortable conditions and to reduce fuel consumption without significantly raising of ticket prices.

In XXI century Russian water transport received more than 200 new passenger vessels, ferries and running boats. 20 passenger vessels were built for liner transportations, 33 ferries and 21 rolling-on barges with ramps which are also often used on crossings included in the count. However it is absolutely not enough for the solution of all available problems.

CONCLUSIONS

Mean age of river passenger vessels for local routes makes 36 years. Mean age of river cargo-passenger vessels for local routes makes 30.2 years. Mean age of all river passenger fleet for local routes makes 33.1 years. Normative operation term of vessels makes 25-35 years with maximum possible operation term of 40 years. Therefore more than 50% of operated fleet has to be written off. Decommissioning certainly will lead to collapse of volumes of river passenger transportations for many regions of the country (regions where there is no alternative to river transportations).

As reflected from above-mentioned forthcoming write-off of passenger fleet will cause essential damage to social passenger transportations against almost total absence of new fleet building.

Region-wise analysis of passenger transportations, morally and physically outdated passenger and cargo-passenger fleet for local routes, problems with lack of fleet with necessary ice strengthenings for possibility of operation during ice formation and drift show need of building of new generation river passenger and cargo-passenger vessels for local lines (including for majority of Russian regions with strengthened ice class).

In general the situation is characterised by burning need in development of short local and interregional passenger traffic. First of all it is connected with the solution of the problem of their economic efficiency. Operation of passenger fleet is carried out or on the directions subsidized by local budgets (social transportations) or for the tourist purposes (St. Petersburg, Moscow, Seliger, Valdai, Ilmen, etc.). The sizes of required subventions so much the more than vessels are less adapted for operating conditions.

Therefore new modern and attractive passenger and ferry fleet having minimum of need for subventions is necessary for saving and in long term for growth of liner passenger traffic. For example, RPF14, RPF15, PV16 projects of Marine Engineering Bureau which have already been developed to solve this socially important problem [6].

REFERENCES

- [1] Overview of Russian inland water cargo and passenger transportations in 2009-2010. CJSC "Mortsentr-TEK" (in Russian).
- [2] "Arkhangelsk" official web-portal. URL: <http://www.arhcity.ru> (in Russian).
- [3] Information portal "News29". "Timetable of tugs operation on local passenger lines has been changed". URL: <http://www.news29.ru/> (in Russian).
- [4] Official web-portal of Arkhangelsk region governor. URL: <http://www.orlov29.ru/> (in Russian).
- [5] B.M. Sakhnovskiy. *Development of methodology of justification of design characteristics of river-sea vessels with taking into account dominating operational factors*. St. Petersburg, Russia, 2006, 319 p (in Russian).
- [6] G.V. Egorov, A.G. Egorov. Passenger vessels for local and interregional social routes // Transport of Russian Federation, 2017. - N6 (73), pp. 58-61 (in Russian).

ANALYSIS OF APPLICABILITY OF RIVER PASSENGER AND CARGO-PASSENGER CONCEPTS FOR LINEAR SERVICES

Gennadiy V. EGOROV*, Alexander G. EGOROV**

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – Marine Engineering Bureau (Odessa, Ukraine), chief researcher, Dr, RINA member

Abstract. In paper decisions which are applicable for perspective river passenger and cargo-passenger vessels for local routes according to results of the analysis of operating experience, design and construction of native and foreign river vessels for local routes are marked.

The water transport of the researched region needs 6 "cabin" passenger vessels with capacity of 150-200 passengers (PV11 project) for interregional and "long-distance" transportations, 109 passenger vessels with capacity from 150 to 12 passengers (including 42 of PV16M, 49 of PV14, 10 of KS-110 projects), 35 cargo-passenger ferries (25 of RPF15, 10 of RPF14 projects).

Of course authors do not insist on concrete use of Marine Engineering Bureau projects, the main thing is to provide the solution of external design task with determination of basic features of vessels' types required on the routes. Everything will be defined by economy of transportations and opportunities of regions for ensuring necessary subsidising.

Keywords: design, ferry, passenger vessel, social task, variability.

INITIAL PROBLEM

Theoretically for Russian waterways two types of passenger transportations cruise (tourist) or, in other words, commercial providing rest on water and linear passenger necessary for people movement (communication tasks) are the most interesting for research.

River crossings (which connect opposite river side), suburban (up to 100 km) and local lines (up to 500 km) including interregional have the greatest social implication for people. In many regions and settlements river passenger transportations are the only type of transport.

Therefore the problem of creation of new passenger and cargo-passenger vessels for providing of communication tasks is actual and important for the water transport industry.

AIM OF THE PAPER

Grounding of Marine Engineering Bureau design "line-up" of new river passenger and cargo-passenger vessels on basis of researches of passenger transportations, existing fleet which are operated on local and interregional lines, operational conditions in expected areas of work.

MAIN TEXT

By results of analysis of operating experience, design and building of Russian and foreign river vessels following decisions which are applicable for perspective river passenger vessels for local lines are marked [1-7].

1. On main principles: - presence of restrictions of way conditions of operation area of the vessel is defining (depths, fairway dimensions, sizes of hydraulic engineering constructions etc.); - with total or partial absence of restrictions ratio of main dimensions received as results of optimization of running and weight/dimensional characteristics of the vessel is defining.

2. On architectural construction type (ACT) depending on climatic conditions of operation area of the vessel there are two main types of exterior of vessels: - "southern" with maximal glass covering of passenger saloons with possibility of opening, navigation bridges with open wings; - "northern" with all breadth closed navigation bridge of the vessel with minimization of glass covering (for reduction of calorific losses) passenger saloon.

3. Concept of choice of Russian River Register (RRR) class for perspective river passenger vessels for local lines assumes following: - according to expected directions of transportations for passenger and cargo-passenger vessels to assign RRR "O" class; - in reasonable cases where wind-wave conditions require to assign RRR "M" class; - for shallow-draught passenger vessels and ferries to assign RRR "R" class to minimize metal hull consumption if wind-wave conditions allow; - for "northern" variants of passenger vessels which are operated in Siberia, Northern and Far East regions acceptance of RRR ice strengthenings category "ice 30" and "ice 40" is reasonable; - for "southern" variants of passenger vessels (which are not providing operation in winter conditions) and especially for shallow-draught vessels for the purpose of hull metal consumption decrease it is reasonable not to have ice strengthenings at all; - in reasonable cases for "southern" options of passenger vessels

if extension of operation is provided in ice conditions acceptance of RRR ice strengthenings category "ice 40" is possible.

For example in Arkhangelsk port Rules it is specified that with beginning of ice formation only vessels having ice category "Ice 1" (Russian Maritime Register of Shipping (RMRS)) are allowed to work within Arkhangelsk district (or RRR "Ice 40" equivalent class) in ice brush with thickness up to 40 cm. At formation of ice more than 40 cm thick it is allowed to organize pedestrian and transport ice crossings and need for use of vessels disappears.

As a rule investigated river passenger and cargo-passenger vessels for local lines on duration of voyage and assignment belong to the III group of Hygienic standards for river and river-sea vessels. These vessels are intended for intercity and suburban lines that actually defines their architectural design type, availability of special rooms, requirements to areas of rooms, illumination, water supply systems, ventilation and air conditioning etc.

Typical crew structure of vessel for local lines: captain-mechanic; sailor; cashier (as rule, woman). For example as for Arkhangelsk conditions vessels can stay overnight on islands. Therefore crew rest rooms with allocation of rest spot for cashier and place for food warming up are to be provided. Vessels for local lines can have depending on operating conditions simplified hull form. From extremely simplified "pontoon" form for rather low-speed passenger vessels and ferries working at short lines of shallow-water crossings from one river side to another with operation speeds up to 10-12 km/h to moderately simplified (bilge knuckles and lack of diplane curvature of after end bottom) for ferries with operation speeds up to 15-24 km/h. For landing and disembarkation of passengers from fore end bow contours above waterline with flare for ensuring sufficient forecastle deck area are often used on passenger vessels of suburban and intercity lines. Cargo-passenger ferries of "shuttle" type in above-water part have symmetric forms of fore and aft ends for ensuring uniformity of loading / unloading conditions both from bow and stern.

Stem of passenger vessels is carried out raking in above-water part and with bottom rising in underwater part for mooring possibility to unequipped coast for landing and disembarkation of passengers from bow. For the same reason bulbous fore end is not applied because of high probability of emergency damages at soil contact by fore end and frequent moorings in constrained conditions.

Cargo-passenger ferries in above-water part have bow transom for ensuring mounting of ramp and fore end mooring to loading / unloading places. Aft end of passenger vessels is carried out, as rule, transom for reduction of overall length of the vessel. Aft end contours in underwater part (especially for vessels with extremely small draughts) have characteristic tunnel formations for providing operating conditions of propellers.

Engine-room (ER), crew spaces on all vessels are situated in aft part for ensuring availability of connection of crew with ER and wheel house, optimal configuration of passenger area. For "northern" variants of vessels with taking into account climatic conditions side-to-side closed navigation bridges are provided.

On passenger vessels following placements are located: - one level saloon for passengers in middle and fore part which provides landing and disembarkation from bow and both sides (in aft part of passenger area); - wheel house in aft part from passenger area (for convenience of control of passenger area, landing / disembarkation of passengers) and in direct proximity from ER; - in-hull dimensions of superstructure and navigation wings.

On cargo-passenger ferries of "shuttle" type (with fore and aft ramps) following placements are located: - one level saloon / saloons for passengers in side superstructures of middle part of the vessel from one or both sides; - central part of main deck is provided for placement of cars and other vehicles with possibility of through passage from fore to aft part and vice versa; - wheel house is placed in middle part of the vessel on the bridge over cargo area with possibility of all-round view (for convenience of control of passenger and cargo areas).

Passenger vessel, as a rule, is flush-deck with raised forecastle and poop. Herewith roof of closed passenger saloon has inclination to fore end. For "southern" variants movable glass covering of roof or telescopic roof are usually provided. Cargo-passenger ferry also is flush-deck with rather small cargo deck sheer in fore part and stern (at ramps). Roofs of fully closed wheel houses have sheer for ensuring draining of rain water.

On such vessels ship power plant is of diesel type. Usually two main engines with two-shaft plant with propellers and rudders / nozzles providing corresponding propulsion qualities and sufficient maneuverability are applied for vessels with big ratio of breadth to draught.

For shallow-draught vessels (with extremely small draughts) application of modern propeller wheels (as example, passenger vessels of "Sura" type) or water-jet propellers is reasonable.

General features of river passenger vessels for local lines. Analysis of operating experience of river passenger and cargo-passenger vessels allowed to build parametrical row of vessels which are objectively demanded by native Shipowners and on its basis to develop in Marine Engineering Bureau projects of new passenger vessels.

Version of such "line-up" of new projects is shown in Table 1. Among other projects following passenger and cargo-passenger vessels are demanded at modern market of passenger and transport services:

PV11 passenger vessel for interregional transportations in East basins with passenger capacity of 150 passengers. The vessel is assigned for operation on long-haul lines in Lena, Ob'-Irtys and Yenisei basins.

The vessel's ACT: steel three-screw motor ship with raking stem and transom aft end, with excess freeboard, with forecastle superstructure, with middle arrangement of three-tier superstructure, with fore arrangement of wheel house, with aft ER. Routes Krasnoyarsk – Dudinka (1984 km length), Salekhard – Antipayuta (718 km length), Omsk – Tobolsk – Salekhard (2714 km length) are taken as base lines for passenger vessel of PV11 project. Passenger vessel of PV11 project has following main characteristics: RRR class $\boxtimes$ O 2,0 (ice 20) A, overall length – 89.09 m, length between perpendiculars – 85.41 m, overall breadth – 15.00 m, molded breadth – 13.50 m, depth – 4.00 m, CWL draught – 1.60 m, CWL draught displacement – 1358 t, maximal ME power – 3×331 kW, speed – 10.8 kn, volume of cargo hold – 540 m^3 . Crew and operational staff – 45 persons. Scheme of general arrangement is given in Fig. 1.

For providing rest of passengers on the vessel there are restaurant, all-round view saloon and gym. For movement of passengers between decks passenger lift and for loading / unloading of cargoes from coast the 6 t crane are foreseen. In cargo area there are two cargo lifts with loading capacity of 500 kg.

Passenger vessel for local routes in "southern" variant of PV16M project. The vessel is assigned for operation on local routes in European part of Russian Federation.

The vessel's ACT: steel twin-screw motor ship with transom fore and aft ends, with excess freeboard, with midship superstructure made from alloy AMg5, with aft ER and wheel house, with RRR class $\boxtimes$ O 2,0 (ice 20) A.. Passenger vessel of PV16M project has following main characteristics: overall length – 39.60 m, length between perpendiculars – 38.22 m, overall breadth – 10.20 m, molded breadth – 10.00 m, depth – 4.20 m, CWL draught – 2.40 m, CWL draught displacement – 364 t, maximal ME power – 2×479 kW, speed – 20.0 km/h, volume of cargo hold – 102 m^3 , propulsion complex – 2 fixed-pitch propellers + 2 spade rudders. Crew – 5 persons. Scheme of general arrangement of PV16M project is given in Fig. 2.

Two doubles and one single cabin (Master's one) and also duty room in which equipment for storage and heating of food are intend for placement of 5 crew members. 100 passengers accommodate on sitting places in passenger saloon and in two double cabins. On bulkhead of passenger saloon before the first rows folding babies' cots are installed. Extension of interregional lines in East part of Russian Federation is very considerable (the vessel's autonomy is of 5 days) therefore for placement of 150 passengers separate cabins are provided (as on cruise passenger vessel). Loading / unloading of cargoes on the vessel is carried out by cargo crane installed in fore part with maximal handling radius is about 10 m with loading capacity about 300 kg (loading capacity is about 700 kg while handling radius is 7 m). Fore cargo hold is closed by folding covers openings or closings of which are carried out by crab winch. 74 cabins with two-seat placements (including 2 cabins with occasional seats) including 4 luxury cabins with balcony, 4 cabins for physically disabled people, 64 standard cabins, 2 standard cabins with occasional seats. Cabins for passengers are placed in middle vertical zone on 3 tiers of superstructure.

Figure 1. Scheme of general arrangement of PV11 passenger vessel for interregional transportations in East basins with passenger capacity of 150 passengers

Figure 2. Scheme of general arrangement of PV16M project for 100 passengers for operation on local routes in European part of Russian Federation

Table 1. Main principles of Marine Engineering Bureau displacement passenger and cargo-passenger vessels with possibility of operation on local, suburb and interregional lines

Marine Engineering Bureau project	Side view, № of view (see Table 2)	Overall length x breadth x depth, m	Passenger capacity, pers.	Autonomy, days	Speed, km/h	Register class	Notes
Passenger vessels for long-haul and interregional lines							
PV11		89.09x15.0 x4.0	150 (74 cabins)	10	20.0	✠ O 2,0 (ice 20) A	Possibility of operation on interregional lines as cruise vessel with ability of cargo transportation (volume of cargo hold is 540 m ³). Designed for long-haul lines of the North, Siberia and the Far East
PV16M		39.60x10.20 x4.20	100	5	20.0	✠ O 2,0 (ice 20) A	Possibility of cargo transportation (volume of cargo hold is 102 m ³). Designed for interregional lines in European part of Russian inland waterways
Passenger vessels for local lines							
PV16		39.60x10.40 x4.20	250	5	20.0	✠ P 1,2 (ice 40) A (sailing area can be increased)	High ice class (ice 40) for operation in East basins. Possibility of cargo transportation (volume of cargo hold is 100 m ³)
RPV03		31.90x6.40 x2.50	150	2	20.4	✠ O 2,0 (ice 20) A	
PV14		26.50x6.62 x2.50	100	2	20.0	✠ O 2,0 (ice 30) A	High ice class (ice 30) for prolongation of operation. There is pleasure craft modification
RPV02		26.50x6.40 x2.50	100	2	21.1	✠ O 2,0 (ice 20) A	Closed superstructure for operation in East basins
RPV01		26.50x5.20 x1.70	50	2	22.4	✠ O 2,0 (ice 20) A	
River cargo-passenger ferries							
RPF05		48.40x14.40 x3.40	up to 100	2	17.2	✠ O 2,0 (ice 20) A	Deadweight is of 553.1 t. Possibility of transportation of vehicles, availability of passenger saloon
RPF14		39.60x10.40 x4.20	up to 200	5	20.0	✠ P 1,2 (ice 40) A (sailing area can be increased)	High ice class (ice 40) for prolongation of operation, deadweight is of 349.0 t. Possibility of transportation of vehicles, availability of passenger saloon
RPF15		37.68x8.614 x1.40	up to 50	2	14.8	✠ P 1,2 (ice 40) A (sailing area can be increased)	High ice class (ice 40) for prolongation of operation, deadweight is of 75.8 t. Possibility of transportation of vehicles, availability of passenger saloon
RPF04		35.97x10.80 x1.50	up to 50	2	16.0	✠ O 2,0 (ice 20) A	Deadweight is of 46.7 t. Possibility of transportation of vehicles, availability of passenger saloon

Passenger vessel for local lines in "northern" variant (with glassed passenger saloon) and high ice class of PV14 project. The vessel is assigned for operation on local lines.

The vessel's ACT: steel self-propelled double-screw vessel with raking stem and transom aft end, with excess freeboard, with forecastle and poop, with middle superstructure (passenger saloon), with ER and wheel house, located in aft part of vessel, with RRR class ∇ O 2,0 (ice 30) A. Passenger vessel of PV14 project has following main characteristics: RRR class ∇ O 2,0 (ice 30) A, overall length – 26.50 m, length between perpendiculars – 24.35 m, overall breadth – 6.62 m, molded breadth – 6.30 m, depth – 2.50 m, CWL draught – 1.30 m, CWL draught displacement – 17 t, maximal ME power – 2x102 kW, speed – 20.0 km/h.

Scheme of general arrangement of PV14 project is given in Fig. 3. For accommodation of crew in quantity of 3 persons the duty room is foreseen where devices for food storage and heating are installed. Passengers are located on sitting places in passenger saloon. Installation of individual seats is foreseen. Distance between rows of seats is not less than 400 mm. For convenience of passengers there are luggage shelves, passengers' toilets, bar and buffet onboard.

The first row is assigned for transportation of passengers with babies. In accordance with Sanitary Rules and Regulations there are folding babies' cots on bulkheads in front of three last side chairs in first row. The fire protection of the vessel is carried out in accordance to requirements of RRR Rules. The fire protection of the vessel is provided by structural elements of hull and superstructure, fire-extinguishing systems, fire detection system, materials of fire-resistant insulation and also by complete set of fire-prevention supply. Herewith operation conditions of Gulf of Ob were accepted as main. Such decision provides additional level of safety at moorages.

There is one anchor-mooring capstan for mooring operations in bow. Manual control is provided from local control station. For moorings mooring bollards and cast hawses of required sizes are foreseen. There are 6 throw-off life rafts (3 from each side) capacity of 20 persons each.

River cargo-passenger ferry with enhanced ice class of RPF14 project on 200 passengers. As studying of operating conditions of vessels near Arkhangelsk has shown depth on main course is about 4 m but near coasts is about 2.5-3 m, so draught of RPF14 project has not to be more than 2.4 m.

Side port is intended for disembarkation of passengers (if no cars onboard). In accordance with features of operation (vessels carry out functions of stand-by vessel remaining at night on islands for fast delivery of ill persons, solutions of tasks of Ministry of Internal Affairs and Ministry of Emergency Situations providing express delivery of products and medicines for the population of islands) fuel autonomy is 5 days. Scheme of general arrangement of RPF14 project is given in Fig. 4. The project is assigned for operation on island territories of Arkhangelsk in the Northern Dvina estuary in northern regions of Russian Federation in ice conditions.

Figure 3. Scheme of general arrangement of PV14 project for 100 passengers for operation on local routes in "northern" variant

Figure 4. Scheme of general arrangement of RPF14 project for 200 passengers and 2 cargo vehicles

Accepted ACT type: steel self-propelled double-screw vessel with transom bow and transom stern, with excess freeboard, with side superstructures which are made from AMg5 alloy, with bow and aft ramps, with wheel house located amidship and with engines' and diesel-generators' rooms located in the aft part of vessel. Passengers are located on sitting places in two passengers' saloons also on sits on open parts of promenade deck. There are passengers' toilets onboard. There are folding babies' cots on transverse bulkheads in passengers' saloons near each last in a row seats (8 units). For accommodation of crew in quantity of 3 persons the duty room is foreseen, where devices for food storage and heating are installed. Also places for short-time resting of crew are foreseen. Passenger vessel of RPF14 project has following main characteristics: RRR class ∇ R 1,2

(ice 40) A, overall length – 39.60 m, length between perpendiculars – 38.22 m, overall breadth – 10.40 m, molded breadth – 10.00 m, depth – 4.20 m, CWL draught – 2.40 m, CWL draught displacement – 349 t, cargo area of deck – 150 m², maximal ME power – 2x479 kW, speed – 10.8 kn, propulsion complex – 2 fixed-pitch propellers + 2 spade rudders, crew – 3 persons.

River shallow-draught cargo-passenger ferry of RPF15 project for 40 passengers. Ferry is assigned for local regional lines for crossings with shallow water areas.

Length of free deck is about 20 m (for placement in length of dump truck or road-trains). Axle loading is of 15 t. 40 sitting places are foreseen. Others can be transported by standing. 5x5 m fore ramp for securing unloading of vehicles on non-equipped coast is foreseen. According to operating conditions autonomy is of 2 days. Scheme of general arrangement of RPF15 project is given in Fig. 5.

Figure 5. Scheme of general arrangement of RPF15 project for 50 passengers and 1 cargo vehicle

Accepted ACT type: steel self-propelled double-screw vessel with raking bow and transom astern, with excess freeboard, without forecastle and with poop, with aft superstructure, ER and wheel house located in aft part of vessel, with ramp in fore part of vessel. Passengers are located on sitting places (40 pers.) in passengers' saloons on main deck and also on open parts of main deck, others – by standing. There are folding babies' cots on transverse bulkheads in passengers' saloons near each last in a row seats (4 units). For accommodation of crew in quantity of 3 persons rest room and duty room where devices for food storage and heating are installed are foreseen. Passenger vessel of RPF15 project has following main characteristics: RRR class $\boxtimes$ R 1,2 (ice 40) A, overall length – 37.68 m, length between perpendiculars – 34.995 m, overall breadth – 8.614 m, molded breadth – 8.50 m, depth – 1.40 m, CWL draught – 0.70 m, CWL draught displacement – 75.8 t, cargo area of deck – 130 m², maximal ME power – 2x148 kW, speed – 8 kn, propulsion complex – 2 fixed-pitch propellers + 2 spade rudders, crew – 3 persons.

CONCLUSIONS

The water transport of the researched region needs 6 "cabin" passenger vessels with capacity of 150-200 passengers (PV11 project) for interregional and "long-distance" transportations, 109 passenger vessels with capacity from 150 to 12 passengers (including 42 of PV16M, 49 of PV14, 10 of KS-110 projects), 35 cargo-passenger ferries (25 of RPF15, 10 of RPF14 projects).

REFERENCES

- [1] G.V Egorov. "Line-up" of cargo and cargo-passenger ferries for Black Sea // Maritime Market. - 2014. - №1 (47). - pp. 14-27 (in Russian).
- [2] G.V Egorov, N.V. Avtutov, Ya.V. Kalugin. Main principles of organisation of passenger transportations // Materials of VI international sc.-tech. conf. "Innovations in shipbuilding and ocean engineering", - Nikolayev: NUS, 2015. - pp. 62-64 (in Russian).
- [3] G.V. Egorov, A.G. Egorov. Risk analysis of operation of native river passenger vessels // Maritime Reporter. - 2013. - №1 (45). - pp. 100-105 (in Russian).
- [4] G.V. Egorov, A.G. Egorov. Vessels and ferries for Russian linear services // Maritime Market. - 2016. - №4 (58) - pp. 26-45 (in Russian).
- [5] G.V. Egorov, Ya.V. Kalugin, A.G. Egorov. Analysis of conditions of Russian river passenger fleet // Problems of technics. - 2012. - №4. - pp. 6-39 (in Russian).
- [6] G.V. Egorov, V.I. Tonyuk, A.G. Egorov. Backgrounds and main results of design of cargo-passenger vessels for the Northern Dvina // Maritime Reporter. - 2014. - №1 (49). - pp. 21-27 (in Russian).
- [7] G.V. Egorov, V.I. Tonyuk, A.G. Egorov. Grounding of concepts of new passenger vessels for Arkhangelsk region // ONMU Reporter. - Odessa: ONMU, 2014. - Vol. 1 (40). - pp. 37-60 (in Russian).

FORECAST OF RIVER-SEA VESSELS' FLEET STRUCTURE TILL 2025 WITH DEFINITION OF THE MOST DEMANDED TYPES OF VESSELS

Gennadiy V. EGOROV*, Alexander G. EGOROV**

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – Marine Engineering Bureau (Odessa, Ukraine), chief researcher, Dr, RINA member

Abstract. In paper information about decommissioning of river-sea vessels of main "classic" projects including emergency cases is provided. The analysis of dynamics and technical condition of fleet of river-sea vessels is made according to projects. The disposition forecast of these vessels is given, and also types of vessel optimum for the existing market conditions are offered for building.

Decommissioning level of two types of vessels is rather low both on technical and moral condition. These are "Volga-Don max" class vessels (provide the most possible loading capacity on river draughts from all existing vessels) and "Omskiy" type vessels (loading capacity of 3000 tons at draught about 3.20 m which, in fact, does not depend on weather).

It allows to recommend to build new vessels of "Volga-Don max" type in dry-cargo, oil-chemical and combined options and vessels instead of "Omskiy" type as the types which are actually chosen by the market.

Keywords: decommissioning, disposition, forecast, river-sea vessel, utilization.

INITIAL PROBLEM

At the beginning of XXI century it seemed that river-sea vessels (RSV) of Soviet types are "immortal". Because of advantageous unique main characteristics ("lot-based" 5000 / 3000 / 2000 tons loading capacities at shallow draughts at relatively small cost) these vessels were out of competition in comparison with other world fleet types of vessels. Exactly protectability of market "niche" has allowed them to be economically interesting rather long time for native owners including small private companies.

But the world economic crisis which has begun in 2008 and its subsequent waves made considerable impacts on this fleet.

AIM OF THE PAPER

Grounding of necessity of building of new river-sea vessels on the basis of research of statistical regularities of write-off of river-sea vessels and forecast of fleet structure for perspective till 2025 with identification of types of vessels which are most demanded in the market of transport services.

MAIN TEXT

It is clear that utilization is absolutely objective process of vessels' scrapping. Because of this process sufficient level of safety of sea and river transport is ensured.

As it shown in [1, 3-5] India, Bangladesh, Pakistan, China and Turkey are the main markets of vessels' utilization. The first three countries specialize on ocean ships (70-80% of the market), China and Turkey – on other vessels including river-sea vessels (scrap center in Aliaga in Turkey is the most popular place for scrapping of native vessels, on the second place – Cherepovets in Russian Federation).

Volumes (in million tons of DWT) and prices of scrap sales (ratio of \$ to tons of light ship displacement) for 2007-2016 are shown in Fig. 1. In 2016 933 vessels with total deadweight of 44.4 million tons have officially been decommissioned (average deadweight of vessels is of 47600 tons).

65% and 18% of all decommissioned vessels were bulk carriers and container ships respectively. Despite on low prices of cutting in China, India, Bangladesh and Pakistan rate made 290 \$/t of light ship displacement for the end of 2016 (in comparison with "failure" of 2015). China market of utilization is characterised by orientation for work with fleet under Chinese flag (87% of all utilized vessels in 2013, in 2016 this indicator has slightly fallen). In 2016 Chinese plants utilized 111 vessels with total deadweight of 4.9 million tons (average deadweight of vessels is of 44000 t), Turkish – 84 vessels with total deadweight of 0.9 million tons (average deadweight of vessels is of 10700 t). It is necessary to notice that utilization plants in India, Bangladesh and Pakistan are positioned as "dirty" production herewith the same plants in China and Turkey are more technological and ecologically safer.

Researches of authors have unambiguously shown that utilization of "old" series of RSV is in progress. The peak was in 2008-2015 and this process is proceeding now (see Fig. 2).

Figure 1. Volumes and prices of scrap sales for 2007-2016. Source: Clarksons Research

Figure 2. Number of utilized river-sea vessels of all projects by year distribution

By June, 2017 from 76 vessels of well-known 781 project of "Baltic" type (in fact, the first series of Soviet vessels which are specially designed for river-sea transportations which were under construction in 1962-1968) 91% – 69 are written off (10% – 7 vessels were lost in accidents, 49% – 38 vessels were utilized in XXI century, till 2000 – 24 vessels). 7 vessels are in operation with mean age of 51.9 years, 5 of them are under flag of Russian Federation. Mean age of utilization – 37 years. Thus the peak of utilization was observed (see Fig. 3) in 2009-2010 when 16 vessels of 781 project (21% of the series) have been written off at once. It is interesting to note that 39 vessels (57% of all are written off) have been utilized not under flag of Russian Federation (as a rule Turkish Shipowners). The main diagram of write-off of vessels (see Fig. 3), as a rule, keeps linear character that is sign of equable utilization of objects. Usually it answers to write-off on technical conditions and only in 2009-2010 there was jump because of economic reasons.

From 40 not less well-known vessels of 791 project of "Volgo-Balt" type of Soviet construction (were under construction in 1962-1969) 90% – 36 are written off (19% – 7 vessels were lost in accidents, 33% – 13 vessels were utilized in XXI century, till 2000 – 16 vessels). 3 vessels are in operation with mean age of 51 years. Mean age of utilization – 34 years, therein it must be kept in mind that the considerable part of vessels has been written off in Soviet period. The main diagram of write-off of vessels, as a rule, keeps linear character.

From 152 vessels of 2-95, 2-95A/R projects of "Volgo-Balt" type of Czechoslovak Socialist Republic construction (were under construction in 1967-1984) 35.5% – 54 are written off (17% – 9 vessels were lost in accidents, 45 vessels were utilized). 91 vessels are in operation with mean age of 40.5 years, 7 vessels are out of operation with mean age of 45.7 years. Mean age of utilization – 40 years (see Fig. 4). The main diagram of write-off of vessels (see Fig. 4) after 2008 has strongly marked exponential character. Usually it reflects moral aging by economic reasons (in 2011 9 vessels were utilized, in 2010 – 8 vessels). It is interesting to note that 46 vessels (85% of all are written off) have been utilized not under flag of Russian Federation (as a rule Turkish Shipowners).

Figure 3. Number of utilized vessels in % ratio to all vessels of 781, 781e projects of "Baltic" type

Figure 4. Number of utilized vessels in % ratio to all vessels of 2-95, 2-95A/R projects of "Volgo-Balt" type

If to detach the first series from 73 vessels of 2-95 project of "Volgo-Balt" type (were under construction in 1967-1974) 60.0% – 44 are written off (16% – 7 vessels were lost in accidents, 51% – 37 vessels were utilized in XXI century, till 2000 – 1 vessel). 27 vessels are in operation with mean age of 46.4 years, only 9 – under flag of Russian Federation.

From 121 vessels of 1557 project of "Sormovskiy" type (were under construction in 1967-1986) 39.7% – 48 are written off (17% – 8 vessels were lost in accidents, 40 vessels were utilized). 63 vessels are in operation with mean age of 39.0 years. Mean age of utilization – 38.4 years. The main diagram of write-off of vessels after 2008 has strongly marked exponential character (in 2011 9 vessels were utilized), utilization is in progress, for example in 2017 7 vessels were utilized. 10 vessels are out of operation with mean age of 43.5 years (they probably also will be scrapped in near future). 41 vessels (85% of all are written off) have been utilized not under flag of Russian Federation (as a rule Turkish Shipowners).

From 118 vessels of 21-88 project of "Czech" type (in fact, one of the first series of Soviet vessels which were used for river-sea transportations which were under construction in 1962-1968) 47.5% – 56 (21% – 12 vessels were lost in accidents, 44 vessels were utilized) are written off. 53 vessels are in operation with mean age of 52.4 years from them practically all (52 vessels) under flag of Russian Federation. Mean age of utilization – 36.8 years. The main diagram of write-off of vessels (see Fig. 5), as a rule, keeps "convex" form that is sign of equable utilization of objects. Usually it answers to write-off on technical conditions. Vessels now are under operation, as a rule, in river that is actually visible from the diagram of write-off which is characteristic for river vessels. 9 vessels are out of operation with mean age of 51.9 years.

Figure 5. Number of utilized vessels in % ratio to all vessels of 21-88, 21-89 projects of "Czech" type

From 252 vessels of 576 project of "Shestaya pyatiletka" type (in fact, also one of the first series of Soviet vessels which were used for river-sea transportations which were under construction in 1956-1967) 69.4% – 175 (3% – 5 vessels were lost in accidents, 170 vessels were utilized) are written off. 53 vessels are in operation with mean age of 55.9 years from them all under flag of Russian Federation. Mean age of utilization – 38.1 years. The main diagram of write-off of vessels, as a rule, keeps linear character that is sign of equable utilization of objects. Vessels now are under operation, as a rule, in river that is actually visible from the diagram of write-off which is characteristic for river vessels. 24 vessels are out of operation with mean age of 55.8 years.

From 87 relatively new vessels of 19620, P-168, 191 projects of "ST" type (were under construction in 1983-1994) 27.5% – 24 (29% – 7 vessels were lost in accidents, 17 vessels were utilized, almost all under flag of Russian Federation) are written off. 49 vessels are in operation with mean age of 29.3 years. Mean age of utilization – 22.5 years (!!!!!). The main diagram of write-off of vessels after 2003 has strongly marked exponential character, utilization is in progress, for example in 2016 2 vessels were utilized. 14 vessels are out of operation with mean age of 30.0 years (they probably also will be scrapped in near future). Relatively big number of lost vessels reflects attempts of owners to use such objects for non-standard transportations (for example in Indian Ocean etc.).

Ecological requirements made considerable impact on known series of combined vessels – oil-bulk ore carriers of 1570, 1553 projects (were under construction in 1968-1992). By the beginning of 2017, from 59 vessels 25.4% – 15 (6% – 1 was lost in accident, 14 were utilized) were written off. 25 vessels are in operation with mean age of 35.6 years. Mean age of utilization – 36.7 years. The main diagram of write-off of vessels after 2010 has strongly marked exponential character, utilization is in progress, for example in 2017 2 vessels were utilized. 19 vessels (!!!!!) are out of operation with mean age of 38.5 years, they probably also will be scrapped in near future.

From 66 tankers of the first series of 550, 558 projects of "Volgoneft" type (in fact, the first series of tankers which were used for river-sea oil transportations which were under construction in 1963-1972) 65.2% – 43 (4.7% – 2 vessels were lost in accidents, 41 vessels were utilized) are written off. 21 vessels are in operation with mean age of 48.3 years from them all under flag of Russian Federation. Mean age of utilization – 34 years. The main diagram of write-off of vessels, as a rule, keeps linear character that is sign of equable utilization of objects. Vessels now are under operation, as a rule, in river that is actually visible from the diagram of write-off which is characteristic for river vessels. 2 vessels are out of operation with mean age of 49.5 years. The series is obviously demanded by the market that is actually visible from "equable" dynamics of utilization. Process of

write-off of the second series of 1577, 550A projects of "Volgoneft" type (were under construction in 1967-1982) is of great interest. From 131 tankers 8.3% – 11 (2 tankers were lost in accidents, 9 vessels were utilized) are written off. 105 tankers are in operation with mean age of 41.9 years from them all under flag of Russian Federation. Mean age of utilization – 37.8 years. 15 vessels are out of operation with mean age of 42.2 years. The main diagram of write-off of vessels after 2009 has strongly marked exponential character. Usually it reflects moral aging by MARPOL requirements to double bottom height. In 2009 5 tankers were written off at once. The series is obviously demanded by the market that is actually visible from "equable" dynamics of utilization.

Rather new dry-cargo vessels of 285, 289 and 787 projects of "Ladoga" type (were under construction in Finland in 1972-1989) oriented on river-sea transportations with operation on Saimaa Canal are not demanded by the market. From 27 dry-cargo vessels of this type 59.3% – 16 were utilized. 8 vessels are in operation with mean age of 34.2 years. 3 vessels are out of operation with mean age of 31.7 years. Mean age of utilization – 32.6 years. The main diagram of write-off of vessels after 2010 has strongly marked exponential character. It is seemed that the same destiny is prepared by the market to 2000 t vessels of 613, 620 projects of "Baltic" type (were under construction in Finland in 1977-1981). From 16 dry-cargo vessels of this type 25.0% – 4 were utilized. 8 vessels are in operation with mean age of 38.4 years. 4 vessels are out of operation with mean age of 36.7 years. Mean age of utilization – 33.3 years. The main diagram of write-off of vessels after 2010 has strongly marked exponential character.

Directly opposed tendency is observed with dry-cargo vessels of "Omskiy" type (were under construction in Russia and Romania in 1972-1995) special feature of which is possibility of transportation of 3000 tons at 3.20 m river draught that is extremely important for "shallow water" years. From 138 dry-cargo vessels of this type only 10.0% – 14 were written off. 111 vessels are in operation with mean age of 33.8 years. 13 vessels are out of operation with mean age of 29.5 years (generally because of bankruptcy of operators, for example, of Kent Shipping company). 87 vessels of this type are in operation under flag of Russian Federation.

Vessels of "Volgo-Don Max" class are definitely demanded not less than vessels of "Omskiy" type. For example, from 63 dry-cargo vessels of 05074 project of "Volzhskiy" type (were under construction in 1981-1999) 19% – 12 (2 vessels were lost in accidents, 10 vessels were utilized with mean age of 18.8 years) are written off. 47 vessels are in operation with mean age of 27.2 years. 4 vessels are out of operation with mean age of 27.0 years (generally because of bankruptcy of operators, for example, of Kent Shipping company). 20 vessels of this type are in operation under flag of Russian Federation. From 108 dry-cargo vessels of 1565 project of "Volgo-Don" type (were under construction in 1968-1990) 17% – 18 (5 vessels were lost in accidents, 13 vessels were utilized with mean age of 34.7 years) are written off. 81 vessels are in operation with mean age of 39.0 years. 9 vessels are out of operation with mean age of 44.6 years. 66 vessels of this type are in operation under flag of Russian Federation. From 119 dry-cargo vessels of 507, 507A, 507B projects of "Volgo-Don" type (were under construction in 1960-1980) 39% – 46 (4 vessels were lost in accidents, 42 vessels were utilized with mean age of 37.8 years) are written off. 51 vessels are in operation with mean age of 42.0 years. 22 vessels are out of operation with mean age of 46.3 years. The main diagram of write-off of vessels, as a rule, keeps linear character. The series is obviously demanded by the market that is actually visible from "equable" dynamics of utilization. However in 2017 9 vessels were written off at once because of physical aging.

Similar with dry-cargo vessels of "Omskiy" type tendency is observed on tankers of R-77 project of "Lenanef" type (were under construction in Russia and Bulgaria in 1972-1984) feature of which is small draught that is extremely important for operation on Siberian rivers for "Northern" delivery. From 53 tankers 13% – 7 (3 vessels were lost in accidents, 4 vessels were utilized with mean age of 37.0 years) are written off. 41 vessels are in operation with mean age of 38.6 years (all with flag of Russian Federation). 5 vessels are out of operation with mean age of 40.2 years.

With taking into account results of analysis of write-off of river-sea vessels of all projects it is possible to make conclusion about three models of write-off which are characteristic for native RSV: - write-off by classical scheme (1st model) in which considerable part of vessels of series is written off by reaching of maximal possible life term of vessels (as a rule, 25-30 years) and remained in operation vessels are written off by residual principle (by decreasing); - write-off by moral aging (2nd model) at which considerable part of vessels of series is written off at occurrence of certain external circumstances (collapse of the market, loss of economy in work of the vessel, discrepancy of the vessel to market conditions). Therein mean age of write-offs of vessels of series may be less than design life term ("ST" type vessels of 19620, R-168, 191 projects) or much higher ("Volgo-Balt" type vessels of 2-95, 2-95A/R projects); - write-off by combined scheme (3rd model) at which river-sea vessels of series are written off gradually depending on reaching of possible life term, operation models and Shipowner.

Write-off by classical scheme is characteristic for river-sea vessels which were / are operated mainly in river (21-88, 21-89 projects of "Czech" type, 576 project of "Shestaya pyatiletka" type) or at sea areas only (566 project of "Oleg Koshevoy" type (1st series), 1588 project of "Vasiliy Shukshin" type, 1572 project of "Kishinev" type).

Write-off by moral aging is characteristic for river-sea vessels built for special purposes which are not actual as for today (19620, P-168, 191, 037 projects of "ST" type, 2-95, 2-95A/R projects of "Volgo-Balt" type, 326, 326.1 projects of "STK" type, combined vessels – oil-bulk ore carriers of 1570, 1553 projects, 285, 289 and 787 projects of "Ladoga" type, 1810, 1841 projects of "Morskoy" type, D-080, D-080M projects of "Slavutich" type, 1557 project of "Sormovskiy" type).

Write-off by combined scheme is characteristic for river-sea vessels actual as for today but which are being scrapped by different reasons - technical condition, emergency cases, bankruptcy of Shipowner etc. (781, 781e, 613, 620 projects of "Baltic" type, 550, 558, 550A, 1577 projects of "Volgoneft" type, R-77, 621 projects of "Lenanef" type, 507A, 507B, 1565 projects of "Volgo-Don" type, 05074 project of "Volzhskiy" type, 1743, 1743.1 projects of "Omskiy" type, 292, 0225 projects of "Sibirskiy" type, 19610, 19611 projects of "Volga" type).

Thus many of such vessels can lose their actuality in future and the first or the third model of write-off will be changed to the second one.

For example, tankers which do not meet MARPOL requirements since 2018 or vessels which are not equipped additionally with ballast water treatment system according to the Ballast Water Management Convention BWM-2004 to the next after 2017 September survey [3].

It is possible to predict write-off of river-sea vessels generally for all fleet of all projects but such estimation will be very rough as curves of write-off of different projects considerably differ from each other and have probabilistic character.

For each project with account of research data and models of write-off it is possible to predict following terms of decommissioning (see Table 1).

CONCLUSIONS

From 2195 investigated river and river-sea vessels of the most known series, which were built from 1956 to 1999, 812 vessels (37%) are written off for today. 98 vessels (12%) were lost in accidents with mean age of 29.7 years. 714 vessels were utilized with mean age of scrapping of 35.2 years, 342 (48%) of which were not under flag of Russian Federation.

1179 vessels are in operation with mean age of 37.5 years (948 are under flag of Russian Federation). 204 vessels are out of operation with mean age of 40.6 years. Forecast on 2020 – 835 vessels of old types in operation, on 2025 – 362 vessels. So in 5-10 years more than 50-70% of operated nowadays fleet will be quite objectively written off that will lead to collapse of volumes of transportations on water transport.

The main criteria of future mass write-off of river and river-sea vessels are as follows [2, 3]: - extreme physical wear; - moral aging because of economy, ecology requirements and own vessels' characteristics; - high investments in maintenance of due technical condition of vessels for passing of Register classification survey (documents are active within 5 years on condition of annual confirmation). As a result repair costs and confirmation of classification documents do not pay off within 4-5 years on those directions and cargoes where the vessel works, i.e. repair and confirmation of class are economically inexpedient; - in case when further operation of the vessel threatens safety of navigation and it is connected with high risks of accident; - in case when growth of operational expenses connected with maintenance of vessels in operation (fuel, oil, spare parts, materials, insurance etc.) does its further operation unprofitable. As is evident from the foregoing forthcoming write-off of water transport industry fleet will make essential, almost irreplaceable damage, first of all, to inland and river-sea transportations. Despite on high in the series mean age write-off process of two types of vessels is slow and, as a rule, is connected with technical conditions. These are "Volgo-Don Max" class type vessels which provide the maximal river loading capacity and "Omskiy" type vessels loading capacity of which is about 3000 tons on draught of 3.20 m.

It allows to recommend to build new vessels with such philosophy of work – "Volgo-Don Max" in dry-cargo, oil and combined variants and vessels instead of "Omskiy" type as vessels which are actually chosen by the market.

Table 1. Forecast of RSVs write-off on June, 2017

Type / project	Forecast year of the series write-off	Residual operation time, years	Number of vessels in operation on 2017, un.	Forecast number of vessels on 2020, un.	Forecast number of vessels on 2025, un.
"Baltic" (613, 620 pr.)	2026	9.0	8	5	1
"Baltic" (781, 781e pr.)	2020	3.0	7	1	-
"Amur" (92-040 pr.)	2029	12.0	34	28	17
"Vasiliy Shukshin" (1588 pr.)	2020	3.0	4	1	-
"Volga" (19610, 19611 pr.)	2036	19.0	41	37	31
"Volgo-Balt" (791 pr.)	2018	1.0	3	-	-
"Volgo-Balt" (2-95A/R, 2-95 pr.)	2025	8.0	91	60	5
"Volgo-Don" (507A, 507B pr.)	2030	13.0	51	38	14
"Volgo-Don" (1565 pr.)	2034	17.0	81	70	56
"Volzhskiy" (05074 pr.)	2036	19.0	47	40	27
"Ivan Schepetov" (16510 pr.)	2035	18.0	3	3	2
"Czech" (21-88, 21-89 pr.)	2025	8.0	53	29	4
"Kishinev" (1572 pr.)	2020	3.0	6	1	-
"Ladoga" (285, 289, 787 pr.)	2021	4.0	8	3	-
"Nevskiy" (R-32, R-32A, R-32K pr.)	2034	17.0	36	30	18
"Omskiy" (1743, 1743.1 pr.)	2029	12.0	111	86	41
"Morskoy" (1814dwt, 1810 dwt pr.)	2019	2.0	2	-	-
"Refrigerator" (037 pr.)	2019	2.0	2	-	-
"Sibirskiy" (292, 0225 pr.)	2028	11.0	31	27	11
"Slavutich" (D-080, D-080MK pr.)	2023	6.0	9	5	-
"Sormovskiy" (1557 pr.)	2027	10.0	63	44	19
"Sormovskiy" (488 pr.)	2033	16.0	34	29	17
"STK" (326, 326.1 pr.)	2024	7.0	38	16	-
"ST" (191, 19620, 19621, R-168 pr.)	2026	9.0	49	32	9
"Finskiy" (1000 pr.)	2030	13.0	14	10	4
"Shestaya pyatiletka" (576 pr.)	2022	5.0	53	28	-
"Neftodovoz" (1570 pr.)	2023	6.0	25	12	-
"Volgoneft" (550, 558 pr.)	2024	7.0	21	14	-
"Volgoneft" (630 pr.)	2038	21.0	9	8	6
"Volgoneft" (550A, 1577 pr.)	2027	10.0	105	78	30
"Lenaneft" (R-77 pr.)	2027	10.0	41	29	11
"Lenaneft" (621 pr.)	2038	21.0	28	25	20
"Bunkrovshik" (610 pr.)	2028	11.0	49	35	16
"Oleg Koshevoy" (1677 pr.)	2026	9.0	22	11	3
"Oleg Koshevoy" 1st series (566 pr.)	2018	1.0	0	-	-
Total			1179	835	362

REFERENCES

- [1] V.A. Voynichencko. Market of dry-cargo vessels: when forecasts are failed // Ukrainian ports. - 2014. - №10 (in Russian).
- [2] G.V. Egorov, A.G. Egorov. River and river-sea vessels: roles of "old" series of vessels and their perspectives // Maritime Market. - 2017. - №1 (59) - pp. 18-30 (in Russian).
- [3] G.V. Egorov, A.E. Nilva, D.V. Kolesnyk. Operation of ballast water systems on new and existing vessels: practical experience and existing problems // Maritime Market. - 2017. - №2 (60) - pp. 22-34 (in Russian).
- [4] Official website of Hellenic Shipping news. URL: <http://www.hellenicshippingnews.com/ship-demolition-market-hits-standstill-while-shipping-needs-more-scraping-to-recover/>.
- [5] Official website of Compass Maritime company. URL: <http://www.compassmar.com/reports/Compass%20Maritime%20Weekly%20Market%20Report.pdf>.

DESIGN FEATURES OF DIVING VESSELS FOR CASPIAN REGION

Gennadiy V. EGOROV*, V.O. MUSTAFAYEV**, Oyrad M. ABDULLAEV***

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – The State Maritime Administration of Azerbaijan Republic (Baku, Azerbaijan)

*** – Caspian Marine Engineering Bureau (Baku, Azerbaijan)

Abstract. In paper main features of Caspian region existing vessels intended for execution of underwater technological operations are provided.

The perspective 1550 project vessel with diving complex is supposed to operate at works connected with building and operation of offshore structures. The analysis of functions of the modern diving vessel, launching and lifting gear and diving equipment with its impact assessment on sizes and main characteristics of vessels, including underwater cutting and welding, underwater explosive works, mounting and laying of subsea pipelines, repair of subsea pipelines is made.

For carrying-out of works provided by 1550 project vessel, as a part of diving complex mounting of multi-section decompression tank, diving bell, launching and lifting gear and electric power plant of diving complex is supposed.

Keywords: decommissioning, disposition, forecast, river-sea vessel, utilization.

INITIAL PROBLEM

Construction and operation of objects of sea oilfield are not possible without carrying out of underwater and technical works. In turn organization of such works requires availability of self-propelled platform – vessel on which installation of diving complex allowing main types of diving works is foreseen.

Main working depths which are of interest on Azerbaijan oilfields are up to 60 m. With taking into account used organisation and technology of underwater and technical works requirements to parametres of stationary diving complex can be formed that in turn determines also parametres of future vessel on which this complex will be based. However existing publications are generally dedicated to design of vessels for providing emergency salvage readiness [5, 6, 7].

AIM OF THE PAPER

Formulation of goals and tasks of research of system analysis and optimization of parametres of stationary diving complex for performance of main diving works at depths up to 60 m.

MAIN TEXT

Earlier questions appeared at design stage of such vessels including problems and approaches to formation of diving complex were investigated.

For example in [16, 17] classic ventilated diving equipment and tools for underwater immersions and underwater works were reviewed, description of vessels for work at depths up to 60 m – diving raid and sea boats with description of their operation area and applied equipment is given. It has been shown that sea diving vessels provided functioning of two diving stations (6-7 people) with recompression chamber.

In [12] fundamentals of carrying out underwater and technical works on building stage including of hydraulic structures and fixed drilling rigs, on laying and repair of underwater pipelines, underwater welding and metal cutting were explicated.

In publications of R.N. Karayev [10, 11] classification of underwater and technical works based on types of operations is offered; factors defining efficiency of diver actions under water when executing underwater and technical works on sea oil and gas fields are considered. Nomenclature of works which are carried out at inspection of sea bed, and also features of underwater inspections of sea oil and gas structures of different types are specified.

In [2] underwater equipment for work on sea oilfields including for observation of established estuarial equipment, for repair and pipe laying is presented. Descriptions of diving complexes including decompression chambers, control posts of diving operations, systems of supply of diving complexes with energy and gases, communication systems, diving stages, diving bells, breathing apparatus, means of mechanization of works are given. It is shown that feature of diving vessels is presence of stationary diving complex, cranes, and also equipment for dynamic positioning onboard.

In [9] fundamentals of diving business, equipment and tools, specifics of diver immersions on oilfields, and also features of underwater works on floating drilling rigs, pipe-laying barges and other structures were reviewed in detail.

Big number of publications is dedicated to modern decisions for underwater works at all stages of construction and operation of sea oilfield objects. For example in [1] machines and mechanisms for underwater works including underwater tools are provided. In [15] description of equipment and tools applied at underwater welding and cutting is given. In [14] modern methods of underwater welding and cutting are proved. In [19] basics of choice of working tools for divers and underwater vehicles are given; descriptions of manual and mechanized underwater tools, standard items applied in the USA underwater technologies are provided. In [18] modern systems of underwater communication are described. In [4] analysis of modern load-transfer diving chambers was executed.

In publication [8] sound-imaging devices – high-resolution compact underwater sound systems, small-type multi-beam sonars working at high frequency from 450 kHz to 2.25 MHz were described.

In [13] micro and mini remotely operated underwater vehicles (ROUV) are given. Modern micro ROUVs with weight up to 5 kg can work at depths up to 150 m. They equipped with low light video cameras, laser pointers, one / two-degree grasp manipulators, devices of non-destructive testing, etc. Mini ROUVs already have weight up to 30 kg and can solve the widest range of underwater and technical tasks. Usage of ROUVs as additional tool of control of underwater situation during diver immersions allows considerably to increase efficiency and safety of works.

However publications connected with choice of optimal parametres of new diving vessels with modern diving complexes onboard for work on oilfields do not exist.

Taking into account that the problem of optimization of parametres of diving complex is multi-objective and multi-level it is foreseen to make systematization of parametres of research and to create main directions of optimization of parametres of diving complex with taking into account operational risks of diving complex. It is supposed to make the solution of problem of systematization of object of research in three stages. At the first stage it is provided to systematize criteria of optimization of diving complex. At the second stage to systematize criteria of optimization of configuration of diving equipment. At the final stage formation of main task of research by making generalized system analysis and selection of the most important criteria of optimization is provided.

For task solution it is supposed to formulate main problem of research and to create main directions of research namely to externalize main scope of works performed by stationary diving complex.

Formation of block diagram reflecting interrelation of elements of diving complex, configuration of diving equipment, criterion of risk and formation of optimization criteria of diving complex is supposed.

Volume of supposed works which will be carried out by perspective vessel of 1550 project

Scope of works of 1550 project diving vessel can be based, for example, on functions of new diving vessels of SDS08 project:

- providing of diving and underwater works on depth up to 100 m and at sea up to 3 Beaufort scale;
- participation in rescue, ship-raising and underwater works in accordance with installed means;
- inspection of sea bed, sunk objects, underwater part of ships' hull and hydraulic structures;
- providing of ROUVs work at sea up to 4 Beaufort scale;
- scanning of sea bed, underwater parts of ships and rudder-propeller devices of ships, underwater parts of hydraulic structures and providing of underwater works with divers;
- providing of underwater welding on depth up to 25 m and underwater cutting on depth up to 100 m;
- lifting from depth up to 100 m objects of weight up to 2.0 t;
- soil abrasion and removal;
- pumping of water from ship in distress;
- air blow of pontoons;
- work with hydraulic tools.

Main characteristics of SDS08 sea diving vessels are shown in Table 1.

Perspective vessel of 1550 project on which installation of diving complex is supposed is going to be operated at works connected both with building and operation of objects of sea oilfield [2, 9, 10, 11]. Following works will be performed: works connected with underwater cutting and welding, underwater explosive works, mounting and laying of subsea pipelines, repair of subsea pipelines, installation of stationary offshore platforms on ground, mounting of protectors of electrochemical protection on objects of sea oilfield, mounting of estuarial equipment, etc. All abovementioned works will be carried out at depths up to 60 m.

System analysis and optimization criteria of diving complex equipment

For performance of works provided on perspective vessel of 1550 project as part of diving complex installation of multi-section decompression chamber, diving bell, launching and lifting gear [3, 4] and power plant of diving complex is supposed. Characteristics of above mentioned equipment directly depend on number of working simultaneously divers and nature of executing operations. Interrelation of diving complex equipment is reflected on block diagram (see Fig. 1).

Table 1. Main characteristics of SDS08 sea diving vessels

Name	Value
Length overall, m	38.64
Length, m	36.35
Breadth overall, m	7.90
Breadth, m	7.70
Depth, m	3.20
L x B x H	38.64 x 7.90 x 3.20 = 977
Draught at SLWL, m	2.35
Deadweight in sea at draught 2.35 m, t	42
Endurance, days	5
Navigation range at economic speed, nautical miles	500
Russian Maritime Register of Shipping class	KM Ice2 R2 AUT3-C OMBO SDS >60
ME power, kW	2 x 442
Screw and Rudder	2 CPP + 2 rudders
Cargo crane, capacity, t / boom, m	3 / 11.5
Bow thruster, kW	120
Auxiliary diesel-generators, kW	2 x 136
Crew / berth	12 / 15
Speed (at draft 2.35 m and 100% MCR), knots	11.4
Economic speed, knots (at draft 2.10 m)	8.0
Diving equipment	Compression chamber for 4 divers; "Wet" diving bell with launching gear; Diving equipment with helmet SUPERLITE and ventilated helmet DESCO; Universal diving equipment of "dry" type; Means of diver's heating; Means of communication; Underwater lighting; Underwater television; Underwater welding/cutting; Hydraulic tools; Pontoons; Pumping means; Soil man-induced means; Remote operated underwater vehicle; Diving ladder.

Number of working simultaneously divers, number of decompression chamber sections, type of diving bell, type of launching and lifting gear and structure of power plant of diving complex are foreseen as criteria of optimization of diving complex.

System analysis and optimization criteria of diving gear

Onboard perspective vessel of 1550 project presence of gear necessary for performance of diving works is foreseen. As part of diving complex ventilated equipment, diving masks and helmets, underwater television, diving suits, voice communication, cargo belt, diver's breathing hose, autonomous equipment and underwater tools are foreseen. For ensuring safety and reliability of diving works with taking into account risk conditions optimization of configuration of diving gear is provided. Specific configuration and criteria of optimization of diving gear are reflected at block diagram in Fig. 2.

Figure 1. Block diagram of diving complex optimization model

Figure 2. Block diagram of diving gear optimization model

For example up-to-date equipment for diving and salvage works was mounted onboard SDS08 vessel for carrying out mentioned special functions.

Double-compartment stream-decompression low-pressure chamber (see Fig. 3) with inner diameter of 1600 mm allows to carry out simultaneous decompression of two turns of divers with different pressures.

Capacity of each compartment is of two lying and four seat places. Working pressure is of 10 kg per sq. cm.

Monoblock for storage of compressed helium and oxygen are included in set for helium and oxygen feeding of low-pressure chamber and also for carrying out diving immersions into diving bell using 10% gas mixture of oxygen-nitrogen-helium. Monoblocks consist of six balloons with capacity of 50 liters and working pressure of 200 kg per sq. cm. There are six monoblocks for helium storage (two monoblocks for feeding the low-pressure chamber and four ones for carrying out immersions), and two monoblocks for oxygen storage (first monoblock for feeding the low-pressure chamber and second one for carrying out immersions). Monoblocks of balloons are mounted onto vessel's deck. Monoblocks assigned for carrying out diving immersions can be stored both onboard and on shore and can be mounted onboard only for carrying out works at depth down to 60 m and 100 m.

Compressors of "BAUER" company are applied for charging the air balloons used for low-pressure chamber and diving immersions. Compressors mounted onboard the vessel are of special navy type (increased vibrodamping and burst-proof quality, durability to the corrosion in sea conditions and ability for operation during roll up to 30 degrees).

Integrated control panel mounted at diving station (see Fig. 4 and Fig. 5).

Figure 3. Example of diving altitude chamber on SDS08 vessel

Figure 4. Integrated control panel

Integrated control panel carries out following functions:

- control of launch and lifting of "wet" diving bell;
- feeding the air and oxygen to the "wet" diving bell;
- gas feeding to the low-pressure chamber;

- communication with divers that are submerged and into the low-pressure chamber;
- video surveillance and control of divers' work that are submerged and into the low-pressure chamber;
- video surveillance and control of immersions of "wet" diving bell.

Configuration of panel allows to control all technological process from single work station.

Immersion of divers can be carried out both using diving ladder and "wet" diving bell.

"Wet" diving bell mounted onboard is assigned for immersion of three persons – two working divers and single operator of diving bell to the depth up to 60 m using air and up to 100 m using breathing diving gas. "Wet" diving bell is equipped with system of gas distribution and gas feed system, systems of external and internal lighting and video surveillance, system of oxygen breathing BIBS-mask, communication system with helium speech corrector.

Launch and lifting gear of "wet" diving bell provides its carry-over outboard, launch/lifting of "wet" diving bell with specified rate, automatic delivery of cable-hose bundle of diving bell. General view of launch and lifting gear of "wet" diving bell is shown on Fig. 6.

Plant for divers' water-heating is foreseen for heating and feeding of outside water through cable-hose bundle to the diving equipment. Number of divers connected to the plant is of 3. Water consumption is of 15...41 liters per minute. Water temperature is of 30...60°C.

Delivery of diving equipment onboard the vessel is foreseen. Diving equipment consists of: facilities of working diver; facilities of "wet" diving bell operator; underwater illumination facilities; underwater television; divers' water-heater facilities; set for underwater welding/cutting; soil man facilities.

Figure 5. Integrated control panel

Figure 6. Launch and lifting gear of "wet" diving bell

System analysis and generalized optimization criteria of diving complex

By synthesis of block diagrams of diving equipment and gear optimization models formation of block diagram of diving complex optimization model is made (see Fig. 7).

On block diagram in Fig. 7 interaction of elements of diving complex, configuration of diving gear and power plant of diving complex is considered and criteria of optimization of diving complex of perspective vessel of 1550 project is formed.

CONCLUSIONS

Within considered task systematization of elements of stationary diving complex supposed for installation on perspective diving vessel of 1550 project for performance of diving works at depth up to 60 m was carried out and criteria of optimization of diving complex which is the main goal of research is formulated.

Figure 7. Block diagram of diving complex optimization model

REFERENCES

- [1] V.L. Baladinskiy, V.A. Lobanov, B.A. Galanov. *Technique and mechanisms for underwater work*. - SPb: Shipbuilding, 1979. - 192 p (in Russian).
- [2] P.A. Borovikov, V.N. Samarskiy. *Underwater technique of sea oilfield*. - SPb: Shipbuilding, 1980. - 176 p (in Russian).
- [3] B.A. Bugaenko, V.E. Magula. *Special ship gears*. - SPb: Shipbuilding. - 1983. - 392 p (in Russian).
- [4] A.F. Gal', M.A. Dubina. Analysis of modern load-transfer diving chambers as objects of ship salvaging // Collection book of NUS. - Nikolayev: NUS, 2008. - No2. - pp. 32-37 (in Russian).
- [5] A.N. Gurovich, A.V. Rodionov. *Design of salvage and firefighting vessels*. - SPb: Shipbuilding, 1971. - 284 p (in Russian).
- [6] G.V. Egorov. Grounding of "lineup" of multifunctional rescue and salvage vessels for work in adjacent seas of Russia // Marine innovative technologies: Proceedings of Maritime State university named after Admiral G.I. Nevelskoy. - 2015. - Vol. No3 (29). - Part 1. - pp. 28-44 (in Russian).
- [7] G.V. Egorov, V.I. Tonyuk. Sea diving vessels of "Stolnyi grad Yaroslavl" type // Shipbuilding. - 2012. - No3. - pp. 17-23 (in Russian).
- [8] Sound-imaging device of "Triton-900" type // Neptune. - 2015. - No5. - pp. 96-98 (in Russian).
- [9] N.B. Zinkovskiy. *Underwater works on oilfield*. - SPb: Shipbuilding. - 1984. - 232 p (in Russian).
- [10] R.N. Karaev, V.N. Razuvaev. Classification and organization fundamentals of underwater and technical works on sea oilfield // Maritime Reporter. - 2012. - Special issue 1(9). - pp. 82-84 (in Russian).
- [11] R.N. Karaev, V.N. Razuvaev. Underwater inspections carried out on sea oilfield aquatic area // Maritime Reporter. - 2012. - Special issue 1(9). - pp. 84-86 (in Russian).
- [12] N.A. Kitsak, K.A. Zabela. *Underwater and technical works in building process*. - Kiev: Budivelnik. - 1970. - 164 p (in Russian).
- [13] L.M. Klyachko, A.V. Rogozhnikov, V.V. Sukhomosov. Remotely operated underwater vehicles of "micro" and "mini" classes // Neptune. - 2014. - No4. - pp. 94-98 (in Russian).
- [14] V.Ya. Kononenko. Underwater welding and cutting in CIS countries // Automatic welding: Institute of electric welding named after E.O. Paton of Ukrainian NAS. - 2014. - No6-7. - pp. 43-48 (in Russian).
- [15] N.M. Madatov. *Underwater welding and metal cutting*. - SPb: Shipbuilding. - 1966. - 164 p (in Russian).
- [16] I.V. Merenov. *Diving works*. - M: Transport. - 1971. - 184 p (in Russian).
- [17] I.V. Merenov, V.V. Smolin. *Guidance for diver. Questions and answers* - SPb: Shipbuilding. - 1990. - 400 p (in Russian).
- [18] S. Polyakov. Systems of underwater telecom of "Ocean Reef" type // Neptune. - 2015. - No5. - pp. 102-107 (in Russian).
- [19] D. Hackman, D. Kodi. *Underwater tools*. - SPb: Shipbuilding. - 1985. - 128 p (in Russian).

RESEARCH OF INFLUENCE OF RESTRICTED AREA NAVIGATION CLASSES ON METAL CONSUMPTION OF RIVER-SEA VESSEL

Olga G. EGOROVA

Marine Engineering Bureau (Odessa, Ukraine), scientific researcher, PhD Student

Abstract. It is shown in paper that the classes of restricted area of navigation R2, R2-RSN and R2-RSN4,5 will have a small difference in the hull's weight for the vessel designed according to the hull's minimum thicknesses due to the Rules' requirements.

As the reduction of the area of navigation gives the reserve in the required section modulus, the hull's elements, due to which is possible to vary hull's weight are the elements that are involved in ensuring of the longitudinal strength of the vessel.

Changing of the vessel's class to the limited area of navigation R3-RS (R3-RSN) gives a noticeable difference in the hull's weight, which is possible due to the coefficient that reduces the hull's minimum thicknesses, according to the Rules' requirements as well as a significant difference in the required section modulus of the deck and bottom under the general hull's bending.

Keywords: hull, metal consumption, river-sea vessel, Rules, strength.

INITIAL PROBLEM

The fleet of mixed river-sea going vessels is morally and physically obsolete and its renewal is required up to date [1]. From the economic point of view, new vessels, especially those which carrying bulk cargo (tankers [2], universal multi-purpose dry cargo vessels, combined vessels [3]) should have the maximum possible carrying capacity [4].

Oil and oil products are the main energy resource, which has no full alternative replacement. Despite the negative temporary trends in the market, its transportation is quite profitable over the long term. So, the replacement of mixed river-sea going oil tankers' fleet will be required first of all.

AIM OF THE PAPER

Optimization of the design of mixed river-sea going oil tankers' hulls due to rational class assignment.

MAIN TEXT

Class assignment by the areas of navigation depends on the planned direction of cargo transportation; estimation of possible loss of running time from downtime in expectation of weather; definition of ice category in accordance with the accumulated work experience; assigning of an economically justified vessel's service life [5, 6, 7].

The main object for the study is a "super-fat" mixed river-sea going tanker with the block coefficient of 0.932 designed by Marine Engineering Bureau [2].

Calculation of the required dimensions of hull parts' members of the tanker for restricted areas of navigation was carried out according to the Rules of the Shipping Register of Ukraine (RSU) [8-11] and the Rules of the Russian Maritime Register of Shipping (RMRS) [12] for classes R2, R2-RS, R2-RS (4.5), R3-RS and R2, R2-RSN, R2-RSN (4.5) and R3-RSN respectively.

Analysis of the required thickness for the tanker, among other things, showed the difference between the RSU and RMRS for some types of hull structures and coefficients. It will be shown below.

Requirements for the minimum thickness of the center girder of a single bottom

So, for example, the requirements for the minimum thickness of the center girder of a single bottom are set out in p. 2.3.4.1.2 and p.2.3.4.2.8 of the RSU Rules for sea-going vessels. Thus, according to the p. 2.3.4.1.2 (see Eqn. 1.) of the RSU Rules (this paragraph gives a more strict result), for the vessel of restricted area of navigation R2 in the area of $0.1 L$ from the fore and aft perpendiculars the thickness of the center girder's wall of the single bottom s , mm, should not be less than defined by the formula:

$$(1) \quad s = (0.06L + 6)K - 1 = (0.06 \cdot 136.29 + 6) \cdot 0.9 - 1 = 11.76 \text{ mm.}$$

In turn, according to p. 2.3.4.3 (see Eqn. 2) of the RMRS Rules, for the vessel of restricted area of navigation R2 with the length more than 80 m, the thickness of the center girder's wall of the single bottom, mm, should be not less than the determined by the formula:

$$(2) \quad s = (0.025L + 6.5)K - 1 = (0.025 \cdot 136.29 + 6.5) \cdot 0.9 + 1.5 = 10.42 \text{ mm.}$$

Further, according to p. 2.3.4.1.2 (see Eqn. 1) of the RSU Rules for sea-going vessels, the thickness of the center girder's flange should be 2 mm larger than the thickness of the center girder's wall, which makes the central girder size for the considered tanker of $s_{12/14} \cdot 120$ – while the central girder size of the single bottom by the RMRS Rules is possible as $s_{1/2} \cdot 120$.

Requirements for the minimum thickness of the side girders in the forepeak and afterpeak

According to p. 2.8.4.7 (see Eqn. 3) of the RSU Rules for sea-going vessels with restricted area of navigation R2, the thickness of the side girder's wall in the forepeak and afterpeak for transverse framing, s , mm, should not be less than defined by the formula:

$$(3) \quad s = (0.025L + 5.75)K = (0.025 \cdot 136.29 + 5.75) \cdot 0.9 = 8.24 \text{ mm.}$$

While, according to p. 2.8.4.5 (see Eqn. 4) of the RMRS Rules for the vessel of the restricted area of navigation R2, the thickness of the side girder's wall of steel with yield strength of 315 MPa in the forepeak and afterpeak, s , mm, should be not less than defined by the formula:

$$(4) \quad s = (0.02L + 5)K\sqrt{\eta} = (0.02 \cdot 136.29 + 5) \cdot 0.9 \cdot \sqrt{0.78} = 6.14 \text{ mm,}$$

but not less than 5 mm.

Requirements for the minimum thickness of plates and frame of a non-tight platform

According to p. 2.8.4.1.4 (see Eqn. 5) of the RMRS Rules for a vessel of the restricted area of navigation R2, the thickness of the non-tight platform's plating with a yield strength of 315 MPa, s , mm, should be not less than defined by the formula:

$$(5) \quad s = (0.02L + 5)K\sqrt{\eta} = (0.02 \cdot 136.29 + 5) \cdot 0.9 \cdot \sqrt{0.78} = 6.14 \text{ mm,}$$

but not less than 5 mm.

In the RSU Rules for sea-going vessels, there are no requirements for minimum thickness of plating and framing of the non-tight platform.

The minimum thickness of the superstructures' side shells

According to p. 2.12.4.1 (see Eqn. 6) of the RSU Rules for sea-going vessels of the restricted area of navigation R2, the thickness of the forecastle's side shell, s , mm, should be not less than defined by the formula:

$$(6) \quad s = (0.045L + 4)K\alpha = (0.045 \cdot 136.29 + 4) \cdot 0.9 \cdot 0.9 = 8.21 \text{ mm.}$$

According to p. 2.12.4.1 (see Eqn. 7) of the RSU Rules for sea-going vessels of the restricted area of navigation R2, the thickness of the poop's side shell, s , mm, should be not less than defined by the formula:

$$(7) \quad s = (0.04L + 4)K\alpha = (0.04 \cdot 136.29 + 4) \cdot 0.9 \cdot 0.9 = 7.66 \text{ mm.}$$

In turn, according to p. 2.12.4.1-1 (see Eqn. 8) of the RMRS Rules of the restricted area of navigation R2, the thickness of the side shell of poop and forecastle with a yield strength of 235 MPa, s , mm, should be not less than defined by the formula:

$$(8) \quad s = (0.025L + 4.5)K\sqrt{\eta} = (0.025 \cdot 136.29 + 4.5) \cdot 0.9 \cdot \sqrt{1} = 7.12 \text{ mm.}$$

Minimum thickness of forecastle's deck plating

According to p. 2.12.4.1 (see Eqn. 9) of the RSU Rules for sea-going vessels of the restricted area of navigation R2, the thickness of the forecastle deck plating, s , mm, should be not less than defined by the formula:

$$(9) \quad s = (0.03L + 3.5)K\alpha = (0.03 \cdot 136.29 + 3.5) \cdot 0.9 \cdot 0.9 = 6.15 \text{ mm.}$$

According to p. 2.12.4.2 (see Eqn. 10) of the RSU Rules for sea-going vessels of the restricted area of navigation R2 with a length greater than 100 m, the thickness of the forecastle's deck plating with a yield strength of 235 MPa, s , mm, should be not less than defined by the formula:

$$(10) \quad s = (0.01L + 7.0)K\sqrt{\eta} = (0.01 \cdot 136.29 + 7.0) \cdot 0.9 \cdot \sqrt{1} = 7.53 \text{ mm.}$$

According to p. 2.12.4.2 (see Eqn. 11) of the RSU Rules for sea-going vessels of the restricted area of navigation R2, the thickness of the forecastle's deck plating with a yield strength of 235 MPa, s , mm, should be not less than defined by the formula:

$$(11) \quad s = (0.01L + 5.0)K\sqrt{\eta} = (0.01 \cdot 136.29 + 5.0) \cdot 0.9 \cdot \sqrt{1} = 5.73 \text{ mm.}$$

Factors of permissible normal and sheer stresses $k\sigma$ and $k\tau$

The principle of including of the normal and sheer stresses factors $k\sigma$ and $k\tau$ during determining the hull members according to the RSU Rules for sea-going vessels differs significantly from the factors of permissible normal and sheer stresses $k\sigma$ and $k\tau$ according to the RMRS Rules.

This can be seen from the example of determining the thickness of the bottom and side shell plating, where according to the RSU Rules for sea-going vessels for determining the bottom shell plating with a longitudinal framing system in the midship region, the permissible stress factor $k\sigma$, according to p. 2.2.4.1 (see Eqn. 12), is defined as follows:

$$(12) \quad k\sigma = 0.9 + 0.75 \cdot 0.2 = 1.05.$$

And the thickness of the bottom shell plating with the longitudinal framing system in the midship region, according to the RMRS Rules (p. 2.2.2.1, see Eqn. 13) is as follows:

$$(13) \quad k\sigma = 0.6.$$

When determining the thickness of the bottom plating with a longitudinal framing system in the region $x_1/L \geq 0.4$ from midship to the ends, according to the RSU Rules for sea-going vessels, the permissible stress factor $k\sigma$, according to 2.2.4.1 (see Eqn. 14), is defined as follows:

$$(14) \quad k\sigma = 0.9 + 0.75 \cdot 0.4 = 1.20.$$

The thickness of the bottom shell plating with a longitudinal framing system within the region $0.1L$ from the fore or aft perpendicular, according to the RMRS Rules (p. 2.2.2.1, see Eqn. 15) is as follows:

$$(15) \quad k\sigma = 0.7.$$

This difference in approaches to the determination of normal and sheer stress factors becomes equal by using other factors in the further formulas during hull elements' calculation. The result is similar at the last (RSU Rules for sea-going vessels often gives the largest required elements' dimensions than RMRS Rules). Permissible stress factor $k\sigma$ that is more than 1 poses a question of possibility of its using in direct calculations of bottom and side shell plating according to the RSU Rules for sea-going vessels.

In addition, there is also a noticeable difference in the values of the safety factors $k\sigma$ and $k\tau$ in determination of the thickness of inner side vertical web depending on the load that acts on it.

According to p. 2.7.4.3 (see Eqn. 16) of the RSU Rules for sea-going vessels, the safety factors $k\sigma$ and $k\tau$ of the bulkheads' vertical web (for longitudinal bulkheads of tankers in the tank area, when tanks are filled to the top of the air tube):

$$(16) \quad k\sigma = 0.65, \quad k\tau = 0.55.$$

According to p. 2.7.4.3 (see Eqn. 17) of the RMRS Rules, the safety factors $k\sigma$ and $k\tau$ of the bulkheads' vertical web are as follows:

$$(17) \quad k\sigma = k\tau = 0.75.$$

As a result, according to the RSU Rules for the tanker of the restricted area of navigation R2, the required dimension of the inner side's vertical web in the area of cargo tanks is $12 \cdot 400 / 12 \cdot 110$, while according to the RMRS Rules for the same vessel in the corresponding class is $9 \cdot 400 / 12 \cdot 110$.

Coefficient ω_k according to the RSU Rules for sea-going vessels and RMRS Rules

Besides that, the approach to determination of the coefficient ω_k is different according to the RSU Rules for sea-going vessels and the RMRS Rules.

According to p. 1.1.5.3 (see Eqn. 18) of the RSU Rules for sea-going vessels, the coefficient ω_k which takes into account the corrosion and wear allowance to the section modulus of the framing members is as follows:

$$(18) \quad \omega_k = (0.85 / \sqrt[3]{W'}) + \sqrt[3]{\Delta s / 2},$$

but not less than 1.05 (not including the hull members with $\omega_k = 1$, according to the Rules)

While, according to p. 1.1.5.3 (see Eqn. 19) of the RMRS Rules, the coefficient ω_k , should be:

$$(19) \quad \omega_k = 1 + \alpha_k \Delta s, \text{ where } \alpha_k = 0.07 + \frac{6}{W'} \leq 0.25, \text{ due to } W'' < 200 \text{ cm}^3; \alpha_k = \frac{1}{0.15} \left(0.01 + \frac{1}{W'} \right) \text{ due to } W'' \geq 200 \text{ cm}^3.$$

Such a difference in approaches to the determination of the coefficient ω_k leads to the decrease of the section modulus' requirements of the members of rolled section by an average of 15-20% according to the RSU Rules for sea-going vessels in comparison with the RMRS Rules.

Slamming by the RSU Rules for sea-going vessels and by RMRS Rules

Consider the requirements for the slamming for the tanker of the restricted area of navigation R2 with the speed limitation during the slamming of $V_0 = 4.8$ knots. Dimensions for the bottom shell plating (600 x 1000 mm) with a yield strength of 315 MPa in the area of ballast tanks, according to the RSU Rules for sea-going vessels and the RMRS Rules should be as follows:

According to p. 2.8.4.2 (see Eqn. 20) of the RSU Rules for sea-going vessels, the thickness of the shell plating s , mm, should be not less than defined by the formula:

$$(20) \quad s = 13k_1 a \sqrt{p/R_{eH}} + \Delta s = 13 \cdot 0.95 \cdot 0.6 \cdot \sqrt{589.6/315} + 2.4 = 2.54 \text{ mm.}$$

While, according to p. 2.8.8.2 (see Eqn. 21) of the RMRS Rules, the thickness of the bottom shell plating of the same dimensions with the same initial conditions of the vessel s , mm, should not be less than the determined by the formula:

$$(21) \quad s = mak \sqrt{p/k_{\sigma} \sigma_n} + \Delta s = 15.8 \cdot 1 \cdot 0.6 \cdot \sqrt{235.8/0.7 \cdot 301.3} + 2.4 = 11.42 \text{ mm.}$$

According to p. 2.8.4.2 (see Eqn. 22) of the RSU Rules for sea-going vessels, the section modulus of bottom longitudinals W , cm^3 , should be not less than that determined by the formula:

$$(22) \quad W = 47 \frac{pa_1 l^2}{k_2 R_{eH}} k_3 \omega_k = 47 \frac{589.6 \cdot 0.5 \cdot 0.65^2}{1.25 \cdot 315} 1.75 \cdot 1.311 = 52.66 \text{ cm}^3.$$

While, according to p. 2.8.8.2 (see Eqn. 23) of the RMRS Rules, the section modulus of bottom longitudinals with the same dimensions and the same initial conditions W , cm^3 , should be not less than that determined by the formula:

$$(23) \quad W = 0.75 \frac{pal^2}{mk_{\sigma} \sigma_n} \omega_k \cdot 10^3 = 0.75 \frac{235.84 \cdot 0.5 \cdot 0.65^2}{16 \cdot 0.65 \cdot 301.3} 1.6 = 19.08 \text{ cm}^3.$$

According to p. 2.8.4.3 (see Eqn. 24) of the RSU Rules for sea-going vessels, the thickness of the floor web and the bottom girder s , mm, should be no less than defined by the formula:

$$(24) \quad s_{\phi} = \frac{0.76 p (L_0 - 50)}{(6.1 - a_2)(1.2 h_k + n h_{\phi} + 2 \sum h_c + 2 \sum h_{nc}) R_{eH}} = \frac{0.76 \cdot 589.6 (136.29 - 50)}{(6.1 - 0.6)(1.2 \cdot 1 + 5.577 \cdot 1 + 2 \cdot 3 + 2 \cdot 0) 315} = 4.15 \text{ mm.}$$

According to p. 2.8.4.3 (see Eqn. 25) of the RSU Rules for sea-going vessels, the thickness of central girder's web s , mm, should be not less than defined by the formula:

$$(25) \quad s_{\phi K} = 1.2 \cdot s_{\phi} = 1.2 \cdot 4.15 = 4.98 \text{ mm.}$$

While, according to p. 2.8.8.2 (see Eqn. 26) of the RMRS Rules, the wall's thicknesses of the floor web, the bottom girder and the central girder with the same dimensions and the same initial conditions of the vessel s , mm, should not be less than the determined by the formula:

$$(26) \quad s = 0.75 \frac{pab}{k_{\tau} \tau_n h} + \Delta s = 0.75 \frac{235.84 \cdot 0.5 \cdot 1.0}{0.65 \cdot 171.7 \cdot 0.98} + 2.4 = 3.35 \text{ mm.}$$

Comparison of the weight characteristics of the vessel for different areas of navigation is shown in Table. 1.

Table 1. Comparison of the weight characteristics of the vessel for different areas of navigation

Parametr	R2	R2-RS	R2-RS (4,5)	R3-RS
Deadweight, t :				
River	5354	5380	5387	5463
Sea	6955	6981	6988	7064
Displacement in sea at $d = 4.20$ m, t	9483	9483	9483	9483
Displacement in river at $d = 3.60$ m, t	7882	7882	7882	7882
Light weight (RSU Rules), t	2528	2502	2495	2419
Light weight (RMRS Rules), t	2512	2492	-	2402

Influence of classes of the restricted area of navigation on the metal capacity of the tanker' hull under consideration, designed according to the RSU Rules, is given in Table. 2.

Table 2. Influence the restricted area of navigation classes on the metal capacity of the tanker' hull under consideration, designed according to the RSU Rules

Vessel's class	R2	R2-RS	R2-RS (4,5)	R3-RS
Metal consumption in %	100	99	98.8	95.6

CONCLUSIONS

Based on obtained results, it can be concluded which thicknesses affect to the weight of the metal hull, depending on the classification society.

Considered vessel designed by required hull's minimum thicknesses that makes it possible to say that chosen design construction is rational in terms of its frame, the distance between the web members, the framing system and the hull material. In this case, it can be seen that for the classes of the restricted areas of navigation R2, R2- RS/ R2-RSN and R2-RS (4.5)/ R2-RSN (4.5), the weight of the metal hull will have a small difference due to the fact that the coefficients by which the minimum thickness of the hull can be reduced, is the same.

As the reduction of the area of navigation gives the reserve at the required hull's section modulus, the hull's members, due to whom its weight can be varied, are the members that are involved in ensuring of the overall vessel's longitudinal strength.

Therefore, the weight of the restricted areas of navigation R2, R2-RS/ R2-RSN and R2-RS (4.5)/ R2-RSN (4.5) differs only due to changes of the thickness of wall and flange of the trunk, which in turn can't be greatly reduced due to the buckling check of the trunk deck during sagging.

Changing of the vessel's class to a restricted area of navigation R3-RS/ R3-RSN gives a noticeable difference in the weight of the hull, which is possible due to the coefficients that can reduce the minimum thickness of the hull, and also because of the significant difference in the required section modulus of the deck and bottom in calculations of the overall strength.

REFERENCES

- [1] Egorov G.V., Egorov A.G. Perspectives of existent river-sea and river vessels // ONMU Reporter. - Odessa: ONMU, 2017. - Vol. 2 (51). - pp. 5-39 (in Russian).
- [2] Egorov G.V., Shablikov N.V. Mass construction of "superfat" river-sea cargo vessels // Maritime Market. - 2016. - No3 (57) - pp. 20-31 (in Russian).
- [3] Egorov G.V., Tonyuk V.I., Durnev E.Yu. "Superfat" combined RST54 vessels for transportation of oil products and dry cargo, as well as containers, rolling equipment and project cargoes // Shipbuilding. - 2017. - No4 - pp. 17-24 (in Russian).
- [4] Egorov A.G. Determination of the optimal value of block coefficient and operating speed of river-sea tug-barge combinations and integrated vessels // Maritime Reporter. - 2015. - No3 (55). - pp. 19-24 (in Russian).
- [5] Egorova O.G. Optimization of metal consumption of RST27 "Volga-Don Max" oil tanker of "VF Tanker" type due to rational class assignment // Materials of V int. scientific and technical. conf. "Innovations in shipbuilding and ocean engineering" - Nikolaev: NUS, 2014. - pp. 68-69 (in Russian).
- [6] Egorova O.G. Reducing of metal consumption of the mixed river-sea dry-cargo vessels due to choosing of an effective class by the area of navigation and rational geometry of the hull's cross-section // Materials of the all-ukrainian scientific-technical. conf. with int. part. "Modern technologies of design, construction, operation and repair of vessels, marine technical equipment and engineering structures" - Nikolaev: NUS, 2016. - pp. 41-43 (in Russian).
- [7] Egorov G.V. *Design and construction of coasters and mixed river-sea vessels*. - Odessa: "Shipbuilding and ship repair", 2008. - 128 p (in Russian).
- [8] *Rules for Classification and Construction of Sea-Going Ships*. Part 2. - Kiev, 2018 - 696 p (in Russian).
- [9] *Rules for Classification and Construction of Sea-Going Ships* - Bulletin 1. - Kiev, 2014 - 428 p (in Russian).
- [10] *Rules for Classification and Construction of Sea-Going Ships* - Bulletin 2. - Kiev, 2016 - 130 p (in Russian).
- [11] *Rules for Classification and Construction of Sea-Going Ships* - Bulletin 3. - Kiev, 2017 - 138 p (in Russian).
- [12] *Rules of Russian Maritime Register of Shipping*. Part 2. - SPb.: 2018 (in Russian).

APPLICATION OF UNIFIED DIMENSIONLESS FACTORS FOR ESTIMATION OF RESIDUAL OVERALL STRENGTH OF RIVER-SEA VESSEL'S HULL

Vladimir A. Nilva

Marine Engineering Bureau (Odessa, Ukraine), AMRINA, scientific researcher

Abstract. In the paper it is shown, that the estimation of the vessel's damaged hull strength is performed in conditions of incomplete initial information of damage, i.e. its type and size. The use of specific damage models allows to produce the dependence of the damage characteristics due to probable damage's size.

Specific damage models were used to determine the dimensionless values specified in the work. The models were developed on the basis of the relevant requirements of different regulatory documents.

The resulting dimensionless unified coefficients can be used to determine the geometric characteristics of the cross sections of a damaged ship for different river-sea vessels. Accordingly, different combinations of unified damage models allow to assess the condition of the damaged ship in conditions of incomplete initial information and to produce more correct conclusions about the damage's type and its possible consequences.

Keywords: emergency situations, residual overall strength, river-sea vessel, unified dimensionless factors.

INITIAL PROBLEM

The operation of any vessel in areas with restricted navigation, narrow and shallow water is always connected with an increased probability of an emergency which can lead not only to disruption of navigation in the area, but also to environmental pollution both in a separate closed water area and in the whole region. Such emergency situations include grounding, collision in the bridge supports or in the walls of the lock, collisions with other vessels, etc. In this case, the underwater part of the hull is damaged, and the damage type and its dimensions remain unknown until the diving inspection of the emergency vessel.

The condition of the damaged hull of the vessel must be estimate as soon as possible, under incomplete initial information, but with sufficient certainty for making operational solutions. For sea going vessels of unrestricted navigation, a complex approach for estimating the survivability of a damaged vessel was developed by prof. G.V. Egorov [4-9]. It is especially important to develop this approach for inland and river-sea going vessels taking into account the specifics of the work of such vessels (frequent river voyages) and structural features of the hull (low standard of overall strength, hull flexibility).

AIM OF THE PAPER

Definition of the dimensionless unified coefficients of geometric characteristics of the transverse section of the damaged part of the hull for estimating the residual overall strength of the hull of the mixed river-sea going vessel.

MAIN TEXT

Author carried out the adaptation of the complex approach for sea going vessels developed by prof. G.V. Egorov to the river-sea going ones in [1, 2]. The complex approach included estimation of the emergency strength, stability and unsinkability of a vessel.

The residual overall longitudinal strength is estimated, as for sea going vessels, by the criteria of normal stresses' increasing in comparison with the hull initial state. After received hull damage (see Fig. 1) the group of longitudinal hull elements is excluded from the scheme of hull girder with the following characteristics: the total damage area ΔF , CoG coordinates Y_D and Z_D , and own inertia moments i_y and i_z . Initial coordinate axes are main central axes of undamaged hull. Inertia moments of the damaged hull in the terms of initial coordinate axes are I'_Y and I'_Z :

$$(1) \quad I'_Y = I_Y - \Delta F \cdot Z_D^2 - i_y, \quad I'_Z = I_Z - \Delta F \cdot Y_D^2 - i_z.$$

The determination of the coefficient of normal stresses' increasing K_Δ in the structures of a damaged vessel ($\sigma_{\max}$) in comparison with the initial state (σ_0) allows to estimate the residual overall strength of the damaged vessel's hull.

Figure 1. Transverse section scheme of damaged vessel

$$(2) \quad K_{\Delta} = \frac{\sigma_{\max}}{\sigma_0} = \frac{Z_A}{Z_{A1}} \frac{I_Y}{I_{Ym}} \beta, \text{ where } \beta = \cos \alpha \left(1 + \frac{Y_A}{Z_A} \frac{I_{Ym}}{I_{Zm}} \operatorname{tg} \alpha \right);$$

α , rad – the rotation angle of the main central axes of the damaged section in comparison with the initial axes;

I_{Ym} , I_{Zm} , m^4 – main moments of inertia of the damaged hull section.

Parameters α , I_Y , I_Z , I_{Ym} , I_{Zm} are defined with the help of program complex "ElBrus-MEB", developed in the Marine Engineering Bureau. Y_A , Z_A , Y_{A1} , Z_{A1} – coordinates of the most far point of the damaged and initial vessel. We find the required coefficient for increasing the normal stresses, after determining the geometric characteristics of the damaged section and the coordinates of the most far points. It is possible to estimate the residual overall strength of the vessel after receiving damage, knowing the normal stresses in the deck/bottom elements of the cross section of the undamaged hull.

In addition, the author has developed an analytical method for determining the geometric characteristics of a damaged hull of a mixed river-sea going vessel and the specifics of its application for mixed and inland navigation vessels [3]. This method allows to determine the main moments of inertia of the damaged vessel's hull with the following initial data: the area of the cross section of the intact vessel F , its moments of inertia I_y , I_z , the area of damage ΔF , the own moments of inertia of the damage i_y^{own} , i_z^{own} , the coordinates of the center of gravity of the damage Z_D , Y_D .

And if the geometric characteristics of the transverse section of an undamaged vessel are known, then data about the type of the damage, its size and localization in most emergency cases are uncertain.

The choice of the damage type and its model for mixed river-sea going vessels was carried out by the author in [3]. Determined damage models were chosen as the design models based on the requirements of classification societies and international conventions: Russian River Register of Shipping (RRR) Regulations for Inland Vessels (RIV), RRR Regulations for Mixed Navigation Vessels (MNV), European agreement concerning the International carriage of Dangerous Goods by Inland Waterways (ADN) and International Convention MARPOL. Also, the fifth model – a coaming crack – was chosen as the design one, which reflects the dangerous damage to the hull with a high probability of occurrence during operation for dry-cargo vessels of mixed river-sea navigation.

The following most common types of mixed river-sea going vessels were chosen as research objects:

- dry cargo vessel of the new generation of RSD44 project of "Volgo-Don Max" type designed by Marine Engineering Bureau,
- dry cargo vessel of 507b project of classic "Volgo-Don" type,
- tanker of 1577 project of "Vologoneft" type.

Typical section in the middle part and the transverse section in the area of the fore engine room (ER) bulkhead were considered both while modeling damage to the vessel's hull. Hull damage (fracture) in the area of the fore ER bulkhead is exactly characteristic for vessels of mixed river-sea going navigation, under the condition that the ER, accommodation and wheelhouse are located aft for such vessels. The sizes of the "typical" damage for the projects under consideration are shown in Table 1.

Table 1. Dimensions of "typical" damages

Chatacteristics		RRR (RIV)	RRR (MNV)	ADN	MARPOL
Side	Length	5.556 m	8.94 m	13.89 m	–
	Depth	0.9 m	3.3 m	0.59 m	–
	Vertical size	From the base line upwards without limit			–
Bottom	Length	5.556 m	8.94 m (	13.89 m	13.89 m
	Breadth	1.65 m	2.75 m	3.0 m	16.5 m
	Vertical size	0.8 m	1.1 m	0.49 m	1.1 m

The listed "typical" damage can be represented by the eleven models:

1. Collision, depth 0.9 m.
2. Collision, depth $B/5$.
3. Collision, depth 0.59 m.
4. Grounding on a stone, CL region, depth 0.8 m, breadth 1.65 m.
5. Grounding on a stone, CL region, depth $B/15$, breadth $B/6$.
6. Grounding on a stone, CL region, depth 0.49 m, breadth 3.0 m.
7. Grounding on a stone, bilge region, depth 0.8 m, breadth 1.65 m.
8. Grounding on a stone, bilge region, depth $B/15$, breadth $B/6$.
9. Grounding on a stone, bilge region, depth 0.49 m, breadth 3.0 m;
10. Grounding, depth $B/15$.

11. Coaming's crack (full height of coaming wall is cracked above deck edge with deck plating remained undamaged).

A comparison was made between the geometric characteristics of the transverse sections of the damaged vessel (its main moments of inertia) to verify the compliance of this analytical method with the output data of the "ElBrus-MEB" software package. The difference between the compared values is less than 1% (see Table 2).

On the one hand, any damage to the vessel's hull can not be occurred place without consequences, so it is possible to make a conclusion about the size of damage and its localization by change of the vessel trim (heel and pitch), the deflection, the ship's draft, the change speed of draft, roll and pitch, by the stress change in vessel's hull (under condition of stress recorder mounted onboard the vessel). On the other hand, the use of specific damage models allows to create both the dependence of the damage characteristics on its expected size and the "standard line" of damages [1, 2].

Accordingly, it is possible to select the type of damage from the "standard line" "according to the criteria specified above with sufficient certainty when analyzing an accident, if the initial data on the actual damage is uncertain. Let's consider a "standard line" based on determined types of damage – see Table 1. The presented "typical" models form a sequence of damage by increase of the area of the deformed hull section. The greatest impact on the residual strength of the transverse section is provided by the depth of the damage, i.e. whether the "internal watertight hull" of the hull is damaged.

The type of the damage in the models under consideration (depth and width of the damage) allows to include a very wide range of possible actual damages to the hull of the vessel: from a slight damage in the bottom or side to complete damage to the outer and inner sides or the bottom plating and the double bottom plating.

Table 2. Comparison of the geometric characteristics of the transverse sections of a damaged vessel

No	Own inertia momens			Analytical method		ElBrus-MEB		Error	
	i_y, m^4	i_z, m^4	i_{yz}, m^4	I_{ym}, m^4	I_{zm}, m^4	I_{ym}, m^4	I_{zm}, m^4	$\delta_y, \%$	$\delta_z, \%$
1577 (midship)									
1	0.25	–	–	3.025	13.179	3.025	13.17	-0.01	0.07
2	0.72	0.169	0.025	2.551	7.313	2.551	7.309	-0.01	0.05
3	0.203	–	–	3.071	13.683	3.071	13.68	0.00	0.02
4	–	–	–	3.141	17.95	3.139	17.94	0.07	0.06
5	–	–	–	3.005	17.873	2.997	17.82	0.27	0.3
6	–	–	–	3.082	17.903	3.082	17.87	-0.01	0.18
7	–	–	–	3.152	16.803	3.152	16.79	0.01	0.08

8	–	–	–	2.965	15.128	2.955	15.08	0.33	0.32
9	–	–	–	3.068	16.538	3.068	16.51	0.00	0.17
10	0.054	7.113	0	0.68	10.847	0.681	10.84	-0.13	0.06
1577 (170 fr.)									
1	0.165	–	–	2.62	8.912	2.62	8.909	0.00	0.03
2	0.543	0.128	0.033	2.243	5.694	2.243	5.694	-0.02	0.00
3	0.125	–	–	2.657	9.356	2.657	9.355	0.01	0.01
4	–	–	–	2.639	13.07	2.636	13.06	0.1	0.07
5	–	–	–	2.54	13.025	2.535	13	0.19	0.19
6	–	–	–	2.496	12.985	2.49	12.94	0.25	0.35
7	–	–	–	2.668	12.098	2.667	12.09	0.05	0.06
8	–	–	–	2.533	11.351	2.529	11.32	0.17	0.27
9	–	–	–	2.502	11.66	2.497	11.63	0.18	0.26
10	0.032	4.455	0	0.414	8.625	0.415	8.626	-0.33	-0.01

Let us suppose that the coefficient of the relative damage area $\overline{\Delta F}$ is the ratio of the area of damage to the original cross-sectional area and the relative own inertia moment of damage $\overline{i_y}$, $\overline{i_z}$ is the ratio of the own inertia moment of the damage to the corresponding inertia moment of the transverse section of the initial vessel. Dimensionless unified coefficients are defined for three projects (research objects), each of which is "characteristic" in its architectural and constructive type. Thus, these coefficients will allow to determine the geometric characteristics of the damages not only for vessels of these projects, but also similar in type and dimension.

The relative damage areas $\overline{\Delta F}$ for specific damage models are shown in Table 3.

As a result of the collision the relative damage area is in the range of 0.10-0.15 for the damaged outer side, 0.25-0.35 for the damaged outer and inner sides both and 0.05-0.10 for the damaged coaming. As a result of the grounding on a stone in the CL area the relative damage area $\overline{\Delta F}$ is in the range of 0.05-0.15 for the damaged bottom and 0.45-0.55 – for the "grounding" damage type (the damage zone includes the bottom plating and the double bottom plating across full-width of the vessel). As a result of the grounding on a stone in the bilge area the relative damage area is in the range of 0.03-0.09 for the damaged bottom in the CL.

The CoG coordinates of the damaged area are determined by the same criteria as the damage type. Thus, the relative area of the damage and the CoG coordinates of the damage can be used with sufficient reliability as initial data in determining the geometric characteristics of the damaged section of the vessel's hull depending on the type of the damage. The own inertia moments of the transverse damaged section of the hull remain unknown among the required initial values. Let us consider these geometrical characteristics of the transverse damaged section in more detail.

The use of the own inertia moment of the transverse damaged section is necessary for determining the main moments of inertia of the transverse section of the damaged vessel only for certain types of damage. The calculations' error is no more than 1% for models of damage 4-9 (the grounding on a stone in the CL and bilge area). In other words, the values of the main inertia moments of the transverse section of the damaged hull can be defined without usage of the own inertia moments of the damaged section for variants of bottom damage when vessel grounded on a stone (the width of the damage is not more than 3.0 m, the depth is no more than 0.8 m) at any point of bottom across width.

Table 3. Relative damage area

Damage localization	RRR (CCINV)	RRR (CCMNV)	ADN	MARPOL	"Crack"
RSD44					
Side (midship)	0.095	0.343	0.087	–	0.111
Bottom (midship)	0.037	0.097	0.048	0.496	–
Bilge (midship)	0.034	0.075	0.045	–	–
Side (38 fr.)	0.130	0.307	0.118	–	–
Bottom (38 fr.)	0.044	0.120	0.067	0.525	–
Bilge (38 fr.)	0.044	0.071	0.054	–	–
507b					
Side (midship)	0.117	0.320	0.104	–	0.043
Bottom (midship)	0.038	0.110	0.054	0.551	–
Bilge (midship)	0.033	0.076	0.052	–	–
Side (183 fr.)	0.146	0.311	0.132	–	–
Bottom (183 fr.)	0.034	0.107	0.049	0.561	–

Bilge (183 fr.)	0.031	0.073	0.049	–	–
1577					
Side (midship)	0.108	0.260	0.096	–	–
Bottom (midship)	0.041	0.090	0.049	0.484	–
Bilge (midship)	0.032	0.089	0.048	–	–
Side (170 fr.)	0.126	0.243	0.113	–	–
Bottom (170 fr.)	0.056	0.086	0.100	0.469	–
Bilge (170 fr.)	0.044	0.083	0.086	–	–

$$(3) \quad \varepsilon = \frac{I_{ymC/zmC} - I_{ymE/zmE}}{I_{ymC/zmC}}.$$

As a result of the collision the relative own inertia moment of a damage area $\bar{i}_y$ is in the range of 0.29-0.33 for the damaged outer side and inner sides both including coaming and 0.20-0.22 – for similar type of damage of the tanker. As a result of the collision the relative own inertia moment of a damage area $\bar{i}_y$ is in the range of 0.05-0.10 for the damaged outer side and 0.02-0.025 – for the "grounding" damage type.

The relative own inertia moment of damage are shown in Table 4 for models from 1 to 3 and 10.

Table 4. Relative own inertia moment of a damage

Project	Damage type		1	2	3	10
RSD44	Midship	$\bar{i}_y$	0.044	0.331	0.037	0.0158
	38 fr.		0.099	0.29	0.08	0.0254
507b	Midship		0.086	0.33	0.066	0.0197
	183 fr.		0.102	0.31	0.081	0.0213
1577	Midship		0.076	0.219	0.062	0.0165
	170 fr.		0.059	0.194	0.045	0.0115
RSD44	Midship	$\bar{i}_z$	-	0.0064	-	0.288
	38 fr.		-	0.0083	-	0.301
507b	Midship		-	0.0081	-	0.316
	183 fr.		-	0.0103	-	0.316
1577	Midship		-	0.0094	-	0.396
	170 fr.		-	0.0098	-	0.341

As a result of the grounding the relative own inertia moment of a damage area $\bar{i}_z$ is in the range of 0.29-0.32 for the damaged full-width bottom and double bottom both and 0.35-0.40 – for similar type of damage of the tanker. As a result of the collision the relative own inertia moment of a damage area $\bar{i}_z$ is in the range of 0.009-0.01 for the damaged outer side and inner sides both

The values of the determined coefficients represent the actual response of the structure to the hull damage: the higher the value of the own inertia moment of the damage, the greater the overall hull strength decreases. The most dangerous are the damages of both hull contours, i.e. damage of the outer and inner sides plating both, bottom and double bottom plating both. At the same time, similar damage to the outer and inner sides plating both affects the construction of dry cargo and tanker in different ways. Even if the initial values of the geometric characteristics of undamaged dry cargo vessel and tanker are similar, then after such side damage (damage depth $B/5$), the normal stresses in the most far elements of the deck of the dry cargo vessel will increase by more than 4 times, while for the tanker – only 1.3 times.

CONCLUSIONS

1. A "standard line" is proposed on the basis of determined types of damage, the models of which form a sequence of damage by increase of the area of the deformed hull section. The damage type in the models under consideration (depth and width of the damage) allows to cover a very wide range of possible actual damage to the vessel's hull: from a small damage to the bottom or side to complete great damage to the outer and inner sides or bottom and the double bottom plating.

2. The unified dimensionless coefficients of the relative damage area $\overline{\Delta F}$ and the relative own inertia moment $\bar{i}_y$, $\bar{i}_z$ are obtained. They allow to determine the geometric characteristics of damaged hull part not only for the vessels of the projects under consideration, but similar to them in the architectural and constructive

type and dimensions due to the developed complex approach to estimation of the survivability of a damaged mixed river-sea going vessel.

REFERENCES

- [1] V.A. Nilva. Assessment of load-carrying strength of river-sea going dry-cargo vessel's hull with the loss of the part of longitudinals // ONMU Reporter. - Odessa: ONMU, 2013. - Vol. 3 (39). - pp. 96-108 (in Russian)
- [2] V.A. Nilva. Assessment of load-carrying strength of river-sea going tanker's hull with the loss of the part of longitudinals // ONMU Reporter. - Odessa: ONMU, 2014. - Vol. 1 (40). - pp. 72-82 (in Russian).
- [3] V.A. Nilva. Analytic method of definition of geometric characteristics of inland or river-sea navigation dry-cargo vessel after receiving damage // ONMU Reporter. - Odessa: ONMU, 2015. - Vol. 2 (44). - pp. 60-69 (in Russian).
- [4] G.V. Egorov. *Development of optimization methods of strength solutions during vessels' operation*: PhD dissertation. - Odessa: OIME, 1993. - 431 p.
- [5] G.V. Egorov. Residual hull strength in the calculation of flooding and providing damage control. Definitions and experience // ONMU Reporter. - Odessa: ONMU, 2005. - Vol. 18. - pp. 57-72 (in Russian).
- [6] G.V. Egorov. Residual hull strength in the calculation of flooding and providing damage control. Extent of damage and accident conditions // Problems of technics. - 2006. - No1. - pp. 3-23 (in Russian).
- [7] G.V. Egorov. Residual hull strength in the calculation of flooding and providing damage control. Criteria and examples // ONMU Reporter. - Odessa: ONMU, 2006. - Vol. 19. - pp. 49-63 (in Russian).
- [8] G.V. Egorov. Residual hull strength in the calculation of flooding and providing damage control. Constrained torsion and heel taken into account // Proceedings of NUS. - Nikolayev: NUS, 2006. - No2. - pp. 39-48 (in Russian).
- [9] G.V. Egorov. Residual hull strength in the calculation of flooding and providing damage control. Loss of the part of longitudinals taken into account // Proceedings of NUS. - Nikolayev: NUS, 2007. - No3. - pp. 38-50 (in Russian).

OIL-CHEMICAL TANKERS OF "VOLGA-DON MAX" CLASS WITH ENHANCED SEA FUNCTION

Gennadiy V. EGOROV*, Valery I. TONYUK**

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – Marine Engineering Bureau (Odessa, Ukraine), technical director, RINA member

Abstract. In paper it is shown that vessels with "superfull" contours of "Volgo-Don max" class, created by Marine Engineering Bureau, are the most modern and the most cost-efficient in that class today.

Features of RST27M tanker concept, its difference from RST27 basic tanker are emphasised. New RST27M chemical tanker has strengthened sea function. The actual deadweight makes 7902 tons on maximal draught of 4.60 m. The volume of cargo tanks is calculated for Caspian region oil products transportation and increased to 8970 m³ due to trunk raising. Therewith possibility of simultaneous transportation of three cargo grades is provided.

Keywords: block coefficient, design, economy, freight nomenclature, river-sea tanker.

INITIAL PROBLEM

Today the most noticeable phenomenon in native water transport industry is mass building of unusual to all practice of world shipbuilding of river-sea "superfull" tankers of RST27 project and created on their base combined vessels of RST54 project and chemical tankers of RST27M project [1, 2].

It is not difficult to notice how in three years 54 vessels of these projects were built by native shipyards.

Such frequency and such mass series were characteristic for the best periods of Soviet shipbuilding and it is, of course, very worthy comparison for today's Russian shipyards [3].

In 2012 and 2013 Britain Royal Institution of Naval Architects (RINA) included RST27 in the list of the best vessels (Significant Ships 2012 and 2013), what is happens hardly ever.

In 2014 RST54 vessels were included in the Significant Ships list, in 2017 – RST27M vessels.

In process of building of vessels of RST27 projects there was essential spread of spectrum of transported liquid cargoes: except of oil and oil products "vegetable oil" was included on first stage (including components of biofuel and well-known palm oil) and then other "light" chemistry, however, requiring fulfilment of unsinkability standards and other requirements to equipment and tanks coverings in accordance with IMO2 class.

At last growth of transportations across Caspian Sea requested rising of sea loading capacity.

As a result new concept of RST27M has been created.

AIM OF THE PAPER

Description and grounding of main characteristics of RST27M concept of oil product and chemical tanker of IMO2 type.

MAIN TEXT

Solution of external design task including definitions of main characteristics of oil river-sea tankers is based on the analysis of freight traffics of oil and oil products with definition of main types of liquid loads, loading and unloading points, commercial features and duration of runs. Such researches were made in [4, 5, 6] (European part of Russia), in [7, 8, 9, 10] (East basins), and also in summarized form in [3, 11, 12].

The main tendency is building of cargo vessels for European part of Russian inland waterways namely RST27 river-sea "superfull" tankers of "Volgo-Don max" class with significantly increased river cargo capacity and vessels created on RST27 base [1, 2, 4].

The character feature of this enhanced river function concept is "expanding" of narrow places of inland water transport by using new technical decisions. Other words, transportation ability is increased by maximal usage of actual way characteristics (maximal available vessel's length and breadth), and mainly by usage extremely fat hull contours, that have never used before in world's practice.

In 2011 RST27 river-sea "superfull" tanker of "Volgo-Don max" class of "VF Tanker" type was created on basis of received by Marine Engineering Bureau (MEB) theoretical decision on possibility of block coefficient increase. Such tanker has increased river function comparing to "Armada" type tankers of RST22 and RST22M projects, while increased hull's strength (vessel is of R2 sailing region), practically keeping the same

fuel consumption, keeping increase capacity of cargo tanks. Deadweight of RST27 tanker is about 5420 tons with river draught of 3.60 m.

And in 2017-2018 new RST27M "superfull" chemical tankers enhancement of technical and economic parameters of which has been carried out due to growth of effective height of hull section (increase of height of continuous trunk) were put into operation.

In comparison with initial RST27 tanker RST27M oil chemical tanker has enhanced sea function: - deadweight is of 7902 tons at maximal draught of 4.60 m (RST27 tanker deadweight is of 7022 tons), more than 880 tons; - volume of cargo tanks is calculated for transportation of oil of the Caspian region and increased due to high trunk up to 8970 m³ (8100 m³ on RST27), more than 870 m³; - possibility of simultaneous transportation of 3 cargo types (2 types on RST27). Comparison of characteristics of RST27 and RST27M tankers is shown in Table 1.

Table 1. Development of projects of chemical tankers on base of RST27 project

Parameters	Project		Advantages
	RST27M	RST27	
Actual deadweight while maximal draught, t	7875	6980	+895
Cargo tanks volume, m ³	8970 (optimized for oil products transportation in Caspian region, increased because of trunk deck rising)	8100	+870
Number of cargo types	3 (check-list of transported cargoes is significantly expanded)	2	+1

Certainly, new vessels have to be the best in their class for Shipowners. It is clear that for achievement of the greatest economic effect of cargo vessel operation the vessel should have maximally possible deadweight. For river-sea vessels dimensions of which are limited by way conditions rational design of hull constructions, block coefficient increase and optimisation of propulsive complex are determined.

MEB successfully dealt with issues of optimisation of work of fleet since foundation of the company in 1995 [5]. Conception of RST27M vessels can be formulated as follows: tanker with full usage of inland waterways dimensions, with 0.932 block coefficient, with increased cargo capacity at sea and in river, with sufficient cargo tanks volume at minimal depth, with increased manoeuvrability in the constrained conditions and in the shallow waters, with proved operational reliability of hull structures at optimum metal consumption for the hull on R2 RS class. Main feature of RST27M river-sea tankers, in comparison with other vessels of new generation, is spread of spectrum of transported liquid cargoes. In one voyage simultaneous transportation of three cargo grades is possible.

Except of oil and oil products the vessel can transport other liquid cargoes such as: castor oil, cocoa oil, coconut oil, corn oil, cotton seed oil, groundnut oil, illipe oil, linseed oil, mango kernel oil, olive oil, palm kernel oil, palm kernel olein, palm kernel stearin, palm mid-fraction, palm oil, palm olein, palm stearin, rapeseed oil, rice bran oil, safflower oil, shea butter, soyabean oil, sunflower seed oil, tung oil, methyl alcohol, methyl tert-butyl ether (MTBE), ethyl tert-butyl ether, ethylene glycol, calcium lignosulphonate solution, ethyl acetate, hexane (all isomers), octanol (all isomers), sodium hydroxide solution, toluene, carbamide / ammonium nitrate solution, xylenes, acetone, ethyl alcohol, isopropyl alcohol, diethylene glycol, glycerine.

Concerning technical solutions following has been realized: - RS class R2 was accepted according to prospective transportation directions and to estimation of probable running time losses due to weather waiting; this class allows sea vessel's operation full year including voyages around the Europe and in Caspian Sea; - ice class Ice1 was accepted for operation at Azov Sea and Caspian Sea in winter according to the accumulated operational experience; - cargo capacity increase due to growth of effective height of hull section (application of trunk). Same time expenses in domestic ports are reduced on. All this were done with providing sufficient for the accepted class the overall longitudinal strength without increase of thickness of the overwhelming majority of constructions in comparison with the minimal thickness of RS Rules; - block coefficient remained the same as on RST27 tanker 0.932; - maneuverability and propulsion were secured by usage of full-revolving rudder propellers; - identical, whenever possible, thickness of plates of web and ordinary structure elements and shell for providing equal wear durability were assigned; - sides and bottoms structures designed on operational loads, which in majority are considered till now "not design" (contacts to waterside structures, ground, etc.); - structure elements inside cargo tanks of tankers were excluded (an external structure of the upper deck and trunk); - "smooth" flanges of hull girder with a minimum quantity of technological openings and weld fittings in order to increase in actual fatigue durability were designed; rationally executed assemblies of structure element crossings and smooth changes of the areas of longitudinal structure elements of the hull through its length were applied; - due to rational distribution of ballast and buoyancy tanks and compartments in double sides and double bottom longitudinal bulkhead in CL is excluded. Hull metal consumption is reduced.

Vessel satisfies dimensions of the Volga-Don Canal and Volga-Baltic Way. Overall RST27M vessel's length is of 140.85 m, breadth is of 16.6 m, depth is of 6.0 m. She belongs to "Volgo-Don Max" class type.

Russian Maritime Registry of Shipping class notation is KM Ice1 1 R2 AUT1-ICS VCS ECO-S OMBO Oil tanker /Chemical tanker type 2 (ESP).

Special requirements of the Russian and world petroleum companies, additional ecological RS limitations of "ECO PROJECT" (ECO-S) class were taken into consideration during designing. Total capacity of six cargo tanks and two slop ones is of 8970 m³ at 98% loading. It should be noted that despite on negligible increase of light displacement actual deadweight in river remains virtually the same as on RST27 tanker (5363 tons on RST27M against 5420 tons on RST27). That is why RST27M tanker will be also successfully operated in river.

On architectural-structural type RST27M project is steel single-deck motorship with two full-revolving rudder propellers, with forecastle and poop, with aft engine room (ER) and deckhouses, with 6 cargo tanks, with double bottom, double sides and trunk deck in cargo tanks area. General arrangement of RST27M tanker is shown on Fig. 1.

Figure 1. General arrangement of RST27M tanker

Main characteristics of the project are given in Table 2.

In fore end high and longwise developed forecastle, forepeak, log and echo sounder trunk, boat-swain's store, hydraulic station, paint room, deck storeroom, and also 230 kW bow thruster are located.

In aft end ER and high developed poop superstructure are located. Two-deck aft deckhouse with office and accommodation spaces for 12 people crew housing (14 places + pilot) is designed with taking into account limited vessel's air draught (13.9 m at draught of 3.00 m).

Theoretical hull forms with 0.78L parallel middle body length and record block coefficient 0.932 (as at RST27 vessels) were developed by MEB, see Fig. 2-4.

Fore end of bulb-type and transom aft end with semi-tunnels and skeg were used. Towing tests modeling was carried out by solving Reynolds equation by using finite-volume method within calculated area where 3D vessel's hull model is placed. Motion equations are closed with help of statistical $\kappa - \epsilon$ turbulence model for case of incompressible liquid

Special form of aft end is optimized for arrangement of fixed-pitch propellers. From position of fuel efficiency for "Volgo-Don max" class vessels variant of two-shaft propulsive complex with fixed-pitch propellers in nozzles is optimal [1]. RST27M motion and maneuverability provided by two aft full-rotated rudder propellers with fixed-pitch propellers in nozzles with 1900 mm diameter. Rudder propeller drive is carried out from main engines through mechanical Z-gear. The power input to each rudder propeller is 1200 kW. The rudder propellers are controlled from wheelhouse on pilot control console, from side control panels, and also emergency from ER.

Table 2. Main characteristics of RST27M tanker

Parameters	Values
Length overall, m	140.85
Length between PP, m	137.10
Breadth scantling, m	16.70
Depth, m	6.00
L x B x H	140.85 x 16.70 x 6.00 = 14 113
Draught, m (at sea / in river)	4.60 / 3.60
Deadweight, t (at sea / river)	7902 / 5363
Endurance, days (at sea / river)	20 / 12
Cargo tanks capacity (including slop tanks), m ³	8970
Number of cargo/slop tanks	8 (6 / 2)
RMRS class	KM Ice1 R2 AUT1-ICS OMBO VCS ECO-S Oil tanker/Chemical tanker type 2 (ESP)
ME power and type, kW	2 x 1200
Screw and Rudder	2 x Rudder propellers
Bow thruster, kW	230
Emergency diesel-generator + Harbour diesel-generator, kW	3 x 296 kW + 136 kW
Auxiliary steam-boiler, t/h	2 x 2.5
Crew / berth, pers.	12 / 14 + pilot
Cargo pumps output, m ³ /h	6 x 200
Number of manifolds / Sorts of cargo	2 at the middle + 1 aft StB / 3 sorts
Cargo heating	Coils
Tank wash system and cleaning of washing liquid	Slop tank's pump 80 m ³ /h
Speed (at draft 4.60 m and 100% MCR), knots	10.5

Figure 2. General view of "superfull" RST27M tanker on building berth of "Krasnoe Sormovo" shipyard **Figure 3.** General view of "superfull" RST27M tanker (bow view)

Constructions of hull, mechanisms, equipment and vessel's systems meet requirements of International MARPOL 73/78 Convention. The vessel's hull is designed on Ice1 class which intends following operation conditions: occasional all year round in non-freezing seas, in fine-broken rarefied ice of the non-Arctic seas (independent sailing in fine-broken rarefied ice of depth 0.40 m at speed 5 knots; sailing in a channel behind the icebreaker in solid ice of depth 0.35 m at speed 3 knots). For main hull constructions shipbuilding steel of categories RSD32 with 315 MPa yield strength and RSA with 235 MPa yield strength for ensuring operation in conditions of designed temperature is used. Upper deck, side and inner side, bottom and inner bottom are constructed by longitudinal framing system, at ends and in ER – by transverse framing system. Transversal frame spacing in middle part is 650 mm; at ends – 600 mm. Frame space of longitudinal framework: double bottom – 500 mm, double sides – 550 mm. Midship frame of RST27M tanker is presented on Fig. 5.

Figure 4. General view of "superfull" RST27M tanker (stern view)

Figure 5. Midship frame of RST27M tanker

On the vessel there are mounted 8 main water-tight transverse bulkheads, sectioning the hull into 9 impermeable compartments. Main transverse bulkheads between cargo tanks are made corrugated with vertical corrugations, other bulkheads are flat with framework of rolled and welded profile. Main and trunk decks in cargo part are constructed by longitudinal framing system with longitudinals of rolled profiles, deck carlings and transverses (arranged in 3 frame spaces) of welded profile. Double bottom in cargo part is arranged by longitudinal framing system with installation of longitudinal girders of rolled profiles, centre keelson, 2 bottom girders, solid floors through 2... 3 frame spaces (2 frame spaces in the fore end of cargo part). Transverse framing system is applied in ER. In cargo part of the hull double sides framed by longitudinal system are arranged. Transverse framing system is applied with frames of rolled profiles, web frames and shell stringer of welded profile in ER. Extremities structures are made by transversal framing system. For corrosion protection of underwater part of the vessel's hull, sea chests, aft rake and thrust tube short-circuit protection is foreseen. For corrosion protection of ballast tanks protectors and paint coating are used.

The vessel is fitted with two heightened holding power (HHP) bow anchors of weight of 1710 kg each and one HHP stern anchor of weight of 1305 kg. Anchors are retracted into hawses in anchor lugs. For vessel's towage towing rope, bollards, hawse which arranged in centerplane of the vessel in the forepeak area are used. For warping mooring and towing bollards, cast hawses, hawses with rollers of required sizes are foreseen.

On vessel's stern lifeboat handling gear with enclosed tanker free-falling lifeboat of 16 persons capacity descent by the device of gravitational type with hydraulic boat winch both by free fall and controlled descent method is mounted. Rescue boat of 6 persons capacity is mounted on bridge deck from portside. Explosive-proof 3 t cargo capacity hydraulic crane with 12 m boom is installed for handling and removal of hoses. For handling and removal of hoses of aft manifold the same crane with 10 m boom is used. Weather decks are equipped with 4-row railing with stationary rail stanchions of height of 1100 mm.

Main power plant consists of two diesel engines of WARTSILA 6L20 type with maximal continuous rate (MCR) of 1200 kW at 1000 rpm frequency which are working on 2 full-revolving rudder propellers securing 10 kn operational speed at 85% of MCR. Main engines work on heavy fuel oils with viscosity up to 380 cSt.

Cargo system provides simultaneous transportation of 3 cargo grades. Cargo pumps capacity is 6 x 200 m³/hour. Two auxiliary steam boilers with capacity of 2.5 t/hour each and two exhaust gas steam boilers with capacity of 0.3 t/hour each are installed onboard. Pipeline cargo heating system is applied on the vessel. The heating system secures transported cargo temperature during voyage at +60°C at outside air temperature -23°C, and also heating cargo from 50°C to 60°C in 48 hours for petroleum products. Also heating system secures transported cargo temperature during voyage at +45°C at outside air temperature -23°C, and also heating cargo from 45°C to 65°C in 96 hours for vegetable oils. Valves of cargo system ensuring cargo handling have remote electric drive. Remote operation is foreseen from cargo-ballast operations control console located in wheelhouse. Valves with remote control have also local manual operation. Cargo tanks are divided into three groups (each group for its type of cargo). The fore group includes cargo tanks No1 and No2, the middle group includes cargo tanks No3 and No4, the aft group includes cargo tanks No5 and No6. Each group of tanks has its own manifold which providing loading and discharge of cargo on both sides. When operating with one cargo grade the aft tank group manifold is used as common manifold.

As the sources of electric power in structure of the vessel's electric power plant following sources are foreseen: - three generators of three-phase current, synchronic, of 296 kW nominal capacity at voltage 400 V, 50 Hz, at power coefficient 0.8, with automatic voltage control and system of self-excitation, diesel-driven; - one emergency-harbor diesel-generator with automatic launch at voltage escape on main switchboard buses, with synchronous generator of three-phase current, of 136 kW nominal capacity at voltage 400 V, 50 Hz, at power coefficient 0.8, with automatic voltage control and system of self-excitation.

For continuous indicating of the vessel's compass heading, determination of relative bearings and taking bearings on the arc of horizon in 360° on the vessel main magnetic compass with remote transmission of the

readings to wheelhouse is installed. To raise efficiency and reliability of control of vessel's production processes the vessel is equipped with computer automatic control system. Scope and degree of automation of technical means of the vessel correspond to AUT1-ICS class in accordance with RS Rules. Vessel's operation is executed by one operator from wheelhouse.

CONCLUSIONS

Realized sea trials showed great vessel's maneuverability and good sea performances. The vessel of RST27M project with 0.932 block coefficient (as on MEB RST27, RST54 vessels) showed speed of 11.7 kn at running line with main engines power of 2100 kW (87.5% of full output) and fore/aft draughts 3.2/3.3 m.

Reasonably chosen power of main engines and enhanced forecastle and poop superstructures secured seaworthiness in conditions of rough water with 7 m wave height of 3% occurrence. Results of operation of RST27M series vessels built at "Krasnoe Sormovo" shipyard (see Table 3) fully confirmed new decisions accepted on design stage.

Table 3. Timeline of building of RST27M tankers

Name	Shipyard, building No	Keel laying date	Launching date	Delivery date
Balt-Flot 16	02022	25.01.17	21.07.17	06.09.17
Balt-Flot 17	02025	15.03.17	08.09.17	13.10.17
Balt-Flot 18	02026	25.04.17	23.10.17	28.11.17
Balt-Flot 19	02027	27.06.17	22.12.17	03.05.18
Balt-Flot 20	02028	18.08.17	22.02.18	07.05.18

General need in river-sea tankers of "Volgo-Don max" class is estimated as 100-120 units. Presence of demand on such new river-sea vessels creates conducive conditions for native shipbuilding.

REFERENCES

- [1] G.V. Egorov. About creation of new generation extra-full river and river-sea cargo vessels // ONMU Reporter. - Odessa: ONMU, 2016. - Vol.2 (48). - pp. 12-48 (in Russian).
- [2] G.V. Egorov, V.I. Tonyuk, E.Yu. Durnev. «Super-full» combined vessels of RST54 project for transportation of oil products and dry cargoes, and also containers, vehicles and designed cargoes // Shipbuilding. - 2017. - No4 - pp. 17-24 (in Russian).
- [3] G.V. Egorov, A.G. Egorov. River and river-sea vessels: role of "old" series of vessels and its perspectives // Maritime Market. - 2017. - No1 (59) - pp. 18-30 (in Russian).
- [4] R.D. Bagautdinov, G.V. Egorov. Concept of river-sea tanker of new generation // Maritime Market. - 2012. - No2 (40). - pp. 22-35 (in Russian).
- [5] G.V. Egorov. *Design of restricted sailing area vessels based on risk theory*. - SPb: Shipbuilding, 2007. - 384 p (in Russian).
- [6] G.V. Egorov. Choose of main elements of river-sea dry-cargo vessels and oil product tankers // Shipbuilding. - 2004. - No6. - pp. 10-16 (in Russian).
- [7] G.V. Egorov. Choose of main parameters of hulls of river-sea vessels for "Northern delivery" // Proceedings of Krylov State research center. - 2010. - No55 (339). - pp. 47-56 (in Russian).
- [8] G.V. Egorov. Analysis of backgrounds of creation of new generation river and river-sea vessels for Lena basin // Problems of technique. - 2010. - No3. - pp. 3-22 (in Russian).
- [9] G.V. Egorov, V.I. Tonyuk. Analysis of backgrounds of creation of new generation river and river-sea vessels for Yenisei basin // Problems of technique. - 2010. - No4. - pp. 3-19 (in Russian).
- [10] G.V. Egorov, V.I. Tonyuk. Analysis of backgrounds of creation of new generation river and river-sea vessels for West-Siberian region // Problems of technique. - 2011. - No1. - pp. 68-89 (in Russian).
- [11] G.V. Egorov, N.A. Efremov, N.V. Shablikov. Civil river shipbuilding of XXI century: analysis and tasks // Maritime Market. - 2016. - No1 (55) - pp. 18-29 (in Russian).
- [12] G.V. Egorov, A.G. Egorov. Reliability and risk of damages of hulls of "Vologoneft" type tankers // Proceedings of Krylov State research center. - 2014. - No82 (366). - pp. 5-16 (in Russian).

REALIZATION OF REQUIREMENTS OF THE INTERNATIONAL CONVENTION FOR THE CONTROL AND MANAGEMENT OF SHIPS' BALLAST WATER AND SEDIMENTS ON THE DESIGN STAGE

Gennadiy V. EGOROV*, Alexander E. NILVA**, Dmitriy V. KOLESNIK***

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – Marine Engineering Bureau (Odessa, Ukraine), chief researcher, Dr, RINA member

*** – Marine Engineering Bureau (Odessa, Ukraine), deputy head of electromechanical department

Abstract. In paper history of creation and main theses of The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) which requires for new vessels and after a while for existing vessels, onboard availability of special equipment for treatment of ballast – ballast water treatment system (BWTS) are described. Possible ways of decrease in risk of transfer of harmful aquatic organisms are shown.

Marine Engineering Bureau has successfully developed grounding of possibility of application of such method and applies to each specific vessel at the request of the Customer. Expenses on modernization to requirements of BWM-2004 on existing vessel can make up to 500-800 thousand dollars and higher. For new (i.e. constructed relative recently) "Volga-Don max" class vessels such BWTS, depending on supplier, costs about 210-270 thousand dollars, and taking into account works expenses will make up to 350 thousand dollars on the vessel.

Keywords: ballast water treatment system, BWM Convention, design, ecology, existing and new vessels.

INITIAL PROBLEM

Mankind has saved up considerable negative experience connected with undeliberate distribution of different harmful and dangerous organisms. Automobiles, transported cargoes and often people were sources of such transfer. Herewith organisms could be dangerous for new biosystem in other conditions.

It is interesting to mark that, as a rule, people paid attention to such changes in the world in cases when they concerned immediate vital interests whether it be trading, agriculture, industrial activity and etc.

Maritime transport is not exception. Vessels transport significant amount of cargoes, people and also move themselves, so there is possibility of movement of some types of harmful aquatic organisms and pathogens (HAOP), bacteria and diseases' viruses.

Traditionally government bodies of sanitary and epidemic inspection controlled transported by maritime transport cargoes and people. Special actions, for example, fumigation of grain cargoes and etc. which have allowed significantly to reduce risk of transfer of HAOP carried out.

The basis for illegal HAOP transfer is ballast water (BW) which vessels accept for securing safe operations in following conditions: without load; with load in voyage for compensation of expenditure of stocks; with deck load and with movable bulk cargo for securing stability; with light load for securing acceptable seaworthiness and strength; in other situations depending on architectural design type of the vessel and transported loads. To imagine scale it is possible to give an example of Novorossiysk port where only in one 2016 more than 50 million tons of water ballast have been offloaded [1]. Accepted at the beginning or in voyage BW at the end of voyage usually offloaded in coastal area, on raid, in ports or in shipping rivers. Together with BW HAOP got to the specified water areas. The damage from getting of HAOP was different: blasting stocks of trade aquatic organisms; distribution of activators of epidemics and epizootics; toxic water blooming; foulness and biocorrosion of hydraulic engineering and water-intake constructions. According to information [1-7] for the last two decades more than 70 cases of dangerous transfer of HAOP were found out.

AIM OF THE PAPER

Search and options of implementation of requirements of BWM Convention-2004 which requires for new vessels (and after a while for existing vessels) onboard availability of BWTS equipment.

MAIN TEXT

RST27, RST27M, RST25 tankers and also RSD49, RSD59 dry-cargo vessels will be the first native vessels with BWTS equipment onboard. On RST27 chemical tanker such equipment will be installed in container on trunk deck (see Fig. 1), on dry-cargo vessels – in engine room (ER).

Figure 1. Arrangement of BWTS equipment on RST27 chemical tanker

Requirements of BWM-2004 extend on all vessels with gross tonnage of 400 and more, regardless of their date of building and type, which have right of operation under the flag of the Party which has signed the Convention. In accordance with Article 3 of BWM-2004 this Convention shall not apply to:

1. Warships, naval auxiliary or other ships owned or operated by a State and used, for the time being, only on government non-commercial service;
2. Vessels of a Party which only operate in waters under the jurisdiction of that Party. For example vessels under flag of the Russian Federation operating on raid complexes near Caucasus port. But if such voyage will be carried out by the vessel with different from flag of the Russian Federation, such vessel should meet requirements of BWM-2004;
3. Vessels not designed or constructed to carry BW;
4. Vessels with permanent BW in sealed tanks on vessels that are not subject to discharge (analogue of solid ballast);
5. Vessels which offloaded BW in special receiving stations (for example in port or on other specially equipped vessel – BW collector and processor). For example, it is possible to apply "single-hull" tankers equipped additionally with BWTS as such vessels–collectors.

Two ballast water exchange standards D-1 and D-2 are foreseen:

1. **D-1 Standard** supposes possibility of ballast change in open seas on distance not less than 50 nautical miles from coast with depth not less than 200 metres. Vessels have to make ballast water change with 95% efficiency of their volume or by pumping of triple volume of each ballast tank.

Such ballast water change at sea or pumping have to be carried out according to special Ballast water management plan approved by class (developed according to IMO Resolution MEPC.127(53)) and to be fixed in special Ballast water operation log book. The log book is stored on the vessel within two years after last record and after that not less than three years under control of shipping company.

2. **D-2 Standard** requires availability onboard of special BWTS equipment. Minimal quantity of treated live organisms which can be contained in BW are assigned by means of this special system.

Vessels, which keel was laid down on September 8, 2017 or after this date, have to be already built with BWTS onboard. Other vessels have transition period. They have to be equipped additionally with BWTS to the first after September 8, 2019 survey. Before that survey they have to meet requirements of D-1 standard, i.e. it is allowed for them to change ballast at sea. For example, Russian Maritime Register of Shipping (RS) is ready to provide vessels' survey with its class till September 8, 2019 that will allow to operate existing fleet without BWTS equipment for 5 more years till next survey. Expenses on fulfillment of BWM-2004 requirements for built in 1960-1980 river-sea vessels can be close to 500-800 thousand dollars and even more. Thus BW treatment methods and BW discharge in ports are able to solve this problem but price of such actions is too high.

That is why for operating vessels within existing technical and economic conditions method of ballast change in open seas on distance not less than 200 nautical miles from coast with depth not less than 2000 metres is quite possible for real usage for the nearest five years.

Identification of hazards for the vessel in the process of ballast change at sea. All existing normative documents disallow ballast acceptance at sea till it is not confirmed with special calculations. Existing operational documents on vessels prohibit BW operations at sea. However only specially mentioned tanks (as a rule, it is rather narrow tanks with small free surface) are allowed to fill or empty at sea for achievement of normal ship sitting, herewith their influence on stability is definitely checked by calculation. Usually it is considered that problem of ballast change at sea appears only in passages without load. However such presentations proceed from model of round voyage when load run is unambiguously replaced (interchanged) with non-loaded run. Actually everything is not so well-defined because optimal operation of the vessel provides "return" loading also.

The analysis of seakeeping and strength performances of existing vessels during ballast change which was carried out by Prof. G.V. Egorov has shown that any similar changes of vessel's loading at sea pose real danger and require comprehensive study. The work was carried out with use of formalized assessment of safety method [8-10].

Hydrodynamic impacts under condition of partial filling of compartments. Under condition of partial filling of compartments resonance (coincidence of vibratory frequencies of free surface of ballast in compartment with frequency of external compensating force – sea states) leads to growth of dynamic loads on elements of transverse, longitudinal bulkheads and board from BW slaps. Number of large bulk carriers lost because of holds destruction during ballast acceptance in hold (exactly these casualties have forced to study problem of impact loads from liquid cargo under condition of partial filling of compartments at sea).

In rather small ballast compartments with length is no more than $0.13L$ and breadth is no more than $0.6B$ assessment of such loads can be made in accordance with RS Rules. As a rule, for such placements design loads at partial filling do not exceed loads from full filling of ballast with account of wave conditions and rolling. However by an unlucky train of events even in rather small ballast compartments construction damages are possible if effects from BW slaps in compartment will be strengthened by construction faults, external wave impacts etc. For example, "David Bakradze" tanker in process of ballast accepting during voyage suffered damage of side ballast tanks (see Fig. 2). Partial filling of tanks could be one of the possible reasons of strong deformation of bulkheads and board.

Figure 2. Deformations of all-round frames of tank No3 of "David Bakradze" tanker after ballast change at sea

For ballast compartments with big relative sizes (holds of bulk carriers, cargo tanks of tankers and so on, which are used for BW acceptance) loads at partial filling with liquid can be rather big and exceed corresponding design loads. As example possibility of partial filling of hold of ore-oil carrier of 1570 project with ballast on seaway with heights of 3% probability waves of 7.0 m has been investigated. Length of checked for safe operation of ballast change hold makes 70.4 m (63% of vessel's length L). Ballast acceptance in such holds in practice is carried out since vessels of this project have volumes of ballast tanks which provide non-loaded ship sitting only with shallow fore draught about 1.20-1.40 m that is not enough for operation at sea with R2-RSN class.

Special calculations of extreme and operational hydrodynamic pressures of BW on constructions of cargo hold carried-out with account of rolling on seaway with partial filling have shown that maximum values of hydrodynamic pressures with partial filling of hold with level of ballast up to 2.55 m from double-bottom plating made 97.4 kPa under operational and 123.9 kPa under extreme conditions. Assigned values considerably (more than twofold) exceed loads from test pressure which makes 43.65 kPa. Herewith normal stresses in the most loaded lower cross-sections of off-loaded stiffeners of transverse bulkheads made 96% from safe stresses.

Significant level of actual normal stresses close to allowed level attracts attention. Mentioned loads are dangerous with partial filling if to account possible construction faults or / and excessive wear.

Tanks' overpressure. As it was earlier mentioned, in process of BW change at sea there is also danger of ballast tanks' overpressure. The special role in process of BW change belongs to air pipes which provide free access of air to tanks under draining and its output in process of BW acceptance. Diameter of ballast tanks air pipes is not less than 50 mm herewith value of total cross-sectional area of these pipes is not less than 125% of value of total area of filling pipes. At non-operational condition when cross-sectional area of air pipes decreased because of icing, corrosion products and mechanical damages ballast tank's overpressure with deformation of bulkheads which enclose this tank is possible. Such emergency situations can be avoided if to apply following organizational arrangements: control of BW filling level; control of BW loose from air pipes; control of free air output from air pipes; broad application of tanks' filling with gravity flow; when using ballast pump pressure should not exceed 0.15 MPas with manometer control; not to allow formation of ice jams in air and sounding pipes; to maintain system of ballast tanks heating if exists.

Risk assessment of ballast change at sea. Carried-out analysis of seakeeping and strength performances of existing vessels during ballast change revealed following dangers: - in case of wrong order of BW change problems with ensuring general structural strength of vessel's hull are possible. Probable consequence – vessel's hull breakdown (consequence ratio (CR) = 5); - in case of emergence of partially filled BW tanks and holds vessel's stability significantly decreases. Probable consequence – vessel's capsize (CR = 5); - during BW removing from highly located tanks there is intensification of vessel's rolling. Probable consequences – cargo shifting without vessel's loss (CR = 2...4 depending on damage of property, hull constructions and injury of crew); cargo shifting with subsequent vessel's capsizing (CR = 5); deterioration of crew habitability (CR = 1...2); - dangerous fore end waves slaps appear at bow shallow draught (CR = 1...2 depending on damage to hull constructions); - vessel's screw emergence at aft shallow draught. Probable consequence – main engine incapacitation (CR = 2...5 depending on further scenario which can end with non-scheduled repair or can lead to vessel's loss in storm conditions); - at storm sea and under the influence of wind vessel becomes unhandy at shallow mean draught. Probable consequences – grounding, collision with another vessel (CR = 1...5 depending on further scenario which can end with non-scheduled repair or can lead to vessel's loss); - in case of emergence of partially filled BW tanks and holds resonance can appear (coincidence of free frequencies of liquid in partially filled ballast tanks and holds with frequency of external compensating force from sea states) which leads to high impact loads on hull construction until its destruction. Probable consequences – vessel's hull damages (CR = 1...5 depending on further scenario which can end with non-scheduled repair or can lead to vessel's loss in storm conditions); - in process of BW acceptance and discharge high water pressure differential in adjacent compartments can appear. Probable consequence – vessel's hull damages (CR = 1...3); - in case of appliance of flow-through method of BW change and because of bad control of BW change by sequential method tanks' overpressure is possible. Probable consequence – vessel's hull damages (CR = 1...3).

Received results allow to draw conclusion that during ballast change occurrence of dangerous situations is possible (in order of severity level of consequences): - stability loss including because of cargo shifting; - hull breakdown or severe damages of hull structures because of violation of general longitudinal strength restrictions; - emergency stop of main engine; - controllability loss; - damages of separate structures and deck gears because of slamming, wettability and violation of ice class restrictions.

Risk control and management. Procedure of safe ballast change at sea. Thus ballast change at sea for existing vessels can be really dangerous. That is why required by D-1 standard Ballast water management plan (BWMP) for existing vessels has to provide risk control on following positions: - bending moments, shearing forces, torsion torques (if required) should not exceed allowed by RS for given sailing area. Possible additional measures of risk management – assignment of special restrictions of wind and wave conditions; - stability with account of free surface effect correction in partially filled tanks has to be not lower required by RS; - acceleration criteria has to be not less than 1.0. Possible measures – assignment of special restrictions of wind and wave conditions; - fore draught has to be not less than safe by slamming condition value. Possible measures – assignment of special restrictions of wind and wave conditions; - aft draught has to provide screw immersion sufficient for main engine work. Possible measures – assignment of special restrictions of wind and wave conditions; - mean draught has to be sufficient for safe vessel's operation. Possible measures – assignment of special restrictions of wind and wave conditions; - situations with occurrence of hydrodynamic impacts in condition of partial filling should be predicted by calculations and, whenever possible, should be avoided. Possible measures – assignment of special restrictions of wind and wave conditions; - to avoid in process of BW acceptance and discharge high water pressure differentials in adjacent compartments which are not checked by local strength calculation of tanks and holds constructions. Measures for prevention of tanks' overpressure have to be assumed.

In process of BWMP development for specific vessel changes in actual operational documents for the purpose of unification and ensuring mutual harmonization of requirements to conditions of vessel's loadings can

be required. It is important that procedure of ballast operations control and draughts has to be effective and environment friendly, almost practicable, developed to minimize cost of ballasting and vessel's delay. It is necessary to take measures for exception of unnecessary discharges of ballast waters.

Developed plan has to include all loading cases which include acceptance and discharge of additional ballast in accordance with "Stability and strength booklet for the Master", "Stability booklet for grain transportation", "Stability and strength booklet for bulky cargoes transportation", "Loading manual", and also other loading cases connected with operating conditions of specific vessel. For each loading case admissible methods of ballast change at sea and corresponding to them environmental conditions have to be defined. In case of possibility of usage of two methods of ballast change (sequential and flow-through) each method has to be described separately.

Circumstances under which is inadmissible to make ballast water change have to be defined. Such circumstances can appear as a result of critical situations of exclusive character or force majeure circumstances because of force of nature or other circumstances under which human life or safety of the vessel are under the threat.

Such "Manual" has to be developed for each specific vessel with taking into account its design and operational features, and also features of sailing area with indication of allowed wind and wave conditions and zones where it is possible safely to accept and change BW.

Ballast water treatment system. In 2016 from all vessels calling at Novorossiysk port less than 2.5% have been equipped with BWTS [1].

Other vessels have transition period. They have to be equipped additionally with BWTS to the first after September 8, 2019 survey. Marine Engineering Bureau showed how on new RST25, RST27, RSD49 and SDS18 projects such systems are installed (or can be mounted since from building stage mounting location and corresponding connections to ballasting system and ship's electric powerplant have been foreseen) – see Fig. 3.

As to expert evaluations for new (i.e. recently built) "Volga-Don max" class vessels such BWTS, depending on supplier, costs about 210-270 thousand dollars, and taking into account works expenses will make up to 350 thousand dollars on the vessel. For "Soviet" construction vessels expenses can be significantly higher as there are difficulties with BWTS installation. It is quite probable that power of ship's electric powerplant will be insufficient and it may become necessary to change diesel-generator, etc. It is important to estimate time which is required for water ballast treatment because ship's electric powerplant will work and additional fuel will be consumed. As it has been noted in the report of chief specialist of RS mechanical department V.K. Shurpyak [11] at "BWM Convention Implementation in Russia" conference in process of development of project of BWTS installation on existing vessels it is necessary to fix-up with following: - ship's space for installation of system and its pipelines; - sufficient power of ship's electric powerplant; - availability of ballast pumps with necessary delivery head with account of pressure losses in BWTS; - access for possibility of sediments removal and their delivery to receiving sections; - access for drawing of ballast water and sediments samples; - to consider possible features of existing ballasting system scheme (ballast pumps can be located in different compartments, several discharge outlets, cargo tank can be used as ballast tank and so forth). Expenses on modernization to requirements of BWM-2004 on such vessel can be close to 500-800 thousand dollars and higher.

As IAA PortNews noted the representative of Damen shipbuilding group (The Netherlands) Peter Anssems has declared that since September 8, 2017 there will be need of 20-40 modernizations of vessels for BWTS installation per day around the world. Damen group developed InvaSave system which is optimal decision for implementation of BWM Convention. InvaSave system is first-ever ballast water purification system which can be used in sea ports as mobile installation for those vessels whose owners will not be in time or will not want to re-equip vessels until September 8, 2019. InvaSave can be delivered as independent unit in container. The system can then be installed on barge or other platform for free transportation within port area. For increase of system's power of treatment some blocks can be installed in parallel.

Figure 3. Arrangement of BWTS equipment on Marine Engineering Bureau RSD49 dry-cargo vessel

CONCLUSIONS

Methods of BW treatment and discharge in ports are able to solve the problem with ballast but cost of such arrangements is too high. Therefore for operating vessels within existing technical and economic conditions method of ballast change in open seas on distance not less than 200 nautical miles from coast with depth not less than 2000 metres is quite possible for real usage for the nearest five years.

Marine Engineering Bureau successfully substantiates (with classification societies' approval) Ballast water management plans for many native ship operators of sea and river-sea vessels.

REFERENCES

- [1] N.A. Korolev. Organization of Port State Control within the framework of The International Convention for the Control and Management of Ships' Ballast Water and Sediments on example of the Novorossiysk port // Implementation of BW-2004 Convention in Russia: presentations of reports. IA "Portnews". - M.: Chamber of Commerce and Industry, 2017 (in Russian).
- [2] S. Limanchuk. Transfer of alien harmful aquatic organisms through oceans // Maritime fleet. - M, No3, 2001. - pp. 20-22 (in Russian).
- [3] A.P. Polnikova. Results of the analysis of qualitative composition of ballast waters discharged in the North-Western part of the Black Sea in 1997-2001 // Ecologic problems of the Black Sea: Proceedings of 4th International Symposium / Odessa center of science-technical and economic information (OCSTEI) - Odessa: OCSTEI, 2002. - pp. 172-180 (in Russian).
- [4] N.A. Reshetov, L.Ya. Parfenov. Problems of ballast water discharge restrictions // Maritime fleet. - M, No5, 2002. - pp. 28-29 (in Russian).
- [5] D.Ya. Faschuk, V.V. Sapozhnikov. *Man-made burden on "sea-hydrographic water basin" geosystem and its influence on fishery (methods of the Black Sea diagnosis and prognosis)*. - M.: VNIRO publishing house, 1999. - 124 p (in Russian).
- [6] E. Halvorsen. Alien organisms threaten marine ecosystem // DNV Forum. - 2000. - No.3/2000. - pp. 32-33.
- [7] The spectre of shipping lost // The Naval Architect. - June 2001. - pp. 51-53.
- [8] G.V. Egorov. Technical problems of ballast changing at sea for minimization of transfer of harmful aquatic organisms and pathogens // Ecologic problems of the Black Sea: Collection of articles / OCSTEI - Odessa: OCSTEI, 1999 - pp. 93-97 (in Russian).
- [9] G.V. Egorov. Identification of hazards and risk reduction measures in the process of ballast changing at sea by existing vessels // Navigation: OSMA collection of articles. - Odessa: Latstar, 2001. - Vol. 3. - pp. 64-75 (in Russian).
- [10] G.V. Egorov. Research of risk of hull constructions damages in the process of ballast changing at sea // Proceedings of Ship structural design science-technical conference named for prof. Yu.A. Shimanskiy. - SPb: Krylov state research center, 2001. - pp. 31-32 (in Russian).
- [11] V.K. Schurpyak. Fulfillment of requirements of The International Convention for the Control and Management of Ships' Ballast Water and Sediments // Implementation of BW-2004 Convention in Russia: presentations of reports. IA «Portnews». - M.: Chamber of Commerce and Industry, 2017 (in Russian).

PV300 CONCEPT OF RIVER CRUISE PASSENGER VESSEL FOR REPLACEMENT OF MAIN PART OF EXISTING FLEET

Gennadiy V. EGOROV*, Igor A. ILNYTSKII**, Yaroslav V. KALUGIN***

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – Marine Engineering Bureau (Odessa, Ukraine), deputy general director, chief designer, RINA fellow

*** – Marine Engineering Bureau (Odessa, Ukraine), chief designer, RINA member

Abstract. Today river cruise vessels transport about 350-400 thousand tourists on Russian rivers, which includes 75 thousand foreigners. Average age of Russian existing cruise vessels makes 43 years. In the next decade this fleet most likely will be decommissioned and we will have only about 40-50 vessels. By some expert estimates the market size will make 1.0 million tourists by 2030.

The market assessment including previous years experiment on operation of first-class vessels PV08 "Alexander Grin" and "Victoria" with native tourists and PV09 "Shtandart" allows to draw conclusion that, with taking into account the predicted reduction of vessels of old series, not less than eight new cruise vessels of PV300VD, PV300 concepts will be required by 2025.

New concepts have quite acceptable draughts: PV300VD – 3.20 m, PV300 – 3.00 m and that their "five-stars" opportunities are demanded both foreign, and Russian tourists.

Keywords: comfort, design, hull structure, river and river-sea passenger vessel, safety.

INITIAL PROBLEM

In last years native river cruise market is characterised by active moral and physical ageing of passenger vessels, and as a result, their withdrawal.

Thus, problem of creation of river and river-sea cruise vessels (CV) became actual and important for Russian water transport and tourist industries.

AIM OF THE PAPER

Grounding (on basis of 2010-2015 Marine Engineering Bureau (MEB) researches) of PV300 concept of modern river CV which is of interest for native shipping companies. This vessel will be operated on classical river lines, and also make episodic cruises in coastal zones in accordance with assigned class.

MAIN TEXT

Works on PV300 concept creation were based on the general approaches to design of the river and river-sea vessels as well as on the basis of special decisions [1-9]. The basic role was played by detailed and repeated problems' discussion with leading experts of passenger branch: K.O. Anisimov, V.F. Berezin, A.A. Trofimov, D.G. Ryabov, D.N. Galkin, A.E. Smolin, A.A. Syomin, O.F. Malinin and many others.

Especially grandiose role of the successful experience which is saved up in process of creation of PV08 "Alexander Grin" CV [3] and other Marine Engineering Bureau projects for Moscow River Shipping Company, and also experience of design and building at Moscow Shipbuilding and Ship-repair plant of river-sea PV09 "Shtandart" CV should be noted.

To our opinion, new generation of cruise vessels for Russian inland waterways will be characterized by the following features:

1. Due to main dimensions. Restrictions of way conditions of vessel's operational region are determinative (e.g. depths, dimensions of vessel's navigation pass, dimensions of hydraulic engineering facilities, etc.) – "Volgo-Balt Max", "Volgo-Don Max" / "Dnipro Max", "BBK Max", "Danube Max" classes.

Main dimensions of CVs' concepts are accepted depending on data, which are shown in Table 1. For further details see [5, 6].

It is clear that abovementioned concept will have restrictions on passengers' capacity as length and breadth of the vessel appointed in accordance with way conditions will limit useful area which can be allocated for cabins and for passenger serving spaces (restaurants, salons etc.). The number of decks is defined by air draught.

MEB PV300 "Volgo-Don Max" class vessel concept will work on lines Moscow – St. Petersburg, and also will make voyages in coastal zones in accordance with assigned class.

2. Due to architectural and constructive vessel's type, as follows [2]:

a) so called "floating hotels" with superstructure at all vessel's breadth without passages by sides (with full-grown balconies / terraces or with French balconies at cabins for CVs that are oriented to foreign tourists. Upper "sun" deck is equipped with swimming pool and tents;

Table 1. Cumulative information about main particulars of river-sea CVs

Vessel's class		Overall length L_M , m	Overall breadth D_M , m	Draught d , m	Air draught H_{NG} , m
"Volgo-Balt Max"		≤ 185	$\leq 16.95-20.1$	2.90-3.80	≤ 13.2
"Volgo-Don Max"		≤ 140	≤ 17.0	3.20-3.70	≤ 13.2
"BBK Max"		≤ 132	≤ 13.63	2.90-3.80	≤ 11.9
"Danube Max"	Danube – Passau	≤ 135	≤ 13.40	2.00-2.50	≤ 6.7
	Upstream Passau*	≤ 135	≤ 11.45	1.70-2.00	≤ 6.03
*including pass-through to Northern Sea (Danube-Main- Rhine system)					

b) with promenade gallery by sides on all decks; such arrangement provides all-round view for tourists. This variant is used rarely for new projects because many tourists don't like when other people are close to the windows of their cabins;

c) with fore saloon that provides both-sides view.

Interim option (for CVs oriented on Russian tourists) is applied. This option combines variants mentioned above in different degrees. Practically all new CVs (sea and river going) built abroad are foreseen with maximal number of balconies.

MEB PV300 concept designed in "floating hotel" version with full-grown balconies/ terraces at cabins, with swimming pool and tents on upper "sun" deck and with both-sides view fore saloon.

3. Due to inner compartments planning: module principles of forming living blocks in total and cabins themselves (standard cabins) and vertical zoning of living and public compartments were used; restaurant, salons and bars are arranged in vertical zones separate from living compartments; noise spaces are not arranged above passenger or crew cabins.

Total cabins area is 16-43 sq.m including balcony / French balcony (cabins are double usually). Restaurants with total places equivalent to passengers' number, conference hall, bars, internet-salon, babies rooms, beauty salon, souvenir shop, fitness salon; solarium are located on the open sun deck. Lifts connected all decks, communications and toilets are foreseen for physically challenged people.

4. It is unequivocally that during designing of new vessels one should start from the comfort level set by the customer as a quantity of conditional stars or comfort factor which will serve as the regulating factor of the future vessel's efficiency as function that determines required areas of decks and compartments, overall vessel's dimensions, vessel's propulsive characteristic, and vessel's economic efficiency as a result.

As a criterion of an estimation of passenger vessels design comfortableness it is possible to apply the five-stars scale informally used practically by all tour operators [9]. The quantity of stars increases according to increase of service quality and comfort.

It is necessary to emphasize especially CVs with enhanced comfort (per se, yachts) and vessels for single-day cruises (cabinless). Such vessels often don't relate to CVs due to their significant differences in the approaches to passenger zone and a number of special questions (availability of additional opportunities for water types of activity, etc.).

However such vessels are often become platform for development including for classical cruise transportations. Example of this thesis is shown on Fig. 1 (comparison of side views of PV09 and PV300 projects).

5. Choice of classification society class of perspective cruise passenger vessel assumed following [4]:

- assignment of class based on sailing areas in accordance with planned directions of transportations;
- definition of ice class in accordance with saved-up experience and tendencies to extension of the navigation period including winter operation;
- assignment of economically reasonable life-time cycle of the vessel.

So for "Volgo-Don Max" PV300 concept with possibility of operation in coastal zone RRR class $\boxtimes$ M-PR 2,5 has assigned.

6. For safe and accelerated process of passengers' evacuation modern evacuation systems consisting of sleeve and accepting platform (sometimes landing of passengers can be carried out straight on rescue device) on

which passengers during evacuation go down and with which passengers move on rescue vessel boats and rafts can be used.

7. Crew has to be formed with taking into account ship power plant automation, automation of deck works (automatic anchor mooring winches), automation of process of loading of supplies and mechanization of process of cleaning of decks (washing machines, etc.) and with taking into account usage of specialties combination.

8. Choice of main particulars of river and river-sea CVs is defined by way conditions, such as tour operator strategy and his position in the market, adherence to those or other lines and comfort level in view of necessities, propensities and interests of passengers for which these vessels are built [9].

Such external subjective choice should be carried out basing on discrete number of the alternatives which quite objectively have arisen in the domestic tourist market as a result of the compromise due to choice of way restrictions and sizes of tourist groups (400-500 people, 250-300 people, 200-250 people, 100-150 people).

Analysis of such alternatives has allowed to build parametrical line-up of river and river-sea cruise vessels objectively demanded by native Shipowners and on its basis to develop in MEB projects of new vessels [3, 5, 6, 7].

The most attractive is "Volgo-Don Max" / "Dnipro Max" PV300 concept (dimensions are defined by way conditions of Volga-Don Ship canal, Dnipro River, passengers' capacity is about 300 people). The vessel is planned to be operated on lines connecting St. Petersburg port and Moscow port, on Volga-Don Ship Canal with exit in Azov and Black Seas, on Volga with exit in Caspian Sea, on Volga-Baltic waterway with exit in Baltic Sea or on Kiev – Kherson – Nikolayev – Odessa – Izmail line. Sea operation is provided within RRR class M-PR, in fact this is coastal operation in 20-mile zone from seashore with season restrictions.

PV300 concept architectural-structural type is as follows: steel, self-propelled river-sea (M-PR class) motor ship with two full-rotated rudder propellers, with plumb stem and transom stern, with excess freeboard, with extended forecastle, with four-tiers living superstructures through the whole vessel's length, with wheelhouse located fore and engine-room located aft.

General arrangement of concept is given on Fig. 2, general view is on Fig. 3.

Vessel's main particulars are as follows: length overall 141 m; length between perpendiculars 135.36 m; breadth overall 16.80 m; breadth 16.60 m; depth 5.00 m; draught maximal 3.00 m; air draught from BL 16.25 m; crew and service staff 144 people; autonomy by fuel 15 days; autonomy by other stores 5 days.

Passenger capacity of the vessel can be varied from 300 to 400 depending on the type of cabin modules used (area of cabins is 16-43 m²) and usage of additional places for children.

Arrangement of the cruise vessel in the basic variant of "Vodohod" shipping company foresees 342 passengers who travel in 171 comfortable cabins of different classes:

- 1 luxury cabin of about 29 m² area;
- 1 luxury cabin of about 26 m² area;
- 168 standard cabins of about 19 m² area (see Fig. 4);
- 1 standard cabin for disabled people of about 29 m² area.

Passenger cabins are located in the middle vertical zone on 3 superstructure decks.

All passenger cabins are equipped with double beds, lavatory and douche, air-conditioner, wardrobe, safe, TV set with satellite and internal vessel's channels, hairdryer, sockets 220V and 110V, wireless Internet (Wi-Fi), vessel's radio translation, external and internal telephone connection.

Fore, middle and aft vertical zones are used for providing rest of passengers on the vessel.

On sun deck rest area for taking of solar baths and run track are foreseen.

Figure 1. Comparison of side views of PV09 and PV300 / PV300VD concepts

Figure 2. Scheme of general arrangement of PV300 cruise passenger vessel of "Volgo-Don Max" / "Dnipro Max" class

Figure 3. General view of PV300 cruise passenger vessel of "Volgo-Don Max" / "Dnipro Max" class

Figure 4. View of PV300 standard passenger cabin

On main deck rest areas with passenger lifts and reception desks are foreseen in fore and aft lobbies (atriums).

Souvenir shop is foreseen in fore lobby on main deck.

PV300 concept is not only up-to-date high comfortable and handy vessel but also safe, ecology “clear” passenger one that fully meets requirements of all Russian requirements such as Sanitary Regulations and Norms, Fire Safety Regulations, Technical Regulations for Safety of Inland Water transport Objects.

The vessel fully satisfies all normative requirements of Russian River Register Rules for passenger vessels.

Main 7 watertight transverse bulkheads are installed on the vessel. They divide hull into 8 impermeable compartments.

At the aft part of the vessel from each side two fast 48 persons' capacity life-boats and two workboats are installed.

For safe and accelerated process of passengers' evacuation 2 evacuation systems with closed inflatable self-righting rafts (2 rafts on 100 persons each) with fore anteroom are installed on vessel.

Middle part of vessel's hull is constructed by mixed framing system. Main and upper decks are constructed by longitudinal framing system on whole length. Lower, boat and tent decks are constructed by transverse framing system on whole length. Bottom and double bottom are constructed by longitudinal framing system in middle part and transverse framing system in ends and in ER. Outer side is constructed by transverse framing system on whole length. Constructions of ends are constructed by transverse framing system.

Construction of sides and bottom is reinforced in accordance with RRR rules and ice class "Ice 30".

Construction of vessel's decks in area of big cutaways under atriums is reinforced with thickened sheets and additional connections.

Fire safety of new concept is provided by division of the vessel into main vertical zones with constructive and thermal barriers; subdivision of accommodation spaces from other spaces with thermal and constructive barriers; exception of application of inflammable materials; detection of any seat of fire in zone of its emergence; restriction of distribution and fire extinction in places of its emergence; protection of means of escape and accesses to them for fight against the fire and readiness of fire-protection equipment to fast application.

From each waterproof compartment located below bulkhead deck two outmost from each other exits are made.

Special requirements to equipment of ventilation systems of the vessel were revealed on design stage. Spaces which are in different vertical fire zones are not connected between each other through vent ducts. Vent ducts are arranged in way so that they could be blocked from the outside of ventilated spaces.

Ventilation control is executed from two posts located on maximal outmost from each other.

Except meaningful measures of fire protection, complex of actions for fit out of accommodation, public and service spaces by automatic systems of fire detection and automatic sprinkler systems in local vertical fire zones is executed.

In aft part of the vessel two full-rotated fixed pitch rudder propellers (FPRP) with mechanical power on input shaft is of 1200 kW each are installed. For improvement of controllability at low speeds, at passing narrow waters and at moorings bow thruster is foreseen.

As special researches have shown better maneuverability of the vessel is provided on wide angles at FPRP turn. In process of decrease in motion speed of the vessel advantage of FPRP increases up to the most low speed <3 kn when the vessel with rudders becomes almost uncontrolled and FPRP allow to carry out vessel turn in pos.

Usage of FPRP is especially effective while vessel's operation in river when passing narrow places and numerous river turns the vessel cannot move with maximum speed and efficiency of rudders falls down. Thus the vessel equipped with FPRP can pass the same way section faster.

If to operate vessel on one FPRP there is no loss of controllability and thus vessel speed falls slightly to 7.5-8.0 kn. In economy mode of operation on one FPRP considerable fuel saving exists.

Purchase value of FPRP is approximate equal to the total cost of speed-reduction gear, shaft line, stern gear, screw, nozzle, steering gear and rudder.

Therewith FPRP installation is simpler: there is no need for laying of shaft line, thus less qualified personnel can be used, time of FPRP installation is less than time of mechanical transmission installation. All this allows to cut down expenses on mounting.

FPRP installation can be carried out afloat after vessel's launching. Delivery and installation of equipment of rudder propeller system can be made for some months later that also leads to economy of funds.

Therefore FPRPs have been applied on PV300 concept.

For providing full control over the vessel's movement while maneuvering on slow speed, mooring operations and docking installation of vessel's control system which unites all propulsion units of the vessel

(screws, FPRPs and bow thrusters) in integral module is provided and thus control of all these propulsion units is executed by means of one joystick.

Main power plant is diesel. It consists of two main diesel engines Wartsila 6L20 of maximum continuous power 1200 kW each.

Auxiliary power plant consists of:

- three diesel-generators of electrical power of 760 kW each;
- emergency diesel-generator of 214 kW electrical power;
- auxiliary mechanisms and apparatus working for power plant.

Auxiliary boiler plant consists of:

- one oil fired thermal oil heater with heat power 800 kW;
- three thermal oil exhaust gas heaters with heat power 170 kW each.

As fuel for main engines IFO380 with viscosity 380 cSt at 50°C and low sulfur content is used. For emergency diesel-generator MDO with low sulfur content with flash point over 60°C is used.

CONCLUSIONS

The most serious restraining factor of growth of native cruise tourism industry is lack of modern cruise vessels.

Mean age of such vessels makes 42 years, thus age of half of 90 existing CVs is 50-60 years. In the next decade this fleet most likely will be written off and we will have only about 40 vessels.

For the solution of problem of updating it is offered to connect river and some coastal sea routes on the basis of modern cruise vessel of PV300 project.

This is the diesel engine vessel which fits to all standards of modern cruise and hotel industries. There are all types of necessary rest (restaurants, Spa centres, fitness, bars, etc.). All leading native cruise operators took part in development of the vessel therefore concept completely meets their requirements.

PV300 concept is not only up-to-date high comfortable and handy vessel but also safe, ecology "clear" passenger one that fully meets requirements of all Russian requirements such as Sanitary Regulations and Norms, Fire Safety Regulations, Technical Regulations for Safety of Inland Water transport Objects.

PV300 vessels will be operated on classical river lines with replacing classical cruise vessels of 301 and 302 projects, and also make episodic cruises in coastal zones in accordance with assigned class.

REFERENCES

- [1] G.V. Egorov. Risk-oriented approaches to grounding of distortions from regulatory requirements for restricted sailing area vessels // Problems of technique. - 2005. - No3. - pp. 3-13 (in Russian).
- [2] G.V. Egorov. Analysis of European river cruise experience and its influence on native cruise vessels of new generation // Maritime Reporter. - 2012. - No3 (43). - pp. 23-28 (in Russian).
- [3] G.V. Egorov, K.O. Anisimov. Three-decked cruise passenger vessel "Alexander Grin" of PV08 project // Shipbuilding and shiprepair. - 2012. - No53. - pp. 22-33 (in Russian).
- [4] G.V. Egorov, A.G. Egorov. Research of reliability and operational risk of native river cruise passenger vessels // ONMU Reporter. - Odessa: ONMU, 2015. - Vol. 1 (43). - pp. 5-31 (in Russian).
- [5] G.V. Egorov, I.A. Ilnytskiy, Ya.V. Kalugin. Principles of hull designs of cruise passenger vessels for European part of Russian IWW // Trans. of sc. conf. in memory of academician of Shimanskiy Yu.A. - SPb: Krylov State Research Center, 2011. - pp. 30-31 (in Russian).
- [6] G.V. Egorov, I.A. Ilnytskiy, Ya.V. Kalugin. "Lineup" of river cruise passenger vessels // ONMU Reporter. - Odessa: ONMU, 2013. - Vol. 2 (38). - pp. 20-40 (in Russian).
- [7] G.V. Egorov, Ya.V. Kalugin. Creation of new passenger vessels with account of experience of European cruises // NUS Collection book. - Nikolayev: NUS, 2013. - No1. - pp. 4-10 (in Russian).
- [8] G.V. Egorov, Ya.V. Kalugin, A.G. Egorov. Analysis of Russian passenger fleet conditions // Problems of technique. - 2012. - No4. - pp. 6-39 (in Russian).
- [9] A.A. Semin. Influence of comfortableness on choice of main dimensions of river and river-sea passenger cruise vessels // ONMU Reporter. - Odessa: ONMU, 2005. - Vol. 17. - pp. 39-45 (in Russian).

ABOUT APPROACHES TO DESIGN OF ONE-DAY TRIP VESSELS FOR PLEASURE CRUISES FOR THE BLACK AND CASPIAN SEAS

Gennadiy V. Egorov*, Igor A. Ilnytskii**, Nickolay V. Avtutov***

* – Marine Engineering Bureau (Odessa, Ukraine), general director, Professor, Dr, RINA fellow

** – Marine Engineering Bureau (Odessa, Ukraine), deputy general director, chief designer, RINA fellow

*** – Marine Engineering Bureau (Odessa, Ukraine), perspective development director, chief designer, RINA member

Abstract. In paper it is shown that vessels for short cruises are widely known around the world and are part of tourist infrastructure of any seaside city and resort.

The new one-day trip PV01M "Imperia" vessel was the first for more than ten years passenger vessel built for transportations of passengers on coastal lines and sea routes near Black Sea coast. In total there are 300 seats for passengers at restaurants and on open decks of the 1st and 2nd tiers on the vessel. In aft part of 2nd tier deck pool with leisure area for passengers is equipped.

The project of PV20 passenger one-day trip vessel-restaurant has been developed for operation in Baku gulf. Upper opened promenade deck with bar on 100 places, restaurant on 100 places on main deck, 2 two-place VIP cabins on lower deck in middle part are foreseen for recreation of 150 passengers.

Keywords: comfort level, design, one-day trips, passenger vessel, pleasure cruises.

INITIAL PROBLEM

Vessels for short (about one day) cruises are widely known around the world and are part of tourist infrastructure of any seaside city and (or) resort. When in 2008 in Gelendzhik new vessel for pleasure cruises "Imperiya" of PV01M project has appeared, she was the first for more than ten years passenger vessel built for passengers' transportations on coastal lines in resort towns of the Black Sea coast of former USSR.

It is interesting to note for the first time same functions vessels ("Zarya" and "Zarnitsya" types) have been built in 1928 at Odessa Ship repair plant. They could transport up to 235 passengers each. In 1934 in Odessa and Taganrog serial building of pleasure crafts for Big Sochi resorts which were roughly developing has been organized. After the Great Patriotic War well-known series "Lastochka", "Almaz", "Magnolia", "Arkadiya", "Raduga", "Alexander Grin" well acquainted to senior generation people have appeared. By 1970 annual volume of transportations on one-day trip vessels has reached 40 million passengers and 40% from them made the Black Sea and Azov resort and coastal lines. For the last 15-20 years quantity of pleasure crafts in the Black Sea has sharply decreased, number of short sea trips has reduced practically to zero.

AIM OF THE PAPER

Description of design "lineup" of one-day trip vessels for pleasure cruises in the Black and Caspian Seas on the basis of Marine Engineering Bureau (MEB) passenger traffic and existing fleet researches and way conditions in expected areas of operation of new vessels.

MAIN TEXT

By results of the analysis of operating experience, design and building of Russian and foreign passenger one-day trip vessels following decisions applicable for perspective pleasure crafts are marked [1-5].

1. Due to main dimensions of vessels:

- restrictions of way and weather conditions of vessel's operational region are determinative;
- ratio of principal dimensions received as a result of optimization of vessel's running performances and weight / space characteristics is defining.

2. Due to architectural and constructive vessel's type depending on climatic conditions of operation area of the vessel two main types of exterior of vessels have the greatest distribution:

- "southern" with maximal glass covering of passenger saloons with possibility of opening, navigation bridges with open wings;
- "northern" with all breadth closed navigation bridge of the vessel with minimization of glass covering (for reduction of calorific losses) passenger saloon.

In some cases intermediate variant representing in varying degree combination of above mentioned options is applied.

3. Main design principles for design of hulls of specified vessels:

- due to growth of effective height of hull section (including of superstructure decks in overall longitudinal strength) securing of sufficient for the accepted class overall longitudinal strength without increase of thickness of the overwhelming majority of constructions in comparison with the minimal thickness of RS Rules;

- keeping thickness of sheathing and shell at minimal ones level in order to minimize steel hull weight and to provide required local strength and steadiness due to rational application of the ordinary and web elements;

- assignment of identical, whenever possible, thicknesses of plates of web and ordinary structure elements and shells for providing equal wear durability;

- design sides and bottoms structures on operational loads, which in majority are considered till now "not design" (contacts to hydraulic structures, ground, etc.);

- design "smooth" flanges of hull girder with a minimum quantity of technological openings and weld fittings in order to increase in actual fatigue durability, usage rationally executed assemblies of structure element crossing and smooth change of the areas of longitudinal structure elements of the hull through its length.

4. From the position of shipping and ecologic safety the following technical measures can be proposed in order to minimize risk at the level of passenger vessels design:

- don't permit usage of opened holes (illuminators) within watertight hull boundaries;

- don't permit non-symmetrical stores arrangement, which can lead to the list appearance during operation;

- don't permit placing of oil liquids (fuel oil, lubricated oil, oily water) in tanks adjacent with outboard water;

- equip vessels by duty activity storing apparatus (voyage recorders) and means of emergency outer signaling.

General features of one-day trip vessels for pleasure cruises.

The analysis of operating experience of one-day trip vessels allowed to build up parametrical row of objectively demanded by native Shipowners vessels and on its basis to develop in MEB new designs.

Version of such "lineup" of new projects is given in Table 1.

Following passenger vessels are demanded on modern native market:

1. Coastal passenger pleasure and running vessel of PV02 project

The vessel is assigned for pleasure cruises on inland waterways of Russia including Ladoga and Onega Lakes, and also in Gulf of Finland of Baltic Sea with 10 VIP passengers onboard.

Architectural-structural type is as follows: steel, two-screw motor ship, with raked stern and cruiser aft extremity, with middle arrangement of superstructure, wheelhouse and engine-room, RRR class M-PR 2,5 A.

Main characteristics of coastal passenger pleasure and running vessel of PV02 project for 10 passengers: overall length is of 44.20 m, length (due to design draught) is of 40.60 m, overall breadth is of 7.015 m, depth is of 2.50 m, design draught is of 1.85 m, passenger capacity – 10 persons, crew – 6 persons, autonomy of sailing – 5 days, main engine power - 2 x 215 kW, operational speed – 12 kn.

Scheme of general arrangement is given in Fig. 1.

Main engines are located amidship. Passenger cabins are located fore and crew living quarters are located aft.

Vessel's air draught allows to sail under undrawn bridges of St. Petersburg.

For passengers' accommodation there are provided 6 double block-cabins, consisting of bedroom and individual sanitary unit. Sauna compartments are located amidship. Saloon and promenade deck for passengers' recreation are arranged in the aft superstructure. There is beam crane for fast speed boat and aquabike launching from the boat deck. Aft crinoline is equipped by two ladders for passengers decent into the water.

Six life rafts of throw-off type of 10-persons capacity each are mounted on shade deck. Three are from port side and three – from star board.

Table 1. Main characteristics of one-day trip vessels designed by Marine Engineering Bureau

Marine Engineering Bureau project	Side view, number of view	Overall length x breadth x depth, m	Passenger capacity, pers.	Sailing autonomy, days	Operational speed, km/h	Class register notation	Remarks
Pleasure, running and banquet vessels							
PV07		45.84x 8.94x 4.45	12 (7 cabins)	2	31.5	✠ M-SP 3,5	Possibility of operation in river and in coastal zone
PV01M		45.03x 14.05x 2.82	300	14 hours	20.4	✠ M-SP 3,5	Possibility of operation in river and in coastal zone as passenger vessel
PV02		44.20x 7.02x 2.50	10	5	22.2	✠ M-PR 2,5A	Possibility of operation in river and in coastal zone
PV05		44.16x 7.015x 3.74	6 / 48 (voyages up to 8 hours)	10	20.9	✠ O 2,0 A	Possibility of operation in river as passenger vessel
PV20		42.70x 8.60x 3.40	150	3	18.5	KM ⚙ R3 AUT3-C Passenger Ship	Possibility of operation in river and in coastal zone as banquet vessel / floating restaurant
PV10		39.85x 8.60x 3.30	150	5	19.25	✠ L 0,6	Possibility of operation in river as banquet vessel / floating restaurant

2. River / coastal one-day trip banquet vessel for pleasure cruises of PV10 project

The vessel is assigned for pleasure cruises on coastal lines (optionally) and in river with 150 passengers onboard.

Architectural-structural type is as follows: steel, two-screw motor ship, with raked stern and cruiser aft extremity, with middle arrangement of superstructure, wheelhouse and engine-room, RRR class ✠ L 0,6.

Main characteristics of coastal one-day trip banquet vessel for pleasure cruises of PV10 project for 150 passengers: overall length is of 39.85 m, length (due to design draught) is of 32.54 m, overall breadth is of 8.60 m, depth is of 3.30 m, design draught is of 2.21 m, passenger capacity – 150 persons, crew – 16 persons, autonomy of sailing – 5 days, main engine power – 2 x 368 kW, operational speed – 10.4 kn.

Scheme of general arrangement is given in Fig. 2.

Figure 1. Scheme of general arrangement of passenger vessel for 10 passengers of PV02 project

Figure 2. Scheme of general arrangement of passenger vessel for 150 passengers of PV10 project

Berths for crew and passengers are not foreseen onboard.

For household purposes of crew there are crew compartment on upper deck and locker room near the block of lavatories below main deck.

For passengers sitting places in main deck (88 places), upper deck (44 places) and navigation deck (60 places) restaurants are foreseen.

Simultaneously there will be no more than 150 passengers on the vessel when operating on coastal lines.

Six life rafts of throw-off type of 25-persons capacity each and two life rafts of throw-off type of 100-persons capacity each are mounted on upper and navigation decks from both sides of vessel of PV10 project.

3. Coastal passenger one-day trip vessel for pleasure cruises of PV01M project

The vessel is assigned for pleasure cruises along the coastline of the Black Sea. Bay of the Gelendzhik port is a constant place of vessel's location from where regular coastline voyages are carried out.

Architectural-structural type is as follows: steel, three-deck, two-screw motor ship with forecastle, without poop, with deck sheering and hogging, with middle wheelhouse allocation, with aft ER, single sides, with raked stern and transom aft extremity, with RRR class $\boxtimes$ M-SP 3,5.

Main characteristics of coastal one-day trip vessel for pleasure cruises of PV01M project for 300 passengers: overall length is of 45.03 m, length (due to design draught) is of 43.20 m, overall breadth is of 14.05 m, depth is of 2.82 m, design draught is of 2.28 m, passenger capacity – 300 persons, crew – 17 persons, autonomy of sailing – 14 hours, main engine power – 2 x 375 kW, operational speed – 11.0 kn.

Scheme of general arrangement is given in Fig. 3.

Totally 300 sitting places for passengers are foreseen in restaurants and on opened 1st and 2nd tier decks.

Restaurants are located in the first and second tiers of superstructure. Restaurants of the first tier are equipped with stage and dressing room. VIP zone is organized in second tier restaurant. Dance floor with bar is situated on the open deck of the first tier. Swimming pool with the passengers' relaxation zone is equipped on the second tier of the deck in the aft end.

Level of the vessel's comfort level due to organizing separate zones with tables "for two" at each side of the vessel in first tier restaurant is significantly improved. Customers of the restaurant, sitting at the tables in such "special" areas, are able to enjoy the sea view through the large windows. Tables are installed directly in front of these windows.

Modern life-saving equipment is installed on both sides in order to improve safety level. Two marine evacuation systems with total capacity of 326 persons are arranged.

In aft part of the vessel on the second tier duty boat with its own lifting gear is installed.

4. Passenger pleasure and running vessel of PV05 project

The vessel is assigned for pleasure cruises on inland waterways of Russia with 6 VIP passengers onboard, and also with 48 passengers onboard with voyages up to 8 hours.

Architectural-structural type is as follows: steel, two-screw motor ship, with raked stern and cruiser aft extremity, with middle arrangement of superstructure, wheelhouse and engine-room, RRR class $\boxtimes$ O 2,0 A.

Main characteristics of passenger pleasure and running vessel of PV05 project for up to 48 passengers: overall length is of 44.16 m, length (due to design draught) is of 40.73 m, depth is of 3.74 m, design draught is of 1.50 m, passenger capacity – up to 48 persons, crew – 6 persons, autonomy of sailing – 5 days, main engine power – 2 x 170 kW, operational speed – 10.8 kn.

Scheme of general arrangement is given in Fig. 4.

For passengers' accommodation there are provided 3 double block-cabins, consisting of a bedroom and an individual sanitary unit. Sauna compartments with exit to the open deck are located aft (near crinoline). Saloon and promenade deck for passengers' recreation are arranged in the aft superstructure. There is conference room located fore in the superstructure. There is cargo crane for fast speed boat mounted on the shade deck.

In aft part of the vessel duty boat with capacity of 6 passengers is installed.

Duty boat is equipped as life-boat and fully fulfills requirements of RRR Rules to life-boats.

Six life rafts of throw-off type of 10-persons capacity each are mounted on shade deck in middle part of the vessel. Three are from port side and three – from star board.

Figure 3. Scheme of general arrangement of passenger vessel for 300 passengers of PV01M project

Figure 4. Scheme of general arrangement of passenger vessel for up to 48 passengers of PV05 project

5. Coastal one-day trip banquet vessel for pleasure cruises of PV20 project

The banquet vessel is assigned for pleasure cruises and coastal voyages in Caspian Sea.

Architectural-structural type is as follows: steel self-propelled double-deck, twin-screw motor ship with vertical stem and transom aft end, with excessive freeboard, with forecastle, with wheelhouse amidship, with aft engine room, with bow thruster, with RS class KM ★ R3 AUT3-C Passenger ship.

Main characteristics of coastal one-day trip vessel for pleasure cruises of PV20 project for 150 passengers: overall length is of 42.70 m, length (due to design draught) is of 41.25 m, overall breadth is of 8.60 m, depth is of 3.40 m, design draught is of 2.20 m, deadweight on design draught – 90 tons, passenger capacity – 150 persons, crew – 5 persons, operating crew – 15-20 persons, autonomy of sailing – 3 days, main engine power – 2 x 250 kW, operational speed – 11.0 kn.

Scheme of general arrangement is given in Fig. 5.

Figure 5. Scheme of general arrangement of passenger banquet vessel of PV20 project

For providing of rest of up to 150 passengers upper opened promenade deck with 100-places bar, 100-places restaurant on main deck, wardrobe and lavatories on lower deck in fore part, 2 two-seat VIP cabins on lower deck in middle part are foreseen. There are also galley (for restaurant needs), lobby and scullery.

The aquabike is installed on upper deck from port side.

In aft part of the vessel on upper deck duty boat for 6 passengers with its own lifting gear is installed.

Six life rafts of throw-off type of 100-persons capacity each are mounted on the vessel. Three are from port side and three – from star board.

The vessel is equipped with basin place and access to water-based floating facilities.

CONCLUSIONS

Offered design "lineup" of pleasure crafts based on following principles:

- account of features of region and rest trends of passengers;
- multifunctionality of vessels, combination of pleasure, excursion and restaurant functions;
- account of actual way and weather conditions

- ice reinforcements for navigation extension (optionally "long season");
- keeping of thicknesses of sheathings and shells at minimal ones level in order to minimize steel hull weight and to provide required local strength and steadiness due to rational application of the ordinary and web elements;
- prohibition of usage of opened holes (illuminators) within watertight hull boundaries;
- prohibition of non-symmetrical stores arrangement which can lead to the list appearance during operation;
- prohibition of placing of oil liquids (fuel oil, lubricated oil, oily water) in tanks adjacent with outboard water.

Effective and safe operation built per Marine Engineering Bureau PV01M, PV02, PV05, PV07, PV10 projects of one-day trip vessels for pleasure cruises proves correctness of above mentioned theses.

REFERENCES

- [1] G.V. Egorov, I.A. Ilitskiy, D.V. Chernikov. Parametrical row of Black sea cargo and cargo-passenger ferries // ONMU Reporter. - Odessa: ONMU, 2014. - Vol. 3 (42). - pp. 5-31 (in Russian).
- [2] G.V. Egorov, N.V. Avtutov, Ya.V. Kalugin. Main principles of organisation of passenger transportations // Materials of VI international sc.-tech. conf. "Innovations in shipbuilding and ocean engineering", - Nikolayev: NUS, 2015. - pp. 62-64 (in Russian).
- [3] G.V. Egorov, A.G. Egorov. Risk analysis of operation of native river passenger vessels // Maritime Reporter. - 2013. - No1 (45). - pp. 100-105 (in Russian).
- [4] G.V. Egorov, A.G. Egorov. Vessels and ferries for Russian linear services // Maritime Market. - 2016. - No4 (58) - pp. 26-45 (in Russian).
- [5] G.V. Egorov, Ya.V. Kalugin, A.G. Egorov. Analysis of conditions of Russian river passenger fleet // Problems of technics. - 2012. - No4. - pp. 6-39 (in Russian).

Black Sea S2018

SHIP HYDRODYNAMICS

SPECIAL CONSIDERATIONS IN MODEL TESTS OF HIGH SPEED VESSELS

Marta Pedišić Buča, M.Sc.Nav.Arch*

*Brodarski Institute, Zagreb, Croatia

Abstract. Demands regarding speed and performances of high speed vessels are increasing, which poses new challenges to already well established testing methods. Within this paper the usual scope of model tests in a towing tank in calm water conditions will be elaborated. Those tests most commonly include trim optimization and testing of influence of the appendages. Tests of dynamic instability phenomena in calm water are also of interest for some designs. The main challenges of typical testing programme for high speed vessels, including scaling issues, visual monitoring of flow phenomena, systematic approach details etc., will be elaborated. Examples of best practice examples for establishing testing programme are presented. The main aim is to find out as many ship features as possible in order to enable early modifications and improvements of the design.

KEY WORDS: appendages, dynamic trim, fast vessels, resistance test

INTRODUCTION

Ship hulls which are operating near or in fully planing condition have some features which require special approach in model testing due to dynamic forces. Throughout the years, extensive experience is collected while conducting such tests. Nevertheless, constant involvement is needed due to new trends and new features introduced to the projects. As to the testing procedures for high speed vessels, they are applied regularly for planing and semi-displacement hulls, but also for fast displacement hulls. Within this paper the focus will be on monohulls.

Fast displacement hulls are usually working boats and naval vessels (frigates, corvettes) [1]. The maximum Froude number at which they operate is up to $Fr = 0.4 - 0.6$. It means that their top speed is actually close to the beginning of planing condition. Once they reach their top speed the resistance curve will have very steep gradient, since the hydrodynamic lift is considerably small. They have most often a round bilge hull type with centerline skeg, while the bow lines are V shaped [1].

Semi-displacement hulls achieve higher speeds due to the increased dynamic lift and they are usually pleasure yachts and patrol boats [1]. Their operational limit is around $Fr = 1.0$. Planing hulls develop speeds over $Fr > 1.0$ and they are usually fast patrol boats, racing yachts, SAR vessels, passenger ferries etc. Their hulls are typically with hard chines.

Once the hull design is accomplished, it is strongly recommended to conduct model tests and the best available option is to combine them with CFD calculations. While CFD tools are very useful to test variants of the hull shape and determine details of flow around the hull (such as streamlines), it is common to test in the towing tank the final hull version. Results of CFD calculations, especially for higher speeds when hydrodynamic lift becomes more dominant could be misleading. During design phase, estimation of resistance values could be done via systematical series (Bailey, Blount and Clement etc.) or similar vessels etc.

Model test results include resistance values, dynamic trim and rise/fall values, running wetted surface and lengths.

Obtaining reliable values is important for proper dimensioning of propulsion system and weight distribution. In this sense, the influence of the change of static trim and possible improvements of dynamic trim and rise/fall with trim control devices is very easily achievable with model tests. Correct application of spray rails enables improvements in spray deflections and can influence trim, which is often checked during tank testing. Further on, the tests often include appended hull. They reveal possibility of improvements of layout and orientation of appendages. Common configuration of appendages for some pleasure craft consists of: shafts, brackets (V or I), stabilizer fins, rudders, bow thruster tunnels, exhaust scoops. In some cases bilge keels are applied and for some naval and working vessels sonar domes are also present.

Besides the mentioned improvements, if some more serious problems are noticed during testing, it is possible to conduct local hull modifications and check their effects. Most common modifications are local re-shaping of the stern tunnels, local chine changes and changes of the bow (with and without bulb for example).

Besides testing of resistance, if the hull is sensitive to dynamic instabilities, they can be easily determined via additional tests in calm water.

Conducting of seakeeping model tests for such projects is not so common in practice, most probably due to the budget and time restrictions, although they could reveal very useful information and serve as a basis for further project improvements.

GENERAL CONSIDERATIONS REGARDING RESISTANCE TESTS

Model test results include resistance values, dynamic trim and rise/fall values, running wetted surface and lengths. In order to recalculate results for full scale, correlation allowance is applied varying for fast hulls between $0.2 - 0.4 \times 10^{-3}$ according to the Brodarski institute practice.

Arrangements for testing include trimming (proper LCB value), balancing (VCG value achievement) and determination of towing line in the direction of propeller thrust at LCB. When horizontal towing is applied (waterjet, Azipod propulsion) or in some other cases, this not achievable, even for fairly large ship models [2]. Additionally, setting a proper VCG value (if it is higher) can be problematic, due to the limited height of the model. Namely, it should be avoided to install the weights too high (above the ship model) because this can affect air resistance for large speeds. Consequently, artificial trim moments occur and change of dynamic trim value and rise/fall affects resistance values. Best practice in such cases would be to compare results of several achievable positions/alignments and estimate the influence of deviation for particular design. Examples from practice show that for majority of the designs smaller deviations do not influence results.

Of course, in self propulsion condition dynamic trim values will be larger and according to the practice these differences for speeds over Fr 0.5 range between $0.2 - 0.3$ deg.

Values of running wetted surfaces and lengths usually do not affect resistance results significantly, and in most cases the change of resistance force is less than 1%. Only when regimes are tested where the running wetted surface is significantly smaller than the static one (fully planing regime) then the final resistance value can be up to 2 – 3 % higher. Running values of wetted surfaces and lengths are mostly determined visually based on photo and video material and the reliability of such approach is on a satisfactory level.

Statical trim influence upon resistance values is usually significant amounting even to about 10% for some projects. Also, the effect is usually opposite in a lower speed range.

Increasing displacement rarely leads to linear increment of the resistance i.e. for 10% larger displacement 10% larger resistance. This is especially delicate in the hump region around $Fr = 0.5$ where resistance is significantly larger, while for $Fr > 1$ the resistance increment due to displacement increment is usually less pronounced. Therefore, it is recommendable to measure it.

TESTING OF SPRAY RAILS EFFICIENCY

As the hull speed increases, the bow wave rises up the hull and this can be significantly pronounced. Blunt waterlines can additionally enforce such occurrence. Significant spray can develop which increases both, frictional and wave making resistance and causes wetting of the deck and superstructures, which is inconvenient for any kind of vessel [3].

Spray rails most commonly consist of triangular profile and usually extend from stem to about midship. Besides deflecting spray, they influence dynamic lift in the forebody region and change dynamic trim, which also influences resistance. One to three pairs of spray rails are usually applied. Usually, the increment of dynamic trim is present for larger speeds and is moderate in amount (up to 0.2 deg).

Although they have positive effects, the final resistance value is often slightly larger with spray rails, especially for lower speeds. Therefore, it is recommended to evaluate them carefully and cut off the parts which are ineffective. The increment can be even more than 10% for some three-pair spray rail configuration, although visually the spray will be deflected.

Figure 1 Configuration of three spray rails at $Fr = 0.8$

Figure 2 Configuration of three spray rails at $Fr = 1.1$

Figures 1 and 2 show example of spray rail configuration with three pairs for Froude numbers $Fr = 0.85$ and $Fr = 1.15$ where their effect may be observed. For different speeds different pair of spray rails takes function of spray deflecting and as the speed rises, a larger portion of the spray rail is out of the water.

TESTING OF DYNAMIC TRIM CONTROL DEVICES

For control of the dynamic trim trim wedges, flaps or interceptors (intruders) are applied. The trim wedges are most effective in the resistance hump region around $Fr = 0.5$, while for $Fr > 1$ their effect usually diminishes. Deficiency is that they are fixed, so their effect cannot be controlled.

Stern flap is plate extending aft of the transom. The flap geometry is defined with chord length (up to 2.5% L_{pp}), span and flap angle which is in most cases adjustable. Larger chord lengths and angles lead to stronger effect. Flaps induce dynamic trim angle reduction and modify the wave around the stern. Performance improvement gets more significant at higher speeds.

An interceptor or intruder is actually extension of the transom consisting of a vertical thin plate. It can encompass entire breadth of the transom or just symmetrical portions portside and starboard. The amount of extension in full scale is usually not more than 20 mm, which means that in model scale it is barely several millimeters. The principle of functioning is such that the flow decelerates in front of the interceptor and local pressure increases. This causes generation of the lift force to the stern. The main effect is of course correction i.e. decrement of dynamic trim, but also it can contribute to hull stabilization [4].

Prediction of efficiency of all trim control devices is not easy theoretically, so model tests are most often recommended.

Figure 3 Hull without flaps at $Fr = 0.74$

Figures 3 and 4 represent changes in local stern flow for application of flaps for semi-displacement hull at $Fr = 0.74$. Although the resistance is decreased only 2% it is evident that locally the flow is changed.

The percentage of resistance reduction is often above 5%, for higher speeds especially.

Figure 4 Hull with flaps at $Fr = 0.74$, resistance decrease of 2%

Based on these examples, one can conclude that an interceptor with variable height can be considered when the operative speed range of ship is larger. Near humps, interceptor heights should be reduced to avoid too large reductions of dynamic trim. Positive effect of interceptor is more evident in pre-planing speed range [5].

Generally, interceptors are most effective since they provide the largest angle reduction for larger speed range. They are completely in the boundary layer and therefore their added resistance is negligible. Also, production and installation costs are considerably low.

When testing such devices, it is recommended to test three different heights / configurations in order to estimate optimum final value.

TESTING OF APPENDAGES

Generally, model tests can be of great help during design of model appendages with aim to improve hydrodynamic effects. Appendages increase both, frictional and wave resistance.

General recommendation for any appendage is not to oversize them and to avoid sharp edges and steps, i.e. apply streamlined profiles whenever possible. Too robust configuration will enlarge resistance unnecessarily and can also induce cavitation. CFD calculations are excellent tool for careful alignment i.e. orientation of appendages, while model tests are most suitable for evaluation of total effect and interaction. Large shaft inclinations should regularly require robust shafting construction, which is detrimental for propulsion efficiency.

Bow thruster tunnels are usually designed with the shaped scallop. The size of the tunnel depends on the maneuverability requirements and it is not to be affected by hydrodynamics i.e. resistance. From the hydrodynamics point of view, the shaped scallop can be carefully designed and oriented in the direction of the flow according to the streamlines. From the practice, the measured contribution to the total resistance in cases of thrusters with well-designed scallops is in average below 2%.

Size and location of fin stabilizers are influenced by functional demands, but neutral angle of attack and alignment in vertical plane can be adjusted with the flow and contribute to the resistance reduction. In practice, their contribution to total resistance can be up to 6%, while for a well-designed and aligned configuration most often it is even below 3%, and almost constant with the speed.

Stern appendages most often include rudders, shafts with shaft brackets (V or I type) and bossings. Their influence is measured in resistance tests and there is not much visual information available from the model test. The most common is two shaft configuration, but three and four shafts are also used. The estimated resistance increment per one shaft line in case of a well-designed solution can be even below 4%. It is recommended to use paint flow test or CFD calculations to align shaft brackets and rudder neutral angles. From practice, trailing edges are oriented several degrees inwards (i.e. towards the shaft) [6].

Appendages which are closer to the water surface such as stabilizer fins, bilge keels, exhaust scoops sometimes create local wavecrests and interact. Visual observation is best way to monitor these phenomena while the influence upon measured resistance and trim can be negligible. Figure 5 shows the local flow around the hull with a stabilizer fin where the local wavecrest is present.

Figure 5 Local flow around stabilizer fins

The dynamic trim of the fully appended model in resistance condition is in most cases larger than the trim for the bare hull condition for app 0.2 – 0.3 deg. The rise value at LCB is also usually slightly larger. The change in the trim angle affects wave making resistance, so overall influence of appendages contains this effect as well.

It is worth to mention the stern platform which is not submerged but can influence and alter the stern flow. Visual observations are of great help to determine its optimum position. Local wetting of the platform in certain speed condition does not usually affect resistance values, but should be corrected due to functionality and aesthetics.

DYNAMIC INSTABILITY TESTS

Tendency to phenomena of dynamic instability is of course strongly speed dependent, since dynamic forces become significant over buoyant forces. Also, dynamic instabilities are more pronounced for heavier vessels and vessels with LCG more forward. More complex configuration of appendages and certain characteristics of hull form can induce such effects. Local low pressure areas develop around the hull bottom, so hulls with highly curved buttocks are more prone to such development. Appendages can induce ventilation at stern which can cause sudden pressure changes [5].

Phenomena include non-zero heel, chine walking, bow steering, bow diving and porpoising. They can be oscillatory and non-oscillatory [7,8].

Detecting tendencies to such phenomena is possible during regular resistance tests and via some additional calm water tests.

Non-zero heel and chine walking occur due to decreased transverse stability [8]. This is tested applying a dynamic inclining test. The test is conducted as the towing test in calm water with the model initially inclined for several degrees to one side. During the run it is monitored whether the heel increases or decreases and comparison with initially non inclined model is done [5]. Tendency of heel increasing with the speed points to transverse stability issues [5].

Porpoising i.e. combined heave and pitch are noticeable during regular resistance tests. In order to evaluate the phenomena properly, one should assure that the water in the tank is calm enough i.e. that there are no disturbing waves from previous runs.

Regular resistance test analysis may yield trim-speed relationship if the speeds for testing are chosen correctly. These results indicate bow diving tendency. When analyzing trim-speed dependence it is evident that the hull which have negative slope of the trim curve in the region of volume Froude number between 1 and 2 is more prone to this effect [5].

ESTABLISHING OF TESTING PROGRAMME

Once it was decided by the boat designer or boat builder to conduct model tests, choice of range and sequence of tests should be carefully considered. The goal is to collect as much useful information as possible which leads to possibilities to improve project.

Main imperative should be systematic approach i.e. to introduce changes one by one in order to monitor and evaluate their effects. Bare hull should be evaluated first, which will define whether trim control devices and / or spray rails are needed. When investigating effect of interceptors or other devices, three different heights / configurations should be checked in order to estimate optimum.

After finalizing this phase, appendages should be introduced. All appendages can be installed at the model at the same time, or if some are of special interest (usually bow thruster tunnel or fin stabilizers) they can be tested separately in order to determine their isolated effect.

Within speed range of interest, points should be distributed in a manner to describe properly hump regions (Froude numbers 0.3 and 0.5) and also region of high speeds (Fr above 1.0) since non linear effects might be more pronounced and resistance curve features steep gradients.

Once accomplishing these phases, tests at other displacements (most commonly maximum) are useful since the effect of changed displacement is not linear within the entire speed range.

In order to distinguish small changes and effects of variations, the model should be properly balanced and towing line established correctly. For smaller models i.e. larger scales this could be not achievable. Too small appendages may also give unreliable results due to scaling issues. In such cases, it is not recommendable to conduct detailed investigations, since the results might be misleading. From practice, models of length of 3.5 m and more having displacements of 250 kg and more are usually suitable for all the tests described.

CONCLUSION

Within this paper a typical scope of model tests for fast hull is presented and special requirements during testing concerning only high speed vessels are elaborated. Usual scope and sequence of tests is presented as well as the range of valuable information that can be gathered during testing. Besides measured values, visual observations are of high importance. The aim is to arrange the tests in a manner to obtain as much useful data as possible and ensure that these data are unambiguous and provide information for further improvement of the project design.

Average values of change of resistance force due to variations are presented based on long term practice in Brodarski Institute. Having some estimation in advance helps a designer to choose the a correct set up of tests.

The main benefits of the tests are as follows:

- Influence of change of statical trim is helpful in design phase for final weight distribution, but also for future operative conditions of the ship in full scale.
- Findings of influence of different displacements helps in better propulsion system definition.
- Careful evaluation of trim control devices, which is important since it often leads to gains of more than 5% in power demand.
- Definition of spray rail configuration from the resistance and aesthetic point of view.
- Improvements of hydrodynamic design of appendages and reduction of resistance.
- Detection of tendency to dynamic instability, which is very difficult to deal with in full scale since it compromises ship's function.

To conclude, model tests will certainly reveal possibilities of further improvements and prevent flaws in hydrodynamic aspects of the design.

REFERENCES

- [1] M.Fritsch, V.Bertram: Hydrodynamic Design Aspects for Fast Conventional Vessels
- [2] C.Bertorello, D.Bruzzzone, P.Cassella, I.Zotti: High Speed Craft – Investigation on the Resistance Towing Test Procedure
- [3] P. van Oossanen, J. Heimann, J.Henrichs, K.Hochkirch: Motor Yacht Hull Form Design for the Displacement to Semi-Displacement Speed Range, 10th Conference on Fast Sea Transportation, FAST 2009, Greece, 2009
- [4] A.Mancini, A.Moriconi: Intruder: A Device to improve hull performances
- [5] D. Blount, L.T.Codega: Dynamic Stability of Planing Boats, Marine Technology, Vol.29, No.1, Jan 1992, pp.4-12
- [6] S.John: Ship Hull Appendages: A Case Study, Conference Paper, Dec 2012.
- [7] T.Katayama: Experimental Techniques to Assess Dynamic Instability of High Speed Planing Craft – Non-zero Heel, Bow-Diving, Porpoising and Transverse Porpoising, 6th International Ship Stability Workshop, New York, 2002
- [8] O.M.Faltinsen, H.Sun: Dynamic Behaviour of Semi-Displacement and Planing Vessels in Calm Water and Waves, IX HSMV Naples 2011: Keynote

ON THE FOREBODY SHAPE EFFECT ON SHIP RESISTANCE IN STILL WATER AND SEAWAY

Ihor P. DAVYDOV*, Andriy V. PECHENYUK**

* – Marine Engineering Bureau (Odessa, Ukraine), National University “Odessa Maritime Academy” (Odessa, Ukraine), As. Prof., Dr, senior researcher, head of vessel's theory and design department of University

** – National University “Odessa Maritime Academy”, (Odessa, Ukraine), PhD

Abstract. In recent years CFD technologies are actively used for the practice in the design and optimization of the ship hull form. The suggested method of in-detail hull form design uses CFD for hull resistance determination. The obtained results can be presented as the optimum distribution of the required hull volume and, eventually, the optimized shape of hull surface. The method was applied to forebody of the well-known KCS hull form and showed interesting characteristics. This paper describes farther development of the method as well as diversified analysis of its reliability and practical feasibility. It is shown that precision can be noticeably improved, however correctness strongly depends on CFD model and computational grid. At last, it has been taken into account that the optimization process manages hull resistance in still water only. Therefore the overall design assessment of the optimized forebody shape is supported by estimation of resistance in seaway.

Keywords: computational fluid dynamics, hull form design, hull form optimization, ship resistance in seaway.

INITIAL PROBLEM

Hull form optimization is a well-known problem of ship design, which is hackneyed and topical at the same time. In practice, lines design is still to some extent an art. There is no accepted formalized method, which allows designing a hull form with guaranteed minimum resistance, not to mention highest propulsion qualities. Although a great amount of experimental and theoretical researches have been carried out in that field, and perfect hull forms were designed in particular cases, their optimality in strict sense remained questionable.

A special research direction was established for developing scientifically grounded way of hull form design. Seemingly first attempts to arrange an optimization process for hull form were made on the base of Mitchell's formula for wave resistance [1, 2]. Statistical analysis of experimental results [3] and developing original methods based on CFD [4] are examples of present-day approach. The represented method of optimum foreship transformation (MOFT) may be considered as some combination of several approaches, which complement each other. The MOFT showed interesting characteristics [5, 6] and it's now being developed further.

AIM OF THE PAPER

Grounding of efficiency of results received with usage of MOFT. The MOFT manages hull resistance in still water only. Nonetheless, effect of modified forebody shape on resistance increase in seaway can be additionally estimated. The corresponding results are also included.

MAIN TEXT

MOFT conception

MOFT conception implies a reasonable compromise between mathematically strict optimization process and practically available methods of hull geometry variation and resistance evaluation. Principal dimensions of the ship, including displacement volume, are considered constant, as well as the side contour of the hull. It corresponds to intention of isolating shape effect from more intense effect of principal dimensions.

Well-known specific resistance R/∇ remains the main criteria of hull form efficiency, though it is now applied to separate regions of hull surface. If we considered some individual region of hull surface and altered it with causing some hull volume increment $\delta\nabla$, but without changing the rest surface, the volume increment $\delta\nabla$ can be corresponded then to appropriate resistance increment δR . When there was more than one alteration of each surface region, resistance increments can be expressed versus volume increments as continuous functions. These functions can be set up for several selected surface regions and used for searching the combination of volume increment values, which meets two conditions:

$$(1) \quad \sum \delta R = \min ;$$

$$(2) \quad \sum \delta \nabla = 0 .$$

Eqn. 1 – expresses condition of minimum resistance; Eqn. 2 – expresses condition of constant displacement volume. The Eqn. 1 is practically realized through hypothesis of independent effect of different hull surface regions. Thus the optimization process leads to decreasing specific resistance or to proving optimality of the initial hull form.

Similar approaches were suggested earlier [1, 2], but they managed points of hull surface equation instead of actual surface regions and used analytical formulas of resistance. Those features eventually showed their impracticality. For its part, MOFT provides specially devised model of systematic hull transformations, which regularizes variation of hull surface, and CFD simulation methods for determining resistance responses.

CFD simulation method

CFD methods based on solving the Reynolds-Averaged Navier-Stokes equations (RANS) appear the most advanced numerical approach to the ship hydrodynamics now. Since MOFT conception has high requirements to accuracy of resistance responses on relatively subtle hull shape variation, RANS CFD method is involved. The FlowVision CFD code has been used. Its technical features, as well as verification and validation results demonstrated fine capabilities of the CAE-CFD tool for ship design. Corresponded data and the details of the physical and numerical model can be found in the paper [6]. This work has been carried out using computing resources of the federal collective usage center Complex for Simulation and Data Processing for Mega-science Facilities at NRC "Kurchatov Institute".

The interesting and convenient feature of the numerical model is the grid generation technology, which is Cartesian adaptive locally refined grid (CALRG). The essence of CALRG generation is Boolean subtraction of the volume, which is determined by closed surface, from the Cartesian grid. The cells of the computational grid, when were crossed by the freeform surface, are converted into complex polyhedrals with an approximation of the solved equations inside them by high-order schemes.

The main practical advantage of CALRG is its automatic generation. User arranges initial Cartesian grid only, whereas converting the initial cells at interface with boundary condition (e.g. the ship hull) into the computational ones is completely automatic. This allows preparing and varying computational grids very fast. The easiest way to resolve grid is the adaptation technology, when selected cells are being divided into smaller ones (the existing 3D cell is divided into eight new ones) near assigned BC or within assigned volume.

Systematic transformations of hull surface

When the principal dimensions and hull volume were fixed, longitudinal and vertical distributions of hull volume mostly set a shape of hull surface. If we consider modifying the existing hull form in view to decrease ship resistance, we may neglect vertical distribution of hull volume in optimization process. The reason is that vertical distribution of hull volume has no optimum with respect to wave resistance: the deeper hull volume is submerged, the less wave resistance it produces. Thus there is no special purpose in modifying section forms, but they are still changed together with the sectional area curve, so they should be subdued to some clear mechanism, which allows to preserve or control vertical volume distribution.

An example of suggested sectional area curve modifications is shown in Fig. 1 for an entrance. Each modification affects a certain segment of the curve and causes positive or negative hull volume increment. Any modification smoothly joints to the initial curve, so we have got a set of new sectional area curves, which can describe a set of new hull forms. If we combine different modifications of opposite sign, we'll be able to compose new sectional area curves with initial hull volume as well.

Every hull surface region wherein the sectional area curve was modified should be transformed. The suggested method is affine transversal transformation of the initial sections. The affine transformation completely preserves the vertical distribution of section area. In this way the vertical distribution of hull volume can also be preserved. Unfortunately, some sections near parallel middle body may exceed hull breadth, when affine transformation is applied. In those cases special methods [7] can be used. The affine transformation is also unusable, when some particular requirements to sections were put, e.g. to not allow changes in deck form (see Fig. 1). In fact, MOFT uses complex transformation method, which has taken all those options into account. Its main idea is keeping close to affine transformation, when possible, to reduce volume redistribution in vertical direction. Faint redistribution can be controlled by tracking a center of buoyancy above keel. Described functions were worked out in detail for an entrance yet, that's why whole optimization method is limited to ship forebody.

Cases of MOFT application

Two examples of ship hull were used for MOFT demonstration [5, 8]: slow-moving river-sea ship (RSS) with high fullness and transoceanic containership KCS, the well-known test object [9]. Their main characteristics are shown in Table 1.

Figure 1. Modifications of the sectional area curve and corresponding transformations of sections (entrance)

Table 1. Main characteristics of the researched ships

Characteristic name	KCS	RSS
Length of waterline L_{WL} , m	232.1	137.8
Breadth B , m	32.2	16.5
Draught d , m	10.8	4.6
Block coefficient C_B	0.651	0.892
Froude number set in MOFT, Fr	0.28	0.18

Decrease in resistance of RSS hull amounted to 4.1% due to transferring some volume closer to stem within the entrance. Decrease in resistance of KCS hull reached 8.9% under similar circumstances. Higher gain for KCS was explained by the more developed wave-making and freer geometry transformation due to lower fullness.

The ways to improve MOFT accuracy and reliability. Effect of computational grid

Grid meshing is one of paramount problems in CFD simulations. Since sufficient concentration of cells can scarcely be provided throughout the whole flow, a question of rational distributing small cells becomes very important. In practice, the method of grid convergence helps to control scheme errors occurred by varying grid. That method implies a set of calculations, wherein grid density is sequentially varied. One may consider that grid convergence has been reached, when an error in the controlled characteristic (e.g. hull resistance) becomes random, i.e. doesn't depend upon grid density any more. However, each grid could be mostly new not only by its density, but also by its structure. In that case research of grid convergence becomes perfunctory. Otherwise, special methods of grid formation should be involved.

At first we used the adaptation technology for grid formation on the basis of convergence research. It means that some initial grid had been prepared and it was then adapted. But the number of cells grew too fast, when adaptation was applied to whole grid. Thus we allocated some box around a hull and adapted the grid inside it only. Although good verification results were got, grid structure caused the problems in wave propagation because of too sharp drop in cell sizes on the box boundaries [6]. Avoiding adaptation allowed resolving those problems [10], but new grids also showed some shifts of resistance. Whereas the test case of KCS hull form showed almost the same resistance in different grids, the hull form obtained by MOFT showed in new grid much higher resistance. To clarify that situation more strict demands to grid convergence were made. In accordance with them, cell sizes should change smoothly without sharp drops and changes in general grid structure.

Suggested grid formation method implies setting relative sizes of cells as continuous functions of coordinate axes x , y , z . Those functions may stay constant, while absolute sizes of all cells are simultaneously changed by setting a proportionality factor – Fig. 2. The method idea is rather simple, but it can be easily implemented in the case of structured (Cartesian) grid only. The grid convergence was once again researched for KCS and RSS according to suggested method. We varied the cell sizes along x axis only, because other cell sizes could be set sufficiently small without great effect on general cell number. The obtained results are shown in Fig. 3.

The grid convergence results show that permissible cell number is about $1M$ for KCS and about $1.5M$ for RSS. It is logical that the ship with lower Froude number is more exacting to grid density because of wave system structure, which strongly depends on interference. The parameters of grid for RSS with $1.69M$ have been used for revising the MOFT results. Resistance decrease is 3.8% instead of 4.1% in old grid, hence little has changed. For KCS the parameters of grid with $1.77M$ have been used. Resistance decrease becomes 3.4% only instead of 8.9%. Obviously, since resistance decreasing was based on wave interference, defective

grid caused deceptive errors in physics of KCS hull flow and influenced on the MOFT functioning. In our opinion, the results of KCS optimization fundamentally differ from case of RSS due to much more developed wave-making and larger dimensions of ship waves in relation to the hull. Relative wave dimensions also explain why no problems with wave propagation were met in RSS simulation results.

Figure 2. Grid density variation in research of the grid convergence

Figure 3. The grid convergence (error in respect to resistance at maximum grid density)

Effect of more detailed transformations of hull surface

In view of the detected grid effect on the results of KCS optimization it was decided to redo MOFT procedures with new, well-grounded grids. In addition, the more detailed transformations of hull surface were examined to search more accurate solution. For the first time sectional area curve of KCS entrance was subdivided into three segments, which didn't overlay each other (see Fig. 1). That configuration allowed Boolean algebra: when area increased near one segment, it decreased near others to satisfy condition (2). In total, six models corresponded to extreme variations of the sectional area curve were studied. Transitional areas were involved through interpolation.

In theory, number of segments should be increased to improve MOFT accuracy. In practice, small segments lead to small distinctions from initial hull form, which could barely noticed by CFD simulations. The other problem is general smoothness of ship hull, which can't accept small local dents or swells. Thus another way of more detailed transformations has been suggested. It is an overlay of relatively large segments along the sectional area curve – Fig. 4. The overlay of segments can be taken into consideration through connecting resistance responses δR with section area increments δA near segment's midpoint instead of volume increments δV . Condition of constant displacement volume (2) corresponds then to constant area of the modified sectional area curve.

The most sensitive region of the bulb was elaborated by involving two variants of sectional area curves within corresponding segment. Since segment shortening may cause problems with simulation sensitivity, this limited element of "trial and error" method was used. According to Fig. 4, twelve variants of forebody form were examined at the first step, plus the extra variant of surface near the bulb. After first step the MOFT algorithm reached extreme sectional area curves on some segments, so the second step was carried out. Two new segments were chosen and corresponding hull models examined. In this way all possibilities of resistance decrease were thoroughly investigated, and the final hull form has been worked out on the base of fifteen studied variants. Resistance decrease is 4.0%. It's quite visual in Fig. 5, where the wave systems of initial and devised hull form are compared.

Figure 4. Modifications of the KCS sectional area curve (entrance)

Figure 5. Wave system of initial (left) and devised (right) hull form, $Fr = 0.28$

Assessment of MOFT results in view of seaway conditions. Added resistance in head regular waves

Added resistance calculations were carried out by well-known Gerritsma & Beukelman method [11]. All calculations including motion amplitudes and phases were performed using computer program [12]. Non-dimensional added resistance coefficient for initial and devised hull form, $Fr = 0.28$ as a function of non-dimensional encounter frequency is shown in Fig. 6.

Added resistance in head long-crested irregular waves

Irregular wave calculations were carried out for $h_l/3 = 1$ m and mean wave period 6, 9, 12 15s. ISSC-2 was adopted for calculations. Results of calculations are shown in Fig. 6.

Both results in regular and irregular waves fit each other. Differences between them are within accuracy of calculation. So, forebody hull form variation has not effect on added resistance in regular and irregular seaway, but leads to still water resistance significant decrease of a fast container ship.

CONCLUSIONS

The undertaken researches have proved once again an important effect of ship forebody shape on resistance in still water: 3-4% of hull resistance can be removed due to optimal shaping. Resistance decrease may vary, but appears rather valuable for two considered ships of different types.

Figure 6. Added resistance coefficient (left) and resistance increase (right) for KCS hull forms, $Fr = 0.28$

Estimation of resistance decrease contains certain risks, when CFD technologies are involved. Nevertheless, the ways to improve accuracy can be found and developed. Their application showed an interesting result that estimated resistance decrease value changed only, when suggested way of geometry modification remained nearly the same. It seems basic physics in CFD is more robust than quantitative characteristics.

Forebody shape variations of KCS can be considered as small and has no effect on resistance increase in a real seaway and, thereby, on ship propulsion in operation from initial design point of view.

REFERENCES

- [1] V.G. Sizov. About a method of ship form improvement. ONMU Reporter, vol. 19, 2006, pp. 14-19 (in Russian).
- [2] E. Hogner. Influence lines for the wave resistance of ships. Proc. R. Soc. Lond., ser. A, vol. 155, 1936, pp. 292-301.
- [3] C. Haichao et al. Sample selection method for ship resistance performance optimization based on approximated model. J. Ship Res., vol. 60, 2016, pp. 1-13.
- [4] D. Legović and R. Dejhalla. Numerical hydrodynamic optimization of a tanker hull form. Towards Green Marine Technology and Transport - Proc. of 16th Int. Congress of IMAM, IMAM 2015, 2015, pp. 75-82.
- [5] A.V. Pechenyuk. The method of optimum foreship transformation in the problem of total resistance decreasing in the still water. NUK collection book, No.2, 2016, pp. 40-45 (in Russian).
- [6] A.A. Aksenov, A.V. Pechenyuk and D. Vučinić. Ship hull form design and optimization based on CFD. Towards Green Marine Technology and Transport - Proc. of 16th Int. Congress of IMAM, IMAM 2015, 2015, pp. 215-223.
- [7] H. Lackenby. On the systematic geometrical variation of ship forms. RINA Transactions, 1950, pp. 289-316.
- [8] I.P. Davydov and A.V. Pechenyuk. About practical significance and reliability of the results obtained by the method of optimum foreship transformation. NUK collection book, No.3, 2016, pp. 3-10 (in Russian).
- [9] L. Larsson, F. Stern and V. Bertram. Benchmarking of computational fluid dynamics for ship flow: Gothenburg 2000 Workshop. J. Ship Res., vol. 47, 2003, pp. 63-81.
- [10] A.A. Aksenov et al. Investigating the problems of ship propulsion on a supercomputer. Proc. of Ivannikov ISPRAS Open Conference, ISPRAS 2017, 2018, pp. 124-131.
- [11] J. Gerritsma, W. Beukelman. Analysis of the Resistance Increase in Waves of a Fast Cargo Ship. ISP, Vol. 19, No.217, 1972.
- [12] J.M. Guliev, I.P. Davydov, J.M. Elis. System of Computer Programs for Prediction of Seakeeping Qualities of Ships and Marine Structures. Proc. of 13th Session SMSSH, Vol. 1, Paper No.33, Varna, Bulgaria, 1984.

SYSTEMATIC INVESTIGATION OF THE SHIP GEOMETRY CHARACTERISTICS INFLUENCE ON THE AVERAGE LOSS OF SPEED IN WAVES

SILVIA KIRILOVA

Bulgarian Ship Hydrodynamics Centre at IMSETCHA-BAS

Abstract. Taking into account the need for improvement of the procedure for determining the so called “weather factor” included in the IMO methodology for calculation of the EEDI Index, an application of the statistical rank method is developed, essential part of which is the sensitivity analysis of speed loss in waves from the ship's main geometric parameters. The paper presents the results of the systematic analysis and the selection of the representative set of parameters in the speed loss assessment procedure.

Key words: seakeeping, speed loss, ship design, regression analysis

INTRODUCTION

At BSHC, application of statistical “ranking” method [3] has been widely studied and mastered for various tasks related to assessment of ships and floating structures behavior in real environment [4], [7], [8], [10], [11] etc. The core of the ranking approach is the assumption for existence of some statistical relationship between a set of certain ship design parameters, G , and some generalized operational estimator, R :

$$(1) \quad R = f(G)$$

The approach operates with statistical hypotheses built on a limited but already representative number of observations about the relationships between a large number of ship design parameters and parameters of external conditions. The correctness of these hypotheses is to be checked by application of sensitivity analysis and regression, at availability of ordered observations with normal statistics.

The response based statistically weighted criterion, R , is related to the vessel's type and assignment, and must reflect overall vessel operability or specific operational measure.

In this study, ranking method has been applied to assessment of speed loss at seas, which is directly related to IMO Energy Effectiveness Design Index (EEDI) [1], [2]. Correspondingly, the non-dimensional speed loss coefficient, V/V_0 , has been assumed as generalized rank estimator.

The set of governing ship identity parameters is selected amongst those influencing real operation most. This is done by experience, statistics or sensitivity analysis, considering also scope and resolving abilities of evaluation methods used, as often the calculation scheme insists for application of express methods - simplified but fast.

COMPILING GOVERNING SHIP PARAMETER'S SET

The study is based on seakeeping analysis of large number of ships, containing 2 generic series – containerships [4], [7] and bulk carriers [9], as well as ships subjected to model or full scale measurements at BSHC [5]. For every ship, average added resistance in waves has been calculated or measured and then statistically averaged over operation conditions.

The addressed ship hull set covers a wide range of ship geometry parameters, namely:

$C_b = [0,55 \div 0,85]$; $L_{pp} = [120 \div 320]$ m; $L/B = [5,4 \div 7,6]$;

$B/T = [1,8 \div 3,2]$; $F_n = [0,05 \div 0,30]$

Selection of variables in the governing ship parameter's vector, G , has been done by following considerations:

- Principal differences have been observed in reaction of various types of ship forms to wave action and specifically to speed loss. This implied grouping of data by ship type and loading condition.
- Parameters describing operation conditions are obviously:
 - Heading angle (to ease statistics, the 180° sector can be divided into four general directions – head seas, quartering seas from the bow, beam seas and following seas).
 - Operational speed of advance in calm water, V_0 , or corresponding Froude number, F_n
 - Sea state severity as indicated by Beaufort scale, B_f (this was preferred instead of more rigorous HS merit, as the wave height observations on-board ships are subjective and can mislead statistics)
- From previous studies on the subject, a primary selection of governing ship hull parameters, based on sensitivity analysis, statistics and experience, was established as:

$$(2) \quad R = f\left(\frac{L}{\lambda}, C_B, C_{WP}, \frac{T}{L}, \frac{B}{T}, LCB, LCF, trim, \frac{S_F}{S_M}, \frac{S_A}{S_M}\right)$$

The contribution of each of above parameters and their relationship have been assessed from the viewpoint of general seakeeping performance, as added resistance and consequently speed loss are product of overall seakeeping response.

Ship Length

In the seakeeping analysis, most frequently and logically, the non-dimensional relation $L/\sqrt[3]{V}$ is utilized, as using directly the ship length leads to some uncertainties. The relative hull elongation principally improves seakeeping by reducing the longitudinal motion amplitudes and related accelerations and deck wetness and consequently reducing the speed loss.

In Figs. 1 and 2, the influence of the relative ship length and the weight displacement on the speed loss is shown at various loading conditions and sea severity. It can be seen, that at lower sea states the speed loss is almost independent from the loading condition, but at more intensive seas the loading has significant effect.

Figure 1. Average speed loss at seas versus relative ship length at various loading conditions and sea states

Figure 2. Average speed loss at seas versus weight displacement at various loading conditions and sea states

Breadth and Draught

Analogously, the influence of non-dimensional ratios B/T , B/L or T/L on speed loss has been investigated. Weak sensitivity index has been however observed, as illustrated in the figures below. In Figs. 3 and 4, comparison is made of results for B/T and T/L influence on the speed loss, obtained by theoretical calculations (*Calc*), regression analysis (*Reg*) as well as by BSHC in-house method [9] at constant displacement condition.

Figure 3. Average speed loss at seas versus B/T ratio at constant displacement

Figure 4. Average speed loss at seas versus T/L ratio at constant displacement

Fullness Coefficients

Obviously, fullness coefficients C_B , C_W , C_P and C_M are strongly interrelated. Traditionally it is considered that C_B significantly influences added resistance in waves, which however could be the effect of simultaneous increase of C_W and C_P . However, the sensitivity analysis shows that C_W has minor effect on the added resistance and speed loss, as illustrated in Fig. 5.

Figure 5. Average speed loss at seas versus waterline fullness coefficient at constant displacement

Stronger dependence can be observed between the speed loss and ship hull block coefficient:

Figure 6. Average speed loss at seas versus block coefficient at constant displacement

Figure 7. Average speed loss at seas versus block coefficient at various loading conditions and sea states

After analysis of available data and following some practical considerations, including availability of geometry data and user friendliness in using the formulation, C_B solely has been finally selected.

On the basis of above analysis of available data and following some general considerations, i.e. [6], [12], etc., two hull form parameters have been finally selected, namely block coefficient, C_B , and volume displacement, ∇ (if needed, volume displacement can be related to deadweight via statistical relationship).

INTEGRATION OF ABOVE RESULTS INTO SPEED LOSS CALCULATION FORMULATION

Within every group of data, regression analysis has been performed. It has been observed, that the dependence of weather factor on selected set of geometry data can be described by low-order polynomials by using non-linear regressand transforms, thus multiple linear regression approach has been used. Finally, the weather factor has been expressed by:

$$(3) \quad f_W = \alpha \cdot \beta \left(k \cdot Bf + \frac{Bf^{2.5}}{m \cdot \nabla^{0.455}} \right)$$

where:

- k, m - coefficients accounting for ship type and loading condition
- Bf - Beaufort sea state index
- ∇ - Volume displacement
- β - heading angle coefficient according to [15]

$$(4) \quad \alpha = \sum_{i=1}^3 \sum_{j=1}^3 A_{ij} F_n^i C_b^j$$

- F_n - Froude number
- C_b - Block coefficient
- A_{ij} - regression coefficients

The above outlined approach has been repeatedly validated, always providing good accuracy, including full scale confirmation [5], [9], [11], etc..

CONCLUSIONS

The reported study has been inspired in the process of development of a new calculation method for prediction of average speed loss at seas for use in shipping offices and on-board ships for route planning. This explains the requirements for simplification of procedure and inclusion of data available to ship operators. In brief, BSHC aimed at some simplified but accurate enough procedure for express estimation of average speed loss, based either on series calculations, model tests or on comprehensive statistics. Basics of such an approach are outlined above. At the same time, this method can be directly used for weather factor predictions in EEDI index assessment.

REFERENCES

- [1] IMO Resolution MEPC.212(63), Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships, 2012.
- [2] IMO Circular MEPC.1/Circ.796, Interim Guidelines for the Calculation of the Coefficient f_w for Decrease in Ship Speed in a Representative Sea Condition for Trial Use, 2012.
- [3] Hajek J., Sidak Z., Theory of Rank Tests, Academia Publ. House of CzAS, Prague, 1967
- [4] Kishev, R., A Generalized Approach to Seakeeping Evaluation in Initial Stages of Ship Design, J.Tecnica Italiana, Vol.4, 1987
- [5] Kishev, R., Sirakov A., Criteria for Good Seakeeping - a Look from the Bridge, 4-th IMAEM Congress, Varna, 1987
- [6] Kishev R., Development of a Procedure for Ship Hull Form Optimization based on Seakeeping Considerations, BSHC Internal Report KP-88-05.58, 1989 (BG)
- [7] Kishev R., Dimitrova S., Gaberova M., A Generalized Procedure for Rank Optimization Application to Ship Design, Proceedings PRADS'89 Int. Conference, Varna, 1989
- [8] Kishev R., General Considerations on Ship Seakeeping Optimization in Design, Proceedings Osaka Meeting on Seakeeping Performance, Osaka, 1992
- [9] Kishev R., Kirilova S., Series Investigation on The Speed Loss at Seas, The Int. Conference BlackSea'2012, Varna, 2012
- [10] Kishev R., Kirilova S., On the Rank Theory Application for Assessment of Marine Structures' Behavior in Real Operational Conditions, J. Engineering Science, Book 4, Year LIII, BAS, 2016
- [11] Kishev R., Kirilova S., An Alternative Approach for Assessment of the Weather Factor in EEDI Formulation Using Statistical Ranking Theory, Proceedings NAV'2018 Int. Conference, Trieste, 2018
- [12] St. Denis M., On the Empiric Design of Seakindly Ships, Proceedings of PRADS 83 Int. Conference, Tokyo, 1983

NUMERICAL INVESTIGATION OF THE FREE SURFACE EFFECTS ON UNDERWATER VEHICLE RESISTANCE

Aleksandrina VASILEVA, Stefan KYULEVCHELIEV

Bulgarian Ship Hydrodynamics Centre, IMST – BAS, Bulgaria

Abstract. Nowadays, with the appearance of new types of underwater vehicles with various applications and the diversification of the submarine navy missions, their behavior close to the free surface becomes a matter of increasing interest. The paper presents results of CFD simulations of the flow around a generic submarine (DARPA SUBOFF) at different submergences for a range of speeds. Subject of observations have been: hydrodynamic forces and moments, pressure distribution, wave and streamline patterns. They have been analyzed in terms of the distance to the free surface.

Keywords: UV, Underwater Vehicles, Submarines, CFD, DARPA SUBOFF

INTRODUCTION

In the past the hydrodynamics of underwater vehicles, mainly warfare submarines, has been investigated primarily in deeply submerged condition.

More and more new types of underwater vehicles are being developed nowadays (Fig. 1).

Figure 1. Types of underwater vehicles

All of them have a variety of practical applications: naval, commercial and industrial, scientific, hobby and leisure.

These applications suggest frequent operation of underwater vehicles close to the free surface and/or in shallow waters. Under these conditions the flow around underwater vehicles and the hydrodynamic forces on them differ considerably from the unbounded fluid case. The reason is the wave pattern generated by the body moving close to the free surface and the resulting additional forces.

The effect of the free surface proximity on the resistance of underwater bodies has been investigated by the methods of computational fluid dynamics (CFD).

SUBJECT AND PLAN OF THE NUMERICAL EXPERIMENT

The generic submarine DARPA SUBOFF has been subjected to investigations. This is a hull form designed and tested comprehensively at DTMB and widely used for validation of numerical results [1], [2]. The dimensions of the original DTMB model were used.

DARPA SUBOFF geometry**Table 1. Main particulars of DARPA SUBOFF**

Length overall, m	LOA	4.356
Diameter moulded, m	D	0.508
Displacement volume (Bare hull), m ³	DISV_bare	0.696
Wetted surface area (Bare hull), m ²	S_bare	6.018
Displacement volume (Appended hull), m ³	DISV_app	0.708
Wetted surface area (Appended hull), m ²	S_app	6.361

Figure 2. 3D view of DARPA SUBOFF body**Available experimental data for validation**

DARPA SUBOFF body, both bare and appended hull, has been tested at DTMB at relative submergence of the axis $h/D = 5.4$ [3]. The tests cover the speed range of 3 to 9 m/s ($Fn = 0.46 - 1.4$).

Tests of the DARPA SUBOFF have been performed recently at BSHC at relative axis submergence $h/D = 3.37$ [4]. The tests cover the speed range of 2 to 5.5 m/s ($Fn = 0.3 - 0.84$).

The experimental data were used for validation of numerical results.

Plan of the numerical experiment**Table 2. Plan of numerical experiments**

<i>Numerical tool</i>	<i>Hull condition</i>	<i>Relative submergence h/D</i>	<i>Velocity m/s</i>
STAR CCM+	Bare hull	1.1, 3.37, 5.4, ∞	3.0 – 9.0
	Appended hull	1.1, 3.37, 5.4, ∞	3.0 – 9.0

RANS SIMULATIONS SETUP

The CFD simulations have been performed using the software STAR CCM+ [5]. The URANS were solved with the free surface flow being simulated by the VOF methods.

The **fluid domain** is a block extending two lengths (2L) upstream and downstream of the hull, one length (1L) below, above and to the side of the body axis. The symmetry of the body with respect to the centre-plane was used modelling only one side of the domain.

The **mesh** consists of trimmed cells in the core volume and (optional) prism layers in the boundary layer. Several mesh blocks are created with gradual refinement towards the hull for better resolution of the boundary layer flow depending on the turbulence model used. A special block of mesh is also created with special shape and cell size about the free surface for better resolution of the wave pattern depending on the Froude number.

Table 3. Boundaries and boundary conditions

Boundary region	Boundary condition
Upstream	Velocity Inlet
Downstream	Pressure Outlet
Tank side	Symmetry Plane
Tank Centre plane	Symmetry Plane
Tank top	Velocity Inlet
Tank bottom	Velocity Inlet
Hull	Wall, no slip

Figs. 3 and 4 illustrate the mesh for the cases of unbounded fluid and with free surface, respectively.

Turbulence was treated by the realizable $k-\varepsilon$ two-layer model.

Figure 3. Numerical mesh, unbounded fluid surface

Figure 4. Numerical mesh, with free surface

RESULTS AND ANALYSIS

Comparison of CFD to EFD results

Before starting the parametric study, the results of CFD simulations were validated with available experimental results in order to adjust the settings of the simulation (Figs. 5 and 6).

Figure 5. Comparison with DTMB experimental results at $h/D = 5.4$

With both data sets the resistance is underestimated by the numerical simulations slightly 3 – 5% (Table 4). This is generally accepted satisfactory. Besides, the difference can be attributed to the experimental procedure involving towing struts and subtraction of their own resistance from the totally measured one.

Form factor evaluation

The computations in unbounded fluid enable the estimation of the form-factor of DARPA SUBOFF. For the bare hull the value of R_T/R_F is 1.11 in the whole investigated speed range. This value agrees well with the popular empirical formulae for axisymmetric bodies [6].

With the appendages – a sail, two rudders and two stabilizers – the form factor increases to 1.23.

Table 4. Prediction accuracy of the CFD simulation

V m/s	Bare Hull	Appended Hull
3,04	-3,0%	-3,1%
6,09	-4,8%	-3,6%
8,23	-5,1%	-4,1%
9,15	-4,4%	-3,7%

Figure 6. Comparison with BSHC experimental results at $h/D = 3.37$

Effect of axis submergence on resistance

Figs. 7 and 8 show the results of resistance computations at different body submergence in a range of speeds. Both bare and appended hull cases were treated. The unbounded fluid results are also included as an extreme case. With increasing the depth of submergence the resistance decreases with decreasing rate. This is obviously due to the increasing wave making and wave resistance closer to the free surface.

Figure 7. Total resistance, bare hull at varied submergence

Figure 8. Total resistance, appended hull at varied submergence

The difference gets smaller for the higher speeds in the investigated range. This can be explained with the fact that the viscous resistance increases monotonously with velocity while the wave resistance coefficient curve modulates with Froude number (Fig.9). There is an absolute maximum (known as “primary hump”) in the range of $Fn = 0.5-0.6$, after which the wave resistance coefficient decreases continuously. In this way the share of wave resistance decreases at high speeds hence the effect of free surface proximity is smaller.

Figure 9. Wave resistance coefficient submergence

Figure 10. Relative increase of resistance w.r.t

The relative increase of resistance compared to the unbounded fluid case is bigger and faster at lower axis submergence (Fig. 10).

Added resistance of appendages

The computations with and without appendages allowed an analysis of the appendage resistance. The increase of resistance due to appendages gets higher for deeper water and maximum in unbounded fluid. At deeper submergence the effect gets bigger for higher speeds but the rate of this growth is lower for deeper water and finally in unbounded the effect is constant (Fig. 11).

A more useful presentation of these results is the non-dimensional one shown in Fig. 12. The velocity is presented by the Froude number based on submergence $Fnh = V/\sqrt{g \cdot h}$. The increase of resistance due to appendages is described by straight parallel lines as a function of Fnh for different submergences, converging to a point (single value) for unbounded fluid.

Figure 11. Appendages resistance vs. speed

Figure 12. Appendages resistance vs. Fnh

CONCLUSIONS

Numerical investigation of the resistance of an underwater vehicle has been performed using STAR CCM+.

The numerical results are in a satisfactory agreement with available experimental data.

The form factor of the vehicle has been evaluated with computations in unbounded fluid. It has been established that, with the considered set of appendages, the form factor increases considerably due to appendages.

The effect of appendages on resistance is its increase with submergence. At smaller submergence the effect grows with speed but tends to a constant value in unbounded fluid.

The resistance increases with approaching the free surface. This effect decreases with speeds corresponding to Froude numbers above the 'primary hump'.

All above observations can be explained with the features of wave making and wave resistance which are produced due to the presence of free surface close to a moving body.

A natural continuation of this research is analysis of free surface and restricted water effects on all hydrodynamic forces and moments on the vehicle and simulation of its 6DOF motion.

ACKNOWLEDGEMENTS

The work was accomplished with the financial support of the Scientific Research Fund of Bulgaria under Project DM07/6 "Hydrodynamics of Underwater Bodies Close to the Free Surface"

REFERENCES

- [1] Groves N.C., Huang T., Chang M., GEOMETRIC CHARACTERISTICS OF DARPA SUBOFF MODELS (DTRC MODEL NOS. 5470 and 5471), David Taylor Research Center, Ship Hydromechanics Department, DTRC/SHD- 1298-01, March 1989
- [2] Huang T., Liu Han-Lieh, Groves N.C., EXPERIMENTS OF THE DARPA SUBOFF PROGRAM, David Taylor Research Center, Ship Hydromechanics Department, DTRC/SHD-1298-02, December 1989
- [3] Han-Lieh Liu, Thomas T. Huang, Summary of DARPA Suboff Experimental Program Data, Naval Surface Warfare Center, Carderock Division (NSWCCD), CRDKNSWC/HD-1298-11, June 1998
- [4] Georgiev S., Vasileva A., Kyulevcheliiev S., Experimental and numerical investigation of the hydrodynamics of underwater vehicles close to the free surface, Report No. B171008, Bulgarian Ship Hydrodynamics Centre, November 2015 (in Bulgarian)
- [5] <https://www.plm.automation.siemens.com/global/en/products/simcenter/STAR-CCM.html>
- [6] Laun A.W, Development and Validation of a Conceptual Design Program for Unmanned Underwater Vehicles, MIT, 2013

MACHINERY AND PROPULSION SYSTEMS

IMPROVEMENT OF MODELS FOR AUTOMATED DESIGN OF ENGINE ROOM ARRANGEMENT ON A TRANSPORT SHIP

Vladimir YORDANOV*, Alexey DANILOVSKIY**, Htet Paing AUNG**

* Technical University of Varna, Bulgaria,

** State Marine Technical University of Saint Petersburg, Russian Federation

Abstract. This paper describes the technique of computer-aided design of the cargo ships engine room arrangement with a propulsion complex with medium-speed engines. The methodology is based on the use of tables of relative coordinates and absolute dimensions of propulsion complex units. Previously, this technique was used in the engine room arrangement with low-speed engines. Currently, in connection with the development of CAD systems, this methodology is applied for engine room with medium-speed engines. Its application allows not only to automate the propulsion complex arrangement in the engine room, but also to perform a number of important auxiliary operations, including checking the feasibility of the location variant, calculating the weight load and moments relative to the main directions, optimizing the location option using the economic efficiency criteria.

Keywords: ship propulsion complex, medium-speed engine, engine room arrangement, cargo ships, automated design

1. INTRODUCTION

Medium-speed engines (MSE) with engine speed of up to 1000 rpm are used in a wide range of ship types and purposes, as main ship engines. These are sea cargo ships – tankers and cargo ships, river-sea mixed ships, coasters, most ships of the river fleet, a significant part of fishing ships, supply ships. These ships are characterized by various schemes of power equipment arrangement in the engine room. To solve the problems of optimizing the locations of power complexes on these types of ships, it is necessary to develop a system of computer-aided design for the arrangement with inclusion of assessing blocks for the admissibility and preferences of the developed options in comparison with alternative ones.

The development of the layout and placement of the propulsion complex elements – main engines, power transmissions, propellers and shaft lines, should be preceded by their selection from the standard series (engines and transmissions) and design (propellers and shafts). The computer-aided design system of the ship's propulsion complex (SPC), including the above work, was created earlier in the framework of research of JSC "Zvezda" (St. Petersburg) under the leadership of L. K. Pomerants [1].

2. METHODOLOGY

The development of the propulsion complex begins with the definition of its main parameters – the power for ship's movement at a given speed, the power reserve factor and the number of ship propellers. These parameters are determined using the data of the prototype ship, and the power by recalculation according to the formula of Admiralty coefficients. The other two parameters are taken depending on the navigation region and the depth of the ship's navigation. Next, the calculation of the maximum permissible diameter of the engine is made depending on the permissible precipitation and tunneling coefficient.

Further, the maximum permissible diameter of the propeller is calculated depending on the allowable draft and the tunnel coefficient. The latter coefficient is according to B. A. Lesyukov [2]. The optimum propeller speed is determined by the formula of L.S.Artyushkov [3]. Water parameters are determined under winter conditions, and in the extended range they change as follows:

$$(1) \quad \nu_{SW} = [1,31 \cdot 10^{-6} \cdot (t_{SW})^4 - 2,1 \cdot 10^{-4} \cdot (t_{SW})^3 + 1,45 \cdot 10^{-2} \cdot (t_{SW})^2 - 0,619 \cdot t_{SW} + 18,5] \cdot 10^{-7}$$

$$(2) \quad \nu_{FW} = [17,91904762 \cdot (t_{FW})^4 - 0,60748413 \cdot (t_{FW})^3 + 1,420833 \cdot 10^{-2} \cdot (t_{FW})^2 - 2,02778 \cdot 10^{-4} \cdot t_{FW} + 1,25 \cdot 10^{-6}] \cdot 10^{-7}$$

$$(3) \quad \rho_{SW} = 1,71 \cdot 10^{-18} \cdot (t_{SW})^4 + 1,85 \cdot 10^{-5} \cdot (t_{SW})^3 - 5,51 \cdot 10^{-3} \cdot (t_{SW})^2 - 5,05 \cdot 10^{-2} \cdot t_{SW} + 1030$$

$$(4) \quad \rho_{FW} = -2,08333 \cdot 10^{-7} \cdot (t_{FW})^4 + 5,32407 \cdot 10^{-5} \cdot (t_{FW})^3 - 0,008159722 \cdot (t_{FW})^2 + 0,064814815 \cdot t_{FW} + 999,80278$$

The designations in the equations are the following (the average salinity of sea water is about 35 grams per liter): ν_{SW} , ν_{FW} - kinematic viscosity of sea water and fresh water, m^2/s ; t_{SW} , t_{FW} - temperature of sea water and fresh water, $^{\circ}C$; ρ_{SW} , ρ_{FW} - density of sea water and fresh (river) water, kg/m^3 .

The engine is selected according to the maximum continuous power and the rating. The rating should not be greater than the rating of the newly designed ship ($R1 - R5$). The excess of the power of the selected engine over the required value obtained by recalculating the characteristics of the engine of the prototype vessel, taking into account the power reserve factor, should not be more than 8-10%. The newly developed database of medium-speed engines has a gradation less than the specified value and allows you to pick up the MSE at the required power with an excess of less than the specified limit.

The reduction gearbox is selected based on the torque value on the input shaft $M = N_e/n$ and the required gear ratio $I = n/n_p$. The engine parameters N_e (engine power) and n (engine speed), and the rotational speed of the propeller (n_p) must correspond to the nominal maximum continuous rating regime. Due to the fact that the standard size series of gear ratios has discreteness, it is impossible to choose the exact equality of the actual and calculated values of the gear ratio.

The nearest value is adopted to the required one in either direction. A consequence of this is the difference between the rotational speed of the propeller and the optimum one. The angle of the blades is specified so, that the propeller efficiency decreases insignificantly.

To create the possibility of computer-aided design of SPC arrangement in an engine room, it is necessary to formalize the description of the outline of the ship's hull. Table 1 presents a description of hull drawing in a generalized relative form. The height from the base line (BL) is related to the height of the board up to the upper deck. The distance from the aft perpendicular to the corresponding theoretical frames is related to the distance to the midship, i.e. to half the length of the ship and the length reading starts from the aft perpendicular. Half of the width of the ship at the intersection of the frame and the waterline (measured as the distance from the diametral plane to the forming hull - the corresponding cross-section of the theoretical frame) is related to the maximum ship width.

The reference system makes this table as a universal approximation of the ship's hulls with certain characteristics - the shape of the hull and the completeness coefficients. When designing a new ship with similar contours, Table 1 should be multiplied by its characteristic dimensions - the coordinates of the waterlines - the hull height of the board (depth) D , the coordinates of the frames - half the length of the ship between perpendiculars ($L_{pp}/2$) and the width - the ship breadth overall (B). After this, the forming coordinates of the new ship's hull will be immediately obtained.

Thus obtained contours of ship's shape can be used for designing of engine room arrangement. It is important to emphasize that such representation is volumetric, since any section can be represented and analyzed.

Table 1. Ship's width in relative coordinates Y/B

J	H	Theoretical frames and their relative distances from the aft perpendicular									
		20	19,5	19	18	17	16	15	14	13	12
		0,0	0,081	0,138	0,242	0,346	0,450	0,554	0,657	0,761	0,869
1	0,0	,025	,458	,057	,087	,119	,160	,192	,213	,240	,264
2	,066	,053	,075	,119	,162	,202	,245	,281	,317	,349	,379
3	,206	,098	,119	,170	,217	,268	,313	,349	,379	,404	,434
4	,291	,145	,170	,238	,289	,336	,372	,402	,428	,450	,468
5	,533	,304	,323	,357	,387	,421	,443	,458	,472	,475	,485
6	,691	,402	,411	,428	,444	,460	,470	,478	,485	,475	,493
7	,848	,443	,455	,466	,477	,485	,488	,492	,494	,475	,498
8	1,0	,458	,469	,478	,486	,485	,492	,495	,497	,498	,499

In table 1 are designated: J - numbering of waterlines (the basic line is numbered by one); H - the distance of the waterline from the base plane, related to the height of the board up to the main deck. The heading of the remaining columns contains the numbering of the theoretical frames and their distance from the aft perpendicular, related to half the length of the ship between the perpendiculars. The columns themselves contain the distance from the diametral plane to the shape of the board measured on this frame and related to the ship breadth in the middle of the ship (midship). Thus, in table 1 the aft part of the theoretical drawing of the ship hull is described. The midship frame is numbered 10. We are interested in the aft end of the ship.

The arrangement of the SPC begins with the placement of the propeller behind the ship. Figure 1 shows a propeller arrangement in the stern and the distances from the characteristic propeller points to the hull structure.

In Fig. 1 are designated: D and R - diameter of the propeller and its radius; Z_0 - elevation of the propeller axis above the base line; T - calculated draught of the ship; h - height of the rudder feather; e_m - the thickness of the feather profile; a, b, l, m - the distances of the propeller disk from the characteristic structures.

Fig.1. Propeller arrangement in the open area stern

Fig.2. Arrangement of the propellers behind the stern of a two-shaft ship

For single-shaft ships: $l/D \geq (0,15+1,1 \cdot 10^{-3}(q-60))$;

For two-shaft ships: $l/D \geq 0,26$; $m/D \geq 0,05$ $a/D \geq 0,2+1,5(e_m/D-0,15)$.

A propeller of single-shaft SPC, which is behind the shaft line, is located in the diametrical plane of the ship in accordance with the limitations, presented in Fig.1. The implementation of the propeller arrangement in the case of a two-shaft installation is shown in Fig.2.

The distance of the blade edge of the propeller from the base plane and from the board plane is 5 - 10% of the propeller diameter. To reduce the noise from hydraulic shocks into the side of the vortices coming off the blades, the edges of the propeller blade should be spaced from the hull outline about 10% of the propeller diameter. Graphically, this position is approximately represented by a dashed arc passing between 17 and 18 theoretical frames. On the longitudinal view, you can determine the axial position of the propeller at a point spaced from the touching the 17th frame at half the distance between 17 and 18 frames.

Software based on the tables of relative coordinates and absolute dimensions of equipment blocks has been developed for the arrangement of the SPC elements in the engine room (Table 2).

Table 2. Example of a table of relative coordinates of the engine room equipment

NC	View	Z_{BL}	R	L_{PP}	L_{ER}	B	D	X_{CPR}	X_{AB}	H_{ER}
4	1	6	0.0	125	18.00	17.8	10.4	1.00	0.08	1.0
ZX	ZY	Z_{LEV}	H1	H2	H3	H4	H5	H6	H7	H8
650	480	5	0.127	0.437	0.72	1.0	1.0	1.0	1.0	1.0
J	I	NCI	ANG	X	Y	Z	L	B	H	
1	Gauge – 1m*1m*1m	8	0.0	0.993	0.5	0.5413	1.0	1.0	1.0	1.0
2	Shaftline - 23	8	0.0	0.1884	0.189	0.1692	6.800	0.26	0.26	
3	Shaftline - 24	8	0.0	0.1884	-0.189	0.1692	6.800	0.26	0.26	
4	Reduction gearbox-21	8	0.0	0.4458	0.189	0.1874	2.45	2.3	2.5	
5	Reduction gearbox-21	8	0.0	0.4458	-0.189	0.1874	2.45	2.3	2.5	
6	Main engine - 2	8	0.0	0.5986	0.189	0.374	6.0	2.3	3.772	
7	Main engine - 1	8	0.0	0.5986	-0.189	0.374	6.0	2.3	3.772	
8	Ship power station	8	0.0	0.1385	0.0	0.2791	5.7	15.0	2.94	

The designations in table 2 are the following:

NC - the color code of the line that bounds the contours of the block when displayed on the screen;

View - the code of the analyzed image projection;

Z_{BL} - number of equipment (blocks and cisterns) in the engine room;

R - the distance from the characteristic plane on which the engine room section is drawn, m;

L_{PP} - the length of the ship between perpendiculars, m;

X_{CPR} - position of the bow bulkhead cargo pump room on the tanker related to the engine room length;

X_{AB} - distance between aft bulkhead of engine room and the aft perpendicular related to the length of ship's waterline; H_{FR} - frame profile height, m;

ZX and ZY - the number of displayed pixels on the display screen horizontally and vertically;

Z_{LEV} - the total number of levels of the analyzed image;

H₁ - elevation of the characteristic level (double bottom) above the ship base line, m;

H₂ - the same for the third platform, m; H₃ - the same for the next platform, m;

H₄ - the same for the upper deck, m; H₅, H₆, H₇, H₈ - the same for the next decks;

J - consecutive numbering of engine room equipment (blocks and cisterns);

NCI - the color number used to represent this block when visualizing the engine room arrangement (this sign has a priority in comparison with NC); ANG - angle of the block installation in relation to diametrical plane (the variable is not activated); L, B and H - the absolute dimensions of the blocks, m.

Relative coordinates (related to the characteristic dimensions of the engine room) of the SPC blocks are the following: X - distance from the aft bulkhead of engine room to the center of the block's size related to the length of engine room; Y - distance from the diametrical plane to the center of the block's size related to half breadth (in the midship) of the ship; Z - distance from the base line to the center of the block's size related to the depth (hull height of the ship's board).

In columns of table 2 which are designated with L_{ER} (length of engine room), B (ship's breadth overall) and D (depth, height of the board, hull height) are the dimensions of the engine room of the new design ship. The software multiplication of Table 2 for the engine room dimensions gives variant of SPC blocks arrangement in the engine room of the new design ship according to the engine room arrangement of the base ship.

The method of engine room design using tables of relative coordinates and absolute dimensions (example - Table 2) allowed to create a system of automated design of engine room, including:

- models of visualization of engine room arrangement with given coordinates of sections - parallel to the main planes;

- model of the admissibility analysis of the engine room variant by checking not overlapping blocks on each other and on restricted areas (walkways and approaches to equipment);

- models of dialogue editing of the engine room variant by moving equipment blocks on the display screen; model of optimization of the engine room variant according to the criteria of economic efficiency;

- model for determining the center of mass of engine room equipment and the moments relative to the 3D main directions. To determine the mass of some elements of the engine room equipment and the propeller mass, information from the catalogues of manufacturers, database of low-speed and medium-speed engines, as well as approximation dependences, are used [5, 6, 7, 8].

CAD arrangement of engine rooms are equally suitable for engine room with low-speed engines and medium-speed engines. For engine room with low-speed engine, there is an additional possibility of pipeline tracing, selection of standard pipes from assortments and calculation of hydraulic resistances.

After working out the variant of the SPC in engine room arrangement with medium-speed engine, it becomes possible to construct a design scheme and perform a calculation of the complex stress state of a statically indeterminate beam and the vibrations of the console and spans of the shaft line using the model. The operating frequency range of rotation of each installation is between n_{min} and n_{max} .

Fig.3. Arrangement of an engine room equipment of a two-shaft ship

Fig.4. Calculation diagram of ship's shaft line

Thus, the frequencies of free oscillations of n_e must be within the following limits:

$$V_{\min} \cdot n_{\min} \leq n_e \leq V_{\max} \cdot n_{\max}$$

For the propeller, practical interest are only the oscillations with a frequency equal to the propeller speed $v=1$, and oscillations with a vane frequency, the order of which is a multiple of the number of the propeller blades z : $v=z$; $v=2z$; $v=3z$; $v=4z$.

The natural oscillation frequency of the propeller shaft and the span of the intermediate shaft are determined using dependences (5) and (6):

$$(5) \quad n = 49,2 \frac{1}{l^2} \sqrt{\frac{EI}{m}} \mu = A \frac{1}{l^2} \mu$$

$$(6) \quad n = 8,64 \frac{1}{l_k^2} \sqrt{\frac{EI}{\frac{M}{l_k} + 0,24m}} \mu = B \mu$$

Designations in the equations are the following: E - the modulus of elasticity of the shaft material, N / mm^2 ; I - moment of inertia of the cross-sectional area of the beam, mm^4 ; m - weight of running unit of beam length, kg ; M - mass of the propeller, kg [8]; l - the span length (distance between adjacent supports of shaft line) of the corresponding shaft, mm ; l_k - the length of the shaft console, mm .

For all spans (distances between adjacent supports of shaft line) of the shafting:

$$(7) \quad \mu_n = \frac{n}{A} l_n^2$$

For the console beam, from the graphics, depending on the coefficient x , is obtained the following:

$$(8) \quad x_{1,n} = \frac{1}{1 - \frac{l_n}{l_{n-1}} \frac{1 - x_{2,(n-1)}}{x_{2,(n-1)}}}$$

Table 3. Scheme for determining the frequencies of free oscillations of the ship's shafting

Span №	1	2	3	...	n	$n+1$	...	$m-1$	m	
l_n	l_1	l_2	l_3	...	l_n	l_{n+1}	...	l_{m-1}	l_m	
$\beta_n = \frac{l_n}{l_{n-1}}$	-	l_2/l_1	l_3/l_2	...	$\frac{l_n}{l_{n-1}}$	$\frac{l_{n+1}}{l_n}$	...	$\frac{l_{m-1}}{l_{m-2}}$	$\frac{l_m}{l_{m-1}}$	
$n=$	μ_n	μ_1	μ_2	μ_3	...	μ_n	μ_{n+1}	...	μ_{m-1}	μ_m
	$x_{1,n} + x_{2,n}$	$x_{1,1} + x_{2,1}$	$x_{1,2} + x_{2,2}$	$x_{1,3} + x_{2,3}$	...	$x_{1,n} + x_{2,n}$	$x_{1,n+1} + x_{2,n+1}$	...	$x_{1,m-1} + x_{2,m-1}$	$x_{1,m} + x_{2,m}$
	$x_{1,n}, x_{2,n}$	$x_{1,1}$ $x_{2,1}$	$x_{1,2}$ $x_{2,2}$	$x_{1,3}$ $x_{2,3}$	...	$x_{1,n}$ $x_{2,n}$	$x_{1,n+1}$ $x_{2,n+1}$	...	$x_{1,m-1}$ $x_{2,m-1}$	$x_{1,m}$ $x_{2,m}$
$n=$										

Table 3 shows the scheme for determining the frequencies of free oscillations of higher harmonics [4].

Fig.5. Diagram of ratio of μ and x

When the frequency of free flexural vibrations of the shaft line is significantly different from the set frequency, its new value is selected and calculation are made again. The refinement is performed by the method of successive approximations

CONCLUSIONS

1. The components of the ship propulsion complex (SPC) are the most major elements of ship power plants (SPP) and they determine the engine room sizes. Therefore, the solution of the task for design of SPC arrangement, as an element of SPP is an important work of engine room designing.
2. It is possible to implement several acceptable variants of SPC arrangement in the engine room, both on the mutual arrangement of the SPC elements, and on the possibility of selecting different variants from the standard series. Therefore, an important question is the development of models and computer-aided design and optimization of the SPC arrangement in the engine room.
3. The methodology of computer-aided design of SPC arrangement in the engine room is developed, based on tables of relative coordinates and absolute dimensions of the SPC blocks.
4. For SPC with medium-speed engines, two tasks not required for SPC with low-speed engines (mainly single-shaft) must be solved. This is the design of two-shaft SPC and special conditions for the design of the ship's shaft line. The design of the shafting is based on the arrangement of the propeller and the main engine (with reduction gear) on one axis, located previously relative to the ship's hull.
5. Medium-speed engines are used on relatively small ships and as part of two-shaft plants, which determines the small diameter of the shafting. This leads to the possibility of the appearance of longitudinal bending and requires verification of the absence of this occurrence.

6. Increased frequencies of the main engines lead to the need to analyze the natural frequencies of the shaft line at higher harmonics. All these problems have been solved in the process of developing of the system of computer-aided design of propulsion plant with medium-speed engines.

REFERENCES

- [1] Померанец Л.К. Развитие системы автоматизированного проектирования пропульсивных комплексов с СОД/ Л.К. Померанец, А.Г. Даниловский, Хтет Паинг Аунг. Актуальные проблемы морской энергетики: материалы седьмой Всероссийской межотраслевой научно-технической конференции в рамках Второго Всероссийского научно-технического форума «Корабельная энергетика: из прошлого в будущее». – СПб.: Изд-во СПбГМТУ, 2018. с.332-335. ISBN 978-5088303-577-6.
- [2] Лесюков, Б.А. *Теория и устройство судов внутреннего плавания*/ Б.А. Лесюков. – М.: Транспорт, 1982.
- [3] Артющков, Л.С. *Судовые движители*/ Л.С. Артющков, А.Ш. Ачкинадзе, А.А. Русецкий. – Л.: Судостроение, 1988.
- [4] Шиманский Ю.А. *Динамический расчет судовых конструкций*. – Л.: Судостроение, 1963.
- [5] Йорданов В., Георгиев В., Петров Н. Зависимости за определяне на показателите за маса на елементи от машинното отделение. Трети международен научен конгрес, Технически Университет – Варна, 04-06 october 2012, Varna , Bulgaria, Proceedings Vol.5, ISBN 978-954-20-0554-4, с.96-99.
- [6] Й Йорданов В., Петров Н. Определяне на показателите за маса на корабното помпено оборудване за машинно отделение. Известия на Съюза на учените – Варна , Серия Технически Науки, №1, 2012, ISSN 1310-5833, с.106-111.
- [7] Йорданов В. Показатели за маса на корабния валопровод за машинно отделение с бавнооборотен главен двигател. Известия на Съюза на учените – Варна , Серия Технически Науки, №1, 2012, ISSN 1310-5833, с.112-115.
- [8] Даниловский А.Г. *Расчет судовых валопроводов с применением ЭВМ.Статические расчеты*. - Л., Изд-во ЛКИ, 1983.

**MARITIME TRANSPORTATION
AND PORT OPERATIONS**

ON IMPROVEMENT OF RADAR OBSERVATION CAPABILITIES OF THE BULGARIAN VESSEL TRACKING MANAGEMENT AND INFORMATION SYSTEM

Chavdar ALEXANDROV*, Miroslav TSVETKOV*, Milen TODOROV**, Iliyan ILIEV* and Yordan SIVKOV*

* Nikola Vaptsarov Naval Academy Varna, Bulgaria, Faculty of Navigation

** Technical University of Varna, Bulgaria, Faculty of Shipbuilding

Abstract. To provide appropriate shore based facilities for Vessel Traffic Services (VTS) and communications in the Global Maritime Distress and Safety System (GMDSS) Areas A1, A2 and NAVTEX broadcasting according to the requirements of the Directive 2002/59/EC and the Protocol of 1988 relating to the International Convention for the Safety of Life at Sea, 1974 (SOLAS), a Vessel Traffic Management and Information System (VTMIS) has been built in Bulgaria for last 10 years. System includes operating and management center, two traffic control centers, a number of sites equipped with radars, VHF and AIS base stations, radio direction finders (RDF), meteo stations and telecommunication infrastructure. The Bulgarian Ports Infrastructure Company, a member of IALA VTS, Aids-to-Navigation (A2N) and e-Navigation committees, made responsible for the development of the VTMIS and A2N in Bulgaria is now in the research stage of launching a project for further modernization according to the newest achievements in the field of vessel traffic assistance. As a part of this research the radar observation subsystem is planned to be enhanced and improved. This paper describes the research has been done to improve the capabilities of radar observation subsystem as a part of modernization of the Bulgarian VTMIS. Specialized software for radio wave propagation as well as a VTMIS simulator have been used to analyze coverage areas of existing radar sensors for different types of targets and to prove need for enhancement. Results are presented both in both digital and graphical formats and include technical specifications for most appropriate sensors as well.

Keywords: Maritime safety and environment protection, Radar observation, VTMIS.

INTRODUCTION

The Vessel Traffic Management and Information System of Bulgaria (VTMIS) has been built to solve the following tasks [1, 2, 10, 13]:

- Constant monitoring of the sea areas of Republic of Bulgaria;
- Vessel traffic management in the ports, Bay of Varna, Bay of Burgas, anchorages, lakes and connecting fairways;
- Improvement of the efficiency in maritime search and rescue in Bulgarian SAR Area;
- Improvement of the information service for the purpose of environmental protection;
- Collecting and providing the whole necessary information for shipping to the authorities;
- Improvement of the efficiency of the maritime industry.

Development of the system passed through several steps.

The Varna Initial System (VIS) is considered as a first step in the development of the Bulgarian VTMIS. The Project PSO99/BG/3/6 Vessel traffic Management and Efficiency in Bulgaria, has been developed between December 1999 and May 2000 and was co-financed by the Bulgarian and Dutch government. The VIS had two radars with 18 feet antennas, two separate daylight displays, both showing a traffic image of the roads, the port approach and the port entrance of Varna, combining radar video and tracks of big and small vessels, human interface and display functionalities and traffic image storage and basis control and monitoring capabilities.

The next step of the extension from VIS to VTMIS, was to build two VTS centers – Varna and Burgas.

The final step was building of the Vessel Traffic Management and Information System of Bulgaria. The objectives of the VTMIS project were:

- Promotion of marine safety in the Bulgarian territorial waters;
- Promotion of the economic development through improvement of maritime transport in Bulgarian Ports and through industrial development in Bulgaria;
- Promotion of the protection of the environment on Bulgarian territorial waters;

Three consecutive phases, supported by European financial instruments have been developed to achieve this aim. The general establishment of the Bulgarian VTMIS after completion of the last phase (VTMIS-Phase 3) includes the following technical means and subsystems:

- Two new built mirror coastal centers, situated in Varna and Burgas, containing the computing core of the system, operational centers for VTS, GMDSS and Maritime Single Window (MSW), situational centers, on-the-job training simulators, all necessary interface and hardware;
- 18 remote controlled equipment sites with navigational and meteorological sensors and radio communication means;
- 16 navigational radars;
- 6 AIS base stations;
- 11 meteorological stations;
- 8 CCTV day/night cameras for vessel traffic monitoring;
- 2 DGPS reference stations;
- A network of radio transceivers for VHF and GMDSS;
- Radio relay data communication environment;

RADAR SUBSYSTEM AND IALA PERFORMANCE STANDARDS

Technical characteristics of RADAR subsystem

Radar is an object detection system which uses radio waves to detect and determine the range (bearing and distance), speed and movement direction (i.e. course) of objects [4]. Radar surveillance systems have a number of significant advantages. They are fully autonomous and independent, and allow continuous observation in poor weather conditions and during the night. Radar systems provide precise determination of ships positions, with accuracy of 1,5% of the range with 95% probability. Among disadvantages a number of limitations can be mentioned as limitations in azimuth and range resolutions and limitations regarding maximum range of detection, especially of small vessels in rough seas.

Radar subsystems used for coastal surveillance are described by their technical characteristics and operational parameters. Technical characteristics include wavelength, pulse shape and duration, power of the transmitter, sensitivity of the receiver and antenna gain and aperture.

The most important operational parameter is coverage or working area. It is limited by minimum and maximum detection range. It is possible also to limit the area and by azimuth angles to provide observation only of the sea surface. Minimum detection range depends on pulse length, antenna height and vertical beamwidth. The expression used to calculate maximum range of radar is named *Radar Range Equation* [3, 4, 9]. Besides technical characteristics of radar, maximum range of detection depends on characteristics of the target of observation:

$$(1) \quad R_{\max} = \sqrt[4]{\frac{P_T G \sigma A_e}{(4\pi)^2 S_{\min}}},$$

where P_T is transmitting power of the Radar, $S_{\min}$ – sensitivity of the receiver, A_e – effective area of the antenna;

$G = \frac{4\pi A_e}{\lambda^2}$ is the antenna directional gain factor and σ – radar cross section of the target.

It is important to emphasize that the equation (1) does not take into account losses in radar system and as such calculates maximum range in ideal conditions. Practically every electronic system has losses, represented by a factor of losses L . Taking into account losses, the power of received signal is calculated as

$$P_R = \frac{P_T G \sigma A_e}{(4\pi)^2 R^4 L}.$$

It is well known that the Signal to Noise Ratio, SNR of the receiver is determined as ratio between power of received signal and power of noise, i.e.:

$$SNR = \frac{P_R}{P_N},$$

where P_N is an average value of the power of noise, calculated as $P_N = kBT_0F_n$, where $k = 1.38 \times 10^{-23}$ is the Boltzmann constant, B is the bandwidth of the receiver, F_n – noise figure of the receiver and T_0 – a standard air temperature.

Signal to Noise Ratio is a standard estimation of the ability of a radar to detect a target at a defined range. For example, at 13dB SNR a target with radar cross section of $10m^2$ ($\sigma = 10m^2$) could be detected at 100nm with probability of detection more than 50%. This statement requires SNR to be included in radar range equation:

$$(2) \quad R_{\max} = \sqrt[4]{\frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 \cdot \text{SNR} k T_0 B F_n L}}.$$

It is important to mention that equation (2) is usually used to calculate maximum range of a radar in free space theoretically. In real conditions of radar observation of the sea surface the form of the Earth should be taking into consideration. In this case not only the radar cross section but the height of target above sea level (ASL) should be considered as well:

$$(3) \quad R_{\max} \approx \sqrt{2R_E} (\sqrt{h_R} + \sqrt{h_T}),$$

where h_R is the height of Radar antenna, h_T – height of the target and R_E – radius of Earth in normal atmospheric conditions. Average value of the radius of Earth is 6379km but due to refraction in the atmosphere the radar beam is bent downward to the sea surface and as a result the radius increases:

$$R_E = 1.33 \times 6379 \text{ km} = 8460 \text{ km}.$$

When due to a reason refractive index of the atmosphere decreases, the radius of curve showing propagation path of radar wave could become negative and waves turn in opposite direction of the curvature of sea surface. This phenomenon is called “Sub-refraction” and could reduce maximum range of detection with about 30%. Factors, that cause sub-refraction are an increase in relative humidity and a rapid fall in temperature with height [4, 9].

Calculations of Minimum and Maximum Detection Range

Calculations of minimum and maximum detection range of coastal surveillance radars according to technical specification of VTMS Project are carried out by using specialized software “Computer Aided Radar Performance Evaluation Tool, CARPET, v.2.13” [5]. Calculations are made for different types of targets and taking into account antenna height of every radar. Sizes of targets and sea state are based on IALA Recommendation V-128 – Operational and Technical Performance Requirements for VTS Equipment [6] (see Table 2).

Table 2. Target reflection features and type of capability recommended

Type of Target	Description	RCS (X-Band)	Height of Target (ASL)
1	Aids to Navigation etc. – without radar reflector; small open boats, fibreglass, wood or rubber with outboard motor and at least 4 meters long, small speedboats, small fishing vessels, small sailing boats and the like.	1 m ²	1 m
2	Inshore fishing vessels, sailing boats, speedboats and the like.	3 m ²	2 m
3	Aids to Navigation with radar reflector X - Band	10 m ²	3 m
4	Small metal ships, fishing vessels, patrol vessels and the like.	100 m ²	5 m
5	Coasters and the like.	1000 m ²	8 m
6	Large coasters, bulk carriers, cargo ships and the like.	10000 m ²	12 m
7	Container carriers, tankers, etc.	100000 m ²	18 m

Initial conditions for calculations include usage of 10m waveguides and probability of detection $P_D = 90\%$.

As mentioned above, Minimum detection range of a radar depends on antenna height, antenna pattern in vertical plane and pulse length. Calculation results for radar sensors installed on RS “Kaliakra” and “Peak Kitka” are shown in Table 3.

Table 3. Minimum detection range of radar sensors

Remote Site	Type of Radar	Antenna Height	Antenna		Minimum Range
			Type	Antenna pattern, Vertical plane	
Kaliakra	SCANTER 5202	80 m	21ft HG-HP-F-38	20°	220 m
Peak Kitka	SCANTER 5202	240 m	21ft HG-HP-F-38	20°	659 m

Result of calculations of maximum detection ranges are presented in Table 4 and Table 5 for radar sensors installed on RS “Kaliakra” and RS “Peak Kitka” respectively. Calculations for two different atmospheric conditions – clear and rain 4mm/h are included as well as in sub-refraction conditions.

Table 4. Maximum detection range of radar sensor “Kaliakra” for different types of targets

Type of Target	Sea State	Maximum Detection Range		
		Clear	Rain, 4mm/h	Sub-refraction, poor atm. conditions
1	3	12.5 nmi	10.4 nmi	7.3 nmi
2	3	15.9 nmi	14.6 nmi	10.2 nmi
3	4	18.1 nmi	17.0 nmi	11.9 nmi
4	5	21.1 nmi	20.2 nmi	14.1 nmi
5	6	24.1 nmi	23.3 nmi	16.3 nmi
6	6	25.1 nmi	24.7 nmi	17.3 nmi
7	6	27.1 nmi	26.3 nmi	18.4 nmi

Table 5. Maximum detection range of radar sensor “Peak Kitka” for different types of targets

Type of Target	Sea State	Maximum Detection Range		
		Clear	Rain, 4mm/h	Sub-refraction, poor atm. conditions
1	3	21.3 nmi	17.4 nmi	12.2 nmi
2	3	27.2 nmi	24.0 nmi	16.8 nmi
3	4	30.4 nmi	27.7 nmi	19.4 nmi
4	5	34.1 nmi	31.9 nmi	22.3 nmi
5	6	37.3 nmi	35.0 nmi	24.5 nmi
6	6	39.1 nmi	37.9 nmi	26.5 nmi
7	6	40.3 nmi	39.0 nmi	27.3 nmi

It is obvious that when the size of target is smaller, the influence of weather conditions on maximum detection range is more significant.

EXPERIMENTS

To prove theoretical investigations an experimental work has been carried out by using VTMISS simulator „Transas VTMISS Navi Trainer 5000”. The simulator is provided as a part of the Bulgarian VTMISS project [13] and installed in the Nikola Vaptsarov Naval Academy for the purposes of education and training of VTS personnel. Operational display units (ODU „Transas Navi Harbour 4.53”) are completely identical to those installed in the Traffic control centers. During the experiments abilities of radars installed on remote sites

“Kaliakra” and “Peak Kitka” to detect and track different types of targets according to IALA Recommendations V – 128, are examined. On fig. 2 tracking of a target type 6 or 7 by the radar installed on RS “Kaliakra” is shown. It is obvious on fig. 2a) that reliable tracking is possible at maximum range of 16.3 nm, i.e. up to the area north of Cape Shabla at latitude of about $43^{\circ}37'N$. Moving northerly of this parallel target disappears on the operator’s display (see fig. 1). The reason is probably not only the range, which is very close to calculated maximum, but the relief of the coastline which is very high in this area and imposes limitations of radar observation north – northeast of Cape Shabla.

Fig. 2. illustrates radar observation of a big target (type 6 or 7) in the area of Peak Kitka. It is obvious that reliable observation and tracking are possible within a range of up to 20nm i.e. north of Resovo, in latitude of about $42^{\circ}00'N$. Moving southerly of this parallel at a range of about 28 nm target disappears on the operator’s display. It is assumed that for smaller targets (targets of type 3, 4, and 5) maximum detection ranges will be smaller than these experimental results.

Figure 1. A type 6 target tracking by the radar installed on RS “Kaliakra”.

Figure 2. A type 6 target tracking by the radar installed on RS “Kaliakra”.

Experimental results show that in certain conditions radar subsystem of Bulgarian VTMISS is not capable of performing the tasks defined by the project and has to be improved. Radar sensor installed on RS “Kaliakra” is not able to cover Bulgarian territorial waters north north-east of Cape Shabla. At the same time radar sensor installed on RS “Peak Kitka” is not able to cover southern Bulgarian territorial waters. The solution is further modernization of the radar observation subsystem according to the newest achievements in the field of vessel traffic assistance. As a part of this modernization the radar observation subsystem has to be enhanced and improved by installation of two new radar sensors. The first one should be installed in RS “Shabla” with coordinates 43°32'40.30"N and 028°36'14.57"E to cover the North area and the second one should be installed in RS “Resovo” with coordinates 41°59'11.15"N and 028°02'0.54"E to cover the South area of the Bulgarian VTMISS with reliable radar observation and tracking capabilities.

Calculations of minimum and maximum detection range of radar sensors to be installed on new positions are carried out by using the same software with same initial conditions as for existing sensors. Calculation results for minimum detection range of radar sensors to be installed on RS “Shabla” and “Resovo” are shown in Table 6.

Table 6. Minimum detection range of radar sensors

Remote Site	Type of Radar	Antenna Height	Antenna		Minimum Range
			Type	Antenna pattern, Vertical plane	
Shabla	Coherent	41 m	18ft CO-HP-F-35	25°	77 m
Resovo	Coherent	32 m	18ft CO-HP-F-35	25°	64 m

Result of calculations of maximum detection ranges are presented in Table 7 and Table 8 for radar sensors to be installed on RS “Shabla” and RS “Resovo” respectively. As for existing sensors calculations for two different atmospheric conditions – clear and rain 4mm/h are included as well as in sub-refraction conditions.

Table 7. Maximum detection range of radar sensor “Shabla” for different types of targets

Type of Target	Sea State	Maximum Detection Range		
		Clear	Rain, 4mm/h	Sub-refraction, poor atm. Conditions
1	3	6.9 nmi	6.5 nmi	4.5 nmi
2	3	9.6 nmi	9.3 nmi	6.5 nmi
3	4	11.6 nmi	11.2 nmi	7.8 nmi
4	5	14.6 nmi	13.3 nmi	9.3 nmi
5	6	17.5 nmi	17.1 nmi	12.0 nmi
6	6	18.3 nmi	18.5 nmi	13.0 nmi
7	6	18.9 nmi	19.0 nmi	13.3 nmi

Table 8. Maximum detection range of radar sensor “Resovo” for different types of targets

Type of Target	Sea State	Maximum Detection Range		
		Clear	Rain, 4mm/h	Sub-refraction, poor atm. Conditions
1	3	6.5 nmi	6.0 nmi	4.2 nmi
2	3	9.1 nmi	8.7 nmi	6.1 nmi

3	4	10.9 nmi	10.5 nmi	7.4 nmi
4	5	13.8 nmi	13.4 nmi	9.3 nmi
5	6	16.6 nmi	16.2 nmi	11.5 nmi
6	6	17.4 nmi	17.5 nmi	12.3 nmi
7	6	17.9 nmi	18.0 nmi	12.6 nmi

4. Predicted coverage areas of new radar sensors for different types of targets are shown on fig. 3 and fig.

CONCLUSIONS

The Bulgaria Vessel Traffic Management and Information System (VTMIS) has been used for more than 10 years to answer the requirements of the Directive 2002/59/EC and the Protocol of 1988 relating to the SOLAS Convention. During this period system's performance was improved by enlarging the infrastructure and by using newest technologies. During the recent years it became obvious that radar observation subsystem needs to be enhanced and improved and this research was a part of the process. By using specialized software for radio wave propagation and a type approved VTMIS simulator, coverage areas of existing radar sensors for different types of targets have been analyzed. By using the simulator's built-in player the studies were proved by playing records of real traffic in different atmospheric conditions, provided by the VTMIS administrators. Installation of two new sensors to improve radar observation in all weather conditions is examined as well. Results are presented both in both digital and graphical forms.

Figure 3. Predicted areas for maximum detection range of different types of targets by the radar to be installed on RS "Shabla".

Figure 4. Predicted areas for maximum detection range of different types of targets by the radar to be installed on RS "Resovo".

ACKNOWLEDGEMENTS

This document is under project BG05M2OP001-2.009-0037-C01 "Support for the development of PhD students, post-doctoral students, young scientists and lecturers in the Nikola Vaptsarov Naval Academy", with the beneficiary of the Nikola Vaptsarov Naval Academy, Varna funded by the Intelligent Growth Science and Education Operational Program, co-financed by the European Union through the European structural and investment funds.

REFERENCES

- [1] Ch. Alexandrov. *Vessel traffic management and information systems*. Nikola Vaptsarov Naval Academy Varna, 2017, ISBN 978-619-7428-02-5 (in Bulgarian)
- [2] Ch. Alexandrov. Bulgarian vessel traffic management and information system and education and training of VTS personnel in Bulgaria. XVI-th IAMU Annual General Assembly, 6-9 October 2015, Rieka, Croatia, pp. 13-21, ISBN 978-953-165-116-5
- [3] D. Barton, S. Leonov. *Radar Technology Encyclopedia*, Artech House, 1998
- [4] A. Bole, B. Dimniley and A. Wall. *Radar and ARPA Manual*, Elsevier Butterworth-Heinemann Publishing, 2005
- [5] CARPET, TNO (Toegepast Natuurkundig Onderzoek) Physics and Electronics Laboratory, <http://www.tno.nl>
- [6] IALA Recommendation V-108 on Operational and Technical Performance Requirements for VTS Equipment, June 2007
- [7] IMO Resolution "A.477(XII) Performance Standards for Radar"
- [8] IMO Resolution "A.422(XI) Performance Standards for Automatic Radar Plotting Aids (ARPA)"
- [9] K. Ivanov. *Radiolocation and radar systems*. Nikola Vaptsarov Naval Academy – Varna, 2016 (in Bulgarian)
- [10] K. Kolev, N. Dimitrov. Cyber threat in maritime industry-situational awareness and educational aspect. XVIII-th IAMU Annual General Assembly, 9-12 October 2017, Varna, Bulgaria, pp. 13-21, ISBN 978-953-165-116-5
- [11] Marine Safety Directorate, Standards for Navigating Appliances and Equipment, Canada, 1983
- [12] Radar Performance Calculations, Radar Sensor System VTMISS Bulgaria, Terma A/S. DK, Jan. 2013
- [13] TRANSAS / TELELINK. Technical description of enhancement and renovation of Bulgarian VTMISS (IT, NCEDMT, RADAR, GMDSS). Document № 450001-01, 2015 (in Bulgarian)

Black Sea S2018

OCEANOLOGY

USE OF MACROALGAE TO ASSESS ECOLOGICAL STATUS OF BULGARIAN COASTAL WATERS FOR THE AIMS OF EUROPEAN WATER FRAMEWORK DIRECTIVE

Kristina Dencheva

Institute of Oceanology, Bulgarian Academy of Sciences, Varna, Bulgaria

Abstract. Coastal macroalgal communities are among the most productive ecosystems, providing habitat and refuge for diverse marine species. However, coastal marine areas are under serious threat as a result of anthropogenic pressures and global climate change. A variety of human disturbances to coastal area such as destructive fishing, recreational activities and coastal development have led to the declining of macroalgal communities, which as main primary producers play very important role in the coastal ecosystem. Nutrients penetrate directly through the macroalgal surface and when exceed their quantities, lead to destruction of sensitive macroalgae. Tolerant to eutrophication species of macroalgae increase and colonize polluted areas.

Various methods have been developed to assess quality of coastal waters and status of macroalgal communities. The EC Water Framework Directive requires that ecological quality be assessed in coastal waters using the abundance and species composition of macroalgae. In Bulgarian coastal waters, species composition is not a suitable measure. In compliance with MSFD and WFD, for Bulgarian coastal waters, two methods were elaborated and used, assessing different ecological state classes of coastal areas in monitoring programs. These methods (indexes) are based on abundance proportion of sensitive (ESGI) and tolerant (ESGII) species of macroalgae. The applied indices use functional characteristics of macroalgae, which are found to be more reliable and robust in estimation of ecological status. In 2014 year, nine polygons were sampled and various indicators were estimated, including the two indices - Ecological index (biomass), Ecological index (percent cover). In the south part of Bulgarian coast (Sinemorets) and in Irakli polygon in central part and Shabla in north part, the highest values of ecological indices were revealed. In these polygons minimal pressures were established. In Varna bay and Burgas bay, the most threatened and being assessed as regions at risk, the lowest values were estimated. The ecological indices, based on the analysis of macroalgal assemblages, has proved to be an effective tool for the assessment of the ecological status of coastal rocky communities.

Key words: ecological indices, macroalgae, MSFD, WFD

INTRODUCTION

The aim of the Marine Strategy Framework Directive is to ensure management of the human activities affecting the environment of the European seas, with protection and use of the seas in balance. The main goal of the MSFD is to achieve or maintain good environmental status (GES) in the Member State's marine environment by the year 2020 [1].

For achieving the goal the Member States shall by 2012 develop marine strategies for their sea-areas, containing an Initial Assessment (IA) of the state of the environment, a definition of good environmental status and establishment of environmental indicators, targets and monitoring programs. The Water Framework Directive (WFD) establishes a framework for the protection of transitional and coastal waters setting out that good ecological status should be evaluated using biological communities that constitute quality elements [2]. Marine benthic macrophytes (macroalgae, angiosperms) are key structural and functional components of many coastal ecosystems, forming extensive, highly productive and spatio-temporally patchy habitats [3]. They are sensitive to anthropogenic stress [4];[5] and have recently been incorporated as quality elements in water quality monitoring programs. Biotic metrics, including biotic indices or parameters, represent an effort to describe different and complex aspects of communities or other different biological organizational levels by integrating them in a formula producing a single numerical output [3]. Macrophyte biotic indices used to evaluate water quality status in coastal areas are often based on community composition analysis at the species level. However, a more predictive approach might be achieved by using appropriate functional classifications [6];[7];[8];[9]. Such an approach could reduce the apparent community complexity [10];[11], allowing comparisons between communities with little species overlap at local, eco region or global scales.

For the aims of the WFD and MSFD along the Bulgarian coast two indices were developed- EI-biomass and EI-percent coverage which use a functional approach. The aim of this paper is to present the two indices, to demonstrate how they work and on this base to estimate the ecological status of some coastal areas.

MATERIAL AND METHODS

Sampling was carried out with method of squares [12] and hydrobotanical transects with help of scuba diving technique [13]; [14]; [15].

Nine to twelve random samples were collected from every transect with help of metal frame - 20x20cm². In laboratory, macrophytobenthic samples were washed with water with sieve, for removing of sediments and animals. Then were sorted and identified to species, with help of stereomicroscope. Species identification was realized according to Zinova, [16] and Konaklieva, [17], Temniskova et al., [18]. Taxonomy was standardized, as used Algae base [19]. Samples were dried on filter paper and weighed on scales with accuracy to second sign. Wet weight was multiplied by coefficient to obtain biomass values in g.m⁻². [9].

The surface covered by each sorted taxon in vertical projection in samples was quantified as % of coverage. In order to estimate percentage coverage, a transparent square PVC container, filled with sea water and having at its bottom a square 20x20 cm matrix divided in 100 squares was used. The surface covered by each sorted taxon in vertical projection floating in sea water was quantified as percentage of coverage (4 cm² = 1% sampling surface). The total coverage often exceeded 100% due to the presence of different layers in the vegetation, i.e. mainly canopy and understorey layers. For species present within significant abundance a coverage value of 0.1% was allocated. [3]; [20].

Ecological status of coastal waters was assessed on the base of initially developed ecological index (EI) and its classification system [1], revised and filled out in process of intercalibration-second phase in frames of GIG Black Sea (21) and approved with regulation 4/14.09.2012 [22]. More in details the ecological index is described in [23]; [24]. In construction of ecological index was taken into account the EEIc index [3]; [6]; [25]; [20]. In the frames of last phase of intercalibration, referent value was revised [26] and in result following borders of EQR were calculated:

Table 1. Biomass proportion of more sensitive species, EI-biomass values and EI-EQR values of macrophyte assemblages on hard substrate for different ecological state classes.

Proportion of biomass of more sensitive species	EI	Ecological status	EI-EQR
> 0.78-1 ESGI	>7.8-10	Excellent	>0.837 - 1
> 0.6-0.78 ESGI	>6-7.8	Good	>0.644 – 0.837
> 0.4-0.6 ESGI	>4-6	Moderate	>0.429 – 0.644
0-0.4 ESGI	>2-4	Poor	>0.21 – 0.429
0-1 ESGII(A+B)	>1-2	Bad	>0.11 – 0.20
0-1 ESGIICa	0-1		0-0.11

The EI index is worked out with own borders (for Black Sea) of EQR, which is one of basic requirements of European Water Framework Directive.

Based on growth [27]; [28], longevity and canopy traits, Orfanidis et al. [6]; [7] have included macroalgae within this functional-form classification scheme. It is in accordance with r- and K-selection theory [29], and it was used to classify the benthic macrophytes in two groups that respond differently to environmental disturbance: the late-successional group with low growth rates and long life cycles (Ecological State Group I, K-selection) and the opportunistic group with high growth rates and short life cycles (ESG II, r-selection). All seaweed species with a thick or calcareous thallus are included in the first group, which grow in good conditions whereas species with a filamentous, sheet-like or coarsely branched thallus and Cyanobacteria are included in the second group which are characteristic of degraded status [25]. The same approach was used in classification of Bulgarian species of macrophytes. For the Ecological index we divided 7 ecological subgroups:

Table 2. Classification of benthic macrophytes in ecological groups. (Kristina Dencheva)

№	Таксон	ESG	№	Таксон	ESG	№	Таксон	ESG
1	Acrochaetium	IICb	30	Gracilaria	IIA	59	Zanardinia sp.	IC
2	Antithamnion	IICb	31	Gracilariopsis	IIA			
3	Bangia	IICb	32	Laurencia	IB	60	Zostera noltei	IB
4	Bryopsis	IICb	33	Osmundea	IB	61	Zostera marina	IA
5	Callithamnion sp.	IICb	34	Padina	IA	62	Zannichellia palustris	IIA
6	Ceramium arborescens	IIB	35	Palisada	IB	63	Ruppia maritima	IIA
7	Ceramium ciliatum	IIB	36	Petalonia	IIA	64	Apoglossum ruscifolium	IC
8	Ceramium diaphanum	IICa	37	Phyllophora	IA			
9	Ceramium diaphanum var. elegans	IICa	38	Polysiphonia elongata	IIA			
10	Ceramium virgatum	IICa	39	Polysiphonia denudata	IICa			
11	Chaetomorpha aerea	IICa	40	Polysiphonia nigrescens	IIA			
12	Chaetomorpha linum	IIA	41	Polysiphonia opaca	IIB			
13	Cladophora albida	IICb	42	<i>Polysiphonia subulifera</i>	IIA			
14	Cladophora coelothrix	IIB	43	Punctaria sp.	IIB			
15	Cladophora laetevirens	IICb	44	Pyropia sp.	IICb			
16	Cladophora	IICb	45	Ralfsia sp.	IB			
17	Cladophora vagabunda	IICb	46	Rhizoclonium	IICb			
18	Cladophora vadorum	IICb	47	Scitosiphon sp.	IIB			
19	Cladostephus spongiosus	IC	48	Sphacelaria sp.	IIA			
20	Colpomenia sp.	IIA	49	Stuckenia pectinata	IIB			
21	Corallina sp.	IC	50	Stylonema alsidii	IICb			
22	Cystoseira sp.	IA	51	Ulva clathrata	IICb			
23	Entocladia sp.	IICb	52	Ulva compressa	IICb			
24	Erythrocladia sp.	IICb	53	Ulva intestinalis	IICb			
25	Erythrotrichia sp.	IICb	54	Ulva flexuosa	IICb			
26	Ectocarpus sp.	IICb	55	Ulva linza	IICa			
27	Feldmannia sp.	IICb	56	Ulva rigida	II Ca			
28	Gelidium crinale	IIA	57	Ulvella sp.	IICb			
29	Gelidium spinosum	IC	58	Vaucheria sp.	IICa			

Ecological index-vertical coverage

New ecological index was established, based on estimation of percent coverage of macroalgae.
The same approach was used as in EI-biomass. The EQR values of the two indices were standardized.

Table 3. EI(v.c.) –EQR, values of macrophytobenthic communities for different classes of ecological status (Dencheva, 2017).

Proportion of vertical projected coverage of more sensitive species.	EI (v.c.)	Ecological status	EI-EQR
> 0.75 – 1 ESGI	> 7.5 – 10	Excellent	> 0.837 - 1
> 0.58- 0.75 ESGI	> 5.8 - 7.5	Good	> 0.644 - 0.837
> 0.39 - 0.58 ESGI	> 3.9 - 5.8	Moderate	> 0.429 - 0.644
0 - 0.39 ESGI	> 1.9 – 3.9	Poor	> 0.214 - 0.429
0-1 ESGII (A+B) 0 - 1 ESGIICa	> 1 – 1.9 0 - 1	Bad	> 0.11 - 0.214 0 - 0.11

For calculation of EI (v.c.) values the following rules and formulae are applied:

$$EI(v.c.)_{\text{excellent, good, moderate}} (3.9 - 10) = \left(\frac{ESGIA}{ESG} * 1 + \frac{ESGIB}{ESG} * 0.8 + \frac{ESGIC}{ESG} * 0.6 \right) * 10$$

$$EI(v.c.)_{\text{poor}} (1.9 - 3.9) = 5.1282 * \left(\frac{ESGIA}{ESG} * 1 + \frac{ESGIB}{ESG} * 0.8 + \frac{ESGIC}{ESG} * 0.6 \right) * +1.9$$

$$EI(v.c.)_{\text{bad}} (1 - 1.9) = 0.9 * \left(\frac{ESGIIA}{ESGII} * 0.6 + \frac{ESGIIIB}{ESGII} * 0.8 \right) + 1, \text{ ESGI}=0$$

$$EI(v.c.)_{\text{bad}} (0 - 1) = \left(\frac{ESGIIICa}{ESGII} \right) \text{ when ESGI}=0, \text{ ESGII(A+B)} = 0$$

Where ESG=ESGIA+ESGIB+ESGIC +ESGIIA+ESGIIIB+ESGIIIC

ESGI= ESGIA+ESGIB+ESGIC

ESGII=ESGIIA+ESGIIIB+ESGIIIC

EI (v.c.) - EQR is equal to EI (v.c.) divided by referent value - 9. Referent value was established on data base from 2014 to 2016 years.

For calculating of EI (v.c.) we use following coefficients:

ESGIA/ESG = 1.0

ESGIB/ESG = 0.8

ESGIC/ESG = 0.6

ESGIIA/ESG = 0.6

ESGIIIB/ESG = 0.8

ESGIIIC/ESG = 1.0

In 2014 year, summer season 124 samples from macroalgae were taken from 10 transects which are part of full monitoring net along the Bulgarian coast. Sampling was carried out according to described above methodology.

RESULTS AND DISCUSSION

In result of investigations in 2014 year, 4 species of brown algae (Ochrophyta), 19 species red (Rhodophyta), 11 - green (Chlorophyta) were established. From them 7 species were sensitive and 27 were tolerant, commonly 34 species.

In summer season, proportion of tolerant and sensitive species was following: the highest percent sensitive species was established in Sinemoretz (84.6%), Shabla (72%), Irakli - 85% followed by Nesebar (64%, Rusalka (64%). From sensitive species dominant are late successional oligosaprobic species from genus *Cystoseira* (figure 1). The highest percent of tolerant species of macrophytes was established in Krapetz, Galata, Kraymorie transects (100%), Pochivka (67%) (figure 1). Dominant were r-strategies and polysaprobic species from genus *Ulva*.

Figure 1. Biomass proportion of sensitive and tolerant species macrophytes in investigated transects (summer season, 2014 year).

For estimation of ecological status was used the ecological index (EI).

High values of ecological index (EI), establish high and good status and lower values-moderate, poor and bad respectively.

Ecological status of macrophytobenthic communities in summer season - 2014 year.

In summer season, highest values for the ecological index (biomass) and ecological quality ratio are established for Sinemoretz (8.46;0.907), Shabla (7.21;0.774), Irakli (8.48;0.910). The lowest values are estimated for Krapetz (0.75;0.08), Galata (1;0.108), Kraymorie (1,16;0.125) and Pochivka (3.25; 0.349) (table 4). The lowest values of ecological index, estimated for Galata and Pochivka transects in Varna bay, are due to many years anthropogenic press in Varna region and incoming contaminated waters from Varna lake through channels [30];[31];[32];[33];[34]. The status of Varna bay changes from bad and poor in south and central parts (Galata and Pochivka) to moderate status in Trakata transect in north. This tendency for spatial changes in status of water body we connect with the negative effect from Varna lake, which is most significant in south part of the bay. Kraymorie is in bad status due to close connection with Burgas bay and Mandra lake which many years is contaminated by different sources of pollution from anthropogenic character. Krapetz transect is in bad status. Here are estimated highest concentrations of phosphorous and nitrogen in marine water. In the region agriculture is developed. In Krapetz are not registered considerable point sources of pollution and it is possible high concentrations of nutrients to be due to underground waters, or Danube river influence. Other explanation is natural conditions as high turbidity of water, registered in this region and substrate which is sandy plate which is more loose and hamper development of sensitive species such as *Cystoseira* spp. Sinemoretz, Irakli were in high status. Nesebar, Shabla and Rusalka were in good status (table 4, figure 2). Trakata south was in moderate status. Pochivka was in poor status. In Burgas bay two transects were monitored: Nesebar, was in good status, Kraymorie was in poor status.

Table 4. Ecological status, ecological quality ratio and ecological index of investigated transects.

№ of polygon	Polygon name	EQR-EI (biomass)	EI (biomass)	Ecological status
10	Sinemorets	0.907	8.46	Excellent
9	Krajmorie	0.125	1.16	Bad
8	Nesebar	0.688	6.41	Good
7	Irakli	0.910	8.48	Excellent
6	Galata	0.108	1.00	Bad
5	IV buna	0.349	3.25	Poor
4	Trakata	0.528	4.92	Moderate
3	Rusalka	0.685	6.39	Good
2	Shabla	0.774	7.21	Good
1	Krapets	0.080	0.75	Bad

Figure 2. Ecological quality ratio of the ecological index-biomass and ecological status of investigated transects. Red-bad status ;Orange-poor; Blue-excellent; yellow-moderate; green-good.

On the base of percent coverage, ecological index-percent coverage was estimated. The highest value was registered in Sinemorets (7.55), followed by that in Irakli (6.04).

The lowest values were established for Krajmorie, Galata and Krapets (1.08; 1.00;0.7).

We used this index to compare results with EI-biomass.

In comparison with Ecological index-biomass, it is obvious that Nesebar is in moderate status not in good as it is in table 4, figure 2 and Irakli is in good status, not in high. Trakata is in poor status, not in a moderate as is in case when estimated with ecological index – biomass. Shabla and Rusalka are in moderate status (table 5), not in good status (table 4). Index values of EI-percent coverage are lower than these of EI-biomass.

Table 5. Ecological status, ecological quality ratio and ecological index-percent coverage of investigated transects and ecological status.

№ of polygon	Polygon name	EQR-EI (coverage)	EI (coverage)	Ecological status
10	Sinemorets	0.839	7.55	Excellent
9	Krajmorie	0.120	1.08	Bad
8	Nesebar	0.493	4.59	Moderate
7	Irakli	0.671	6.04	Good
6	Galata	0.111	1.00	Bad
5	IV buna	0.28	2.52	Poor
4	Trakata	0.323	2.92	Poor
3	Rusalka	0.523	4.71	Moderate
2	Shabla	0.484	4.36	Moderate
1	Krapets	0.075	0.7	Bad

Figure 3. Ecological quality ratio of the ecological index-percent coverage and ecological status of investigated transects. Red-bad status ;orange-poor; blue-excellent; yellow-moderate; green-good.

The lower values of EI-percent coverage are due to the fact, that percent coverage values of *Ulva* are high (tolerant species), in comparison with biomass values and lower the EI-percent coverage. High biomass values of sensitive species (*Cystoseira*) enhance EI-biomass index values. Thus, the two indices are complementary to one another and contribute to more reliable results.

The final ecological status is almost the same as that established with ecological index-biomass with the exception of ecological status in Irakli. It turns from excellent to good ecological status.

Values of ecological index-percent coverage are lower than these of ecological index –biomass.

The final value of EI is average of EI-biomass and EI-coverage (figure 4)

Table 6. Ecological status, ecological quality ratio of the ecological index - percent coverage and biomass of investigated transects.

№ of polygon	Polygon name	EQR-EI (coverage)	EQR-EI (biomass)	Final Ecological status
10	Sinemorets	0.839	0.907	Excellent
9	Krajmorie	0.120	0.125	Bad
8	Nesebar	0.493	0.688	Good
7	Irakli	0.671	0.910	Good
6	Galata	0.111	0.108	Bad
5	IV buna	0.28	0.349	Poor
4	Trakata	0.323	0.528	Moderate
3	Rusalka	0.523	0.685	Good
2	Shabla	0.484	0.774	Good
1	Krapets	0.075	0.080	Bad

Figure 4. Ecological quality ratio of the final ecological index and ecological status. Red-bad status ;Orange-poor; Blue-excellent; yellow-moderate; green-good.

CONCLUSIONS

High status was established for 1 transect, good status- 4 transects, moderate-1 transect, poor -1 and bad – 3 transects.

In the north part of Bulgarian Black Sea coast is supported high level of pressure, as in some zones from Burgas and Varna bay.

Probable kinds of pressures, which provoke the observed bad ecological status of macrophytobenthic communities could be due to contaminants from river inflow of Danube river, Provadijska river, Mandra lake, Shabla lake, from direct inflows of sewerage, inflows of wastewater treatment plants, underground waters.

Nutrients, especially nitrogen excess, shifts the coastal habitat from late-successional species to dominance by opportunistic macroalgae. Such a community change is better indicated by functional metrics, as the biotic index EI.

The two indices are complementary to one another and give reliable estimation of final ecological status.

REFERENCES:

[1]European Parliament Council (EPC), 2008.Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF>.

- [2]EC. 2000. Directive 2000/60/EC, Establishing a framework for community action in the field of water policy. European Commission PE-CONS 3639/1/100 Rev 1: Luxemburg
- [3]ORFANIDIS, S., PINNA, M., SABETTA, L., STAMATIS, N. & NAKOU, K., 2008. Variation of structural and functional metrics in macrophyte communities within two habitats of eastern Mediterranean coastal lagoons: natural versus human effects. *Aquatic Conservation: Marine & Freshwater Ecosystems*, 18 (1): S45-S61.
- [4]Domin A, Schubert H, Krause JC, Schiewer U. 2004. Modelling of pristine depth limits for macrophyte growth in the southern Baltic Sea. *Hydrobiologia* 514: 29–39
- [5]Krause-Jensen D, Greve TM, Nielsen K. 2004. Eelgrass as bioindicator under the European Water Framework Directive. *Water Resources Management* 19: 63–75
- [6]Orfanidis, S, Panayotidis, P. & Stamatis, N. 2001. Ecological evaluation of transitional and coastal waters: A marine benthic macrophytes-based model. – *Medit. Mar. Sci.*, 2(2): 45-65
- [7]Orfanidis S, Panayotidis P, Stamatis N. 2003. An insight to the ecological evaluation index (EEI). *Ecological Indicators* 3:27–33.
- [8]Mouillot D, Spatharis S, Reizopoulou S, Laugier T, Sabetta L, Basset A, Do Chi T. 2006. Alternatives to taxonomic-based approaches to assess changes in transitional water communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16: 469–482.
- [9]Minicheva G. G., A. B. Zotov, M. N. Kosenko. 2003. *Methodical recommendations for determining the complex of morpho-functional parameters of unicellular and multicellular forms of aquatic vegetation*// GEF Project for renewal of the Black Sea ecosystem., INBUM, Odessa, 32 p.
- [10]Steneck RS, Watling L. 1982. Feeding capabilities and limitation of herbivorous molluscs: a functional group approach. *Marine Biology* 68: 299–319.
- [11]Steneck R, Dethier MN. 1994. A functional group approach to the structure of algal dominated communities. *Oikos* 69:476–498.
- [12]Morozova-Vodianitskaja, N. 1936. Quantitative assessment of benthic plants in the Black Sea. – *Trudy Sevastopol'sk. Biol. Stantsii*, 5: 133-139 (in Russian).
- [13]Kalugina-Gutnik. 1975. *Fitobenthos of Black Sea*. M., Naukova dumka, Kiev, 246 p (in Russian).
- [14]OSPAR Commition. 1976 *JAMP eutrophication Monitoring Guidelines. Benthos*. 12pp.
http://www.ospar.org/content/content.asp?menu=00120000000135_000000_000000
- [15] Back S. 1999. *HELCOM Gudelines for monitoring of phytobenthic plant and animal communities in the Balthic Sea*. Annex C9 for HELCOM combine program.
<http://www.helcom.fi/stc/files/CombineManual/PartC/AnnexC9.pdf>)
- [16]Zinova, A. 1967. *Guidebook of the Green, Brown and Red Algae of the Southern Seas of USSR*. Nauka, Moskva (in Russian). 396 p.
- [17]Dimitrova-Konaklieva, S. 2000. *Marine Algae of Bulgaria (Rhodophyta, Phaeophyta, Chlorophyta)*. Pensoft, Sofia (in Bulgarian).
- [18] Temniskova D, Vodenicharov D, Stoyneva M. et al. *Guidance for exercises on systematic of algae and sponges*. PENSOFT, Sofia-Moskva. 315c. (In Bulgarian)
- [19] Guiry, M.D. & G.M. Guiry, 2013. *Algae Base. World-wide electronic publication*, National University of Ireland, Galway.
<http://www.algaebase.org//>
- [20] S. Orfanidis, K. Dencheva, K. Nakou, S. Tsioli, V. Papathanasiou, I. Rosati. Benthic macrophyte metrics as bioindicators of water quality: towards overcoming typological boundaries and methodological tradition in Mediterranean and Black Seas. *Hydrobiologia* (2014) 740:61-78. DOI 10.1007/s10750-014-1938-x
- [21]Dencheva K., Dumitrescu O. 2011. Intercalibration of macrophytobenthos-Black Sea GIG. Technical report (ppt presentation).
- [22]Regulation No 4, 14.09.2012 year. For characterization of surface waters
http://www3.moew.government.bg/files/file/Water/Legislation/Naredbi/Naredba_H4_za_harakterizirane_na_pov_yrhnostnite_vodi.pdf
- [23]Dencheva K., Doncheva V. 2014. Ecological Index (EI) - tool for estimation of ecological status in coastal and transitional waters in compliance with European Water Framework Directive. *Proceedings of Twelfth International Conference On Marine Sciences And Technologies*, pp.219-226
- [24] Dencheva K. 2017. Some macrophyte indicators for assessment of ecological status in south and north parts of Bulgarian Black Sea coast in compliance with WFD and MSFD. *Proceedings of Scientific Union, Varna*.
- [25] ORFANIDIS S., PANAYOTIDIS P., UGLAND K. 2011. Ecological Evaluation Index continuous formula (EEI-c) application: a step forward for functional groups, the formula and reference condition values *Medit. Mar. Sci.*, 12/1, 199-231
- [26]Berov D., Todorov E., Marin O., 2015 - Black Sea GIG – Coastal/Transitional waters- BQE. Technical report, 24 pp

- [27] Nielsen SL, Sand-Jensen K. 1990. Allometric scaling of maximal photosynthesis growth rate to surface/volume ratio. *Limnology and Oceanography* 35: 177–181.
- [28] Duarte CM. 1995. *Submerged aquatic vegetation in relation to different nutrient regimes*. *Ophelia* 41: 87–112.
- [29] MacArthur RH, Wilson EO. 1967. *The Theory of Island Biogeography*. Princeton University Press: Princeton
- [30] Stoyanov, A. 1991, Negative Changes of Hydrochemistry of Beloslav Lake – Varna Lake – Varna Bay.- In: *Proceedings of II-nd. Ecol. Conf., 29-30 October. 1991*, Varna, 1991, 38-46. (in Bulgarian)
- [31] Stefanova K., Todorova, V., Kamburska, L., Dencheva, K. 2005. Black Sea ecosystem along the Bulgarian coast – investigation and contemporary status. – In: Petrova A, (ed.), “ Contemporary status of biodiversity in Bulgaria – problems and perspectives” 447-468. Bulgarian bioplatform, Sofia
- [32] Shtereva, G., B. Dzhurova. 2006. Hydrochemistry of the Beloslav lake–Varna lake–Varna bay system during the spring, *Proceedings of 8th Int. Conference “Black Sea’2006”*, September 2006, Varna, 249-255.
- [33] Shtereva, G., B. Dzhurova. 2007. Varna Lake–recent state and impacts. *J. of Balkan Ecology*, Vol. 10, 1, 35–40
- [34] Dencheva K. 2010. State of macrophytobenthic communities and ecological status of the Varna Bay, Varna lakes and Burgas Bay *PHYTOLOGIA BALCANICA* 16 (1): 43 – 50

MAPPING AND ASSESSMENT OF THE ECOSYSTEM SERVICES TO FISHERIES IN THE BLACK SEA

Marina PANAYOTOVA*, Georgi DASKALOV**, Valentina TODOROVA*, Ioana GEORGIEVA**, Radoslava BEKOVA*, Stefania KLAYN** and Valko BISERKOV**

*Institute of oceanology – BAS, Varna, Bulgaria

** Insitute of biodiversity and ecosystem research – BAS, Sofia, Bulgaria

Abstract. Ecosystem services “Wild animals and their outputs” and “Animals from in-situ aquaculture” were assessed in the Bulgarian Black Sea by application of two indicators - landings of fish and shellfish and aquaculture harvest. The assessment was based on data from the official landings and aquaculture production statistics during 2013 – 2015. A classification scheme was developed to produce five classes of ecosystem service quality status: high, good, moderate, poor and bad. Mapping of landings showed high status in the outer Bourgas Bay and moderate to poor status in the other areas, due to low fishing effort in the remote fishing grounds resulting in minor catches. Good and moderate status of aquaculture harvest was registered in front of capes Kaliakra and Maslen nos, where highly productive blue mussel’s farms have been established. Assessment and mapping of these ecosystem services is very important for formulating reliable scientific advice to the authorities managing the fisheries and marine ecosystems.

Keywords: aquaculture production, Bulgarian Black Sea, ecosystem services, landings.

INTRODUCTION

Marine and coastal ecosystems have essential contribution to the human wellbeing by producing goods and services [1]. Human activities in the marine environment are diverse and numerous and competition between them for space and resources is increasing, especially in coastal zones, leading to high demands for more effective management of marine ecosystems. During the last decades, the tendency for shifts from single activity management to more cross-sector and “ecosystem”- oriented management was observed [2]. The concept of ecosystem services provides useful link between the state of the natural ecosystems, their conservation and the potential human uses. Understanding of the ecosystem services is central to the ecosystem approach assessing the direct and indirect contributions of the ecosystems to human well-being. Ecosystem approach to management (EAM) requires that development of the human activities to be coordinated in a way that minimizes their impact on the environment and integrates thinking across environmental, socioeconomic, political and sectoral realms. Value of the ecosystem by identifying and valuing its goods and services is essential information for the sustainable management of the marine ecosystem. Marine strategy framework directive (MSFD) is another instrument aimed to protect more effectively the marine environment across Europe and to achieve Good Environmental Status (GES) of the EU's marine waters by 2020. The Directive ensures a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use.

Humans living near the coast have probably always used the seas as a source of food and the major ecosystem services in the Bulgarian Black Sea are related to the fisheries and aquaculture production. However, with advances in fishing equipment, larger ships and new tracking technologies, many fish stocks around the world have reduced significantly [3]. Fish stocks on continental shelf areas, including Black Sea, are now widely considered to be overexploited [4]. Aside from reducing fish stocks, unsustainable fishing practices can have other negative impacts on the marine environment. The fisheries sector in Bulgaria has a specific role in the country's economy and encompasses all activities related to fish and shellfish catch, processing, marketing and aquaculture production. During the period 1950 - 2016, the average catches of marine species ranged from 11 109 tones (1970 – 1989) to 6553 tones (1990 - 2003) and during the last years – around 7624 tones (2004 – 2016).

In Bulgaria, the methodology for assessment and mapping of marine ecosystem services is still under development and it is highly dependent on reliable data. Monitoring of fisheries and stock status in Bulgaria has been ongoing since the 1925. Currently, data collection on fisheries is governed by the Data Collection Framework (DCF). Under the DCF, Member States are required to collect data on biological (e.g. stock assessment) and economic aspects of many European fisheries and related fisheries sectors (including the economic situation of the aquaculture and processing industry sectors, and the evaluation of the effects of the fishing sector on the marine ecosystem).

The aim of present study is assess and map the state of marine ecosystem services “Wild animals and their outputs” and “Animals from in-situ aquaculture” (CICES v4.3 classification) in the Bulgarian Black Sea based on the best available data. Two indicators - landings of fish and shellfish and aquaculture harvest was applied and classification systems for quality assessment of ecosystem services was developed to produce five status classes: high, good, moderate, poor and bad.

MATERIAL AND METHODS

The study covers the total area of 10007.13 km² in the Bulgarian Black sea shelf (0 -100 m), where the main fishing activities and aquaculture production are concentrated. The key databases related to the ecosystem services are the official fisheries statistics (landings and aquaculture production) available at national level and the information about distribution of fishing activities, collected by the vessel monitoring system (VMS). All analyses and assessments of the ecosystem services and the mapping were based on the officially collected data during the period 2013 – 2015 and provided by the National Agency for Fisheries and aquaculture (NAFA). Two ecosystem services according to the Common International Classification of Ecosystem Services (CICES v4.3) were assessed and mapped: “Wild animals and their outputs” and “Animals from in-situ aquaculture”. CICES has been designed to help, measure, assess and map ecosystem services at the European scale, in order to meet the commitments made under Action 5 of the EU’s Biodiversity Strategy to 2020 [1, 5].

Ecosystem service “Wild animals and their outputs” take account of all catches from commercial and artisanal fisheries in the Bulgarian Black Sea area. Indicator “Landings of marine fish and shellfish (t)” was applied for assessment of the ecosystem service. Landings include total catches obtained by active (OTM trawls, beam trawls etc.) and passive (gillnets, pound nets etc.) fishing gears, realized in the coastal and shelf zones. For the calculation of the indicator “Landings of marine fish and shellfish (t)”, quantities of the declared catches during the period 2013-2015 were geo-referenced, because at the present, the fishing vessels do not declare the exact location of realized quantities in their declarations to the national authorities (NAFA). For geo-referencing of the total catches, the daily route records (VMS data) of 179 fishing vessels operated in the Bulgarian Black Sea area during the period 2013-2015 were analyzed together with the reported quantities of catches by day. All VMS registered records were filtered to retrieve the information on the potential haul routes from the total traffic of fishing vessels. Only routes with a speed between 2.2 and 3.8 knots were selected. For each identified trawl route, the fishing effort in hours was calculated as the difference between the final and the starting time in the haul track. The officially declared daily catch amounts for each fishing vessel were allocated among the individual trawls. The daily catch data for each of the fishing vessels was mapped as single point and subsequently summed in polygons with grid of 10 x 10 km. The catches from passive fishing gears were also collected and mapped in grid of 10 x 10 km.

For assessment and spatial mapping of the ecosystem service “Landings of marine fish and shellfish (t)”, five-status classes’ classification scheme in grid 10x10 km was developed, based on Jenks Natural Breaks algorithm [6]. Natural breaks finds the “best” way to split up the ranges of values and it is very suitable for application for relatively small number of classes (<7). The method iteratively defines the classes (grades), based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values. The final model was optimized using the least square method. The classification system is presented on Table. 1.

Table 1. Classification system for assessment and mapping of the ecosystem service „Wild animals and their outputs“ based on indicator “Total landings of fish and shellfish (Lan, t)”. Classification boundaries were determined by Jenks Natural breaks algorithm.

State	Landings (t)				
	High	Good	Moderate	Poor	Bad
Classification boundaries	Lan≥270.1	270>Lan≥107.1	107>Lan≥54.1	54>Lan≥18.1	Lan≤18

Ecosystem service “Animals from in-situ aquaculture” encompasses the production of marine aquaculture farms [1]. Statistical data for the period 2013 - 2015, used to assess the service in marine waters in Bulgaria, were officially provided by the National Agency for Fisheries and Aquaculture (2017). The proposed indicator is “Aquaculture harvest” in tones related to the production of blue mussel farms”. Five-status classes’ classification scheme in grid 10x10 km was elaborated, based on the summed monthly catch data in grid of 10 x 10 km – Table 2. Classification boundaries were estimated by Jenks Natural Breaks algorithm [6].

Geographic analyses of spatial distribution of data and assessment of marine ecosystem services regarding landings and aquaculture farms production were made in Geographic information System (GIS) environment.

Table 2. Classification system for assessment and mapping of the ecosystem service „Animals from in-situ aquaculture“ based on indicator „Aquaculture harvest” of marine blue mussel farms (Pm, t). Classification boundaries were determined by the Jenks Natural Breaks algorithm.

State	Pm				
	High	Good	Moderate	Poor	Bad
Classification boundaries	$Pm \geq 554.1$	$554 > Pm \geq 298.1$	$298 > Pm \geq 95.1$	$95 > Pm \geq 67.1$	$Pm \leq 67$

RESULTS AND DISCUSSION

The assessment of the ecosystems services needs spatially explicit mapping to address their different gradients and variations in space and time. During the period 2013 – 2015, two ecosystems services - „Wild animals and their outputs“ and „Animals from in-situ aquaculture“ were assessed and mapped for the Bulgarian Black Sea area based on officially collected data and two selected indicators.

Ecosystem service „Wild animals and their outputs“ was assessed by the indicator “Landings of marine fish and shellfish (t)”, taking into account the total landing realized in the Bulgarian Black Sea area during the period 2013 – 2015. The state of the ecosystem service in the Bulgarian shelf area is mapped on Fig.1, according to the developed five status classes classification system (Table 1), based on the best available data.

Figure 1. Map of the ecosystem service “Wild animals and their outputs” according to the indicator “Landings of marine fish and shellfish” (A) and fish biomass estimated by hydroacoustic and swept area methods (B) during the period 2013 – 2015.

The total landings of Bulgaria include catches of pelagic and demersal fishes and the landings of shellfish. Sprat, bluefish and horse mackerel dominated in catches of pelagic species; demersal fish are presented by turbot, red mullet, picked dogfish, thornback ray and gobies [7]. The shellfish catches are composed by rapa whelk and sand clams landings [7]. The shares in landings of marine fish and shellfish were almost equal for the studied period.

According to Fig.1A, assessment of the ecosystem service „Landings of marine fish and shellfish“ showed the high state in the Southern Bulgarian Black Sea area, mainly in outer Bourgas Bay and in front of cape Maslen nos. The majority of landings in this area were composed by small pelagic species – sprat, bluefish and horse mackerel and from demersal ones – red mullet. The highest potential of the area was proved by the research surveys (hydroacoustic and trawl surveys) carried out in the Southern Black Sea area, where the highest

pelagic fish biomass per square kilometer were observed– Fig.1B. In the Northern part of the Bulgarian shelf, the total landings and, respectively, the ecosystem services are of lower value, respectively in moderate to poor state, mainly due to the remoteness of fishing areas from fishing ports and consequently, the higher costs associated with the resource harvesting. The lower catches per unit effort in the northern direction from cape Kaliakra, do not reflect the real state of the fish and shellfish resources, but rather due to the prevailing use of stationary fishing gears (gill nets) during the limited period of time (mainly spring season), which are characterized by lower catches.

The indicator applied shows only the current status of the ecosystem service along the Bulgarian coast, based only on available data for the period 2013 – 2015, but it is not necessarily indicative for the potential of the area. The state of the ecosystem service could be considerably affected by some economic factors such as proximity to ports, available fishing fleets, opportunities for using different fishing gear, etc.

Ecosystem service “Animals from in-situ aquaculture” was assessed by the indicator “Aquaculture harvest (t)”. Data about production of blue mussels along the Bulgarian Black Sea coast were obtained from 31 farms during the period 2013 – 2015. The state of the ecosystem service is mapped on Fig.2, following the developed five status classes’ classification system - Table 2.

Figure 2. Map of the ecosystem service “Animals from in-situ aquaculture” based on the indicator “Aquaculture harvest (t)” during the period 2013 - 2015.

The indicator shows the current status of use of ecosystem service but it is not indicative for the potential of the area. In high and good state were assessed the areas near cape Kaliakra and cape Maslen nos, where the highly productive mussels farms are established.

The current assessment of the two marine ecosystem services “Wild animals and their outputs” and “Animals from in-situ aquaculture” along the Bulgarian Black Sea coast is the novel contribution to select meaningful indicators based on the best available data at national level and to map the current state of ecosystem services. Selected indicators are proxies for state of the environment and can be used to reflect the provision of a service and how it is changing over time. Measurable indicators are useful for supporting management activities as well as contributing to studies aiming to model and value changes in ecosystem service provision.

The concept of the most appropriate spatial and temporal scale for indicator measurement is still unclear. Many ecosystem services provided by the marine environment and especially related to the fisheries, are global non-proximal [8], meaning that the location does not matter. Furthermore, many marine species are mobile and different locations may be more or less important at different times of the year or during different stages in an organisms’ life-cycle, all affecting the provision of ecosystem services. Proposed indicators need to

reflect this dynamic nature of ecosystem services, together with sensibility to changes in management, which for the marine environment could be challenging and difficult. Despite these challenges, there is potential to apply ecosystem service indicators in marine management. Currently, the EU Marine Strategy Framework Directive is developing indicators to help monitoring the state of marine environment.

Assessment and mapping of the marine ecosystem services in Bulgaria could be useful to fisheries management and also to the integrated ecosystem assessment. Due to existing limitations in available data and partial coverage of the aquatic environment, it is necessary new data to be collected in order to supplement the existing information and to develop and validate indicators and classification systems.

CONCLUSIONS

Exploring the application of an ecosystem service classification and related ecosystem service indicators along the Bulgarian Black Sea coast identified issues related to the data scarcity, spatial coverage and understanding of how a specific locations and areas contribute to the value of the ecosystem service provision.

Assessment and mapping of ecosystem services “Wild animals and their outputs” and “Animals from in-situ aquaculture” along the Bulgarian Black Sea coast by indicators “Landings of marine fish and shellfish” and “Aquaculture harvest” revealed high status in outer Bourgas Bay and moderate to poor status in the other areas and good to moderate status of aquaculture harvest in front of cape Kaliakra and cape Maslen nos.

Assessment of status of the marine ecosystem services in Bulgaria could be very useful for providing advice for fisheries and ecosystem management, but further development of assessment methodology is necessary due to existing gaps in data regarding the origin of landings, as well as elaboration of advanced indicators and classification systems.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the EEA - Norway grant BG03.PDP2 - “Mapping and assessment of freshwater ecosystem services in Bulgaria“ (FEMA), Additional activities - „Mapping and assessment of marine ecosystems and their services in Bulgaria in the areas outside NATURA 2000 zones based on available data”, approved in the frame of program BG03 Biological diversity and ecosystems, according to Agreement № 2/23.08.2016 to Contract № Д-33-87/27.08.2015.

REFERENCES

- [1] J. Maes, Teller, A., Erhard, M., Murphy, P., Paracchini, M.L., Barredo, J.I., Grizzetti, B., Cardoso, A., Somma, F., Petersen, J., Meiner, A., Gelabert, E.R., Zal, N., Kristensen, P., Bastrup-Birk, A., Biala, K., Romao, C., Piroddi, C., Fiorina, C., Santos, F., Naruševičius, V., Verboven, J., Pereira, H.M., Bengtsson, J., Gocheva, K., Marta-Pedroso, C., Snäll, T., Estreguil, C., SanMiguel, J., Braat, L., Grêt-Regamey, A., Perez-Soba, M., Degeorges, P., Beaufron, G., Lillebø, A., Malak, D.A., Lique, C., Condé, S., Moen, J., Östergård, H., Czúcz, B., Drakou, E.G., Zulian, G., Laval, C., 2014. Mapping and Assessment of Ecosystems and their Services: Indicators for Ecosystem Assessments Under Action 5 of the EU Biodiversity Strategy to 2020. Publications Office of the European Union, Luxembourg.
- [2] J.P. Atkins, D. Burdon, M. Elliott, A.J. Gregory, 2011. Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Mar. Pollut. Bull.*, vol. 62, pp. 215-226.
- [3] The State of World Fisheries and Aquaculture, 2018. FAO, <http://www.fao.org/state-of-fisheries-aquaculture>
- [4] Scientific, Technical and Economic Committee for Fisheries (STECF) – Stock assessments in the Black Sea (STECF-17-14). Publications Office of the European Union, Luxembourg, 2017, 498 pp.
- [5] Young H., R. and M.B. Potschin (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.
- [6] G. F. Jenks. 1967. The Data Model Concept in Statistical Mapping. *International Yearbook of Cartography* 7, pp. 186–190
- [7] Agriculture report, 2016. Annual report for the state and development of agriculture. Ministry of Agriculture and Foods, Bulgaria, 253 pp.
- [8] R. Costanza, 2008. Ecosystem services: multiple classification systems are needed. *Biol. Conserv.*, 141 (2008), pp. 350-352.

DISTRIBUTION OF MARINE BIOTOXINS ON SOUTH BULGARIAN COAST OF THE BLACK SEA

Zlatina PETEVA¹, Stanislava GEORGIEVA¹, Mona STANCHEVA¹, Lubomir MAKEDONSKI¹

¹Medical University -Varna, Bulgaria, Tsar Osvooboditel Str.84, zlatina.peteva@mu-varna.bg

Abstract. Harmful algal blooms (HABs), proliferation of biotoxins producing phytoplankton species, are a natural global phenomenon emerging in severity and extent. Incidents have many economic, ecological and human health impacts. Current monitoring program in Bulgaria include measuring marine biotoxin (phycotoxin) levels in shellfish tissue. As these efforts are demanding and labor intensive, methods which improve the efficiency are essential.

The aim of this study is to summarize data and discuss distribution of phycotoxins Bulgarian south coast of the Black Sea (Ravda to Tsarevo). In this regard a multitoxin liquid chromatography-tandem mass spectrometry (LC-MS) and high-performance liquid chromatography with fluorescent detection (HPLC-Fl) methods for determination of biotoxins concentration in plankton and mussel sampled in 2017 are used. Their efficacy is discussed by reviewing and comparing with other chromatographic methods for phycotoxin determination.

Another aspect of this study was to relate biotoxins content in the samples with the presence of potentially toxigenic phytoplankton species proven on the Bulgarian Black Sea coast. In this regard the ecological role of the phycotoxins distribution is discussed.

Keywords: Phycotoxins, LC-MS, HPLC-Fl, DA, PTX2, YTX

INTRODUCTION

Phytoplankton may develop blooms in marine coastal waters with seasonal, regional and species-specific features [1]. Several factors, such as climate change, eutrophication and cysts, together with alien species transported in ballast waters, are noted as important contributors. In recent decades these occurrences have tended to be more frequent, persistent and intense [2]. A phytoplankton bloom is a complex community that can be monospecific or composed of several different species. In both cases, harmful species may not or may be present [3]. Therefore, blooms can be classified as benign or harmful according to their impact on the ecosystem, on public health and on the economy. Benign algal blooms lead to an increase of primary producers boosting the richness of the ecosystem. So far, about 5000 species of phytoplankton have been distinguished, 300 of which form blooms, and are reported as toxic, noxious or as being a nuisance [1] [4]. The frequency of harmful algal blooms (HABs) produced by marine dinoflagellates has increased worldwide over the last several decades, with serious negative impacts on the ecosystem, on public health and on the economies of the affected areas [5] [6] [7].

A bloom can create anoxic zones when it is very extensive and enters into senescence, thereby causing mortalities or deviation of fish migration routes. An example of this is in the Gulf of Mexico, where the Mississippi River delivers heavy loads of urban and agricultural runoff leading to an increase in nitrogen and phosphorus levels and fueling phytoplankton growth. This influx causes extensive blooms whose decomposition eliminates oxygen faster than it can be replaced thereby forming dead zones [8]. HABs could also affect the ecosystem by causing mortality of wildlife, including birds and marine mammals. Over 400 California sea lions (*Zalophus californianus*) died and many others displayed signs of neurological dysfunction along the central California coast during May and June 1998. A bloom of *Pseudo-nitzschia australis* was observed in the Monterey Bay region during the same period [9].

Harmful microalgal species are known to produce marine toxins (phycotoxins) and are responsible for shellfish poisoning syndrome in human, caused by the consumption of contaminated shellfish that feed on these algae and accumulate toxins. International regulations resulting in mandatory and frequent monitoring of the most common syndromes: Paralytic Shellfish Poisoning (PSP), Amnesic Shellfish Poisoning (ASP) and Diarrhetic Shellfish Poisoning (DSP) are established [10] [11] [12]. Nowadays, owing to these regulations, the cases of human intoxications are sporadic [13] and are mostly due to illegal harvest [14].

Additionally, HABs can have economic impacts on the aquaculture industry by leading to closures of shellfish harvest [15]. In France, recurrent shellfish sale closures occur due to blooms of *Alexandrium* sp. in Brittany [16] and in Thau Lagoon [17].

Marine toxins can be categorized in two groups according to their solubility: hydrophilic and lipophilic toxins. Hydrophilic marine toxins include saxitoxins and their derivatives (causing PSP) and domoic acid (DA) and derivatives (causing ASP). Lipophilic toxins include okadaic acid (OA), dinophysistoxins (DTXs) and derivatives (causing DSP), azaspiracids (AZAs) (causing azaspiracid poisoning (AZP), yessotoxins (YTXs), and pectenotoxins (PTXs). Symptoms of intoxication with YTX and PTX are still unknown due to the fact that no human intoxication has been reported to date [18]. PTXs have been reported to be highly hepatotoxic after intraperitoneal (i.p.) injection to mice [19] and have also attracted attention due to their cytotoxicity against several human cancer cell lines [20]. YTX is known to induce endoplasmic reticulum stress [21], apoptosis [22], and endocytosis inhibition [23].

The aim of this study is to summarize data and discuss distribution of phycotoxins on south Bulgarian coast. In this regard a multitoxin LC-MS method for determination of biotoxins concentration in plankton and mussel samples is used. Its efficacy is discussed by comparing it with other methods. A review on chromatographic methods for phycotoxin determination is provided.

MATERIALS AND METHODS

Review on chromatographic methods

The review on chromatographic methods was based on scientific papers published in referenced journals in the last ten years. Papers that were identified through electronic searching were assessed for relevance by initially reviewing the abstracts. Literature searches were undertaken to collate information on:

- Development of chromatographic methods on phycotoxins determination, including chromatographic parameters, e.g. limit of detection (LOD) and/or limit of quantification (LOQ)
- Results on applying chromatographic methods for phycotoxins determination in plankton and shellfish

Study area, sampling and phycotoxins determination

The study area concerned south Bulgarian coast with coordinates starting from 42°38'46.0"N 27°43'21.7"E reaching to 42°10'23.8"N 27°51'52.1"E. Period investigated covered April to October 2017. Wild and farmed mussels (*Mytilus galloprovincialis*) as well as plankton were sampled accordingly Table 1 and sampling procedure described in detail by Peteva et al. (2018) previous study [24] :

Table 1. Number of samples over the study period

Month	Wild mussels	Cultivated mussels	Plankton
April	3	6	3
May	2	7	2
June	8	11	3
July	-	3	-
August	-	2	-
September	-	2	-
October	-	2	-
Total	13	33	8

A chemical method by means of LC-MS/MS described by Krock et al. (2008) [25] was used for performing multitoxin analysis including domoic acid and lipophilic toxins and HPLC-FI by Krock et al (2009) [26] for paralytic toxins. Simultaneous were determined a wide range of phycotoxins (Table 3).

RESULTS AND DISCUSSION

Methods for marine toxins investigation

Current monitoring program in Bulgaria includes measuring marine biotoxin levels in only shellfish tissue [27] [28]. Worldwide also samples from the digestive gland of the shellfish are investigated because toxins tend to accumulate in this organ [29]. Plankton samples were also monitored for presence of phycotoxins in some countries in order to predict the toxin accumulation in species intended for human consumption [30] [31]. Control systems include accurate analytical methods to officially detect and quantify toxins. These methods are considered as reference, although alternative analysis can be used if they provide equivalent levels of protection. Table 2 provides information about the chemical reference methods and their alternatives for detection and quantification of phycotoxins used worldwide.

Table 2. Review on reference methods and their alternatives (29) for detection and quantification of most common phycotoxins

Toxins monitored/ studied	Reference method	Alternatives
Saxitoxin (PSP toxins)	HPLC- FI with precolumn oxidation [32] <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples, Tunisia (2007): highest contamination 832.9 µg /100 g tissue [33] Mussel samples, Bulgaria (2012-2015): highest contamination 51.1 µg /kg [34] 	Hydrophilic interaction chromatography (HILIC) /MS/MS [35] HPLC – FI with postcolumn oxidation [26] <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples: highest contamination 30 µg/100 g [36]
Domoic acid (ASP toxins)	HPLC- ultraviolet detection (UV) [37] <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples, Bulgaria (2012-2015): 0,02 - 0,55 mg DA/kg [27] Mussel samples, Portugal (<i>no period cited</i>): highest contamination 325 µg DA/g hepatopancreas (hp) [38] 	LC-MS/MS <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples, Bulgaria (2017): highest contamination 618.9 ng DA/g hp [24] Plankton samples, Bulgaria (2017): highest levels 963.0 ng DA/net howl (NH) [24] Mussel samples, Tunisia (2008-2009): highest contamination 0.86 µg/g [39] HPLC-FI <i>Examples:</i> <ul style="list-style-type: none"> Plankton samples, Turkey (2011-2012): reaching 94.34 µg/L [40]
Okadaic acid (DSP toxins)	LC-MS [41] <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples, Greece (2006-2007): 0.56-62.07 µg OA/g hp [42] Seawater samples, China (<i>no period cited</i>): 2.71- 14.06 ng L⁻¹ [43] 	HPLC-FL [44] <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples, Greece (2006-2007): 0.40-62.67 µg OA/g hp [42] HPLC–high-resolution mass spectrometry (HR/MS) [45] <i>Examples:</i> <ul style="list-style-type: none"> Seawater samples (dried), Catalan coast (<i>no period cited</i>): 0.11 - 560 µg/g [45]
YTXs	LC-MS [41] <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples, Bulgaria (spring, 2017): highest value 2.645 ng YTX/g hp [24] Mussel samples, Bulgaria (summer, 2017): highest value 5832.86 pg YTX/g hp (own study, <i>not published</i>) Mussel samples, Russian Federation (<i>no period cited</i>): yessotoxin (YTX), 45-hydroxy-yessotoxin (45-OH-YTX), and homoyessotoxin (homoYTX) (<i>no values reported</i>) [29] Mussel samples, Canada (2011): mean YTX 1180 µg/kg [46] 	Reversed phase liquid chromatography (RPLC)/HILIC-HR-MS [47] <i>Examples:</i> <ul style="list-style-type: none"> Plankton (<i>Protoceratium reticulatum</i>) samples 0.011–0.020 ng/cell [48] HPLC-HR/MS [45]
GYMs	<i>No reference method</i>	LC–MS/MS, LOD 290.3 fg/cell [49] <i>Examples:</i> <ul style="list-style-type: none"> Plankton samples, The Netherlands (2013) - 274 pg cell⁻¹ in culture HPLC-UV, LOQ: 8 ng/g hp [50]
PTXs	LC-MS [41] <i>Examples:</i> <ul style="list-style-type: none"> Mussel samples from the Black Sea, Bulgaria (2016) – reaching 597.6 ng/g hp [24] Plankton samples from the Black Sea, Bulgaria (2016) – reaching 0.862 ng/NH 	RPLC/HILIC-HR-MS [47] HPLC-HR/MS [45] Ultra-performance liquid chromatography (UPLC) - tandem mass spectrometry [51] <i>Examples:</i>

	[24] • Seawater samples, China (2011): 0.86 - 7.90 ng L ⁻¹	• Seawater (filtered and dried) samples, China (<i>no period cited</i>): reaching 790 pg g ⁻¹ [51]
AZAs	LC-MS [41] <i>Examples:</i> • Mussel samples from Northern Spain (2016-2017): AZA2 reaching 3 µg/kg [52]	RPLC/HILIC-HR-MS [47] HPLC- HR-MS [45] <i>Examples:</i> • Mussel samples: AZA-1,2,3 reaching 1 ppm [53]
TTX	<i>No reference method</i>	LC-electrospray ionization (ESI) -collision induced dissociation (CID)-MS/MS [54] – LOD (0.08 µg/g) <i>Examples:</i> • puffer fish, Greece (<i>no period cited</i>) [54] - Toxin distribution was different depending on fish size, area, and season where fish were caught; HILIC-UPLC-MS/MS- LOD 3 µg /kg <i>Examples:</i> • Shellfish samples from English coast (2013-2014): 3 µg /kg -120 µg/kg • Shellfish samples from Greece (2012): 61.0 and 194.7 µg/kg [55]

The cited procedures are considered a valuable alternative to reference methods for phycotoxins determination, since they offer a rapid and simultaneous screening of target toxins, reduced organic solvent consumption, and handling of smaller sample volumes, less extraction steps while providing good sensitivity and accuracy.

TTXs and GYM are not monitored routinely anywhere in the world for their presence in bivalves, given the absence of published data demonstrating a risk of TTX intoxication from bivalves and consequently human poisoning. As well in European Union (EU) they are not regulated, although the European Food Safety Authority (EFSA) requires more data to perform conclusive risk assessment for consumers.

Both TTX and GYM are sorted as emerging toxins and this topic was already discussed by Peteva et al (2017) [56]. Hence, although not regulated gymnodimines (GYMs) and tetrodotoxin (TTX) are also of interest. Recent studies showed that some GYM are fast-acting toxins, with high intraperitoneal toxicity in mice [57]. Additionally, some of them show acetylcholine receptor binding activity with potential effects on the peripheral and central nervous system and may have potential for the treatment of neurological disorders such as Alzheimer's disease [58].

On the other hand, TTX is an extremely potent neurotoxin that can block sodium channels and thus inhibit propagation of action potentials in muscle and nerve cells [59]. TTX can cause death by muscular paralysis, respiratory depression and circulatory failure [60]. TTX producing puffer fish was recently caught also in the Black Sea [61].

This pharmacological data seemed sufficient to rise the scientific interest and high efficient techniques for their detection and determination to be developed (Table 2).

Phycotoxins determination

Both multitoxin methods using LC-MS/MS and HPLC-FL were chosen for analyses based on the chemical nature of the toxins. Both methods LC-MS/MS and HPLC-FL are reported to have been used in various studies, resp. [62], [63] and [64], [65] etc. as technically improved, high effective, quick and automated. The methods allowed for several phycotoxins to be determined in parallel at much reduced costs. This ensures the high efficacy of the chosen methods.

LC-MS is the only technique that allows selective detection and precise quantitation of all known toxins at trace levels in plankton and shellfish. The use of LC-MS also facilitates the identification of new toxins, analogues and metabolites by providing structural information with tandem mass spectrometry (MS/MS) [66] [67]. Other advantages and suitability of the method for performing the current analyses are provided by Peteva et al (2018) [68].

LC-MS/MS analyses included investigation on the presence of DA, OA, DTXs, YTX, PTX2 and GYM. Chromatographic were detected only DA, PTX2 and YTX in mussel samples whereas DA content 30%, YTX – 46% and PTX2- 11% of all mussel samples. DA and PTX2 were detected in plankton samples whereas DA was present in 63% and PTX2 in 50% of all plankton samples. Concentration ranges are cited in Table 3.

Table 3. Summary of the results of determination and quantification with method using LC-MS/MS

Toxin determined	Concentration range in positive samples	
	Mussels	Plankton
DA	108.3-618.9 ng /g hp	44.4-963.0 ng /NH
OA	nd	nd
DTXs	nd	nd
PTX2	0.6-597.6 ng /g hp	0.9 – 459.5 ng /NH
YTX	0.01 – 24.56 ng /g hp	nd
GYM	nd	nd

Distribution of detected toxins on the south Bulgarian coast (Figure ...) showed two patterns in DA availability. First, the southernmost (Tsarevo and Primorsko) and northernmost (Nessebar/Ravda and Pomorie) sampling locations showed a similar trend of DA contamination. The second pattern includes sampling sites located in Burgas Bay (Burgas and Sozopol/Kavatsi) – decrease in DA values. On the contrary, PTX2 was elevated in the semi enclosed area of the bay. The YTX values in all sampling locations showed were similar.

The obvious difference in the concentration of the cited phycotoxins in the studied area can be due to the ecology and physiology of the toxin producing microalgae. Furthermore, DA and PTX2 were detected in plankton samples in a wide range of concentration. This could be due to different density of toxigenic phytoplankton in the sampling stations. Parallel phytoplankton and mussel sampling [24], [69] revealed an unambitious relation between the phycotoxin values in plankton samples and accumulation and depuration phases of the mussels.

No YTXs were detected in the plankton samples although YTX was most abundant in mussel samples (46%). This result corresponds to a study by Bacchiochi et al [39] which reported yessotoxins accumulation did not always correlate with the YTX-producers in water (such as *Lingulodinium polyedrum* and *Protoceratium reticulatum*).

Figure 1. Distribution of detected phycotoxins in studied area in 2017*

*Calculation of contamination value included all the samples, positive and negative

Although not detected screening on GYMs, OA, DTXs as well as other lipophilic toxins due to their health effects (e.g. TTX) should be maintained and continued. More frequent sampling is required in order to estimate the duration of the lag period of toxin emerging in plankton and mussels [70] as potentially toxigenic microalgae (Table 4) were detected in the investigated area by BAS-IO (2017) [71].

There are several alternative HPLC methods for PSP toxin determination described in the literature, e.g. by Krock et al (2007) [26], Rossignoli et al (2015) [35]. Most are based on fluorescence detection of oxidized PSP toxins. The formation of fluorescent iminopurine derivatives can be done before or after chromatographic separation. Ion-pair chromatography with post-column derivatization and fluorescence detection is a common method for the determination of the highly hydrophilic PSP toxins. The PSP toxins, as non-fluorescent tetrahydro purine compounds, are first separated on a chromatographic column and after elution they are oxidized to fluorescent imino purine derivatives [26]. HPLC-Fl method is briefly described recently by Peteva et al (2018) [24].

Table 4. Potentially Toxin Producing Phytoplankton Genera from the Southern Bulgarian Black Sea coast [71]

Toxins	Producer
PSP and GYM's	<i>Alexandrium</i>
	<i>Gymnodinium</i>
ASP	<i>Pseudo-nitzschia</i>
OA, DTXs and PTXs	<i>Prorocentrum</i>
	<i>Dinophysis</i>
YTXs	<i>Protoceratium</i>
	<i>Lingulodinium</i>
	<i>Gonyaulax</i>

As determined by HPLC-Fl, paralytic toxins investigated were: C1/C2, GTX1/4, dc GTX2/3, GTX2/3, B1, NeoSTX, dcSTX and STX. One sample of each month in the studied period was investigated, in total 7 samples. Among them only GTX2/3 were detected in concentration range over 1.76 – 2.63 ng/g hp in 3 mussel samples. All plankton samples were negative for paralytic toxins. This sporadic appearance of paralytic toxins did not allow further discussion and even more, conclusions.

CONCLUSION

The distribution of phycotoxins along the south Bulgarian was found to be patchy and not related with detected potentially toxigenic species. Two patterns of occurrence were concluded: inside Burgas Bay – low DA and high PTX2 values, outside the bay – high DA and low PTX concentrations. YTX distribution was ubiquitously.

Because of their robustness and wide appliance multitoxin HPLC-Fl and LC-MS/MS methods used were found to be suitable for this analysis.

ACKNOWLEDGMENTS

This study was conducted as a part of National Science Fund project, № M09/1, 48/05.12.2016.

REFERENCES

- [1] T. Smayda, "What is a bloom? A commentary.," *Limnol. Oceanogr.*, vol. 42, 1997pp. 1132-1136.
- [2] J. Burkholder, P. Glibert and H. Skelton, "Mixotrophy, a major mode of nutrition for harmful," *Harmful Algae*, vol. 8, 2008, pp. 77-93.
- [3] N. Touzet, H. Farrell, A. Ni Rathaille and P. Rodriguez, "Dynamics of co-occurring *Alexandrium minutum* (Global Clade) and *A. tamarense* (West European) (Dinophyceae) during a summer bloom in Cork Harbour, Ireland (2006)," *Deep Sea Res. II*, vol. 57, 2010, pp. 268-278.
- [4] S. Moore, V. Trainer, N. Mantua and M. Parker, "Impacts of climate variability and future climate change on harmful algal blooms and human," *Environ. Health*, vol. 7, 2008, p. S4.
- [5] G. Hallengraef, "Ocean climate change, phytoplankton community responses, and harmful algal blooms: a formidable predictive challenge," *Journal of Phycology*, vol. 46, 2010, pp. 220-235.
- [6] P. Glibert, S. Seitzinger, C. Heil, J. Burkholder and M. Parrow, "The role of eutrophication in coastal proliferation of harmful algal blooms: New perspectives and," *Oceanography*, vol. 18, 2005, pp. 198-209.
- [7] J. Benemann, "Microalgae aquaculture feeds," *J. Appl. Phycol.*, vol. 4, 1992, pp. 233-245.
- [8] N. National Oceanic and Atmospheric Administration, "Dead Zones: Hypoxia in the Gulf of," 2014. [Online]. Available: <http://www.noaanews.noaa.gov/stories2009/pdfs/new%20fact%20fact%20fact.pdf>.
- [9] C. Scholin, F. Gulland, G. Doucette, S. Benson and M. Busman, "Mortality of sea lions along the central California," *Nature*, vol. 403, 2000, pp. 80-84.
- [10] B. Dale and C. Yentsch, "Red tide and paralytic shellfish poisoning," *Oceanus*, vol. 2, 1978, pp. 41-49.
- [11] P. Vale and M. Sampayo, "Domoic acid in Portuguese shellfish and fish," *Toxicon*, vol. 39, 2001, p. 893-904.
- [12] P. Vale and M. Sampayo, "First confirmation of human diarrhoeic poisonings by okadaic acid esters after ingestion of razor clams (*Solen marginatus*) and green crabs (*Carcinus maenas*) in Aveiro lagoon, Portugal and detection of okadaic acid esters in phytoplankton," *Toxicon*, vol. 40, 2002, p. 989-996.

- [13] A. Bazzoni, A. Mudadu, G. Lorenzoni and B. Soro, "Detection of Dinophysis species and associated akadaic acid in farmed shellfish: a two-year study from the western Mediterranean area," *J Vet Res*, vol. 62, 2018, pp. 137-144.
- [14] B. Kirkpatrick, L. Fleming, D. Squicciarini and L. Backer, "Literature review of Florida red tide: implications for hu," *Harmful Algae*, vol. 3, 2004, pp. 99-115.
- [15] V. Bricelj and S. Shumway, "Paralytic Shellfish Toxins in Bivalve Molluscs: Occurrence, Transfer Kinetics, and Biotransformation," *Reviews*, vol. 6, 1998, p. 315.
- [16] A. Chapelle, M. Le Gac, C. Labry, R. Siano and J. Quere, "The Bay of Brest (France), a new risky site for toxic *Alexandrium minutum*," *Harmful Algae News*, vol. 51, 2015-08, pp. 4-5.
- [17] P. Lassus, R. Baron, P. Garen, P. Truquet and P. Masselin, "Paralytic shellfish poison outbreaks in the Penzé estuary: Environmental factors affecting toxin uptake in the oyster, *Crassostrea gigas*," *Aquatic Living Resources*, vol. 17, 2004, pp. 207-214.
- [18] P. Visciano, M. Schirone, R. Tofalo, M. Berti, M. Luciani and N. Ferri, "Detection of yessotoxin by three different methods in *Mytilus galloprovincialis* of Adriatic Sea, Italy," *Chemosphere*, vol. 90, 2013, p. 1077-1082.
- [19] E. Ito, T. Suzuki, Y. Oshima and T. Yasumoto, "Studies of diarrhetic activity on pectenotoxin-6 in the mouse and rat," *Toxicon*, vol. 51, no. 3, 2008, pp. 707-716.
- [20] J. Jung, J. Chung and L. Chong-Ock, "Cytotoxic compounds from a two-sponge association," *J. Nat. Prod.*, vol. 58, no. 11, 1995, pp. 1722-1726.
- [21] J. Rubiolo, H. López-Alonso, P. Martínez, A. Millán, E. Cagide, M. Vieytes, F. Vega and L. Botana, "Yessotoxin induces ER-stress followed by autophagic cell death in glioma cells mediated by mTOR and BNIP3.," *Cell. Signal*, vol. 26, 2014, pp. 419-432.
- [22] M. Korsnes, "Yessotoxin as a tool to study induction of multiple cell death pathways.," *Toxins*, vol. 4, 2012, pp. 568-579.
- [23] F. Callegari and G. Rossini, "Yessotoxin inhibits the complete degradation of E-cadherin.," *Toxicology*, vol. 244, 2008, pp. 133-144.
- [24] Z. Peteva, B. Krock, S. Georgieva and M. Stancheva, "Occurance and variability of marine biotoxins in mussel (*Mytilus galloprovincialis*) and in plankton samples from Bulgarian coast in Spring 2017," *SSRG-IJAS*, 2018, vol. 5, no. 3.
- [25] B. Krock, U. Tillmann, U. John and A. D. Cembella, "LC-MS-MS aboard ship: tandem mass spectrometry in the search for phycotoxins and novel toxigenic plankton from the North Sea," *Anal. Bioanal. Chem.*, vol. 392, no. 5, 2008, pp. 797-803.
- [26] B. Krock, C. Seguel and A. Cembella, "Toxin profile of *Alexandrium catenella* from the Chilean coast as determined by liquid chromatography with fluorescence detection and liquid chromatography coupled with tandem mass spectrometry," *Harmful Algae*, vol. 6, no. 5, 2007, pp. 734-744.
- [27] V. Peneva, Y. Gogov, G. Kalinova and A. Slavova, "Application of HPLC method for determination of ASP toxins in bivalve mollusks.," Jubilee Scientific Session 110 Years NDNIVMI, Sofia, 2011 [In Bulgarian].
- [28] G. Kalinova, P. Mechkarova and M. M., "A study of paralytic toxins in cultured mussels from Bulgairin Black Sea," *Trakia Journal of Sciences*, vol. 13, 2015, pp. 303-308.
- [29] S. Morton, A. Vershinin, T. Leighfield, S. L and M. Quilliam, "Identification of yessotoxin in mussel from the Caucasian Black Sea coast of the Russian Federation," *Toxicon*, vol. 50, 2007, pp. 581-584.
- [30] L. MacKenzie, P. Holland, P. McNabb and V. Beuzenberg, "Complex toxin profile in phytoplankton and Greenshell mussels (*Perna canalicus*), revealed by LC-Ms/Ms analysis," *Toxicon*, vol. 40, 2002, pp. 1321-1330.
- [31] W. Gregg, L. Langlois and S. Morton, "Marine Biotoxin and Harmful Algae Monitoring and Management," in *Harmful Algal Blooms: A Compendium Desk Reference*, S. Shumway, J. Burkholder and S. Morton, Eds., 2018.
- [32] EC, Commission Regulation (EC) No.1664/2006 of 6 November 2006 amending Regulation (EC) No.2074/2005 as regards implementing measures for certain products of animal origin intended for human consumption and repealing certain implementing measures, *Off. J. of the European Union*, vol. L 320, 2006, pp. 13-45.
- [33] I. Kacem, G. Papiol, P. de la Iglesia and J. Diogene, "Comparative toxicity and paralytic shellfish poisoning toxin profiles in the mussel *Mytilus galloprovincialis* and the Oyster *Crassostrea gigas* collected from a Mediterranean Lagoon in Tunisia: A food safety concern," *International Journal of Food Properties*, vol. 18, 2015, no. 5.
- [34] G. Krumova-Valcheva and G. Kalinova, "*Escherichia coli* and Paralytic shellfish toxins contamination of mussels farmed in Bulgarian Black Sea Coast," *Acta Microbiologica Bulgarica*, vol. 33, no. 1, 2017, pp. 30-35.

- [35] A. Rossignoli, C. Mariño, H. Martin and J. Blanco, "Application of hydrophilic interaction liquid chromatography combined with positive and negative ionization mass spectrometry for the analysis of PSP toxins," *Journal of Aquaculture & Marine Biology*, vol. 2, no. 2, 2015, 1-8.
- [36] G. Mustakim, A. Anton and M. Samsur, "Determination of PSP Concentration in shellfish from Kuala Panyu, Sabah using HPLC Method," *Transactions on Science and Technology*, vol. 3, no. 2-2, 2016, pp. 433-438.
- [37] EC, "Commission Regulation (EC) No. 1244/2007 of 24 October 2007 amending Regulation (EC) No. 2074/2005 as regards implementing measures for certain products of animal origin intended for human consumption and laying down specific rules on official controls," vol. L 281, 2007, pp. 12-18.
- [38] P. Vale and M. Sampayo, "Domoic acid in Portuguese shellfish and fish," *Toxicon*, vol. 39, 2001, pp. 893-904.
- [39] D. Bouchouicha-Smida, N. Lundholm, I. Saharaoui and A. Hlaili, "Detection of domoic acid in *Mytilus galloprovincialis* and *Ostrea edulis* linked to the presence of *Nitzschia bizertensis* in Bizerte Lagoon (SW Mediterranean)," *Estuarine Coastal and Shelf Science*, vol. 165, 2015, pp. 270-278.
- [40] F. Dursun, S. Ünlü and T. Yurdun, "Determination of domoic acid in plankton net samples from Golden Horn Estuary, Turkey, Using HPLC with fluorescence detection," *Bulletin of Environmental Contamination and Toxicology*, vol. 100, no. 3, 2018, pp. 457-462.
- [41] EC, "Commission Regulation (EC) No. 15/2011 of 10 November 2011 amending Regulation (EC) No. 2074/2005 as regards testing methods for detecting marine biotoxins in live bivalve mollusks," *Off. J. of the European Communities*, vol. L6, 2011, pp. 3-4.
- [42] A. Louppis, A. Badeka and P. Katikou, "Determination of okadaic acid, dinophysistoxin-1 and related esters in Greek mussels using HPLC with fluorometric detection, LC-MS/MS and mouse bioassay," *Toxicon*, vol. 55, pp. 724-733, 2010.
- [43] J. Chen, X. Li, S. Wang and F. Chen, "Screening of lipophilic marine toxins in marine aquaculture environment using liquid chromatography-mass spectrometry," *Chemosphere*, vol. 168, 2017, pp. 32-40.
- [44] T. Mouratidou, I. Kaniou-Grigoriadou, C. Samara and T. Kouimtzi, "Determination of okadaic acid and related toxins in Greek mussels by HPLC with fluorimetric detection," *Liq. Chromatogr. R.T.*, vol. 27, 2004, p. 2153-2166.
- [45] C. Bosch-Orea, J. Sanchis, M. Farré and D. Barceló, "Analysis of lipophilic marine biotoxins by liquid chromatography coupled with high-resolution mass spectrometry in seawater from the Catalan Coast," *Anal. and Bioan. Chemistry*, vol. 409, no. 23, 2017, pp. 5451-5462.
- [46] P. McCarron, E. Wright and M. Quilliam, "Liquid chromatography/mass spectrometry of domoic acid and lipophilic shellfish toxins with selected reaction monitoring and optional confirmation by library," *Journal of AOAC International*, vol. 97, no. 2, 2014, pp. 316-324.
- [47] J. Chen, L. Gao, Z. Li and S. Wang, "Simultaneous screening for lipophilic and hydrophilic toxins in marine harmful algae using a serially coupled reversed-phase and hydrophilic interaction liquid chromatography separation system with high-resolution mass spectrometry," *Analytica Chimica Acta*, vol. 914, 2016, pp. 117-126.
- [48] I. Cañas, B. Hamilton, M. Amandi and A. Furey, "Nano liquid chromatography with hybrid quadrupole time-of-flight mass spectrometry for the determination of yessotoxin in marine phytoplankton," vol. 1056, no. 1-2, 2004, pp. 253-256.
- [49] H. Martens, U. Tillmann, K. Harju, C. Dell'Aversano and B. Krock, "Toxin Variability estimations of 68 *Alexandrium ostenfeldii* (Dinophyceae) strains from The Netherlands reveal a novel abundant gymnodimine," *Microorganisms*, vol. 5, no. 2, 2017, pp. 1-24.
- [50] R. Marrouchi, F. Dziri and N. Belayouni, "Quantitative determination of gymnodimine-A by high performance liquid chromatography in contaminated clams from Tunisia coastline," *Marine Biotechnology*, vol. 12, no. 5, 2010, pp. 579-585.
- [51] Y. Wang, J. Chen and L. Gao, "Determination of eight typical lipophilic algae toxins in particles suspended in seawater by ultraperformance liquid chromatography- tandem mass spectrometry," *Chinese Journal of Analytical Chemistry*, vol. 44, no. 3, pp. 355-341, 2016.
- [52] J. Blanco, F. Arévalo, A. Morono, J. Correa, S. Muñiz, C. Mariño and H. Martín, "Presence of azaspiracids in bivalve molluscs from Northern Spain," *Toxicon*, vol. 137, 2017, pp. 135-143.
- [53] P. Blay, H. J. and J. Chang, "Screening for multiple classes of marine biotoxins by liquid chromatography-high-resolution mass spectrometry," *Analytical and Bioanalytical Chemistry*, vol. 400, 2011, pp. 577.
- [54] P. Rodriguez, A. Alfonso, P. Otero and P. Katikou, "Liquid chromatography-mass spectrometry method to detect tetrodotoxin and its analogues in the puffer fish *Lagocephalus sceleratus* (Gmelin, 1789) from European waters," *Food Chemistry*, vol. 132, no. 2, 2012, pp. 1103-1111.
- [55] A. Vlamis, P. Katikou, I. Rodriguez, V. Rey, A. Alfonso and A. Papazachariou, "First Detection of tetrodotoxin in Greek shellfish by UPLC-MS/MS potentially linked to the presence of the dinoflagellate *Prorocentrum minimum*," *Toxins*, vol. 7, no. 5, 2015, pp. 1779-1807.

- [56] Z. Peteva, S. Georgieva, M. Stancheva, A. Gerasimova and L. Makedonski, "Emerging Marine Toxins with Increasing Concern in Europe," *Ecology & Safety. Journal of International Scientific Publications*, vol. 11, 2017, pp. 329-343.
- [57] R. Kharrat, D. Servent, E. Girard and G. O. Uanounou, "The marine phycotoxin gymnodimine targets muscular and neuronal nicotinic acetylcholine receptor subtypes with high affinity," *J. Neurochem.*, vol. 107, pp. 952-963, 2008.
- [58] J. Molgo, R. Araoz, B. Iorga, E. Benoit and A. Zakarian, "Cyclic imine neurotoxins acting on muscarinic and nicotinic acetylcholine receptors," in *Toxins and Biologically Active Compounds from Microalgae*, G. Rossini, Ed., CRC Press, 2014, pp. 116-146.
- [59] T. Narahashi, "Pharmacology of tetrodotoxin," *J. Toxicol. Toxin Rev.*, vol. 20, 2001, pp. 67-84.
- [60] J. Field, "Puffer fish poisoning," *J. Accid. Emerg. Med.* vol. 15, 1998, pp. 334-336.
- [61] A. Boltachev, E. Karpova, V. Gubanov and M. Kirin, "The finding *Lagocephalus sceleratus* in the Black Sea, Sevastopol Bay, Crimea," *Marine Ecological Journal*, vol. 4, 2014, no. 13 [In Russian].
- [62] S. Harðardóttir, M. Pančić, A. Tammilehto, B. Krock and E. Møller, "Dangerous relations in the Arctic marine food web: interactions between toxin producing *Pseudo-nitzschia* diatoms and *Calanus* copepodites," *Marine Drugs*, vol. 13, pp. 3809-3835, 2015.
- [63] L. Nielsen, p. k. B. Hansen and B. Vismann, "Accumulation, transformation and breakdown of DSP toxins from the toxic dinoflagellate *Dinophysis acuta* in blue mussels, *Mytilus edulis*," *Toxicon*, vol. 117, 2016, pp. 84-93.
- [64] J. Xu, P. Hansen, L. K. B. Nielsen and U. Tillmann, "Distinctly different behavioral responses of a copepod, *Temora longicornis*, to different strains of toxic dinoflagellates, *Alexandrium* spp.," *Harmful Algae*, vol. 62, 2017, pp. 1-9.
- [65] E. Fabro, G. Almandoz, M. Ferrario, U. John, U. Tillmann, K. Toebe, B. Krock and A. Cembella, "Morphological, molecular, and toxin analysis of field populations of *Alexandrium* genus from the Argentine Sea," *Journal of Phycology*, vol. 53, no. 6, 2017, pp. 1206-1222.
- [66] M. Quilliam, "Liquid chromatography-mass spectrometry: a universal method for the analysis of toxins?," in *Harmful Algae*, B. Reguera, J. Blanco, M. Fernández and T. Wyatt, Eds., Paris, Intergovernmental Oceanographic Commission of UNESCO and X. de Galicia, 1998, pp. 509-14.
- [67] K. J. James, E. Carmody, M. Gillman, S. Kelly, . R. Draisci and L. Lucentini, "Identification of a new diarrhetic toxin in shellfish using liquid chromatography with fluorimetric and mass spectrometric detection," *Toxicon*, vol. 35, 1997, p. 973-8.
- [68] Z. Peteva, S. Georgieva and M. Stancheva, "Recent Updates of HPLC-UV and LC-MS Methods for Domoic acid Detection: A Comparison Review," *Ecology & Safety: Journal of International Scientific Publications*, vol. 12, 2018.
- [69] Z. Peteva, M. Stancheva, S. Georgieva, A. Gerasimova and L. Makedonski, "Phycotoxin profile of plankton net and shellfish samples from Bulgarian Black Sea south coast : A case study," in *Proceedings from 3rd International Conference "Water resources and wetlands"*, Tulca, 2018 [In Press].
- [70] A. Moróño, F. Arévalo, M. Fernández and J. Maneiro, "Accumulation and transformation of DSP toxins in mussels *Mytilus galloprovincialis* during a toxic episode caused by *Dinophysis acuminata*," *Aquatic Toxicology*, vol. 62, no. 4, 2003, pp. 269-280.
- [71] BAS-IO, "Protokols phytoplankton" , 2017, available at http://www.bgodc.io-bas.bg/monitoring_program.html
- [72] A. Vershinin, S. Morton, S. Pankov, L. Smith, M. Quilliam and J. Ramsdell, "*Alexandrium* in the Black Sea - Identity, ecology and PSP toxicity," *African Journal of Marine Science*, vol. 28, 2006, pp. 209-214.
- [73] S. Bacchiocchi, M. Siracusa, A. Ruzzi and S. Gorbi, "Two-year study of lipophilic marine toxin profile in mussels of the North-central Adriatic Sea: First report of azaspiracids in Mediterranean seafood," *Toxicon*, vol. 108, 2015, pp. 115-125.

SETTING THRESHOLD VALUES OF THE ZOOPLANKTON ABUNDANCE INDICATOR

Kremena STEFANOVA*, Valentina DONCHEVA*, Elitsa STEFANOVA*

Institute of Oceanology – BAS, Varna, Bulgaria

Abstract: The abundance, biomass and size structure of the zooplankton community are highly relevant for the zooplankton community state and functioning of the pelagic food web. In this study, we evaluated the indicator performance of zooplankton abundance in the Bulgarian Black Sea area applying signal detection theory and zooplankton long-term data for the period 1967–2016. The aim was to identify, estimate thresholds for the zooplankton standing stock and test indicators according to MSFD requirements. Receiver operating characteristics (ROC curves) were produced to reveal the appropriateness of the indicator.

Key words: Bulgarian Black Sea, indicator, zooplankton standing stock

INTRODUCTION

The main goal of the Directive 2008/56/EC is to achieve Good Environmental Status (GENS) by 2020 across the European marine environment. There are several challenges related to the assessment of GENS within the MSFD. The assessment of an ecosystem state requires setting of adequate reference conditions and/or environmental targets to which data should be compared [1].

The biodiversity assessment under MSFD (Descriptor 1) is associated with the ecosystem elements "species groups" and "broad habitat types". Coast, shelf and open sea (oceanic/beyond shelf) are determined as pelagic broad habitat types in the Black Sea. Zooplankton lives between top-down and bottom-up dynamics and can potentially yield a lot of information on the state and dynamics of the aquatic ecosystem [2]. Zooplankton community characteristics in the context of primary criterion D1C6, according to which "the condition of the habitat type, including its biotic (typical species composition and their relative abundance) and abiotic structure, and its functions, is not adversely affected", were used to assess the pelagic habitats biodiversity.

The main objective of the article is to propose a new indicator and, accordingly, a classification system for the "good status" of the marine environment. For this purpose the zooplankton abundance indicator has been tested, verified and the adequacy of the proposed thresholds for GENS was assessed.

MATERIAL AND METHODS

Database

For the purpose of developing a new zooplankton indicator, integrated mesozooplankton species composition and abundance data of total 2800 samples collected seasonally in the period 1966-2016 were inventoried. The spatial coverage of the data included the areas in front of capes Kaliakra, Galata and Emine in the three types of pelagic habitats - coast (up to 30 m depth), shelf (30-200 m) and open sea (> 200 m).

Methods for thresholds identification

The long term zooplankton data of the three broad habitat types were analyzed for identification of periods of mesozooplankton community alteration, using both: Regime Shift [3] and the CUSUM methods [4]. As a result the period 1966-1973 was derived as a referent. Two statistical approaches were applied to identify threshold values for good environmental status: receiver operating characteristic (ROC) analysis and percentile. The ROC curve is a graph that allows evaluation of the quality of a binary classification by depicting the ratio between true positive rate (TPR, classification algorithm sensitivity) and false positivity rate (FPR, specificity of the classification algorithm). They are plotted on the abscissa, which is 1- specificity, and on the ordinate – sensitivity. The threshold value is the point of maximum sensitivity and specificity. The ROC curve analysis was used to determine the optimal threshold value, through the IBM SPSS Statistical Programming Package [5]. The area under ROC curves (AUC) may also be used as a measure of classifiers. The much larger the area under the ROC curve the much better is the classifier. If the ROC area is under 0.5 [6] this means a non-informative indicator measure. In the environmental studies, AUC values of ≥ 0.8 are considered excellent and ≥ 0.7 for acceptable results [7]. The ROC analysis results are statistically significant if the significance is higher than 0.05.

Verification of the indicator threshold values

The applied baseline approach in setting the thresholds of the proposed indicator is uninfluenced state or negligible impact i.e. a state where pressures and impacts are considered to be negligible. WFD denotes this as a reference state. A primary task in defining the GENS boundaries was to discriminate periods within existing time series of the metric (indicator) – mesozooplankton abundance. Thus, Regime Shift and CUSUM methods

were used to differentiate between periods and determine the reference period, while ROC analysis and the percentile approach were applied simultaneously to establish the GENs limit values of the indicator.

Environmental Protection Agency (EPA) advocates if data existing are from pristine period and from a period with significant deformations due to anthropogenic pressure to use the median value of the intersection of the two percentile of distributions [8]. The estimated threshold for zooplankton abundance is the median of overlap of the 25th percentile from the reference period and 75th for the mixed data.

RESULTS AND DISCUSSION

Indicator description

Mesozooplankton abundance [ind.m^{-3}] – a state indicator, it presents the number of individuals per unit volume. The indicator corresponds to the abundance of the mesozooplankton community and reflects indirectly the grazing potential on phytoplankton and zooplanktivorous fish feeding conditions [9], [10]. This metrics is complemented with an absolute share of ecological groups/species forming the plankton fauna as Copepoda, Cladocera, Meroplankton and *Oikopleura dioica*, *Parasagitta setosa*. Key groups/species standing stock exhibits strong variability in time and space under the natural and anthropogenic factors influence, which reflects their number and the total mesozooplankton abundance, respectively. Zooplankton is indirectly exposed to eutrophication (by altering the amount of food and the size of phytoplankton) and overfishing of commercially exploited fish (through changes in the pelagic food web), while the direct impact is formed by climate change (temperature and salinity regime), fish and jellyfish predation. Additionally, eutrophication favours, particularly, small-sized phytoplankton and detritus production, which, in turn, is particularly accessible for microphagous filtrators, rotifers, herbivorous cladocerans, and naupliar stages of copepods. These are also the conditions promoting microbial loop dominance in the energy pathways within the food web [11].

Indicator's aim

The mesozooplankton community state is not seriously and adversely affected by anthropogenic pressures. The mesozooplankton standing stock is maintained at levels around the average for the reference conditions.

Base line: reference conditions

Applied statistical analysis (Regime shift; CUSUM) of the long-term abundance data distinguished reference period up to 1973, after which a decline in zooplankton was observed. The trend being stable until 2006 when increasing was registered (Fig. 1).

Fig. 1. Detected periods of mesozooplankton abundance alteration in the coastal broad habitat type according to both: Regime shift (left panel) and CUSUM (right panel) methods

In the ROC analysis, 1 - includes years up to 1973 and all other data are denoted as 0. The discriminator ability of the classifier is acceptable applied to the summer data, especially since the AUC is over 0.8, i.e. very good, with the sufficient significance $p < 0.000$ (Fig. 2). Curves show very good results for spring and autumn with AUC 0.854 and 0.865 respectively ($p < 0.000$). An average level of acceptability (AUC - 0.6, $p = 0.5$) was established in the winter, probably due to the gaps in time-series and an irregular sampling process. According to the percentile approach, the seasonal threshold values are very close to those of the ROC analysis (Table 1).

Area Under the Curve

Test Result Variable(s): Mesozooplankton Ab

Area	Std. Error ^a	Asymptotic Sig. ^b	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.833	.040	.000	.755	.912

Fig. 2. ROC analysis results of mesozooplankton abundance in summer in the coastal habitat

Table 1. GENs threshold abundance indicator values for the coastal habitat by seasons according to ROC analysis and percentile approach.

	Winter	Spring	Summer	Autumn
ROC	850-900	5000-6000	10000-12000	8000-9000
Percentile	630	5400	12000	10000

There are no changes in the distribution model of the zooplankton abundance after the referent period at the shelf habitat. (Fig.3). Simultaneously, a median of cross – intersection between reference and mixed period was used.

Fig. 3. Detected periods of mesozooplanktona abundance alteration in the shelf broad habitat type according to both: Regime shift (left panel) and CUSUM (right panel) methods

Applying the ROC analysis for the shelf habitat, the discriminative ability of the classifier showed very good to excellent results. The area under the curve in spring - 0.859 ($p < 0.000$) (Fig. 4), summer - 0.836 ($p < 0.000$), autumn - 0.918 ($p < 0.000$) and winter - 0.970 ($p < 0.001$) gives us enough reasons to accept the GENs indicator thresholds for the shelf reflected in Table 2, which are supported by the results of the percentile approach as well.

Fig. 4. ROC analysis result of mesozooplankton abundance in spring in the shelf habitat

Table 2. GEnS threshold abundance indicator values for the shelf habitat by seasons according to ROC analysis and percentile approach

	Winter	Spring	Summer	Autumn
ROC	2200	2500	6000	4000
Percentile	2317	3142	6682	4639

For the open sea habitat type, the same reference period until 1973 (Fig. 5) and both approaches percentiles and ROC curves were applied. The ROC analysis for summer, autumn and winter demonstrated good to excellent results with "area under the curve" as follows 0.970, 0.918 and 0.771 (significance below 0.001), while the spring result was an exception - discriminative classifier ability showed a mean score of AUC-0.600 (p-0.01) (Fig. 6). The potential thresholds for the GEnS in the open sea using the percentile approach were calculated as the median of crossing the reference period with mixed data after 1973.

Fig. 5. Detected periods of mesozooplankton abundance alteration in the open sea broad habitat type according to both: Regime shift (left panel) and CUSUM (right panel) methods

Compared results of established threshold abundance values of GEnS according to both approaches are presented in Table 3.

Table 3. GEnS threshold abundance indicator values for the open sea habitat by seasons according to ROC analysis and percentile approach

	Winter	Spring	Summer	Autumn
ROC	1000	1200	2400	2200
Percentile	850	1550	2065	1200

Fig.6. ROC analysis results of mesozooplankton abundance in summer (left panel) and spring (right panel) in the open sea habitat

CONCLUSIONS

- The high confidence of the obtained results according to the applied statistical methods (ROC analysis and the percentile approach) with regard to the proposed mesozooplankton abundance indicator, especially in the coastal and shelf habitat types where the data gaps were lower, proves its significance in the assessment of the marine environmental state.
- The ratio of both mesozooplankton biomass indicator applied in the Initial Assessment Report of the Marine Environment and the proposed abundance indicator could be used as an indicator of Descriptor 4 (Food web) which reflects the mean zooplankton size.

Acknowledgments: The research leading to these results has received funding under the project “Investigations on the State of the Marine Environment and Improving Monitoring Programs developed under MSFD”, Invitation BG02.02 “Improved monitoring of marine waters” of Program BG02 “Integrated management of marine and internal waters co-funded by Financial mechanism of the European Economic Area (EEA Grants), partnership Agreement from 21.03.2015 between Black Sea Basin Directorate – Varna and Institute of Oceanology – BAS, Varna (Annex №8 to Contract № Д-34-13/02.04.2015).

REFERENCES

- [1] A. Borja, D.M. Dauer, A. Gremare. The importance of setting targets and reference conditions in assessing marine ecosystem quality. *Ecol. Indic.*, 12, 2012, pp. 1-7
- [2] E. Jeppesen, P. Nöges, T. A. Davidson, J. Haberman, T. Nöges, K. Blank, T. L. Lauridsen, M. Søndergaard, C. Sayer, R. Laugaste, L. S. Johansson, R. Bjerring, S. L. Amsinck Zooplankton as indicators in lakes: a scientific-based plea for including zooplankton in the ecological quality assessment of lakes according to the European Water Framework Directive (WFD). *Hydrobiologia*, 676, 2011, pp. 279-297
- [3] S.N.Rodionov. Detecting regime shifts in the mean and variance: Methods and specific examples. In: *Large-Scale Disturbances (Regime Shifts) and Recovery in Aquatic Ecosystems: Challenges for Management Toward Sustainability*, V. Velikova and N. Chipev (Eds.), UNESCO-ROSTE/BAS Workshop on Regime Shifts, 14-16 June 2005, Varna, Bulgaria, 68-72.
- [4] E. S. Page. Continuous Inspection Schemes. *Biometrika*, vol. 41, no. 1, 1954, pp. 100–115.
- [5] Jr. Hosmer, S. Lemeshow., *Applied Logistic Regression*, second ed. John Wiley & Sons, New York, 2000.
- [6] IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp, IBM Corp. Released, 2011.
- [7] P. A. Murtaugh The statistical evaluation of ecological indicators. *Ecol. Appl.*, 6, 1996, pp. 132–139.
- [8] U.S. EPA (Environmental Protection Agency). 2001. Integrated Risk Information System (IRIS). National Center for Environmental Assessment, Office of Research and Development, Washington, DC. Available online at <http://www.epa.gov/iris/> Office of Solid Waste and Emergency Response, Washington, DC
- [9] M. Cardinale, M. Casini, F. Arrhenius The influence of biotic and abiotic factors on the growth of sprat (*Sprattus sprattus*) in the Baltic Sea. *Aquat. Liv. Res.*, 2002, pp. 273-281.
- [10] S. Rönkkönen, E. Ojaveer, T. Raid, M. Viitasalo. Long-term changes in Baltic herring (*Clupea harengus membras*) growth in the Gulf of Finland. *Canadian Journal of Fisheries and Aquatic Sciences*, 61, 2004, pp. 219-229.
- [11] E. Gorokhova, M. Lehtiniemi, J. Lesutiene, S. Strake, L. Uusitalo, N. Demereckiene, C. Amid. Zooplankton mean size and total abundance. HELCOM Core Indicator Report. 2013, [http://www.helcom.fi/Core%20Indicators/HELCOM-CoreIndicator-Zooplankton mean size and total abundance.pdf](http://www.helcom.fi/Core%20Indicators/HELCOM-CoreIndicator-Zooplankton%20mean%20size%20and%20total%20abundance.pdf)

Institution/Address

Institute of Oceanology – BAS, Varna
Parvi May Str. 40
POBox 152

Authors e-mails

Assoc. Prof. Dr Kremena Stefanova - stefanova@io-bas.bg
Assoc. Prof. Dr Valentina Doncheva - valentine.doncheva@gmail.com
Senior as. Dr Elitsa Stefanova - stefanova_es@io-bas.bg

IDENTIFICATION OF BLACK MUSSEL (*M. GALLOPROVINTIALIS*, LAMARK, 1819) POPULATIONS IN TWO ZONES IN NORTHERN BULGARIAN BLACK SEA PART BASED ON ESTERASES POLYMORPHISM

Petya IVANOVA * and Elitsa PETROVA **

*Institute of Oceanology – Bulgarian Academy of Sciences

** Institute of Fishery Resources (IFR)

Abstract: Esterases as specific markers were analyzed to assess the genetic diversity of investigated black mussel (*Mytilus galloprovincialis*) populations in two zones along the northern Bulgarian Black Sea coast. Isoelectric focusing on muscle unspecified esterases (EST) on polyacrylamide Ampholone gel with pH gradients between 3.5–10.0 was carried out. Two polymorphic loci (*EST-1** and *EST-2**) with three allele system of inheriting were found. Low genetic distance ($D_{Nei} = 0,010$) between the samples from the two localities was observed. The registered excess of homozygosity could be explained with population subdivision structure. The values of mean F_{ST} (0,008) and gene flow (N_m) showed low level of genetic differentiation, which indicate an unrestricted gene flow among them.

Key words: black mussel, Black Sea, esterases, allozyme markers, populations

INTRODUCTION

In Europe, the mussel *Mytilus galloprovincialis* Lmk. is distributed in the Black Sea, the Mediterranean and on the Atlantic coast from the Iberian Peninsula as far north as the British Isles [1]. Marine mussels of the genus *Mytilus* constitute an economically and ecologically important group of organisms in Europe where more than 50% of their annual worldwide harvest is produced [2].

The first investigations on the black mussel stock in Bulgarian in the western Black Sea were performed from Kaneva-Abadjieva and Marinov [3], reassessing the stock biomass at around 300 000 tons, prior to the introduction of rapana snail. Recently, a comprehensive database, including the black mussel and rapana catches, stocks assessment, species distribution and biological parameters was created [4,5,6,7]. The last results estimated mussel stock in 35 metres isobaths over 75 000 tons [8].

For important fisheries and aquaculture resources such as marine bivalves, knowledge of population structure is critical and can aid in refining existing management models [9]. It is widely accepted that population genetics is an essential and efficient tool for the management and conservation of wild and adaptive populations [10,11].

Several types of genetic markers have been frequently applied in population genetic studies of aquatic organisms [11]. Extensive genetic studies of *M. galloprovincialis* populations in the Black Sea [12] and southern Europe [13,14,15,16] have been carried out using allozyme polymorphisms. Although some microsatellites and mt DNA markers [13,17,18,19,20,21,22,23] have been developed for populations identification of *Mytilus* species along the European coast. Large genetic diversity on the mussel population in the Black Sea based on RAPD analyses was proved [24].

Despite the great commercial and economic importance of mussels, *Mytilus galloprovincialis* in Bulgaria, there are no information available concerning their population genetic structure.

The **aim** of the study is to identify *M. galloprovincialis* populations along northern Bulgarian Black Sea coast on the base of esterases polymorphism.

MATERIAL AND METHODS

Sampling

The samples are taken from two zones: Galata (84) and Albena (61). Galata mussel fields are located on profile north of "St. Konstantin and Elena" resort and south to Galata zone in 20 meters depth, 2006 year. The sediment is muddy and muddy mixed with sand. Albena mussel field is situated south of the Albena resort and reaches to the East of Kavarna, in 15 meters depth, in *Mytilus* biocenose (Fig.1).

Fig. 1. Sampling area

The samples were stored at a temperature of -20°C until the isozyme analyses in the laboratory. For the analysis of the enzymes homogenate of muscle and liver tissues was used.

Enzyme electrophoresis

Isoelectric focusing (IEF) on thin polyacrylamide Ampholone gel with pH gradients between 3.5–10.0 with the equipment of LKB (Stockholm, Sweden) was carried out. Parallel with IEF the horizontal starch gel electrophoresis according to Dobrovolov [25] also was used. The visualization of nonspecific esterases was made using Fast Red TR. Buffer systems were elaborated by Clayton and Gee [26] and Dobrovolov [27]. The nomenclature of loci and alleles following the recommendation of Shaklee et al. (1990) [28].

Statistical analyses

After the detection of the isoenzyme activity regions, the phenotypes of discovered loci were recorded. Allele frequencies, effective number of alleles (N_e), test of Hardy-Weinberg equilibrium (HWE), observed (H_o) and expected (H_e) heterozygosity, F-statistics (F_{IS} , F_{ST} and F_{IT}), gene flow (N_m) and Nei's genetic distance [29] were calculated using POPGENE software packages [30]. The deviation from expected heterozygosity for a given locus was estimated with calculation of D. The D was measured by $(H_o - H_e) / H_e$, where H_o is observed heterozygosity and H_e is expected heterozygosity.

RESULTS AND DISCUSSION

Electrophoretic analyses on non-specific esterases on muscle and liver tissue were carried out to detect the genetic markers for determination of the *M. galloprovincialis* populations. Starch electrophoresis and isoelectric focusing were applied, but polymorphism was found only by the second method on the muscle tissue. Two polymorphic zones with esterases activity were visualized in the anodal part of the enzymograms. They are coded from two loci (*EST-1** and *EST-2**) with three allele system of inheriting in the populations analyzed (Fig. 2 and Fig. 3).

Fig.2. Isoelectric focusing of muscle unspecified esterases (EST) on thin polyacrilamide Ampholine gel with pH gradient 3.5 – 10 on *M. galloprovincialis*, catch in front of the cape Galata, Varna Bay. *EST-1** and *EST-2** polymorphic loci, 0-start.

Fig.3. Sheme of muscle unspecified esterases (EST) on polyacrilamide Ampholine gel on *M.galloprovincialis* from Galata and Albena.

The allozyme esterase loci are part of diagnostic loci for *Mytilus edulis* and *M. galloprovincialis* [15,31,32,33, 34,35]. The polymorphism of non-specific esterases (one locus) and leucine-aminopeptidases on *M. galloprovincialis* from 17 different Black Sea areas (from Batumi to Odessa) were registered. The tested black mussel refer to a single population, forming distinct local subpopulations [12].

Using IEF we found two polymorphic esterases loci, which could be useful for investigation of the *Mytilus galloprovincialis* population infrastructure. The mean effective number of alleles per locus varied from 1,74 (Albena) to 1,86 (Galata), Table 1. The expected heterozygosity (H_e) by the polymorphic loci was relatively higher than the observed (H_o) one in tested populations which together with the negative value of D (Table 1), indicating a general excess of homozygosity. There were significant deviation of genotype frequencies from the Hardy-Wainberg expectations in all loci of the tested populations. Heterozygote deficit is a frequent phenomenon in mussel populations and it is usually associated with pollution and low salinity and was reported for *M. galloprovincialis* from the Romanian Black Sea coast [36]. The heterozygote deficit with low value at 15 m in Albena ($D_{Mean} = -0,02$) and at 20 m Galata ($D_{Mean} = -0,046$) was registered. The first value is the same with this, observed for the *M. galloprovincialis* population from the Romanian Black Sea shore [36]. The low value of D parameter and significant deviation from H-W equilibrium in our study confirm the data obtained previously [36] and may indicate the accumulation of pollutants in the sediments, probably associated with the

possible pollution in the costal zone in our sampling localities (Galata and Albena) caused by the antropogenic pressure.

Table 1. Variability of alleles at esterases loci (*EST1** and *EST2**) in *Mytilus galloprovincialis*, Lam., from Galata and Albena, n_a – observed number of alleles, n_e – effective number of alleles, H_{exp} - expected heterozygosity, H_{obs} - observed heterozygosity, D - index for evaluation of heterozygote deficit.

Locus	Allele/parameter	Galata	Albena
<i>EST-1*</i>	A	0,048	0,016
	B	0,792	0,869
	C	0,160	0,115
	n_a	3	3
	n_e	1,527	1,302
	H_{exp}	0,347	0,234
	H_{obs}	0,298	0,230
	D	-0,141	-0,017
<i>EST-2*</i>	A	0,613	0,574
	B	0,244	0,353
	C	0,143	0,074
	n_a	3	3
	n_e	2,191	2,179
	H_{exp}	0,547	0,546
	H_{obs}	0,571	0,541
	D	0,049	-0,014
	D_{Mean}	-0,046	-0,020

The homozygote excess, or heterozygote deficiency, is commonly observed in bivalve moluscs, including species in *Mytilus* complex [37, 38, 39]. However the reasons behind this pattern in this group of animals is not clear. It is often difficult to determine whether it is due to inbreeding, to subpopulations, or other causes [40, 41]. Wahlund effect was proposed as the general explanation of homozygosity excess in bivalves with pelagic larvae [40].

The genetic structure within and among populations was analyzed using Wright's F-statistics (F_{is} , F_{st} and F_{it}). F_{is} and F_{it} , are inbreeding-coefficients. F_{is} is used to determine the genetic variation within the population and F_{it} – among all the populations studied. The F_{is} values (mean 0,031) show that there was no consistent tendency toward heterozygote excess or deficiency within each sampled population, and therefore no indication of inbreeding within populations. Fixation index (F_{ST}) is used to determine the genetic differentiation in the population on the basis of allele frequencies. The estimated mean F_{ST} value was 0,008, which shows that 0,8% of the overall genetic diversity observed was among populations, as opposed to 98,2% within the populations. The low levels of F_{ST} correlated with the high levels of N_m which demonstrated low levels of genetic differentiation between the studied *M. galloprovincialis* populations (Table 2).

Table 2. Summary of F-Statistics (F_{is} , F_{it} and F_{st}) and gene flow (N_m) for all loci between *M. galloprovincialis* populations.

Locus	F_{is}	F_{it}	F_{st}	N_m
<i>EST-1*</i>	0,086	0,093	0,008	31,886
<i>EST-2*</i>	-0,025	-0,017	0,008	30,025
Mean	0,031	0,038	0,008	30,956

The relatively low genetic differentiation of the mussel populations has been reported previously by many authors [23,42,43,44,45,46]. The data received for black mussel samples from two regions (Galata and Albena) of the Black Sea support that opinion. One of the reason for the low level of genetic differentiation probably is its long lived pelagic larva with a high dispersal capacity, which leads to the gene flow and relatively close allelic frequencies obtained. The distribution of genetic variation evidenced from allozyme data and the low value (0,010) of genetic distance (D_{Nei}) between the samples from the two localities could not allow to specify them as a two populations, probably they could belong to different subpopulations.

CONCLUSIONS

The allozyme system studied show a high level of genetic diversity within *M. galloprovincialis* populations Galata and Albena (northern Black Sea coast). The calculated mean F_{ST} , N_m and genetic distances (Nei 1972) showed a low level of genetic differentiation, a high genetic similarity among the studied subpopulation, probably caused by the pelagic larval phases in their life cycles. The study of the variability of the Black Sea mussel is important for the genetic monitoring and the conservation of its genetic diversity. Further investigations, increasing the number of allozyme loci analysed as well as application of additional genetic markers have to be done in order to provide additional information on the genetic structure of *M. galloprovincialis* populations along the Bulgarian Black Sea coast.

REFERENCES

- [1] E. M. Gosling, Systematics and geographic distribution of *Mytilus*. In: Gosling E. (ed) *The Mussel Mytilus: Ecology, Physiology, Genetics and Culture*. Elsevier, Amsterdam, 1992, pp.1-20.
- [2] I. A. Giantsis , T. J. Abatzopoulos , P. Angelidis and A. P. Apostolidis. Mitochondrial Control Region Variability in *Mytilus galloprovincialis* populations from the Central-Eastern Mediterranean Sea. *Int. J. Mol. Sci.*, vol. 15, 2014, pp.11614-11625.
- [3] V. Kaneva-Abadjieva and T. Marinov. Distribution of the *Mytilus galloprovincialis* and the status of mussel fishing in Bulgarian waters. *Proceedings of the Institute of Fisheries*, vol. 8, 1967, pp. 71-79.
- [4] E. Petrova and St. Stoykov. Distribution of the black mussel *Mytilus galloprovincialis* (L.) along the Bulgarian Black Sea coast, *International Journal of Agricultural Science and Technology of TU, St. Zagora*, vol.3, № 4, 2011, pp 368 – 373.
- [5] E. Petrova. Non-fish marine resources and their exploitation along the Bulgarian Black Sea coast. *International Journal of Agricultural Science and Technology*, Vol. 6, No 2, 2014, pp , 2014 215 – 218.
- [6] E. Petrova and St. Stoykov. Non-fish marine resources and their role in the Bulgarian Black Sea Fishery, *International Conference on the Mediterranean Coastal Environment MEDCOAST 2015*, Varna, Bulgaria, E. Özhan (Editor), 2015, pp.459-465.
- [7] E. Petrova, V. Mihneva, St. Stoykov, D. Klisarova, S. Uzunova, S. Dineva and D. Gerdzhikov. Environmental status and dynamics of shellfish resources – veined rapa whelk and black mussel in the Western Black Sea during 2015-2016, *Proceed. of Inst. Fish Resources*, Volume 28, 2017, pp. 7-24.
- [8] E. Petrova, E. Rasmussen, V. Mihneva, St. Stoikov and F. Penchev. Implementation of Measures for Sustainable Management of Shellfish Resources. Model studies with the software product MIKE 21 & ECOLAB, Under the project "Enhancing Black Sea Marine Research and Management Capacity (ECRAMON BLACK SEA)" BG02 Program "Integrated Marine and Inland Water Management", 2017, pp.42.
- [9] J.E. Graves. Molecular insights into the population structures of cosmopolitan marine fishes. *J. Hered.*, 89, 1998, pp. 427-437.
- [10] A.J. Gray. The Genetic Basis of Conservation Biology. In: *Conservation Biology* (Spellerberg IF, ed.). Longman, Edinburgh, 1996, 115-121.
- [11] I.A. Giantsis, N. Kravva and A.P. Apostolidis. Genetic characterization and evaluation of anthropogenic impacts on genetic patterns in cultured and wild populations of mussels (*Mytilus galloprovincialis*) from Greece, *Genetics and Molecular Research*, 11 (4), 2012, pp. 3814-3823.
- [12] E. Zhukovskaya, O. Kodolova, B. Logvinenko. Genetic Studies of Marine Hydrobiotics (Proceeding of the meeting on genetics, selection and fish hybridization, September, 1986, Tartu), Moscow, Ministry of Fisheries USSR, 1987, pp. 204 – 215 (in Russian).
- [13] Y. Karakousis and D. O. Skibinski. An analysis of allozyme, mitochondrial DNA and morphological variation in mussel (*Mytilus galloprovincialis*) populations from Greece *Experientia*, 48, 1992, pp. 878-881.
- [14] N. Kravva, A. Staikou and C. Triantaphyllidis. Genetic composition and temporal genetic variation in *Mytilus galloprovincialis* populations of the Thermaikos gulf (Northern Aegean Sea). *Biologia*, v. 55, 2000, pp. 289-297.
- [15] A. Sanjuan, C. Zapata and G. Alvarez .*Mytilus galloprovincialis* and *M. edulis* on the coasts of the Iberian Peninsula. *Marine Ecology Progress Series*, 113, 1994, pp. 131–146.
- [16] H. Quesada, C. Zapata and G. Alvarez. A multilocus allozyme discontinuity in the mussel *Mytilus galloprovincialis*: the interaction of ecological and life-history factors. *Marine Ecology Progress Series*, 116, 1995, pp. 99–115.

- [17] A.Sanjuan, A.S. Comesaña, A. De Carlos. Macrogeographic differentiation by mtDNA restriction site analysis in the S.W. European *Mytilus galloprovincialis* Lmk. *Journal of Experimental Marine Biology and Ecology*, v.198, 1996,pp. 89–100.
- [18] H. Quesada, C.M. Beynon and D.O. Skibinski. A mitochondrial DNA discontinuity in the mussel *Mytilus galloprovincialis* Lmk: pleistocene vicariance biogeography and secondary intergradation. *Molecular Biology and Evolution*, v. 12, 1995, pp. 521–524.
- [19] P. Venier, L. Tallandini and P.M. Bisol. Characterization of coastal sites by applying genetic and genotoxicity markers in *Mytilus galloprovincialis* and *Tapes philippinarum*. *Journal of Chemical Ecology* 19, 2003, pp. 113–128.
- [20] Luis, J.R.; Comesana, A.S.; Sanjuan, A. mtDNA differentiation in the mussel *Mytilus galloprovincialis* Lmk. on the Iberian Peninsula coast: First results. *Marine Ecology*, v. 32, 2011, pp.102–106.
- [21] E. Ladoukakis, C. Saavedra, A. Magoulas and E. Zouros. Mitochondrial DNA variation in a species with two mitochondrial genomes: the case of *Mytilus galloprovincialis* from the Atlantic, the Mediterranean and the Black Sea. *Molecular Ecology*, v.11, 2002, pp. 755–769.
- [22] A.P. Diz and P. Presa. Regional patterns of microsatellite variation in *Mytilus galloprovincialis* from the Iberian Peninsula. *Marine Biology*, v. 154, 2008, pp. 277–286.
- [23] A. I. Giantsis, N. Mucci, E. Randi, T. J. Abatzopoulos and A. P. Apostolidis. Microsatellite variation of mussels (*Mytilus galloprovincialis*) in central and eastern Mediterranean: genetic panmixia in the Aegean and the Ionian Seas. *Journal of the Marine Biological Association of the United Kingdom*, v. 94 (4), 2014, pp. 797–809.
- [24] A. Kulikova and A. Soldatov, 2017. Genetic characteristics of the four morphological groups of *Mytilus galloprovincialis* Lam. (MYTILIDAE: MOLLUSCA) from the Black Sea. *Transactions of IBIW RAS*, v. 80 (83), 2017, pp. 30-37 (in Russian).
- [25] I.S. Dobrovolov. Micro starch gel electrophoresis. – In: *Proceeding of the Institute of Oceanography and Fisheries*, Varna, vol. 12, 1973, pp 157-162 (in Bulgarian, with English summary).
- [26] J. W. Clayton and G. H. Gee 1969. Lactate dehydrogenase isozymes in long nose and black nose Dace (*Rhinichthys cataractae* and *R. atratulus*) and their hybrid . *J. Fish. Res. Bd. Can.*, v. 26, № 11, 1969, pp. 3049 – 3053.
- [27] I. S. Dobrovolov. Multiple forms of lactate dehydrogenase in anchovy (*Engaulis encrasicolus* L.) from the Black Sea, the Sea of Azov and the Atlantic ocean. *Comptes rendus de l'Academie bulgare des Sciences*.vol. 29, № 6, 1976, pp. 877 –880.
- [28] J. Shaklee, F. W. Allendorf, D. C. Morizot and G. S. Whitt. Gene Nomenclature for protein-coding loci in fish. *Trans. Amer. Fish. Soc.* vol. 119, 1990, pp. 2-15.
- [29] M. Nei Genetic distance between populations. *Amer. Naturalist*. vol.106, 1972, pp. 283 – 292.
- [30] F.C. Yeh, Y. Rong-cai,, T. Boyle. Popgene version 1.31 — freeware for population genetic analysis. <http://www.ualberta.ca/~fyeh/info.htm>, 1999.
- [31] D. O. F. Skibinski, J. A. Beardmore and T. F. Cross Aspects of the population genetics of *Mytilus* (Mytilidae; mollusca) in the British Isles. *Biological Journal of the Linnean Society*, v.19, 1983, pp.137-183.
- [32] J. H. McDonald, R. Seed and R. K. Koehn Allozymes and morphometric characters of three species of *Mytilus* in the northern and southern hemispheres. *Marine Biology*, v.111, 1991, pp. 323-333.
- [33] J. P. Gardner . *Mytilus galloprovincialis* (Lmk.)(Bivalvia, Molluscs) the taxonomic status of the Mediterranean mussel. *Ophelia*, vol. 35, 1992, pp. 219-243.
- [34] E.M. Gosling. Genetics of *Mytilus*, In: *The Mussel Mytilus: Ecology, Physiology, Genetics and Culture*, Amsterdam: Elsevier, ch. 7, 1992, pp. 309–382.
- [35] R. Seed. Systematics, evolution. and distribution of mussels belonging to the genus *Mytilus* an overview. *Am. malacolog. Bull.* 9, 1992, pp. 123- 137.
- [36] A. Novak and L. Fusu. The phenotypic structure of a *Mytilus galloprovincialis* Lmk population from the Romanian Black Sea shore, *Analele Științifice ale Universității „Alexandru Ioan Cuza”, Secțiunea Genetică și Biologie Moleculară*, v.7, 2006, pp. 235-240.
- [37] E. Zouros and D.W. Foltz. Minimal selection requirements for the correlation between heterozygosity and growth, and for the deficiency of heterozygotes in oyster populations. *Develop. Genet.*,v. 4, 1984,pp. 393–405.
- [38] M. Raymond, R.L. Vaanant, F. Thomas, F. Rousste, T. de Meeus and F. Renaud 1997. Heterozygote deficiency in the mussel *Mytilus edulis* species complex revisited. *Marine Ecology Progress Series*,v. 156, 1997, pp. 225-237.

- [39] E. Kalkan , A. Kurtuluş , Ö. Maracı and R. Bilgin. Is the Bosphorus Strait a barrier to gene flow for the Mediterranean mussel, *Mytilus galloprovincialis* (Lamarck, 1819)? , *Marine Biology Research*, 7:7, 2011, pp. 690-700.
- [40] M.L.Tracey, N.F. Bellet, and C.D. Gravem, Excess allozyme homozygosity and breeding population structure in the Mussel *Mytilus californianus* *Mar. Biol.* 32, 1975: 303-311.
- [41] R.Jamanaka andY. Fujio. Heterogenety within and between geographical population of the bay mussel *Mytilus edulis*. *Tohoku Journal of Agricultural Research*, vo.34 (3-4), 1984, pp. 73-84.
- [42] Kartavtsev, Yu.F., Allozyme polymorphism in two species of mussels, in *Genetika i razmnozhenie morskikh zhivotnykh* (Genetics and Reproduction of Marine Animals), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1981, pp. 36–38.
- [43] Yu. F. Kartavtsev, *Molecular Evolution and Population Genetics*, 2nd Ed., Vladivostok: Dal'nevost.Gos. Univ., 2009 (in Russian)
- [44] Yu.F. Kartavtsev, and N.I., Zaslavskaya, Genetic structure and integration and differentiation factors of common mussel (*Mytilus edulis*) populations, *Genetika*, 1982, vol. 18, no. 10, pp. 1653–1666.
- [45] G. I. Zardi1, C. D. McQuaid, P. R. Teske and N. P. Barker. Unexpected genetic structure of mussel populations in South Africa: indigenous *Perna perna* and invasive *Mytilus galloprovincialis*., *Mar Ecol Prog Ser.*,v. 337, 2007, pp.135–144.
- [46] Y. Ph. Kartavtseva, , M. V. Katolikovac, S. N. Sharinaa, , O. V. Chichvarkhina, and N. A. Masalkova. A Population Genetic Study of the Hybrid Zone of *Mytilus trossulus* Gould, 1850 and an Introduced Species, *M. galloprovincialis* Lamarck, 1819, (Bivalvia: Mytilidae) in Peter the Great Bay in the Sea of Japan *Russian Journal of Marine Biology*, 2014, Vol. 40, No. 3, pp. 208–216.

TAXONOMIC DIVERSITY OF MARINE SEDIMENTS FROM THE BLACK SEA: NEXT-GENERATION SEQUENCING SURVEY

Nina DZHEMBEKOVA*, Petya IVANOVA*, Snejana MONCHEVA*, Satoshi NAGAI**

*Institute of Oceanology – Bulgarian Academy of Sciences, Bulgaria

** National Research Institute of Fisheries Science, Research Center for bioinformatics and biosciences, Japan

Abstract. Marine sediment biodiversity from 13 stations located in different areas across the Black Sea (coastal, shelf and open sea) was investigated by a next generation sequencing-based method. A set of primers to target the V7-9 18S rRNA region was applied. From the dataset including a total number of 2,483,047 sequences, 63% were clustered at 98% of similarity. Opisthokonta, Viridiplantae, and Alveolata were the most taxonomically diverse, accounting for over 20% of the total operational taxonomic units number each. The data received confirmed the high eukaryotic diversity harbored in marine sediments. High throughput sequencing is a promising approach to explore the biodiversity stored in environmental sediment samples.

Keywords: Black Sea, NGS, OTUs, sediment biodiversity, supergroups

INTRODUCTION

In recent years, molecular methods, such as metabarcoding has been recognized for its potential to rapidly expand our knowledge of marine biodiversity, supporting assessment, management, and conservation [1,2,3]. Molecular studies of marine eukaryotes have uncovered a high taxonomic diversity, many of which could not be assigned to any accession in taxonomic reference databases [1]. While highly diverse species communities were unveiled from marine benthic habitats in different areas of the world ocean [4,5,6,7,8,9,10] marine benthic molecular studies of surface sediment samples still remain scarce and limited, especially for the Black Sea, but the few data reported confirmed the potential of this approach for investigating Black Sea biodiversity [3,10,11,12].

The **aim** of the research was to explore the taxonomic diversity in the Black Sea surface sediments applying metagenetic approach, to compare the taxonomic composition between different sampling stations/habitats and to assess the resolution of the method for species identification among the different supergroups. To our knowledge this is the first molecular study of surface sediments biodiversity at Black Sea basin scale.

MATERIAL AND METHODS

Sampling

Surface sediment samples were collected with multicorer (2-15 cm of the core) or Van-Veen Grab, by a 10X10 cm frame at 13 stations located in different areas (coastal - CO, shelf - SH and open sea - OS) across the Black Sea during May-June 2016 (Figure 1, Table 1). Samples were stored in the dark at 8°C.

Table 1. Stations coordinates, depth, sediment type and sampling method

Station	Area	Depth, m	Lat	Long	Sediment type	Sampling method
U1	Coastal	13	46° 30,535'	30° 49,432'	mud	grab
U2	Coastal	16	46° 19,474'	31° 27,999'	mud	multicorer
U3	Coastal	20.4	45° 30,969'	29° 51,728'	shell+mud	multicorer
U4	Coastal	20.5	45° 11,999'	29° 48,616'	mud	multicorer
U5	Coastal	22.8	45° 18,676'	29° 51,200'	mud	multicorer
U6	Coastal	28.6	46° 12,098'	30° 49,649'	mud	multicorer
GE1	Coastal	37	42°07,359'	41°36,987'	mud+shell	grab
GE2	Shelf	42	41°54,259'	41°44,948'	mud+shell	grab
GE3	Shelf	63	41°45,763'	41°42,883'	mud+shell	grab
OS1	Shelf	391	44°38,163'	31°23,298'	mud	multicorer
OS2	Open sea	1933	43°22,049'	31°49,994'	mud	multicorer
OS3	Open sea	1904	42°14,070'	39°53,161'	mud	multicorer
OS4	Open sea	2100	43°31,558'	36°04,183'	mud	multicorer

Figure 1. Map of sampling stations

DNA extraction and sequencing

DNAs were extracted from 0.5g of samples by using of ISOIL DNA extraction kit (NIPPON GENE, Tokyo, Japan). To carry out metagenomic analysis using the MiSeq 300PE platform (Illumina, USA) a set of universal primers to amplify the V7–9 hypervariable regions of the 18S-rRNA gene (SSR-F1289-sn, F: TGGAGYGATHTGTCTGGTTDATTCCG; SSR-R1772-sn, R: TCACCTACGGAWACCTTGTTACG) were used [13]. The massively parallel paired-end sequencing workflow was derived from the document 16S metagenomic sequencing library preparation: preparing 16S ribosomal gene amplicons for the Illumina MiSeq system distributed by Illumina (part no. 15044223 Rev. B). Two-step PCR approach was employed to construct the paired-end libraries [11]. The amplified PCR products were quantified and the indexed second PCR products were pooled in equal concentrations and stored at -30 °C until use for sequencing.

Treatment of massively parallel sequences (MPSs) data and selection of operational taxonomic units (OTUs)

Nucleotide sequences were demultiplexed and trimmed using Trimmomatic version 0.35. Trimmed sequences shorter than 200 bp were filtered out. The remaining sequences were merged into paired reads using Usearch version 8.0.1517. Sequences were aligned with each other using Clustal Omega v 1.2.0. Illumina paired-end reads were processed using Mothur v.1.33.0 software [14]. Identical sequences (100% similarity) were collated using the unique.seqs command in Mothur. Erroneous and chimeric sequences were detected and removed in Mothur using the pre.cluster (diffs = 4) and chimera.uchime (minh = 0.1) [15]. Contiguous sequences identified using count.seqs in Mothur were considered OTUs and were used in the subsequent taxonomic analysis.

Taxonomic identification of OTUs

The taxonomic identification of each OTU was done using a BLAST search [16]. Subsequently, the taxonomic information was obtained from the BLAST hit with top bitscores for each query sequence, then, the OTUs of the same top-hit were merged. Removal of sequences containing errors was imperfect after the successive processes of MPS data treatment. Sequences containing different types of errors which derived from original ones remained in the following analytical steps. Therefore, these sequences were detected as some unique OTUs with the same blast top hit name but different similarities. To avoid overestimation of the OTUs, these artificial OTUs were merged into a single OTU with the greatest similarity score.

Statistical analyses

The effective number of sequences registered in the international nucleotide sequence databases (INSDs) for the target region and the amplicon sequence variability were taken as the most influential factors affecting

taxonomic identification power [13]. The frequency distributions of BLAST top hit similarities for OTUs and MPSs were calculated at 1% difference increments. To compare among supergroup levels, frequencies of the OTUs and MPSs that were identical to those in the INSDs scoring > 98% BLAST top hit similarity were calculated for each supergroup. Taxonomic richness (S), abundance (N), Shannon-Wiener diversity (H') and Pielou's evenness (J') for each sample (station) were calculated by PRIMER v.5 package (Primer-E Ltd., Plymouth, UK). Bray-Curtis similarity cluster diagrams were plotted to test the possible clustering of stations based on the data of different taxonomic level – supergroups and species (PRIMER v.5 package).

RESULTS AND DISCUSSION

After running the bioinformatics pipeline, 2,251 OTUs were recovered from total number of 2,483,047 sequences. The number of OTUs between samples ranged from 277 to 748 and the number of MPS from 139,855 to 248,521. No significant positive correlation was detected between them ($r = 0.525$, $p > 0.05$, by Spearman test) meaning that the different sequence number could be related to the species abundance or could be due to the variations in the copy numbers of rRNA genes among different groups [17,18]. The mean OTUs richness estimated on the base of the pooled sediment samples (557) was lower than that observed in other seas [19]. The frequency distribution of the top BLAST hit similarity showed that approximately 39% of the OTUs and 63% of the MPSs were assigned on a 98%-sequence similarity value to the reference database and used for the taxonomic identification (Figure 2). This is in confirmation with previous results that still a high proportion of the benthic OTUs are novel for the reference databases and couldn't be taxonomically assigned [19].

Figure 2. Frequency distributions for the BLAST top hit similarities > 98% for the number of OTUs and MPSs

Clustering at 98% similarity produced 888 operational taxonomic units. Relative abundances of detected OTUs and MPSs at the supergroup levels were calculated (Figure 3). The dominating supergroups were Opisthokonta (24% and 34%) and Alveolata (23% and 38%) similar to the data obtained from other European seas [19]. For the other supergroups the relative taxonomic and sequence composition followed divergent pattern and the portion of OTUs richness and MPSs relative abundance differ from one another. Within Opisthokonta, the most OTU-rich groups were Metazoa and Fungi. For Alveolata the groups with highest OTUs number were Ciliophora and Dinophyceae. The number of OTUs showing similarity over 98% per station varied from 150 to 348 and for the MPSs it ranged between 68,156 and 158,183.

Figure 3. Relative abundance of OTUs and MPSs (> 98% similarity) at the highest taxonomic level.

No pattern of OTUs and MPSs depth distribution at the highest taxonomic level between the stations and the habitats (coastal, shelf and open sea) was discriminated (data not shown). But at the species level a heterogeneity was observed (Table 2, Figure 4) following the general trend in benthic diversity [19] suggesting that for the analyses and comparison of the taxonomic diversity among the stations (β -diversity patterns) higher resolution data (low taxonomic level) is required. Most likely the surprising similarity between the coastal and open sea stations was related to different mechanisms, the observed high diversity in the anoxic depths (~ 2000 m) associated to the rich sedimentation flux of organic matter. However the method applied does not allow to discriminate between species and remnants sedimented out of the water column and the resident community in the surface sediments [20].

Table 2. Diversity indices for the species identified by stations. S: species richness; N: total sequences; J': Pielou's evenness; H': Shannon-Wiener diversity

Station	S	N	J	H (e)
U1	310	119320	0.587	3.367
U2	308	156422	0.528	3.027
U3	129	119588	0.489	2.377
U4	205	130636	0.617	3.283
U5	198	61865	0.547	2.891
U6	142	113754	0.495	2.454
GE1	235	107493	0.677	3.697
GE2	294	100527	0.535	3.041
GE3	197	102779	0.389	2.057
OS1	203	136691	0.359	1.909
OS2	295	101275	0.579	3.294
OS3	127	79232	0.407	1.970
OS4	306	147423	0.429	2.454

Figure 4. Bray-Curtis similarity cluster diagram of stations based on the data at species level

The taxonomic identification of environmental DNA sequence fragments is of critical importance for the accurate analyses and interpretation of biodiversity. The identification power of the OTUs at different taxonomical level within the supergroups was estimated (Table 3).

Table 3. Identification power at different taxonomical level by supergroups

Supergroup	OTUs	Species	Genus		Different genera
			≥ 2 species	sp.	
Alveolata	202	113	13	45	31
Amoebozoa	25	12	0	12	1
Apusozoa	1	1	0	0	0
Archaeplastida	2	1	0	1	0
Excavata	1	0	1	0	0
Hacrobia	26	21	1	3	1
Opisthokonta	211	144	6	32	29
Rhizaria	61	38	4	18	1
Stramenopiles	163	85	21	37	20
unclassified	8	3	0	1	4
Viridiplantae	188	91	15	25	57
Total	888	509	61	174	144

57% of the whole dataset were determined at the species level, 27% at the genus level and 16% couldn't be identified due to the equal similarity between different genera. Among the dominant supergroups the proportion of OTUs identified as a single species varied between 48% and 81%. The frequency of Hacrobia was considerably higher than those of the other superphyla, whereas those of Amoebozoa and Viridiplantae were lower. For the supergroups with OTUs < 10 the percentage was between 0 and 100 because of the low total number of species. Generally about 27% of the OTUs clustered at 98% of similarity could be identified at the genus level. The OTUs frequency was higher in Amoebozoa based on the similarity with sequences deposited in the reference database as "sp.", signifying the need for registration of reference sequences integrating both morphological and genetic information. A lower percentage was registered in Hacrobia. The highest intragenus similarity was observed in Stramenopiles showing the necessity of better primer resolution. As a whole a low proportion of intergenus similarity was found (between 4% and 30% for the major groups) and a small proportion of the OTUs failed to be taxonomically assigned.

Additional problem that could affect the reliability of the DNA-based metagenetic results is the discrimination of the taxa really inhabiting the sediment from the sinking cells and cellular material or extracellular DNA, especially in case of anoxic conditions, known as hotspots of preserved extracellular DNA [20]. This could lead to overestimation of the diversity and misinterpretation of the real taxonomic composition of the sediment. Some authors proposed the use of RNA-based approach for determination of the metabolically active organisms [20], but this methods also could lead to uncertainty in assesment of the current functional sediment community members [12].

CONCLUSIONS

The application of NGS-based method uncovered high biodiversity in the Black Sea sediments. Within the dataset a total number of 2,251 OTUs were recovered and about 39% of them could be assigned at the 98% similarity threshold. The most diverse groups in terms of both OTUs richness and MPSs number were Opisthokonta and Alveolata. At the supergroup level similar patterns of the community structure between localities were observed, but at the species level heterogeneity was present. Generally good taxonomic identification power was detected, however, there is still need of better taxonomic resolution of the primers for increasing the coverage at the species level for some groups. In addition to raise the analysis accuracy and for better interpretation of metabarcoding data, a rich reference database is essential. The accurate discrimination of the actual sediment biodiversity through DNA-based approach is still challenging.

ACKNOWLEDGEMENTS

This work was supported by the National Science Fund, Ministry of Education and Science, Bulgaria under a project "Phytoplankton cysts – an intricacy between a "memory" or a "potential" for Black sea biodiversity and algal blooms" (contract № ДН01/8, 16.12.2016). The authors are thankful to EC/UNDP EMBLAS II Project for providing the opportunity to participate in the cruise and to RV "Mare Nigrum" crew for the assistance in field sampling.

REFERENCES

- [1] C. De Vargas, S. Audic, N. Henry, J. Decelle, F. Mahé, R. Logares, E. Lara, C. Berney, N. Le Bescot, I. Probert and M. Carmichael. Eukaryotic plankton diversity in the sunlit ocean. *Science*, vol. 348(6237), 2015, p.1261605.
- [2] J.K. Pearman, H. Anlauf, X. Irigoien and S. Carvalho. Please mind the gap–Visual census and cryptic biodiversity assessment at central Red Sea coral reefs. *Marine environmental research*, vol. 118, 2016, pp. 20-30.
- [3] A.E. Cahill, J.K. Pearman, A. Borja, L. Carugati, S. Carvalho, R. Danovaro, S. Dashfield, R. David, J.P. Féral, S. Olenin and A. Šiaulys. A comparative analysis of metabarcoding and morphology-based identification of benthic communities across different regional seas. *Ecology and Evolution*. 2018;00, pp. 1–13.
- [4] V.P. Edgcomb, D.T. Kysela, A. Teske, A. de Vera Gomez and M.L. Sogin. Benthic eukaryotic diversity in the Guaymas Basin hydrothermal vent environment. *Proceedings of the National Academy of Sciences*, vol. 99(11), 2002, pp. 7658-7662.

- [5] P. López-García, H. Philippe, F. Gail and D. Moreira. Autochthonous eukaryotic diversity in hydrothermal sediment and experimental microcolonizers at the Mid-Atlantic Ridge. *Proceedings of the National Academy of Sciences*, vol. 100(2), 2003, pp. 697-702.
- [6] T. Stoeck and S. Epstein. Novel eukaryotic lineages inferred from small-subunit rRNA analyses of oxygen-depleted marine environments. *Applied and Environmental Microbiology*, vol. 69(5), 2003, pp. 2657-2663.
- [7] K. Takishita, H. Miyake, M. Kawato and T. Maruyama. Genetic diversity of microbial eukaryotes in anoxic sediment around fumaroles on a submarine caldera floor based on the small-subunit rDNA phylogeny. *Extremophiles*, vol. 9(3), 2005, pp. 185-196.
- [8] K. Andersen, K.L. Bird, M. Rasmussen, J. Haile, H. Breuning, Madsen, K.H. Kjaer, L. Orlando, M.T.P. Gilbert and E. Willerslev. Metabarcoding of 'dirt' DNA from soil reflects vertebrate biodiversity. *Molecular ecology*, vol. 21(8), 2012, pp. 1966-1979.
- [9] D.W. Yu, Y. Ji, B.C. Emerson, X. Wang, C. Ye, C. Yang and Z. Ding. Biodiversity soup: Metabarcoding of arthropods for rapid biodiversity assessment and biomonitoring. *Methods in Ecology and Evolution*, vol. 3, 2012, pp. 613-623.
- [10] R. Massana, A. Gobet, S. Audic, D. Bass, L. Bittner, C. Boutte, A. Chambouvet, R. Christen, J.M. Claverie, J. Decelle and J.R. Dolan. Marine protist diversity in European coastal waters and sediments as revealed by highthroughput sequencing. *Environmental microbiology*, vol. 17(10), 2015, pp. 4035-4049.
- [11] N. Dzhenbekova, S. Urusizaki, S. Moncheva, P. Ivanova and S. Nagai. Applicability of massively parallel sequencing on monitoring harmful algae at Varna Bay in the Black Sea. *Harmful algae*, vol. 68, 2017, pp. 40-51.
- [12] M.J. Coolen and G. Shtereva. Vertical distribution of metabolically active eukaryotes in the water column and sediments of the Black Sea. *FEMS microbiology ecology*, 70(3), 2009. pp. 525-539.
- [13] A.S. Tanabe, S. Nagai, K. Hida, M. Yasuike, A. Fujiwara, Y. Nakamura, Y. Takano and S. Katakura. Comparative study of the validity of three regions of the 18S rRNA gene for massively parallel sequencing-based monitoring of the planktonic eukaryote community. *Molecular ecology resources*, vol. 16(2), 2016, pp. 402-414.
- [14] P.D. Schloss, D. Gevers and S.L. Westcott. Reducing the effects of PCR amplification and sequencing artifacts on 16S rRNA-based studies. *PLoS One*, vol. 6, 2011, p. e27310.
- [15] R.C. Edgar, B.J. Haas, J.C. Clemente, C. Quince and R. Knight. UCHIME improves sensitivity and speed of chimera detection. *Bioinformatics*, vol. 27, 2011, pp. 2194-2200.
- [16] M. Cheung, C. Au, K. Chu, H. Kwan and C. Wong. Composition and genetic diversity of picoeukaryotes in subtropical coastal waters as revealed by 454 pyrosequencing. *The ISME journal*, vol. 4(8), 2010, pp. 1053-1059.
- [17] S.O. Rogers and A.J. Bendich. Ribosomal RNA genes in plants: variability in copy number and in the intergenic spacer. *Plant Molecular Biology*, 9(5), 1987, pp. 509-520.
- [18] A.L. Torres-Machorro, R. Hernández, A.M. Cevallos and I. López-Villaseñor. Ribosomal RNA genes in eukaryotic microorganisms: witnesses of phylogeny?. *FEMS microbiology reviews*, 34(1), 2010, pp. 59-86.
- [19] D. Forster, M. Dunthorn, F. Mahé, J.R. Dolan, S. Audic, D. Bass, L. Bittner, C. Boutte, R. Christen, J.M. Claverie and J. Decelle. Benthic protists: the under-charted majority. *FEMS Microbiology Ecology*, vol. 92(8), 2016, p. 11.
- [20] P. Thureborn, Y.O.O. Hu, A. Franzetti, S. Sjöling, D. Lundin. Accumulation of DNA in an anoxic sediment – rDNA and rRNA presence of members of the microbial community from Landsort Deep, the Baltic Sea. *PeerJ Preprints*, 5, 2017, p. e2051v2.

AGE-SIZE STRUCTURE AND GROWTH RATE OF THE GOLDEN GREY MULLET AND LEAPING MULLET (*Chelon auratus* and *Chelon saliens*) IN BULGARIAN BLACK SEA COAST

Radoslava BEKOVA*, Galerida RAIKOVA-PETROVA**, Marina PANAYOTOVA*,
Bogdan PRODANOV*

*Institute of Oceanology "Fridtjof Nansen," Bulgarian Academy of Science, Varna, Bulgaria

** Department of General and Applied Hydrobiology, Faculty of Biology, Sofia University St. Kl. Ohridski

Abstract. The knowledge of the age and growth of the species in the region is essential for the proper management of the resources. This study aimed to estimate the age and growth of *Chelon auratus* and *Chelon saliens* in Bulgarian Black Sea coast. The fish age was determined from scale readings. Back-calculated lengths at age, as derived using scales readings, were used to estimate the growth parameters of von Bertalanffy equation. The length-weight relation was estimated by the equation: $W = a \cdot L^b$.

Keywords: von Bertalanffy growth parameters, *Chelon auratus*, *Chelon saliens*

INTRODUCTION

The golden grey mullet, *Ch. auratus* (Risso, 1810) and leaping mullet, *Ch. saliens* (Risso, 1810) usually lives inshore, enters lagoons and estuaries, and rarely moves into freshwater. Additionally, they are widely distributed in the Mediterranean Sea and the Black Sea, Atlantic coasts from the Azores and Madeira northward to the British Isles, and the southern coasts of Norway and Sweden.

Information on golden grey mullet and leaping mullet biology come mainly from studies carried out in and around the Mediterranean, Black and the Caspian Sea and eastern Atlantic coast [1,2].

The golden gray mullet is the most common among mullet fish along our Black Sea coast. Like gray mullet, it is a pelagic, shoaling and highly mobile fish. It is a cosmopolitan species. The leaping mullet, like the golden gray mullet, is a pelagic, shoaling and extremely agile fish. In summer they make significant leaps over the water. They slightly tolerate changes in water salinity and are somewhat sensitive to temperature decrease (Minos et al. 1994, 1995).

The maximum length of the golden gray mullet is around 60 cm and weight 1.5 kg [3]. Sexual maturity is gained at the age of 2 or 3 years. The maximum sizes of the golden gray mullet in the Black Sea reach up to 43 cm, but the commercial ones usually range from 18 cm to 25 cm. The leaping mullet reaches a length of up to 35 cm, but here it is generally caught in sizes of 16-18 cm and weight up to 0.8 kg. Spawning starts at 3 years of age [4,5,6,7,8,9,10].

MATERIALS AND METHODS

Ch. auratus and *Ch. saliens* specimens were collected during the period May 2010 – June 2018 from the areas of Bulgarian Black Sea coast (Fig. 1). The samples were collected by cast nets fishing – the size of the eye 22-38 mm, length 50 m and height of the nets between 1.5 and 2 m. 2204 individuals were used to study the size-age structure and the growth rate of the *Ch. auratus* and *Ch. saliens*.

For each specimen standard length ($L \pm 1\text{mm}$), total weight ($TW \pm 1\text{g}$), gutted weight ($W \pm 1\text{g}$) were measured. The age was determined by the scales at a magnification of $17.5\times$ with Projector Dokumator, Lasergeret (Carl Zeiss, Jena). Length and weight at the age were back-calculated, and the received values were used to calculate the von Bertalanffy's growth parameters. To assess if the growth potential of the population was well used the coefficient of Hohendorf was applied. The parameters k , L_∞ / W_∞ , to from von Bertalanffy's equation were also used to compare the growth rate of the populations.

Figure 1. Sampling area for the *Chelon auratus* and *Chelon saliens* along the Bulgarian Black Sea coast

RESULTS

The age structure of the *Ch. auratus* and *Ch. saliens* population is represented by nine and six age groups (Fig. 2). The one-year and 3-year-old fishes are the most numerous for both species. The most comprehensive range is in the four-age group that covers 11-dimensional classes.

Figure 2. Distribution of the age groups (%) of *Ch. auratus* and *Ch. saliens* along the Bulgarian Black Sea coast

The established age structure classifies the population of the golden grey mullet and leaping mullet the middle-life populations (with a maximum age of 6 to 9 respectively) [11, 12]. The average weighted age of the population is 2.58 years for golden grey mullet and 2.52 years for leaping mullet. The smaller digital presence of fish of the larger age groups, as well as the weighted average age, means maintaining a young population. The reason for this probably is overfishing, which is aimed primarily at larger specimens. Another factor that affects the population structure is a lousy food base. It should not underestimate the intense pollution of some coastal areas of the Black Sea, Bourgas, and Varna Lake.

The size structure of the population has represented by 35- and 32-size classes for golden grey mullet and leaping mullet (Fig 3).

Figure 3. The size structure of *Ch. auratus* and *Ch. saliens* along the Bulgarian Black Sea coast

The general equation representing the relationship between L and S for the study population of golden grey mullet and leaping mullet is:

$$L' = 2,3684S + 0,6719, r = 0,9855 - Ch. auratus$$

$$L' = 2.5349S + 0.4681, r^2 = 0.9914 - Ch. saliens$$

The relationship between L and S has represented in Fig. 4.

Figure 4. The relation between the length (L, cm) and the length of the diagonal radius of the scales (S) *Ch. auratus* (a) and *Ch. saliens* (b) along the Bulgarian Black Sea coast

Obtained by reverse calculation values for the length of the body in different age groups give different deviations from the empirically established. The lack of consistently lower values of the back-calculated lengths shows that although fishing pressure individuals in the population are not very fine.

The most likely cause of the uneven growth rate of generations is irregular fishing and the poor ecological status of the primary wintering sites of the flathead mullet.

The relationship between the average lengths of the body of age t years (L_t) and average lengths after one year (L_{t+1}) is well-expressed rights which are described by the equation of the Ford-Walford [13]: $L_{t+1} = 8,1454 - 0,001L_t$ for *Ch. auratus* and for *Ch. saliens* the Ford-Walford equation is $L_{t+1} = 3,7109 - 0,1795L_t$. This shows that, with increasing age, linear growth of the golden grey mullet and leaping mullet on the Bulgarian Black Sea coast can be described with the von Bertalanffy equation [14] (Fig. 5 a,b): $L_t = 118,15 [1 - e^{0,02281(t+1,65685)}]$ for *Ch. auratus* and *Ch. saliens* the von Bertalanffy equation is $L_t = 44,8[1 - e^{0,18(t+0,511)}]$

According to von Bertalanffy's model, the asymptomatic length (L_∞) is 118.15 cm for golden grey mullet and 44.8 cm for leaping mullet. The reason for this result is the low value of the growth factor $k - 0.0228$ (*Ch. auratus*) and 0.18 (*Ch. saliens*), indicating a meager rate of growth of the individuals in the population. Low values we get for k explain the higher values we get for L_∞ since two parameters are inversely related - the smaller the value of the integer k , the greater are the values of L_∞ [15]. In comparing asymptotic to the maximum observed in our capture length ($L_{\max} = 38$ cm – *Ch. auratus*; $L_{\max} = 34.1$ cm – *Ch. saliens*) $L_{\max} : L_\infty$ give little value 0.3 (*Ch. auratus*) and 0.8 (*Ch. saliens*). This indicates that the population of *Ch. auratus* and *Ch. saliens* in the region not used enough growth potential [16].

Figure 5. von Bertalanffy's equation for length growth of the *Ch. auratus* (a) and *Ch. saliens* (b) along the Bulgarian Black Sea coast

Obtaining higher levels of L_{∞} and accordingly, shallow values of k are usually observed in populations with a low initial length and slower growth rate.

General population equation describing the relationship between length and weight is:

$$W' = 0.0202L^{2.8589}, r = 0.9952 - Ch. auratus$$

$$W' = 0.0247L^{2.7654}, r^2 = 0.9933 - Ch. saliens$$

Graphically dependence is shown in Fig. 6.

Figure 6. The relation between the length (L, cm) and weight (W, g) of the *Ch. auratus* (a) and *Ch. saliens* (b) along the Bulgarian Black Sea coast

The asymptotic average weight (W_{∞}) that we get to golden grey mullet and to leaping mullet from the Bulgarian Black Sea coast is 1075 g and 365 g respectively for both species (Fig. 7). By comparing this value to the maximum set in our catches ($W_{\max} = 600$ g for *Ch. auratus* and 311 g for *Ch. saliens*), we obtain 0.86 (*Ch. auratus*) and 0.56 (*Ch. saliens*) by $W_{\max} : W_{\infty}$ of Hohendorf [16]. This Hohendorf coefficient value indicates that the studied population does not fully exploit its growth potential.

As with linear growth, high values for W_{∞} and shallow k values are most likely due to the low weight of fish in the first year and the process of self-regulation of growth.

Figure 7. Graph of the von Bertalanffy equation for the weight growth of the *Ch. auratus* and *Ch. saliens* along the Bulgarian Black Sea coast

CONCLUSIONS

The population of the golden grey mullet and leaping mullet of the Bulgarian Black Sea aquatory is young, characterized by a slow growth rate, which is probably due to the deteriorated living conditions and the early age of sexual maturation. The population of the flathead mullet does not use enough growth potential. The fact is that global fishing for flathead mullet is just as susceptible to overfishing as other marine fish species.

Acknowledgments. The study was realized with the financial support of National Scientific Fund at the Ministry of Education, Youth and Science of Bulgaria through project entitled: "The influence of environmental condition of Varna and Burgas bays on population-biological parameters of mullets species (*Mugil cephalus*, *Liza aurata* and *Liza saliens*)" contract № DM11/2 from 15 Dec 2017.

REFERENCES

[1] Bruslé, J. (1982) Contribution à la connaissance de la sexualité des poissons téléostéens marins gonochoriques (Mugilidés) et hermaphrodites (Serranidés). PhD. Thesis, University of Perpignan, 360 pp

- [2] Quignard, J.P., Farrugio, H. (1981) Age and growth of grey mullet. p. 155-184. In: Aquaculture of grey mullet, International biological programme. Oren O.H (Ed.). Cambridge Univer Cambridge University Press. Cambridge
- [3] Karapetkova M and Zhivkov M. 2006. The fishes of Bulgaria. Gea-Libris Publishing House, Sofia.1-216.
- [4] Ghaninejad D, Abdolmalaki S, Kuliyevev ZM. 2010. Reproductive biology of the golden grey mullet, *Liza aurata* in the Iranian coastal waters of the Caspian Sea. Iranian Journal of Fisheries Sciences 9(3): 402-411. <https://www.researchgate.net/publication/283167011> Reproductive biology of the golden grey mullet *Liza aurata* in the Iranian coastal waters of the Caspian Sea
- [5] Koutrakis M. 2011. Reproductive biology of two grey mullet species (Actinopterygii: Mugiliformes: Mugilidae) in a northern Aegean Sea estuarine system. Acta Ichthyologica Et Piscatoria. 41. 37-46. DOI 10.3750/AIP2011.41.1.06
- [6] Minos G, Katselis G, Kaspiris P and Ondris I. 1994. The differential increase of morphometrical characters during the growth of grey mullet, *Liza ramada* (Risso) and *Liza saliens* (Risso), in the Messolonghi – Etoliko lagoon. Bios (Macedonia, Greece), 2:149-154. <https://www.researchgate.net/publication/236343487> The differential increase of the morphometrical characters during the growth of the grey mullets *Liza ramada* Risso and *Liza saliens* Risso in Messolongi-Etoliko lagoon
- [7] Minos G, Katselis G, Kaspiris P and Ondris I. 1995. Comparison of the change in morphological pattern during the growth in length of the grey mullet *Liza ramada* and *Liza saliens* from western Greece. Fisheries Research, 23:143-155. [https://doi.org/10.1016/0165-7836\(94\)00334-S](https://doi.org/10.1016/0165-7836(94)00334-S)
- [8] Pavlovskaya RM. 1969. On the features of the dynamics of fat content and fertility of three species of the Black Sea mullets. YugNIRO Proceedings, Vol. 26. pp. 62-67.
- [9] Patimar R. 2008. Some biological aspects of the sharpnose mullet *Liza saliens* (Risso, 1810) in Gorgan Bay-Miankaleh Wildlife Refuge (the Southeast Caspian Sea). Turkish Journal of Fisheries and Aquatic Sciences 8: 225-232. <http://trjfas.org/abstract.php?lang=en&id=614>
- [10] Stoyanov St, 1963. The fishes from Black Sea. State Publishing House, Varna. 1-245
- [11] Prodanov K. and Stoyanova M. 1999. *Sustainable development and use of marine biological resources*. Varna. 265 pp
- [12] Quignard, J. P. and H. Farrugio. 1981. Age and growth of grey mullet. Aquaculture of Grey Mullet. Ed. O. H. Oren. International Biological Programme 26. Cambridge University Press:155-184
- [13] Walford, L., 1946: A new graphics method of describing the growth of animals. Biol Bull. 90(2):141-147
- [14] von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquires on growth laws II). Human Biology 10: 181-213
- [15] Ricker, W., 1975: *Computation and interpretation of biological statistics of fish populations*. Bulletin of the Fisheries Research Board of Canada. 191, 382 pp
- [16] Hohendorf, K., 1966: Eine Diskussion der Bertalanffy – Funktionen und Ihre Anwendung zur Charakterisierung des Wachstums von Fishen. Kieler Meeresforschungen. 22(1):70-90.

AGE AND GROWTH OF FLATHEAD GREY MULLET (*Mugil cephalus*, Linnaeus 1758) IN BULGARIAN BLACK SEA COAST

Radoslava BEKOVA*, Galerida RAIKOVA-PETROVA**, Bogdan PRODANOV*,
Marina PANAYOTOVA*

*Institute of Oceanology "Fridtjof Nansen," Bulgarian Academy of Science, Varna, Bulgaria

** Department of General and Applied Hydrobiology, Faculty of Biology, Sofia University St. Kl. Ohridski

Abstract. A population of flathead grey mullet (*Mugil cephalus* (Linnaeus, 1758) was studied to measure seasonal and annual growth rates. The annual growth rates were similar to those reported for other populations from the range of the distribution of the species. As usual, the growth rate of adult males was slower than that of females. Males reached adulthood in their third summer. Females of the same age showed a moderate gonadal development but did not ripen until the next summer. Mulletts of all ages gained weight only when the water temperature was higher than 20°C.

Keywords: von Bertalanffy growth parameters, *Mugil cephalus*, Black Sea coast

INTRODUCTION

The flathead mullet (*Mugil cephalus* L.) is cosmopolitan, occurring in tropical, subtropical and temperate coastal waters in all the world's major oceans [1,2]. This species occupies a wide variety of marine, estuarine and freshwater environments but spawning occurs in the sea [3,4]. As expected with the above distribution pattern, *M. cephalus* is a strongly euryhaline species capable of living in waters ranging from fresh to hyperhaline [5,6]. The flathead mullet is also found in both clear and turbid areas, sandy and muddy habitats, and can survive in waters with a wide range of dissolved oxygen levels [7,8]. Indeed the demand for mullet roe in many parts of the world has grown considerably in recent decades and elevated the status of grey mullet to be being called "grey gold" by fishermen [9]. *M. cephalus* is the most widespread species among the family Mugilidae, which comprises a total of 20 genera and 70 valid species (11 of which belong to the genus *Mugil*) [10].

In Bulgaria, the increase in flathead mullet first works Nechaev [11], but reportedly quite incomplete. Other authors who worked on the flathead mullet on our coast were Grozev (1945) and Drenski (1951) [12,13], and both authors did not affect the growth of the flathead mullet. The only author who makes complete research on the growth of the flathead mullet on the Bulgarian Black Sea coast is Aleksandrova [14,15,16,17,18, 19, 20, 21, 22].

MATERIAL AND METHODS

M. cephalus specimens were collected during the period May 2010 – June 2018 from the areas of Bulgarian Black Sea coast (Fig. 1). The samples were collected by cast nets fishing – the size of the eye 22-38 mm, length 50 m and height of the nets between 1.5 and 2 m. 1359 individuals were used to study the size-age structure and the growth rate of the flathead mullet.

For each specimen standard length ($L \pm 1\text{mm}$), total weight ($TW \pm 1\text{g}$), gutted weight ($W \pm 1\text{g}$) were measured. The age was determined by the scales at a magnification of $17.5\times$ with Projector Dokumator, Lasergeret (Carl Zeiss, Jena). Length and weight at the age were back-calculated, and the received values were used to calculate the von Bertalanffy's growth parameters. To assess if the growth potential of the population was well used the coefficient of Hohendorf was applied. The parameters k , L_{∞} / W_{∞} , to from von Bertalanffy's equation.

Figure 1. Sampling area for the *Mugil cephalus* along the Bulgarian Black Sea coast

RESULTS

The age structure of the flathead mullet population has represented by eight age groups (Fig. 2). The one-year and 4-year-old fish are the most numerous. The most comprehensive range is the second age group that covers 11-dimensional classes.

Figure 2. Distribution of the age groups (%) of *M. cephalus* along the Bulgarian Black Sea coast

The established age structure classifies the population of the flathead mullet the middle-life populations (with a maximum age of 8 to 12) [23, 24]. The average weighted age of the population is 3.3 years. The smaller digital presence of fish of the larger age groups, as well as the weighted average age, means maintaining a young population. The reason for this probably is overfishing, which is aimed primarily at larger specimens. Another factor that affects the population structure is a lousy food base. It should not underestimate the intense pollution of some coastal areas of the Black Sea, Burgas, and Varna Lake.

The size structure of the population has represented by 46-dimensional classes (Fig 3).

Figure 3. The size structure of flathead mullet (*Mugil cephalus* L.) from the Bulgarian Black Sea coast

The general equation representing the relationship between L and S for the study population of flathead mullet is:

$$L' = 2,582S - 1,9712, r = 0.9974$$

The relationship between L and S has represented in Fig. 4.

Figure 4. The relation between the length (L , cm) and the length of the diagonal radius of the scales (S) at flathead mullet (*Mugil cephalus*, L)

Obtained by reverse calculation values for the length of the body in different age groups give different deviations from the empirically established. The lack of consistently lower values of the back-calculated lengths shows that although fishing pressure individuals in the population are not very fine.

The most likely cause of the uneven growth rate of generations is irregular fishing and the poor ecological status of the primary wintering sites of the flathead mullet.

The relationship between the average lengths of the body of age t years (L_t) and average lengths after one year (L_{t+1}) is well-expressed rights which are described by the equation of the Ford-Walford [25]: $L_{t+1} = 5.3152 - 0.0293L_t$ ($r = 0.998$). This shows that, with increasing age, linear growth of the flathead mullet on the Bulgarian Black Sea coast can be described with the von Bertalanffy equation [26] (Fig. 5): $L_t = 04,21[1 - e^{-0.03(t+0.14)}]$

According to von Bertalanffy's model, the asymptomatic length (L_∞) is 204.21 cm. The reason for this result is the low value of the growth factor k - 0.03, indicating a meager rate of growth of the individuals in the population. Low values we get for k explain the higher values we get for L_∞ since two parameters are inversely related - the smaller the value of the integer k , the greater are the values of L_∞ [27]. For the flathead mullet Alexandrova [14] it received values for L_∞ - 69.1 cm, at $k = 0.416$ and $t_0 = 0.0843$. In comparing asymptotic to the maximum observed in our capture length ($L_{\max} = 48,7$ cm) $L_{\max} : L_\infty$ give little value 0.24. This indicates that the population of *M. cephalus* in the region not used enough growth potential [28].

Figure 5. von Bertalanffy's equation for length growth of the flathead mullet (*M. cephalus*, L_t) from the Bulgarian Black Sea coast

Obtaining higher levels of L_∞ and accordingly, shallow values of k are usually observed in populations with a low initial length and slower growth rate.

General population equation describing the relationship between length and weight is:

$$W' = 0.0132L^{3.0654}, r = 0.9938$$

Graphically dependence is shown in Fig. 6.

Figure 6. The relation between the length (L, cm) and weight (W, g) of the flathead mullet (*M. cephalus*, L.)

The asymptotic average weight (W_{∞}) that we get to flathead mullet from the Bulgarian Black Sea coast is 3139 g (Fig. 7). By comparing this value to the maximum set in our catches ($W_{\max} = 1800$ g), we obtain 0.6 by $W_{\max} : W_{\infty}$ of Hohendorf [28]. This Hohendorf coefficient value indicates that the studied population does not fully exploit its growth potential.

As with linear growth, high values for W_{∞} and shallow k values are most likely due to the low weight of fish in the first year and the process of self-regulation of growth.

Figure 7. Graph of the von Bertalanffy equation for the weight growth of the *Mugil cephalus* from the Bulgarian Black Sea coast

CONCLUSIONS

The population of the flathead mullet of the Bulgarian Black Sea aquatory is young, characterized by a slow growth rate, which is probably due to the deteriorated living conditions and the early age of sexual maturation. The population of the flathead mullet does not use enough growth potential. The fact is that global fishing for flathead mullet is just as susceptible to overfishing as other marine fish species.

Acknowledgments. The study is realized with the financial support of National Scientific Fund at the Ministry of Education, Youth and Science of Bulgaria through project entitled: “The influence of environmental condition of Varna and Burgas bays on population-biological parameters of mullets species (*Mugil cephalus*, *Liza aurata* and *Liza saliens*)” contract № DM11/2 from 15 Dec 2017.

REFERENCES

- [1] Briggs JC (1960) Fishes of worldwide (circumtropical) distribution. Copeia 1960:171–180
- [2] Thomson JM (1966) The grey mullets. Oceanogr Mar Biol Ann Rev 4:301–355
- [3] Thomson JM (1955) The movements and migrations of mullet (*Mugil cephalus* L.). Aust J Mar Freshw Res 6:328–347
- [4] Ibanez AL, Gutierrez-Benitez O (2004) Climate variables and spawning migrations of the striped mullet and white mullet in the north-western area of the Gulf of Mexico. J Fish Biol 65:622–63
- [5] Cardona L (2006) Habitat selection by grey mullets (Osteichthyes: Mugilidae) in Mediterranean estuaries: the role of salinity. Sci Mar 70:443–455
- [6] Young GC, Potter IC (2002) Influence of exceptionally high salinities, marked variations in freshwater discharge and the opening of estuary mouth on the characteristics of the ichthyofauna of a normally-closed estuary. Est Coast Shelf Sci 55(2):223–246

- [7] Thomson JM (1963) Synopsis of biological data on the grey mullet, *Mugil cephalus* Linnaeus, 1758. CSIRO Aust Fish Oceanogr Fish Synop 1:1–66
- [8] Hoese HD (1985) Jumping mullet—the internal diving bell hypothesis. *Environ Biol Fish* 13(4):309–314
- [9] Hung C-M, Shaw D (2006) The impact of upstream catch and global warming on the grey mullet fishery in Taiwan: A non-cooperative game analysis. *Mar Res Econ* 21:285–300
- [10] Eschmeyer WN, Fricke R (eds) (2011) *Catalog of fishes*.
- [11] Nechaev AI. (1933) Preliminary report of the flathead mullet survey. *Journal of Experimental Ichthyol. station in Sozopol*, т. 1
- [12] Grozev Gr. (1945). Pontic shads and mullets fish from Bulgaria. In: *Systematics, anatomy and biological features*: 31.
- [13] Drensky, P. 1951. *The fishes of Bulgaria*. Fauna of Bulgaria, vol. 2:268 pp. (in Bulg.)
- [14] Alexandrova K, 1957. The growth of the grey mullet (*Mugil cephalus* L.) of the Bulgarian Black Sea shores. *Bulletin de l'Institut de Pisciculture et de Pecherie, Varna*, 1, 61-76. (in Bulg.)
- [15] Alexandrova K., 1961. Distribution and migrations of fish Mulletts fish (*Mugilidae*) on the Bulgarian Black Sea coast. *Bulletin de l'Institut de Pisciculture et de Pecherie, Varna* т.1
- [16] Alexandrova, K. 1964. Particularities in the growth of *Mugil auratus* Risso along the Bulgarian Black Sea coast. *Trav. l'Inst. Rech. Scient. Peche Varna*, vol. 4:237-252. (in Bulg.)
- [17] Alexandrova K, 1964. The growth of *Mugil saliens* Risso along the Bulgarian coast of the Black Sea. *Bulletin de l'Institut de Pisciculture et de Pecherie, Varna*, 5, 117-128. (in Bulg.)
- [18] Alexandrova K, 1967. Mulletts in the lakes along the Bulgarian Black Sea coast. *Proceeding of Researcher Institute of Fisheries and Oceanography. Varna*, 8, 263-293. (in Bulg.)
- [19] Alexandrova K. 1967. Mulletts fish in Burgas Lake (Vaya). In *Fish stock assessments*, vol. 3
- [20] Alexandrova K., 1973. Catches of mullets fish from the Bulgarian Black Sea coast and its impact on their stocks. *IORS - Varna item. XII*: 122-143(in Bulg.)
- [21] Aleksandrova 1983. Observations on the distribution and number of small fish of some fish species in front of the Bulgarian Black Sea coast. *J. Ins. Fish Resources*, vol. XX: 85-92 (in Bulg.)
- [22] Alexandrova K. 1985. What happened with mullets fishes? *Journal "Far" – Varna*: 138-142 (in Bulg.)
- [23] Prodanov K. and Stoyanova M. 1999. *Sustainable development and use of marine biological resources*. Varna. 265 pp
- [24] Quignard, J. P. and H. Farrugio. 1981. Age and growth of grey mullet. *Aquaculture of Grey Mulletts*. Ed. O. H. Oren. International Biological Programme 26. Cambridge University Press:155-184
- [25] Walford, L., 1946: A new graphics method of describing the growth of animals. *Biol Bull.* 90(2):141-147
- [26] von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquires on growth laws II). *Human Biology* 10: 181-213
- [27] Ricker, W., 1975: *Computation and interpretation of biological statistics of fish populations*. *Bulletin of the Fisheries Reseach Board of Canada*. 191, 382 pp
- [28] Hohendorf, K., 1966: Eine Diskussion der Bertalanffy – Funktionen und Ihre Anwendung zur Charakterisierung des Wachstums von Fishen. *Kieler Meeresforsschungen*. 22(1):70-90.

THE INFLUENCE OF ENVIRONMENTAL CONDITION OF VARNA AND BURGAS BAYS ON POPULATION-BIOLOGICAL PARAMETERS OF MULLET SPECIES (*Mugil cephalus*, *Chelon auratus* and *Chelon saliens*)

Radoslava BEKOVA, Bogdan PRODANOV*, Marina PANAYOTOVA, and Todor LAMBEV

Institute of Oceanology "Fridtjof Nansen," Bulgarian Academy of Science, Varna, Bulgaria

*Corresponding author

Abstract. An ecosystem approach has been chosen for the assessment of the status of the populations of the three species of Mullet fish from the Varna and Bourgas bays. The complex data requirements for both species and physicochemical parameters and sediment are the basis for a peer assessment of the status of the populations of Mullet fish in both bays, and an assessment of local anthropogenic effects by hydrochemical analyzes will be made.

The present project proposal aims to continue and deepen the study of the population-biological characteristics of 3 species of Mullet (Mugil cephalus, Chelon auratus and Chelon saliens) from Varna and Bourgas bays using an ecosystem approach by determining the degree of contamination with Biogenic substances and their impact on Mullet fish.

Keywords: *Mugil cephalus*, *Chelon auratus*, *Chelon saliens*, population-biological parameters

INTRODUCTION

Changes in the environment due to the anthropogenic factors affect all parts of the plant and animal world in inland waters, seas, and oceans. The Black Sea is near to the so-called "red line," behind which ecosystem degradation processes may become irreversible. Industrial fishing is most important because it directly destroys a significant part of the populations of individual species, which in one way or another affects all species that are in strictly specific relation to the intensely exploited species.

Over the last 50 years, at different times, biology studies and monitoring of the stock of 8-10 Black Sea species, including the mullets fish, have been conducted. The fishing press is steadily increasing, stocks are decreasing, but officially published data based on scientific research is almost lacking. Over the last decade, it is necessary to catch the catches of more and more of the Black Sea industrial species, but this requires current data on their population biology (size, age, and sex composition, growth rate, fertility rate, etc.) and catch statistics.

Pending the introduction of the quota and mullets species, but research also missing. The only published data about them are their catch from the Bulgarian Black Sea coast before 40-50 years [1,2,3,4,5,6,7].

The mullets fish, as fast-growing species are sensitive to various anthropogenic impacts and changes. The dynamics of the stocks of these species is heavily dependent on both the magnitude of catches and the changing ecological status of the Black Sea during the various years.

These characteristics of species of the family and the lack of regular data on the state of their populations, require the completion of specialized studies of population parameters and their supplies in Bulgarian aquatories.

All this highlights the relevance of the proposed research problem. The results obtained will be necessary for determining the ecological status of two economically essential bays for the Bulgarian Black Sea coast as well as the state of the populations of three economically valuable fish species such as the Grey mullet, Golden grey mullet, and Leaping mullet.

In the conditions of increased Black Sea productivity due to organic input, industrial fishing dramatically reduces the size of fish populations and, in some cases, leads to the complete disappearance of individual species, which predetermines the imbalance between the different food chain units. Concerning Mullet's species, catches have declined in recent decades, most likely due to multi-year overrun, changes in ecological conditions (mainly habitat loss).

In our country, the highest percentage of the catch of the Grey mullet shall fall to the inflow into the lakes. The main age grey mullet of the autumn lake is caught by 1+ years old fishes [8, 9].

Nechayev [10] reported that in Mandra Lake is predominantly a Grey mullet and a Golden grey mullet, noting their total annual catches in 1935, 1936 and 1937, amounting respectively to 3 t, 151.7 t, and 37.6 t. The statistics for the period 1949 - 1950 show meager catches of the three species of Mullet fishes for this lake - 1.5 t in 1949 and 10t in 1950 [4, 9, 11]. Of the annual catches in 1950, 6.5 t fall on the platter and the shrimp and 3.5 t on the head.

In the period 1950-1970, the average multiannual Grey mullet fishery made on the Bulgarian coast amounted to 192 tonnes, of which 146 tonnes (76% of the total catch of Mulletts) were from the lakes and 46 tonnes (24% of the total catch) - from the sea [7].

The average annual catch for Beloslav Lake in the period 1950-1967 amounted to 7.01 kg/dka [11].

The analysis of the age composition of the Golden grey mullet hunted on the Bulgarian coast shows that the main age group involved in the catches is that of the one-year-olds [3]. Secondly, they are two-year-old, and in 1961 and 1962 they are dominant in catches.

First data on the capture of mullet fish on our Black Sea Coast is reported by Maksimumov [12]. According to him, catches of Mullet fish are of great importance for fishing on the Bulgarian coast, but they are uneven. For Bulgarian Black Sea fishing, mullet fishes account for half of the average annual catch for the period 1942-1958 (180 t, or 54% of the average annual catch of fish at sea). It is based mainly on Grey mullet and Golden grey mullet. Leaping mullet is fished in small quantities [2].

MATERIALS AND METHODS

M. cephalus specimens were collected during the period May 2010 – June 2018 from the areas of Bulgarian Black Sea coast (Fig. 1). The samples were collected by cast nets fishing – the size of the eye 22-38 mm, length 50 m and height of the nets between 1.5 and 2 m. 1359 individuals were used to study the size-age structure and the growth rate of the flathead mullet.

For each specimen standard length ($L \pm 1\text{mm}$), total weight ($TW \pm 1\text{g}$), gutted weight ($W \pm 1\text{g}$) were measured. The age was determined by the scales at a magnification of $17.5\times$ with Projector Dokumator, Lasergeret (Carl Zeiss, Jena). Length and weight at the age were back-calculated, and the received values were used to calculate the von Bertalanffy's growth parameters. To assess if the growth potential of the population was well used the coefficient of Hohendorf was applied. It will be calculated the parameters from von Bertalanffy's equation k , L_{∞} , W_{∞} , t_0 .

The model was generated making use of data from Single beam echosounder Sonarmite BTX, preliminary post-processed by GIS software. In order to reveal the contemporary morphology of the Beloslav, Varna and Uzungeren Lakes, the bathymetry model was generated having a horizontal resolution of 5 m.

Figure 1. Sampling area for the *Mugil cephalus*, *Chelon auratus*, and *Chelon saliens* along the Varna and Burgas Bays

Figure 2. Bathymetric map of the Uzungeren Lake (Burgas Bay)

Figure 3. Bathymetric chart of the Varna and Beloslav Lakes

RESULTS

The particular status of brackish areas in coastal areas, located at the interface between sea and river influences, results in highly variable environmental and ecological conditions that shift over space and time. The combined effects of climatic changes and human activities have tremendous consequences on these ecosystems. The conservation of these environments is one of the biggest challenges for humanity and, in order to achieve integrated management, researchers, ecologists and managers need to select relevant indicators which could be used as tracers for the state of coastal areas. These indicators are generally chosen among living species or physicochemical parameters or a combination of both. Among the fish species living in brackish water, very few occupy these ecosystems in more than one oceanic region. However, there are species from family Mugilidae, which are found worldwide and they are cosmopolitan in almost all tropical and temperate coastal zones. These

fish can live and reproduce in widely different habitats, but the mechanisms which are involved in this process are poorly known or have been studied separately in each area. Moreover these species and related taxa support essential fisheries, especially in developing countries.

The particular status of brackish ecosystems (mouth, firth, and lagoons) in coastal areas, located at the interface between sea and river influences, results in highly variable environmental and ecological conditions that shift over space and time. The combined effects of climatic changes and human activities have tremendous consequences on these ecosystems, modulating natural variations and influencing the resilience capacity of these environments. They are spatially limited but present one of the most biologically productive aquatic areas. Their conservation is one of the biggest challenges for humanity.

At this stage of the project are collected Ichthyological samples from points of Varna and Bourgas bays, as well as the underlying physicochemical parameters. Analyzing and publishing the collected material is forthcoming. A bathymetric model was made at the Varna, Beloslav lakes (fig. 3), as well as on the Uzungeren Lake (fig. 2). The analysis showed that the lakes are suitable for habitats for the feeding of mullets fish. Analysis of physicochemical parameters is to be carried out and this together with the biological quality elements to be analyzed will show to what extent the ecological status affects the biological parameters of mullets fish.

The initial results of the represented multidisciplinary approach completely follow the concept set up in the project “The influence of environmental condition of Varna and Burgas bays on population-biological parameters of mullets species (*Mugil cephalus*, *Liza aurata* and *Liza saliens*)”. The combination of contemporary bathymetric data and assessment of ecological status will allow a complete analysis of the mullet fish biological-population parameters.

CONCLUSIONS

The species from family Mugilidae represents a good candidate as an indicator species in order to follow littoral environmental changes, due to its cosmopolitan distribution in a wide variety of habitats throughout the world. A global observation network coordinating the use of this species as an indicator of the state of coastal areas, by observing the population genetics, the life history trait variations and the physiological responses to salinity or pollution, could be particularly relevant. Initially, further phylogenetic and population genetic investigations are needed to understand the origin, distribution and biology of *M. cephalus* around the world. Secondly, collating the different adaptive responses in term of growth and reproduction (e.g. fecundity, size at first maturation, oocyte size) for different populations could constitute the basis for the characterization of the environmental pressures. The different methods used for life history trait calculation should be standardized at a higher scale.

Finally, the development of (new) biomarkers to identify potential responses of the populations should be an ultimate goal of this investigation.

Acknowledgments. The study was realized with the financial support of National Scientific Fund at the Ministry of Education, Youth and Science of Bulgaria through project entitled: “The influence of environmental condition of Varna and Burgas bays on population-biological parameters of mullets species (*Mugil cephalus*, *Liza aurata* and *Liza saliens*)” contract № DM11/2 from 15 Dec 2017.

REFERENCES

- [1] Alexandrova K. 1957. Migrations of mullet fish on our coast. Fisheries magazine, vol 4: 6-7.
- [2] Alexandrova K., 1961. Distribution and migrations of fish Mulletts fish (Mugilidae) on the Bulgarian Black Sea coast. Bulletin de l'Institut de Pisciculture et de Pecherie, Varna t.I
- [3] Alexandrova K., 1964. The growth of *Mugil saliens* Risso along the Bulgarian coast of the Black Sea. Bulletin de l'Institut de Pisciculture et de Pecherie, Varna, 5, 117-128. (in Bulg.)
- [4] Alexandrova K. 1967. Mulletts fish in Burgas Lake (Vaya). In Fish stock assessments, vol. 3
- [5] Alexandrova K., 1973. Catches of mullets fish from the Bulgarian Black Sea coast and its impact on their stocks. IORS - Varna item. XII: 122-143(in Bulg.)
- [6] Aleksandrova 1983. Observations on the distribution and number of small fish of some fish species in front of the Bulgarian Black Sea coast. J. Ins. Fish Resources, vol. XX: 85-92 (in Bulg.)
- [7] Alexandrova K. 1985. What happened with mullets fishes? Journal “Far” – Varna: 138-142 (in Bulg.)
- [8] Alexandrova K., 1957. The growth of the grey mullet (*Mugil cephalus* L.) of the Bulgarian Black Sea shores. Bulletin de l'Institut de Pisciculture et de Pecherie, Varna, 1, 61-76. (in Bulg.)
- [9] Alexandrova K., 1967. Mulletts in the lakes along the Bulgarian Black Sea coast. Proceeding of Researcher Institute of Fisheries and Oceanography. Varna, 8, 263-293. (in Bulg.)
- [10] Nechaev A.I. (1933) Preliminary report of the flathead mullet survey. Journal of Experimental Ichthyol. station in Sozopol, т. 1
- [11] Mihailova-Neikova M., 1958/59. Hydrobiological studies on Mandren Lake in connection with its fishery use. Yearbook of Sofia University. Biology (Zoology). Science and Art. т.LIII: 57-115
- [12] Maksimov V. 1914. Materials to learn Russian fishing - Marine fishing in Bulgaria "printed in St. Petersburg.

ORGANIC ENRICHMENT IN THE BULGARIAN BLACK SEA COASTAL SEDIMENTS BASED ON GEOCHEMICAL INDICATORS

Valentina Doncheva*, Ognyana Hristova*, Boryana Djurova*, Ekaterina
Trifonova*, Valentina Todorova*

* - Institute of Oceanology –BAS, Varna, Bulgaria

Abstract: Coastal sediments were classified according to their organic enrichment. The physico-chemical parameters pH, Eh, oxygen and organic carbon were measured in the surface layer of the sediments collected at 44 stations during monitoring cruise in June-July 2016. Grain size analyses were performed on all collected samples. The K-Means Cluster Analysis method was used to classify the data based on the closest centroid.

Key words: Black Sea, sediments, pH, Eh, oxygen, organic carbon

INTRODUCTION

Eutrophication is recognized as one of the major threats to the Black Sea ecosystem health. Eutrophication in the coastal marine systems may significantly increase organic sedimentation and storage of organic matter in the surface sediments. Changes in oxic conditions in surface sediments affect the size and taxonomic composition of both microbial and faunal communities in all benthic habitats. Measuring organic enrichment effects in sediments would be useful for quantifying eutrophication in coastal waters (Hargrave 2008).

The main goal of the paper is to scale organic enrichment along the Bulgarian Black Sea coast.

METHODS

In 2016, during a monitoring campaign with R/V *Akademik* under the Water Framework Directive, 44 sediment samples were collected from the coastal water bodies by Van Veen grab 0.1 m². The sediments were analysed for grain-size (dry sieving, wet sieving or hydrometer methods), water content and organic carbon to determine the composition and structure of the bottom substrate. Organic carbon in the sediments was analysed spectrophotometrically. The method is based on measuring the absorbance of a bichromate ion-containing solution at a wavelength of 590 nm after pre-oxidation of the sediment sample with potassium dichromate in sulfuric acid medium [1]. The limit of detection was 0.01%. Water content was determined by weight.

Temperature, hydrogen potential (pH), oxidation-reduction potential (Eh) and oxygen in sediments were measured on board the ship. **Oxygen** and **temperature** were measured with a professional digital multimeter for portable field measurements WTW MultiLine 3410 with dissolved oxygen probes FDO 925 and a digital 4-electrode-IDS conductivity cell TetraCon 925. Salinity was measured in the near bottom layer.

Hydrogen potential (pH), oxidation-reduction potential (Eh) were measured by a HANNA HI83141 multiparameter device with HI1230B electrodes for pH with an accuracy of ± 0.01 for pH and HI3230B for Eh. The pH electrode was calibrated with HI 7007 M solution for pH = 7.01.2. and HI 7010 M solution for pH = 10.01. The accuracy of the Eh electrode was checked by immersing it in test solutions.

Measurement of all parameters using electrodes was done by placing the electrode in the sediment until the indication was stabilized. Due to lack of sufficient ship time, the Eh and oxygen measurements were made after 10 minutes. The measurements of Eh are converted to a normal hydrogen electrode (NHE) after addition of 205 to the indication or $Eh\ NHE = Eo + (224 - T)$ where Eo is the measured Eh value at the measured temperature T.

For the classification of the sediments according to the measured parameters, the K-Means Cluster Analysis method was used, which is based on the so-called sorting regarding the closest centroid. This method takes into account the distance of each unit to the centers of the individual clusters, with the closest distance determining the unit's belonging to the respective cluster. The clusters were interpolated by generation of Thiessen polygons clipped in 1 nautical mile zone.

Figure 1. Map of the sampling stations

RESULTS AND DISCUSSION

The mean values and standard deviations of measured parameters discriminated by sediment type are included in table 1

Table 1. The mean values of investigated parameters discriminated by sediment type

	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Mean	devia tion	pH C	Eh	Eh	Eh (NHE)- T	Eh (NHE)- T	O2 ml/l	O2 ml/l	Corg.,%	Corg.,%	W,%	W,%
Shells	8.62	0.00	16.0	0.00	216.10	0.00	7.17	0.00	0.54*	0.00	57.50	0.00
Myddy sandy shells	8.14	0.22	- 165.7	14.22	33.37	14.37	0.78	1.15	0.39	0.11	38.63	10.38
Shelly coarse sand	8.50	0.42	227.2	15.53	425.66	15.57	6.24	3.09	0.21	0.14	23.73	3.03
Coarse sand	8.63	0.00	238.0	0.00	435.80	0.00	6.67	0.00	0.10	0.00	23.84	0.00
Shelly medium sand	8.66	0.00	235.0	0.00	432.70	0.00	3.43	0.00	0.12	0.00	27.70	0.00
Medium sand	8.18	0.50	71.8	198.41	270.56	199.21	5.16	3.34	0.17	0.21	24.79	3.36
Shelly fine sand	8.45	0.22	-55.0	134.35	145.15	130.74	1.14	1.62	0.58	0.39	36.25	4.89
Fine sand	8.46	0.07	-29.1	95.22	169.33	95.02	3.05	1.86	0.09	0.02	26.78	1.19
Muddy find sand	8.04	0.00	- 118.0	0.00	82.60	0.00	2.11	0.00	0.18	0.00	28.94	0.00
Very find sand	8.24	0.54	- 117.0	29.88	81.38	30.15	0.43	0.36	0.18	0.08	28.24	1.81
Shelly very find sand	8.32	0.00	- 222.0	0.00	-24.30	0.00	2.57	0.00	0.11	0.00	26.60	0.00
Muddy very fine sand	7.77	0.25	- 169.5	41.72	32.75	48.58	0.11	0.16	0.51	0.48	39.96	16.67
Sandy mud	7.74	0.23	- 232.3	48.98	-28.97	52.78	0.00	0.01	0.87	0.26	54.13	7.00
Total	8.20	0.42	-48.7	176.90	151.15	175.91	2.52	2.90	0.36	0.34	34.74	12.93

Hydrogen potential – pH. There are no published data on pH in sediments from the Bulgarian part of the Black Sea. The distribution of pH in surface water and the upper homogeneous layer was relatively even, with winter values around 8.3, and during the transitional seasons and summer it reached 8.4-8.6. In depth pH gradually decreased to 7.7-7.8 in the redox layer [2]. The average pH value in the sediments was 8.2 within a range from 7.34 to 8. The high values over 8 prevailed - about 70% of the observations were in the range 8.2-8.8. The measurements in sand sediments also dominated, 30 out of 43 with an average pH of 8.35.

Measured pH values alone and in combination with Eh did not show deviations in the quality of the environment – Fig. 2. It has been proved that two-dimensional pH graphs against Eh or sulphides, well discriminate areas with varying degrees of organic load [3]. The minimum values of both parameters, pH and Eh, are above the threshold for unacceptable environmental conditions. For a threshold value between unacceptable and transient conditions was adopted 7.1 pH [3]. The minimum measured value was higher than 7.1, namely 7.34 in sediments from Galata station. When combined with Eh, the boundary between unacceptable and transient Eh NHE conditions is -100 mV for a normal hydrogen electrode, while the minimum established oxidizing-reduction potential according to NHE is -95mV, i. e. in a combination of both parameters, pH and Eh, the sediments have acceptable environmental conditions [3], [4] – Fig. 2 probably the lower than 8 pH values, combined with low Eh potential, were an indicator of sulphate reduction in the stations Golden Sands, Balchik, Albena, Kavarna, Rusalka, Galata, Bourgas-2 and Rosenets, where oxygen was absent and organic carbon (Corg) values were relatively higher.

Figure 2. Relationships between pH and Eh NHE in 0–2 cm sediments (after [3], [4])

Oxygen. In the national literature, there is no data of oxygen concentrations in the near bottom water layer and sediments. The average measured value was 2.5 ml/l, the modal value - 0 ml/l, and the maximum one of 9.8 ml/l was found in the coarse sand at Koketra sandbank. To evaluate the properties of the sediments with respect to oxygen, the scale represented in [4], [5] was used, based on the publication [6], dealing with the impact of hypoxia on benthic organisms. There, hypoxia is considered in two categories as a type (seasonal, aperiodic and periodic) and as a level (moderate and severe), with limit values given only for hypoxia. Concentrations between 2 ml/l and 8-10 are referred to as normoxia. The sediments were classified in 3 classes: for Pro-Hypoxia (Normoxia)- >2ml/l, Hypoxia (2-0.5ml/l) and anoxia 0 ml/l – Fig.3. The stations are divided into a 3 point scale according to the oxygen concentration, and at concentrations above 2 ml/l the sediments are considered to be well oxygenated environment.

Figure 3. Map of sediments classified according to oxygen concentrations: anoxia 0 ml/l; Hypoxia (2-0.5ml/l) and for Pro-Hypoxia (Normoxia)- >2ml/l

Oxidation-reduction potential Eh. The available classifications refer to a normal hydrogen electrode [4], but since the measurements did not last until stabilized values, the existing thresholds were shifted approximately with +200 mV. The values lower than 0 mV Eh (NHE) were defined as sediments with hypoxic conditions, and all measured negative values (Eh) or approximately 200 mV Eh (NHE) - as potentially hypoxic or transient with sulphate reduction, over 200 mV Eh (NHE) - as oxygen environment with aerobic metabolism. The mean Eh is -48.7 (Eh (NHE) -295) and the range was from -295 Eh (Eh (NHE) -94.5) to 249 Eh (Eh (NHE) -447.3). The minimum was measured in sandy mud and maximum – in coarse sand-Table 1. 25% of samples were classified as anoxic, 37% as potentially hypoxic or transient and 40 % as aerobic- Fig. 4.

Organic carbon and water content. The organic carbon content at all stations ranged from 0.07% to 1.42%. High content of organic carbon was measured in muddy sediments - 0.87% on the average. These sediments were also characterized by higher water content from 52% to 68%. Low concentrations of organic

carbon were measured in sandy sediments (0.07-0.09%) - Table 1. The water content of the analysed samples along the entire coast ranged from 20% to 68%, with a lower content percentage being characteristic of sandy sediments.

Figure 4. Map of sediments classified according to Eh (NHE) < 0 mV Eh -hypoxic, 1-200 mV as potentially hypoxic or transient with sulphate reduction, > 200 mV Eh (NHE) – oxic.

All measured parameters in the sediments correlated significantly with the grainsize composition. The grainsize composition is a critical factor for the accumulation of organic matter [7].

The finer sediments occur in low hydrodynamic activity conditions (high sorting factor) and have higher relative surface that adsorbs organic matter. Thus, fine-grained sediments have high affinity for organic matter. The sediments with high mud percentage (clay + silt) had the lowest pH and Eh and the highest percentages of organic carbon and water content.

The data sets was reduced by applying the K-Means Cluster Analysis. The results the K-Means Cluster Analysis do not represent a classification but rather reflect the degree of organic load the sediments in the order from the lowest organic load to the highest one: clusters (Tables 2, 3; Fig.5). The parameters included are pH, Eh, oxygen, organic carbon, percentage of fine sediments or mud and sorting. The resulting 3 clusters are characterized by mean values given in Table 2. Cluster 1 corresponds to oxic conditions, Cluster 2 to transient type of sediments (potentially hypoxic), cluster 3 to anoxic- Table 3.

The observation data set was converted into Thiessen polygons. Thiessen polygons were used to spatially extrapolate the sampling points. Thiessen polygons are created by placing a polygon around each point such that the polygon encloses all the space that is closer to the focal point than any other in the set. Then the approximate area of each cluster was calculated in 1 nautical mile zone- Fig.5. The unidentified area is 38.95 km² (2.6%), the area of oxic zone is about 396.04 km² (27%) area of transient sediments was estimated as 698.7 km² (47.6%) and anoxic - 335.35 km² (22.8%).

The most favourable benthic conditions in sense of oxidization and respectively low organic load are in the central part of coastal zone, which lacks anthropogenic sources – Fig. 3, 4, 5.

Table 2. Mean values for clusters obtained by the K-Means Cluster Analysis method

	Cluster - No. 1	Cluster - No. 2	Cluster - No. 3
Eh (NHE)-T	344.98	69.27	-47.36
pH	8.43	8.17	7.88
O2 ml/l	5.54	0.86	0.28
Copr.,%	0.20	0.32	0.73
W, %	27.18	33.52	47.73
Mud	0.77	17.36	55.42
Sorting	2.04	3.51	4.53

Table 3. Key features of clusters and stations within the cluster

Cluster №	Characteristics by parameters
1	Sediments with the highest values for pH, Eh, oxygen and the lowest organic load - in oxygen environment with aerobic metabolism, moderate to poor sorting, relatively more active hydrodynamic environment, large- to medium-grained sands
2	Transient type of sediments (potentially hypoxic), hypoxic sediments and oxygen conditions, poor sorting, mainly small-grained and silty sands
3	Anoxic conditions, with relatively high organic content and predominating fine sediments with very poor sorting, i.e. low hydrodynamic environment

Figure 5 Distribution of the main studied characteristics of sediments, grouped in 3 clusters

Recommendations:

Measuring of parameters like pH, Eh and oxygen is a proven express method for determining the degree of organic matter loading. Better planning is needed for measurement until stabilization of the electrode to analyze additional parameters like sulphides and chlorine ions.

REFERENCES

- [1] Methods for investigations of organic matter in the ocean.1980. (Ed.E. Romankevich), Nauka, M., 343 (In Russian).
- [2] Shterva G., O. Hristova, B. Djurova.2013. Initial assessment of the marine environment in Art. 8 OF MSFD 2008/56/EC and NOOSMV (2010) Republic Of Bulgaria Ministry Of Environment And Water <http://www.bsbd.org/v2/search.php?lang=bg&search=bsbd&text=initial>
- [3] Schaanning, M.T., Hansen, P.K., 2005. The suitability of electrode measurements for assessment of benthic organic impact and their use in a management system for marine fish farms. In: Hargrave, B.T. (Ed.), *Environmental Effects of Marine Finfish Aquaculture*. Springer, Berlin, pp. 381–408.
- [4] Hargrave, B.T., Holmer, M. and Newcombe, C.P., 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. *Marine Pollution Bulletin*, 56(5), pp.810-824.
- [5] Hargrave, B.T., 2010. Empirical relationships describing benthic impacts of salmon aquaculture. *Aquaculture Environment Interactions*, 1(1), pp.33-46.
- [6] Diaz, R.J., Rosenberg, R., 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioral responses of benthic macrofauna. *Oceanogr. Mar. Biol. Annu. Rev.* 33, 245–303.
- [7] Holmer, M., Wildish, D. and Hargrave, B., 2005. Organic enrichment from marine finfish aquaculture and effects on sediment biogeochemical processes. In *Environmental effects of marine finfish aquaculture* (pp. 181-206). Springer Berlin Heidelberg.

GEOARCHAEOLOGY OF SUBMERGED LANDSCAPES IN THE WESTERN BLACK SEA

Preslav Peev*, Raina Hristova*

* Institute of Oceanology – Bulgarian Academy of Sciences, Bulgaria

Abstract. In the recent decades a special interest among the scientific community marks the new scientific field - marine geoarchaeology. The scientific surveys of submerged Eneolithic and Early Bronze age settlements (6500 – 4000 BP) along the Bulgarian Black sea coast opened the discussion on the relationship between the palaeoecological environment at the beginning of the Holocene and the location of these sites, their cultural context and chronology. Especially relevant are the palaeogeographical reconstruction related to the study of climate changes and the sea-level fluctuations, including the presence of humans. In the focus of such integrated study is the man, his daily life, as well as the reconstruction of the basic parameters of the surrounding environment in which he was active, palaeoecological environment during the various historical periods.

Keywords: marine geoarchaeology, Prehistory, submerged sites.

Geoarchaeology, as a scientific discipline, first appeared in the first half of the 20th century and gained momentum in the 1970s [1]. Its rise is linked to palaeogeographic reconstructions, which become especially popular in European archaeological research in the area of Prehistory. For correct reconstruction of events in the most recent geological age of the Earth - the Holocene, which began before 11700 BP, the human factor has also to be analyzed. In the focus of such type of integrated study, on the one hand, is the man, his way of daily life, as well as the reconstruction of the basic parameters of the surrounding environment in which he was active; of the palaeoecological conditions in which he lived during the various historical periods.

The key to exploring the underwater palaeolandscapes is paleogeographic reconstructions related to the survey of global and regional climate change and sea level fluctuations, including the presence of humans [2]. It is necessary to analyze simultaneously the geological, climatic and other physico-geographic features, the flora and fauna of a given site at the moment and the changes that have occurred in the past of palaeolandscapes. The inclusion of Earth sciences and their traditional methods for archaeological purposes is able to contribute to more accurate and efficient interpretation of geological and archaeological data in tracking of space-time relationships between different sites [3]. The probable modification of the terrain caused by nature modulation processes, sedimentation and post-sequential processes and anthropogenic interference should be traced.

The land-sea area has always been of interest to both science and social dynamics. The coastal areas offer the best livelihoods where the first settlements of humans are concentrated at the beginning of the Holocene. The theme of the Black Sea coastal lines and the conditions of their habitation is extremely up to date. At the beginning of the Holocene (before 8000 B.P.) the relationship between the Black Sea and the Mediterranean was restored [4]. As a result of the Holocene post-glacier transgression, there are significant changes in the palaeogeographic situation on the Bulgarian Black Sea coast. A more detailed study, as well as the detail of the curve for the relative sea level, will contribute to the clarification of the character, the exact location of the sunken prehistoric settlements and parts of the ancient residential quarters and fortification facilities of ancient Greek polis on the western coast. All of this would help to predict the future evolution of the Black Sea region in relation to global climate change and the steadily rising sea level.

In palaeogeographic reconstruction the starting point is the fact that Europe is a sea continent whose coastline is dominated by peninsulas, vast coastal regions, archipelagos that are significantly shaped and dynamically altered in its geological history. These marine regions have often been human displacement centers with high population density and cultural innovation over the last millennia, regions with concentrated fruitful resources and sufficient fresh water on land, direct access to fish-rich and other marine food resources [5]. The regions have provided magnificent opportunities for water traveling, cultural contacts, trade and migration. These advantages can be applied to the restoration of the past throughout Europe's human activity. However, when the sea level has stabilized and reached almost the present level about 6000 years ago, relatively little is known about the role of these submerged coastal stripes and landscapes because they are submerged mainly as a result of rising sea levels after the end of the last ice age.

Other factor which stimulates the investigation of underwater landscapes is the potential of Bulgarian Black Sea continental shelf for finding of archaeological sites and artifacts. It is already well known that most of the present European continental shelf has been exposed several times of droughts during the decreasing of global ocean level [6]. At the Last Glacial Maximum (LGM) when the World Ocean level was at its lowest, at about -130 m below present level, an additional enlarge of land [7] become available on the European continental shelf

estimated about 40% of the present-day European land area, amounting to some 4 millions km² [8] (figure 1). This vast dry land, with flora and fauna, has been the areal of modern man, as well as his predecessors, popular as hominids. The shoreline of the Western Black Sea is thus believed to coincide with the 120 m isobath [9]. The existence of LGM lowstand wedge at the shelf edge is observed off the coast of Romania, Bulgaria and Turkey as the presence of coastal sand dunes and bars and wave-cut terraces confirms this [4; 10].

Figure 1. European continental shelf with maximum extent in red of exposed land 20,000 years ago (http://www.splashcos.org/images/european-continental-shelf-maximum-extent-red-exposed-land-20000-years-ago?size=_original).

Although the sea level is rising since the last ice age and lasts around 15000 years [11], the trend of elevation should not be accepted unambiguously, as continuous and constant transgression. The marine transgression of the Black sea has a negative impact on life in the late Paleolithic and Mesolithic, given the favorable conditions of the coastal plains, the diversity of vegetation and fauna in the wetlands. However, at the same time during the rise of the sea level creates new biotope locations similar to those of the already submerged landscapes, especially in the North Sea, the Adriatic coast, along the western and northwestern Black Sea coasts [12]. In these new wetlands should have adapted the population and there was no serious disruption in their way of life.

Along the West Pontic coasts have been found eighteen submerged prehistoric settlements, which cultural layers are found at depth between 6 and 9 m below present Black sea level [13]. Although the late Chalcolithic and the Early Bronze Age sites are found nowadays along the Black Sea shoreline, the geomorphologic and stratigraphic analysis of the sites indicates that during their existence they were river settlements, located at the mouth of lower river valleys [14]. Archaeological data will give a chance to determine the stages of coastal lakes formation and dynamics of palaeogeographic development of these areas where have a human presence. This is proved by the fluctuation curve of the Black Sea level between 6500–4000 BP as well [15](figure 2).

The sites that are of interest for the topic are situated in the zones of palaeo-valleys of the rivers flowing into the Black Sea and the present bays along the Bulgarian Black Sea coast. A special note is paid to the Gulf of Burgas. There are located a numerous rock banks that represent possible sites of ancient metallurgy and salt production. At the present stage the investigations are fragmented and have no systemic nature. Their survey will be a significant scientific contribution to the study of the dynamics and evolution of the Black Sea littoral zone. Of particular interest is the Cocetrice sand bank, which is probably formed on a core of an ancient Neolithic settlement; Chimovo Bank, of which copper slag has been found – an evidence of ancient metallurgical activity; Pomorie Reef and many others. During the investigations of the relict forms of the underwater relief it became clear that the coastline was passing to the rock banks at a lower Black Sea level [16]. It is suggested that the rock banks themselves during some stages of the coastal development were part of the continent and after this were islands [figure 3]. As a result of coastal erosion and wave destruction their surface has decreased significantly, as the process continues today [17].

Figure 2. Fluctuations in the level of the Black Sea during the Holocene based on radiocarbon data from different areas of the Bulgarian coastal zone [11].

In the frame of numerous programs there is a contribution of series of international scientific research projects which were dealing with a submerged archaeological heritage. Most of them cover the shelf zones of the Baltic and the North seas, the Mediterranean and the Black Sea. Among them is distinguished the project "Submerged Prehistoric Archeology and Landscapes of the Continental Shelf (SPLASHCOS)" under the COST program, Action TD 0902. Within the framework of the project, a research network is established including archaeologists, marine geophysicists, environmental scientists, state agencies for cultural – historical heritage, as well as commercial and industrial organizations interested in exploring, managing and preserving archives with archaeological and palaeoclimate information related to the submerged prehistoric landscapes of the European continental shelf. The main tasks of SPLASHCOS are to promote research, interpretation and management of submerged landscapes and prehistoric archeology of the continental shelf, to create a structure for development of new interdisciplinary and international research proposals and to provide guidance to cultural heritage specialists, government agencies and the general public about the meaning of underwater research. Among the main targets is a deeper understanding of European history, paleoclimate reconstruction and sea level change, and their social significance, and the likely future impact of the changes that began in prehistoric times [18].

At the beginning of the 1980s are obtained convincing evidences of existence of ancient coastline of the Black Sea located at depth 90 – 120 m below present level and dated approximately 8000 BP. It was also ascertained the fact that more than 8000 years ago the Black Sea was a freshwater lake. In the result of scientific surveys carried out at the Institute of Oceanology, there are indisputable geological evidences of the events that occurred about 8000 years ago. They are supported by the archaeological evidences, too. The analysis of the spore-pollen spectra from the studied region shows the presence of cereals for the mentioned period, indicating the beginning of the cultural agriculture in the region [19].

The effect of the study of the geoarchaeology of the underwater landscapes is expected to change the existing ideas about the nature of the geological events occurring through the Holocene on the Bulgarian Black Sea coast, which have reflected on the prehistoric cultures in the Eastern Balkan region. At the moment are known more than 2600 submerged prehistoric archaeological sites on the continental shelf across Europe [20]. The preliminary results showed that the Western Black Sea continental shelf has a great potential for future marine exploration in the area of prehistoric archaeology.

Figure 3. Renaissance map of the Black Sea by Batista Agnese from 1544.

REFERENCES

- [1] K. Butzer. 1982. *Archaeology as Human Ecology*. Cambridge University Press. Cambridge.
- [2] *Submerged Prehistory* (Eds. J. Benjamin, C. Bonsall, C. Pickard, A. Fischer). 2011. Oxbow Books. Oxford
- [3] Marriner, N., C. Morhange, G. Goiran. 2010. Coastal and harbor geoarchaeology. *Geology Today* 26.1, pp. 21-27
- [4] Peev, P., R. Hristova. 2016. Black sea continental shelf in the context of offshore European Prehistory. *Comptes rendus de l'Académie bulgare des Sciences* 69.4, pp. 475-480
- [5] Bailey, G., N. Fleming. 2008. Archaeology of the continental shelf: Marine resources, submerged landscapes and underwater archaeology. *Quaternary Science Review* 27.23-24, pp. 2153-2165
- [6] Lambeck, K. 1996. Sea-level changes and shore – line evolution in Aegean Greece since Upper Pleistolithic time. *Antiquity* 70, pp. 588-611
- [7] Lambeck, K., F. Antonioli, M. Anzidei, L. Ferranti, G. Leoni, G. Scicchitano, S. Silenzi. 2011. Sea level change along the Italian coast during the Holocene and projections for the future. *Quaternary International* 232, pp. 250-257
- [8] Flemming, N., J. Harff, D. Moura, A. Burgess, G. Bailey. 2017. Introduction: Prehistoric remains on the continental shelf – Why do sites and landscapes survive inundation. In: Flemming N, Harff J, Moura D, Burgess A, Bailey G. (eds.) *Submerged Landscapes of the Continental Shelf: Quaternary Paleoenvironments*. Wiley Blackwell, pp. 1-10
- [9] Filipova-Marinova, M. 2007. Archaeological and paleontological evidence of climate dynamics, sea-level change, and coastline migration of the Bulgarian sector of the Circum-Pontic region. In Yanko-Hombach V, Gilbert A, Panin N, Dolukhanov P (eds.) *The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement*. Springer, Dordrecht, pp. 453–482
- [10] Lericolais, G. 2017. Late Pleistocene environmental factors defining the Black Sea and submerged landscapes on the Western continental shelf. In: Flemming N, Harff J, Moura D, Burgess A, Bailey G. (eds.) *Submerged Landscapes of the Continental Shelf: Quaternary Paleoenvironments*. Wiley Blackwell, pp. 479– 495
- [11] Hristova, R. 2006. Palaeogeographical reconstruction of the Bulgarian Black Sea shelf and coastal zone during the Quaternary. *Comptes rendus de l'Académie bulgare des Sciences* 59.12, pp. 1277-1284

- [12] Flemming, N.C., Çağatay, M.N., Chiocci, F.L., Galanidou, N., Jöns, H., Lericolais, G., Missiaen, T., Moore, F., Rosentau, A., Sakellariou, D., Skar, B., Stevenson, A., Weerts, H. 2014. Land Beneath the Waves: Submerged landscapes and sea level change. A joint geoscience-humanities strategy for European Continental Shelf Prehistoric Research. Chu, N.C. and McDonough, N. (Eds.) Position Paper 21 of the European Marine Board, Ostend, Belgium
- [13] Лазаров, М. 1996. Потъналите селища по западното Черноморие в контекста на Понтийската и Средиземноморската история. История 1, с. 48-61
- [14] Peev, P. 2004. Submerged settlements along the West Black Sea coast. The Problem of situation. In: Dobrzanska H, Jerem E, Kalicki T (eds.) The Geoarchaeology of River Valleys. Archaeolingua, Budapest, pp. 161–169
- [15] Filipova-Marinoa, M., R. Christova. 2001. Sea level fluctuations in the western part of the Black Sea during the Holocene. Comptes rendus de l'Académie bulgare des Sciences. 54.5, pp. 59-64
- [16] Пеев, П. 2014. Палеогеография на пристанищните акватории в древната морска история и археология на Западното Черноморие. Дисертация за придобиване на образователна и научна степен „доктор”. Институт по океанология – БАН, Варна
- [17] Пеев, П., В. Пейчев. 2001. Българският черноморски бряг по данни от средновековни карти. Трудове на Института по океанология. Том 3, с. 105-109
- [18] Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf (SPLASHCOS). Final evaluation report. 2013
- [19] Tonkov, Sp., E. Marinova, M. Filipova-Marinoa, E. Bozilova. 2014. Holocene palaeocology and human – environmental interactions at the coastal Black Sea Lake Durankulak, northeastern Bulgaria. Quaternary International 3280329, pp. 277-286
- [20] Jöns, H., M. Mennenga, D. Schaap. 2018. The SPLASHCOS – Viewer. A European information system about submerged prehistoric sites on the continental shelf. A product of COST Action TD 0902 SPLASHCOS (Submerged Prehistoric archaeology and landscapes of the continental shelf). Accessible at <http://splashcos.maris2.nl/>

IMPACT OF THE MESOSCALE CIRCULATION ON THE DISPERSION OF OIL POLLUTION IN THE WESTERN BLACK SEA BASIN

Irina Gancheva*, Elisaveta Peneva*
*Sofia University "St. Kliment Ohridski", Bulgaria

Abstract. The Black Sea is a unique ecosystem environment, very sensitive to the pollution and climate change in the region. One of the common pollutants is the oil, accidentally or deliberately discharged in the areas with intense ship traffic. Traces of the oil spills could reach the near coast if the marine conditions are in favour. The probability varies largely in time and space, depending on the season, location of the initial release and the type of pollutant.

The ocean remote sensing gives us a powerful tool to explore the seas and enriches our understanding for the marine system. In this study we have identified the most probable sources of oil pollution in the Western Black Sea, based on satellite observations and reports by other sources. One test case of an identified oil spill is modelled using real currents data and the dispersion of the oil spill is presented.

Keywords: Oil Spill Detection; Black Sea Circulation

INTRODUCTION

The Black Sea is a semi-closed sea, connected with the Mediterranean Sea through the Turkish Straits System (TSS) - Dardanelles and Bosphorus Straits. The TSS region is a subject of very intensive marine traffic which is especially true for the Bosphorus Strait (31 km long, and about 3 km wide in the entrance).

The Bosphorus Straits is hydraulically controlled two-way exchange: upper current from the Black to Marmara Sea, and lower in the opposite direction. The positive fresh water balance and the saline flow from the lower Bosphorus Strait lead to very strong vertical stratification and unique ecosystem: the biological activity is intense in the upper well ventilated layer of about 100 m and almost disappear in the deeper anoxic layers. As a consequence the ecosystem is very vulnerable to pollution near surface. One of the most frequent contamination is by petrol products, especially in the areas of intense marine traffic. Although the negative impact of oil pollution is well known and investigated [1], accidental and deliberate oil discharges are still happening with high temporal frequency and in considerable amounts. According to the European Maritime Safety Agency (EMSA) 45% of the oil entering the European seas is deliberately discharged and only 36% are accidental oil spills, [2]. Still a large part of the pollution cases remains very often untraced and uncommented.

Satellite data provides the scientific community with a new and powerful tool for exploring and monitoring the Global oceans. Nowadays this type of information has become mostly freely available and its high spatial and temporal frequency provides us with valuable information. On satellite images oily waste is mostly clearly visible as it appears as a dark structure on the brighter sea background. The biggest challenge for this method of oil spill detection is the correct classification of the dark objects, as there are some natural phenomena which might have similar appearance. These so called look-alike structures might appear due to local sea currents or wind conditions, alga blooms, rain cells. There are some valuable works reviewing the potential and challenges of oil spill detection with satellite data, evaluating the different algorithms for the automatic oil spill detection [3, 4, 5].

The most intensive marine traffic in the Black sea circulates between the Bosphorus strait and the major ports at Odessa, Sevastopol, Novorossiysk, Tuapse, Batumi, Samsun, Zonguldak, Burgas, Varna and Constanta (Fig. 1). The analysis of the frequency of the cargo traffic visualised by a traffic density map at the official marine traffic website [6] confirms that figure. It becomes clear that the Western Black Sea basin is strongly exposed to potential oil pollution as most of the marine routes are passing through that region. The analysis of satellite data for detection of potential oil pollution, presented in [7] and [8] confirms that statement.

Fig. 1 Routes of the major marine traffic in the Black Sea.

METHODS OF THE STUDY

The objective of the present work is to study the dispersion of a oily waste on the water surface and to evaluate the probability that it reaches the coastal line. The first step is to identify the potential oil spill on satellite images- to look for dark objects, which would indicate possible surface oil pollution.

The satellite data is collected from the satellite missions Sentinel, which are operated and maintained by the European Space Agency (ESA) [9]. In this study the images scanned by a Synthetic Aperture Radar (SAR) from the Sentinel-1 mission are used.

In total over 30 images of the Western Black Sea region are investigated and on 14 of them the oil spill detection mask notifies a detected dark object. Here we present one case, acquired on 13th of June 2017 by the satellite Sentinel-1 in the Western Black Sea (Fig. 2). The image reveals a dark structure detected by the oil spill detection algorithm, implemented in the ocean toolbox of the software SNAP. SNAP is a software provided by ESA especially for processing and analysing satellite data. The red color indicates the areas, detected by the oil spill algorithm and our area of interest is marked with an arrow. The surface of the pollution is estimated to be approximately 21 km². The red squares show the detected ships longer than 30 m.

Fig. 2 A dark structure visible on a satellite image, acquired on 13 June 2017 in the Western Black Sea basin.

The next step is to evaluate the dispersion of this oil spill. The method is based on the dispersal of casually distributed Lagrangian tracers within the initial oil spot, which drift on the surface following the currents. The advection of the tracers is calculated using the real horizontal velocity from the Copernicus Black Sea reanalysis [10]. In order to calculate the diffusion term the casual function is applied controlled by a diffusion coefficient. The result from the simulation are the positions of the Lagrangian tracers after a 10 days period. The variable which affects most the dispersion rate of the pollution is the horizontal diffusion coefficient, that is why it has to be carefully tuned. In this study we present the tracers dispersion for three different values of the diffusion coefficient and suggest the most proper one. Sinking of the tracers is not taken into consideration in the present simulation and it is a subject of a future work.

RESULTS

In the following section we present the simulations of 1500 Lagrangian tracers departing from the initial spot - the detected dark object shown in Fig. 2. The simulation is done for three different diffusion coefficients. The exact position of the pollution (43.7N, 31.5E) is taken from the satellite image is considered to be the tracer-source. It is approximated to have a circular form with surface as the detected dark object – 21 km². Fig. 3 illustrates the surface current for the day of detection and the black dot marks the initial position of the pollution. It is seen that near the oil spill an eddy is formed and most probably it will define the propagation path of the pollutant.

Fig. 3 Surface circulation on 13. June. 2017; velocity is colour-coded in [m/s]. Black dot on 43.7N, 31.5E is the source of pollution.

Fig. 4: Diffusion coefficient $a=1 \text{ m}^2/\text{s}$; left – source and positions of the tracers after 10 days plotted upon the bathymetry; right – probability distribution after 10 days [%].

Fig. 5: Diffusion coefficient $a=10 \text{ m}^2/\text{s}$; left – source and positions of the tracers after 10 days plotted upon the bathymetry; right – probability distribution after 10 days [%].

Fig. 6: Diffusion coefficient $a=30 \text{ m}^2/\text{s}$; left – source and positions of the tracers after 10 days plotted upon the bathymetry; right – probability distribution after 10 days [%].

DISCUSSION AND CONCLUSIONS

The Fig. 4 to 6 show the distribution of the tracers on the sea surface after 10 days of propagation for the study case acquired on 13 June 2017. The bathymetry of the water basin is colour-coded on the figures on the left and on the right is presented the probability distribution map to spot a tracer on a given location 10 days after the release. It actually represents the process of calibration for the Lagrangian tracers simulation.

It is well seen, that the higher the value of the horizontal diffusion, the more the tracers diverge with time and thus the larger area is covered by the pollution. Considering that no tracers sink with the time and thus for the entire simulation period the amount of tracers is preserved, the covered surface is considerably spacious. In real conditions this would rather not be the case as due the impact of sun, wind, rain and waves the amount of surface oil would decrease with time. Considering the shape of the oil spill the first case is closer to reality as it is known that the oil spill disperse as a linear object. The comparison of the three figures shows that it is very important to use real case of oil spill dispersal to tune the numerical simulation.

References

- [1] John M. Teal and Robert W. Howarth. Oil spill studies: A review of ecological effects. *Environmental Management* , 8(1):27-43, Jan 1984
- [2] European Maritime Safety Agency. Pollution preparedness and response activities, 2010
- [3] Merv Fingas and Carl Brown. Review of oil spill remote sensing. *Marine Pollution Bulletin*, 83(1):9 - 23, 2014.
- [4] A. H. S. Solberg. Remote sensing of ocean oil-spill pollution. *Proceedings of the IEEE* , 100(10):2931 – 2945, Oct 2012.
- [5] Konstantinos N Topouzelis. Oil spill detection by SAR images: dark formation detection, feature extraction and classification algorithms. *Sensors* , 8(10):6642{6659, 2008.
- [6] Marine Traffic. Ship live tracking website. <https://www.marinetraffic.com/> (accessed 5. September 2018)
- [7] Mityagina, M. and Lavrova, O. Satellite monitoring of the Black Sea surface pollution. *Geoscience and Remote Sensing Symposium (IGARSS), 2015 IEEE International. IEEE*, 2015.
- [8] Ferraro, G., Monitoring oil pollution vessels through the integration of satellite technology, *JRC55150*, 2009
- [9] European Space Agency. Sentinel missions, <https://sentinel.esa.int/web/sentinel/home> (accessed 5. September 2018)
- [10] Copernicus Marine Service. <http://marine.copernicus.eu/services-portfolio/access-to-products/> (accessed 5.September 2018)

INTERANNUAL VARIABILITY OF THE MIXED LAYER SUMMER SEA WATER TEMPERATURE IN THE WESTERN BLACK SEA

Nadezhda VALCHEVA*

* Institute of Oceanology – Bulgarian Academy of Sciences, Varna, Bulgaria

Abstract. The study investigates on sea water temperature variability of the surface mixed layer in the western Black Sea. This is achieved by analysis of inter-annual summer temperature variability using field survey data gathered during 1997-2016. To this end, the available quality controlled observation data were processed using Barnes' objective analysis scheme to obtain the seasonal climatic mean in a grid of 0.125° horizontal resolution. The time series of annual summer means were subjected to spectral analysis in order to reveal the time scale of sea temperature variability, which is found to be ~5 yr. Furthermore, a temperature increase trend in the mixed layer was found to vary between 0.53 and 0.97°C decade⁻¹ on the average. Results for several open sea locations are presented as well as maps of seasonal temperature differences in the mixed layer valid for 4-yr and 5-yr periods of variation.

Keywords: vertical temperature structure, mixed layer depth, spectral analysis, sea temperature trend, climate change

INTRODUCTION

Oceans and seas, as key components of Earth system, are increasingly influenced by global warming. Ocean surface water temperature has increased due to climate change [1], runoff from impervious surfaces [2] and thermal effluents from industrial processes [3]. The increase of upper ocean layer temperature is considered as an indicator of climate change.

The ocean mixed layer defines a vertically quasi homogeneous surface region of temperature, salinity, or density, which directly interacts with the overlying atmosphere. Atmosphere-ocean interaction, therefore, can be modulated by the ocean mixed layer, whose depth is determined by wind driven mechanical stirring, surface buoyancy forcing, such as heat flux or freshwater flux, or ocean circulation changes [4]. Classically, the surface layer includes both a mixed layer (ML) that is subject to the direct influence of the atmosphere, and also a highly stratified zone below where vertical property gradients are strong. Above the ML right at the ocean surface, a 'skin' exists with lowered temperature caused by the combined heat losses from long-wave radiation, sensible and latent heat fluxes. The cool skin is only a few millimetres thick, and is the actual sea surface temperature (SST) normally measured by airborne infrared radiometers. In contrast, *in situ* sensors generally measure the 'bulk' SST over the top few meters of the water column [5]. Mixed layer temperature (MLT) and bulk SST are frequently used interchangeably or assumed to be proportional in climate studies [6].

An important feature of the mixed layer is its depth. Changes in the mixed layer depth (MLD) influence, for example, the variability of the SST and oceanic uptake of atmospheric CO₂ [7]. Significant changes in circulation in the ocean or the atmosphere have been projected by coupled climate models under global warming [8]. Therefore, MLD would also change in response to the circulation changes under global warming. In addition to air-sea interaction, biological consequences of MLD changes are also to be highlighted because they can affect primary production and timing of autumn and spring phytoplankton blooms by altering nutrients supply and light conditions, thus affecting biological productivity in the ocean and the Black Sea and subsequently higher trophic levels [4, 9].

There exist several methods for determination of MLD, which are based on density depth variations calculated using both T-only and T-S profiles. It was concluded that taking into account pressure effects could considerably increase the density depth gradient resulting in a markedly shallower MLD. This is inconsistent with the MLDs inferred from the corresponding T and S profiles [10]. Therefore, most of the studies assume zero pressure from the density at a reference depth of 3 m. This definition takes full account of density changes due to T and S variations with location as described in [10]. In this study, preference is given to the isothermal mixed layer depth that is evaluated from individual vertical profiles based on the temperature difference from the temperature at a reference depth of 10 m [11, 12]. This reference depth setting the mixed layer basis was shown to be sufficiently deep to avoid introducing distortion by the diurnal signal, but shallow enough to give a reasonable approximation of monthly MLD. It is worth noting that in some areas of shallow mixed layer, such as the Black Sea, or in areas of strong upwelling, the thermocline may shoal above the 10 m reference level. In these particular areas the estimates of the MLD may be biased deep and estimates of the MLT may be biased cold. Nevertheless, in general case, the isothermal MLD is defined as the depth at which temperature changes by $|\Delta T| = 0.2^\circ\text{C}$ relative to its value at 10 m depth [6].

MLD in the Black Sea is distinguished for large seasonal variability. Shallow MLDs in the Black Sea can be attributed to attenuation of solar radiation during summer months [13]. Unlike the Mediterranean Sea, there is generally strong density stratification in Black Sea, typically limiting the MLD and resulting in shallower values. Hence, MLD in the Black Sea rarely exceeds 50 m during winter, and can be very shallow (< 20 m) during spring and summer [12].

With respect to warming in the Black Sea, recent studies have reported existence of a positive trend of SST [14]. Being colder in comparison to Marmara and Aegean Sea, the warming of the Black Sea surface layer was found to be even more pronounced – $0.51^{\circ}\text{C decade}^{-1}$ [15]. Therefore, the present study aims at investigation of changes in the mixed layer temperature in the Black Sea in response to global warming and as an evidence for regional climate change.

STUDY AREA

The object of investigation is Black Sea, which is a nearly enclosed basin connected to the Sea of Marmara and the Sea of Azov by the narrow Bosphorus and Kerch Straits, respectively. Its catchment area covers large parts of Europe and Asia, providing a total freshwater supply of $3 \times 10^2 \text{ km}^3 \text{ yr}^{-1}$ [16]. The large freshwater flux makes the Black Sea a typical estuarine basin with the surface salinity about half that of the oceanic. Unlike other large estuarine basins (e.g., the Baltic Sea), the Black Sea is a deep basin (maximum depth of ~2200 m) with a large shelf. A distinct vertical layering is created between the surface waters in the upper 100 m and the deep waters, limiting the vertical exchange and creating a unique chemical and biological environment [17].

Figure 1. Scheme of the study area and location of observation stations.

The cold intermediate water mass, with temperatures lower than the mean annual temperature of the surface and deep layers, is a consequence of extremely stable stratification. This cold intermediate layer (CIL) is formed by winter cooling followed by spreading of cold intermediate water throughout the sea in a layer approximately 50 to 100 m below the surface. It acts as a boundary between surface and deep waters [16]. In addition to this, the Black Sea is the world's largest marine anoxic basin [18]. The main pycnocline in the Black Sea is dome-shaped. The CIL core is shallower in the interior of the basin (30-50 m) and deepens towards the continental slope to reach a depth of 80 m within the so called convergence zone, i.e. the frontal region of the Rim Current, separating the cyclonic interior from the coastal domain typically comprising a series of anticyclonic eddies.

Some of the anticyclonic eddies are quasi-stationary confined to certain features of coastal and bottom topography [19, 20].

More specifically, the study area covers Bulgarian Black Sea territorial waters, which have been monitored by the Institute of Oceanology – BAS for the last three decades (Fig. 1). In this region, vertical thermo-haline structure in summer is characterized by a difference between cyclonic and anticyclonic regions particularly pronounced in the upper 200 m layer. In the surface 15-25 m-thick quasi isothermal and isohaline mixed layer, temperature difference is within 0.2°C [21]. Below this relatively homogeneous surface layer, the layer of seasonal thermocline lies at about 18 m depth in bays and coastal areas, 25 m in anticyclonic and 15 m in cyclonic areas. In this layer, the average temperature drops to $12-14^{\circ}\text{C}$, salinity increases with about 0.5 psu, and density varies from 11.5 to 14.0 kg m^{-3} . Deeper down, CIL, which identified by temperatures lower than 8°C , extends to 100 m depth. Average temperature in CIL core is 7.6°C that represents the absolute vertical temperature minimum. The CIL core is located at 60-70 m depth, which corresponds to isopycnal surfaces $14.5-14.8 \text{ kg m}^{-3}$ [21].

DATA AND METHODOLOGY

The employed dataset represents CTD casts acquired during the RV 'Akademik' cruises. They were carried out in the western part of the Black Sea during 1997-2016. The spatial distribution of observation stations

is shown in Fig. 1. Measurements were performed prevalingly on a seasonal basis, thus, providing information about the seasonal dynamics of main physical parameters.

Figure 2. Data coverage for each month / year during 1997-2016 and number of profiles processed in the study.

Analysis of regional data [21] on MLD agrees well with monthly MLD climatology produced by [12]. As previously mentioned, MLD in the western Black Sea is distinguished for its large seasonal variability – from 50-75 m in winter to 15-25 m in summer [12]. Moreover, due to varying bathymetry in nearshore waters and dome-shape occurrence of the main stratification features, MLD experience spatial variability as well. As mentioned above, the focus of this study is the MLT during summer when mixed layer is relatively thin due to low intensity of hydrodynamic processes taking place during this season opposed to cooling in course of the winter convection. Summer season is defined as a three-month period comprising July, August and September. Herein, as a lower boundary of the MLD is adopted the minimum depth of the MLD range – 15 m – in order to avoid possible shoaling of the thermocline above it, which could distort statistical and spectral analyses. As upper limit, the depth of 5 m is set. It corresponds to the thickness of the upper 1-5 m layer, referred to as bulk SST, as assumed by operational centers worldwide [23].

Figure 3. Objective analysis interpolation grid with horizontal resolution 0.125° . Grid points, for which time series were extracted, are indicated with numbers.

Temperature data considered in this study were measured with Sea-Bird Electronics *SBE 911 plus* CTD system. It is equipped with dual temperature and conductivity sensors. Collected raw data were processed using a number of modules with consequent averaging to 1 dbar bin corresponding to about 1 m. Data were also subjected to higher level quality control as described in [22]. Fig. 2 gives insight into data temporal coverage per each year/month in consideration.

For the purposes of this study, 0.125° horizontal resolution gridded fields of temperature climatic means in the mixed layer were obtained. Geographical domain falls between 27.25°E and 30.0°E in longitude and between 41.75°N and 43.75°N in latitude (Fig. 3). About 8500 data entries within 812 profiles were processed. Barnes' objective analysis scheme [24] was chosen as interpolation method. This procedure estimates climatic temperature mean at each grid box based on the cumulative weighted difference between the means and first-guess fields within a given 'radius of influence' around each grid node. This scheme implies correction of the first-guess field via an iterative procedure, repeated three times, each time with lesser radius of influence. The input data for objective analysis are the climatological means of all data in 0.5° grid box in the predefined layer, which are calculated using all available measurements. These values represent the first-guess field and are assigned to each 0.125° grid node.

Radii of influence were selected to be proportional to the regional *Rossby radius*, which is 20-30 km [16] as the radius of the last iteration was set to 15 km. This procedure was applied to obtain seasonal climatic means for the entire period 1997-2016 as well as for each year within it.

To complete methodology in use, the annual temperature means time series were subjected to analysis of trend on order to capture the rate of possible warming as well as to spectral analysis with the aim to reveal cycles of temperature variability in the mixed layer.

RESULTS AND DISCUSSION

Good data spatial and temporal coverage is a key element for accomplishment of reliable analytical products. While the spatial coverage of available data does not vary significantly over the study period, the temporal coverage seems problematic in particular in the beginning of it (Fig. 2). More specifically, during 1997-2003 and 2007-2008, data were gathered in one of the summer months solely. Predictably, this may affect negatively the validity of the seasonal means especially if cruises took part in the end of September when the process of cooling had already been started. Therefore, a low pass filter was applied to time series originating from a single month data acquisition. In addition, the data quantity suggests that more coherent results could be expected for the second half of the considered time span.

Fig. 4 presents seasonal temperature means for each year and for the four locations indicated in Fig. 3. Two periods characterized with increase of the mixed layer temperature (MLT) can be identified, namely 1997-2007 and 2008-2016. This suggests quasi-decadal scale of MLT changes. However, during these time spans two disruptions were observed in 2004 and 2013. A fairly well-pronounced positive trend is evident although the coefficients of determination R^2 of linear approximations do not exceed 0.3. It indicates that the linear model does not explain very well the variability of response data around its mean. As for the magnitude of changes, it increases from north to south as follows: (1) $0.53^\circ\text{C decade}^{-1}$; (2) $0.85^\circ\text{C decade}^{-1}$; (3) $0.90^\circ\text{C decade}^{-1}$; (4) $0.97^\circ\text{C decade}^{-1}$ – which means that southern areas were being warmed slightly more with respect to the northern.

Figure 4. Seasonal climatic temperature means obtained for four grid points over 1997-2016 and corresponding linear trends. Coefficients of determination R^2 for each linear approximation are as follows: (1) 0.10; (2) 0.22; (3) 0.25; (4) 0.27.

In attempt to confirm above interpretations and to determine the time scale of the MLT periodic change, spectral analysis was performed. Results for the same four locations are shown in Fig. 5. It can be seen that the spectral density of time series show a well-defined absolute maximum for 4-5 yr with no other significant local maxima except for location 3 (10 yr). Clearly, the temporary disruptions of the MLT growth in 2004 and 2013 possess statistical significance sufficient enough to allow a shift of maxima towards the shorter period.

Figure 5. Spectral density of seasonal climatic temperature means for 20-yr period

This result conforms to certain extent with findings in [25], which studied temperature change in the Black Sea over a 60-yr period and reported a decadal variation of the upper 50 m-layer temperature, showing a spatial increase from north-west towards south-east. They also discover low-frequency variation in phase with large-scale atmospheric processes. According to [25], it ranges within 2°C, varying around 24°C, with summer temperature differences between various areas being smaller in comparison to winter. Obviously, the considered in this study period is not sufficiently long to detect a larger scale signal and only higher frequency variations, with presumably smaller weight over a longer time scale, become evident.

Figure 6. Maps of temperature differences between seasonal MLT means for 4-yr (left) and 5-yr variation period (right)

As mentioned above, the spectral density of seasonal MLT means exhibit 4-5 yr period of variation. Based on this finding, five 4-yr and four 5-yr cycles were established within the studied time span, of which the earliest ones were discarded from analysis due to insufficient data temporal coverage as only post 2000 data were taken into consideration. Consequently, horizontal temperature fields were obtained for the marginal cycles as follows: 2001-2004 and 2013-2016 (for 4-yr variation period) and 2002-2006 and 2012-2016 (for 5-yr

variation period). Then, they were subtracted from each other in order to obtain the temperature differences over the 0.125° spatial grid in use (Fig. 6).

Results indicate an average MLT increase of 0.83°C and 0.27°C when 4-yr and 5-yr variation period were compared, respectively. Thus, slightly higher variation frequency ends in a more pronounced warming of the mixed layer. In both cases though the warming is more marked in the area to the south of 43°N with maxima within the Burgas Bay and the adjacent shelf and deep waters. However, cooling of mixed layer with about 0.3°C also takes place in coastal and shelf waters to the northwest in the area surrounding c. Kaliakra and Varna Bay.

CONCLUSIONS

The study deals with sea water temperature variability of the surface mixed layer in the western Black Sea by analysis of observation data collected over 20-yr period (1997-2016). Data spatial and in particular temporal coverage are deemed to be the main sources of uncertainty. The main outcome consists of elaboration of 0.125° horizontal resolution gridded fields of temperature climatic means employing Barnes' objective analysis interpolation scheme. Results reveal a well-pronounced positive trend of the mean climatic mixed layer temperature estimates as the magnitude of changes ranges between 0.53 and $0.97^\circ\text{C decade}^{-1}$, which suggests that southern areas were being warmed slightly more with respect to the northern. Furthermore, the spectral analysis shows that time series' spectral density has maximum for 4-5 yr, even if a quasi-decadal variation is also discernable. Finally, temperature differences over the 0.125° spatial grid were obtained for both 4-yr and 5-yr variation cycles resulting in average MLT increase of 0.83°C and 0.27°C , respectively. Although slightly higher variation frequency involves a more pronounced warming of the mixed layer, in both cases it is more marked over the southern portion of the study area. Results obtained could serve as evidence for regional climate change.

REFERENCES

- [1] B. L. Preston. Observed winter warming of the Chesapeake Bay Estuary (1949–2002): Implications for ecosystem management. *Environ. Assess.*, 2004, pp. 125–139.
- [2] J. Tan and K. A. Cherkauer. Assessing stream temperature variation in the Pacific Northwest using airborne thermal infrared remote sensing. *J. Environ. Manag.*, 2013, pp. 206–216.
- [3] J. I. Fisher and J. F. Mustard. High spatial resolution sea surface climatology from Landsat thermal infrared data. *Remote Sens. Environ.*, 2004, pp. 293–307.
- [4] C. J. Jang, J. Park, T. Park and S. Yoo. Response of the ocean mixed layer depth to global warming and its impact on primary production: a case for the North Pacific Ocean. *ICES Journal of Marine Science*, 2011, pp. 996–1007.
- [5] J. Sprintall and M. F. Cronin. Upper Ocean Vertical Structure. *Encyclopedia of Ocean Sciences* (Second Edition), 2009, pp. 217–224.
- [6] S. A. Grodsky, J. A. Carton and H. Liu. Comparison of bulk sea surface and mixed layer temperatures. *J. Geophys. Res.*, C10026, 2008.
- [7] E. B. Kraus and J. A. Businger. *Atmosphere-ocean interaction*. 2nd ed. Oxford University Press, Oxford, UK, 1995.
- [8] S-P Xie, C. Deser, G. A. Vecchi, J. Ma, H. Teng, and A. T. Wittenberg, 2010. Global warming pattern formation: sea surface temperature and rainfall. *J. of Climate*, 2010, pp.966-986.
- [9] T. Oguz, H.W. Ducklow and P. Malanotte-Rizzoli. Modeling distinct vertical biogeo-chemical structure of the Black Sea: Dynamical coupling of the oxic, suboxic, and anoxic layer. *Global Biogeochem. Cycles*, vol. 14, 2000, pp. 1331–1352.
- [10] A. B. Kara, P. A. Rochford and H. E. Hurlburt. An optimal definition for ocean mixed layer depth. *J. Geophys. Res.* vol.105, 2000, pp. 16803-16821.
- [11] C. de Boyer Montégut, G. Madec, A. S. Fischer, A. Lazar and D. Iudicone. Mixed layer depth over the global ocean: An examination of profile data and a profile-based climatology. *J. Geophys. Res.*, vol. 109, 2004, C12003.
- [12] A. B. Kara, R. W. Helber, T. P. Boyer and J. B. Elsner. Mixed layer depth in the Aegean, Marmara, Black and Azov Seas: Part I: General features. *J. of Marine Systems*, vol. 78, 2009, pp. S169-S180.
- [13] A. B. Kara, A. J. Wallcraft and H. E. Hurlburt. How does solar attenuation depth affect the ocean mixed layer? Water turbidity and atmospheric forcing impacts on the simulation of seasonal mixed layer variability in the turbid Black Sea. *J. Climate*, 2005, pp. 389-409.
- [14] F. Bengil and S. Mavruk. Warming in Turkish Seas: Comparative Multidecadal Assessment. *Turk. J. Fish.& Aquat. Sci.*, vol. 19, 2018, pp. 51-57.

- [15] M. Shaltout and A. Omstedt. Recent sea surface temperature trends and future scenarios for the Mediterranean Sea. *Oceanologia*, vol. 56, 2014, pp. 411-443.
- [16] E.V. Stanev. Understanding Black Sea dynamics: Overview of recent numerical modeling. *Oceanography*, vol. 18, 2005, pp. 56-75.
- [17] S. K. Konovalov, J.W. Murray, and G.W. Luther III. Basic processes of Black Sea biogeochemistry. *Oceanography*, vol. 18, 2005, pp. 24-35.
- [18] B. B. Jørgensen, H. Fossing, C. O. Wirsen and H. W. Jannasch. Sulfide oxidation in the anoxic Black Sea chemocline. *Deep-Sea Res.*, vol. 38, 1991, pp. S1083-S1104.
- [19] T. Oğuz, V. S. Latun, M. A. Latif, V. V. Vladimirov, H. I. Sur, A. A. Markov, E. Özsoy, B. B. Kotovshchikov, V. V. Eremeev and Ü. Ünlüata. Circulation in the surface and intermediate layers of the Black Sea. *Deep-Sea Res.*, vol. 40, 1993, pp. 1597-1612.
- [20] G. Korotaev, T. Oguz, A. Nikiforov, and C. Koblinsky. Seasonal, interannual, and mesoscale variability of the Black Sea upper layer circulation derived from altimeter data. *J. Geophys. Res.*, vol. 108(C4), 2003, 3122.
- [21] N. Valcheva. Climatic distribution of summer and winter temperature and salinity in the Western Black sea. *Proc. of 12th Int. Conf. on Marine Sciences and Technologies BLACK SEA'2014*, 2014, pp. 189-195.
- [22] N. Valcheva and A. Palazov. Quality control of CTD observations as a basis of estimation of thermohaline climate of the Western Black Sea. *J. of Environmental protection and ecology*, vol.11, No.4, 2010, pp. 1504-1515.
- [23] R. W. Reynolds, N. A. Rayner, T. M. Smith, D. C. Stokes and W. Wang. An improved in situ and satellite SST analysis for climate. *J. Clim.*, vol. 15, 2002, pp. 1609-1625.
- [24] S. L. Barnes. A technique for maximizing details in numerical weather-map analysis. *J. of Applied Meteorology*, vol. 3, 1964, pp. 396-409.
- [25] A.B. Polonsky and I.G. Shokurova. Long-term variability of temperature and salinity in the Black Sea and its causes. *Reports of the National Academy of Sciences of Ukraine*, vol. 1, 2013, pp.105-110 (in Russian).

EVALUATION AND SPATIAL VARIABILITY OF THEORETICAL WAVE POWER ALONG THE BULGARIAN BLACK SEA COAST

Nikolay VALCHEV*

* Institute of Oceanology – Bulgarian Academy of Sciences, Varna, Bulgaria

Abstract. The study deals with evaluation of theoretical wave power resources and their spatial variability in transitional waters along the Bulgarian Black Sea coast. It is based on wave climate data obtained by means of hindcast of wave conditions during 1948-2006. Numerical simulations were performed using a coupled system of third generation spectral wave models WAM-SWAN, in which the WAM wave model was set up to cover the entire Black Sea domain in order to provide boundary conditions for the nested SWAN wave model. Then, theoretical wave power was computed using the SWAN spectral output in terms of energy transport per unit of the wave crest length. Results for wave power means and maxima as well as for total wave energy are presented for twenty locations almost evenly distributed along the study area.

Key words: wave energy, wave hindcast, spatial pattern of energy distribution, wave exposure

INTRODUCTION

The Ocean is a huge energy reservoir. Ocean energy can be derived from tides, currents, waves, thermal gradients and its chemical composition. Among these options perhaps the most challenging is collection of energy from the waves. Generally speaking, there are two groups of energy inputs to the geobiosphere: external (*renewable*) and internal (*non-renewable*). The main external inputs to the geobiosphere include: solar energy with a total amount of $3.93 \times 10^{24} \text{ J yr}^{-1}$ (124619.5 TW in terms of power), heat energy from the bowels of the earth with $6.72 \times 10^{20} \text{ J yr}^{-1}$ (21.309 TW), and tidal energy - $0.52 \times 10^{20} \text{ J yr}^{-1}$ (1.65 TW) [1]. Through various processes in the atmosphere-ocean boundary layer these three main external energy inputs generate secondary renewable energy sources (atmospheric processes – *winds*, ocean processes – *ocean circulation, jet currents*) and tertiary one (ocean processes – *wind waves*) [1].

Wave energy has a key role in meeting world's needs for renewable energy sources. It is in abundance and although it is not as easily predictable as the tidal power, it is still subjected to forecast to a much greater extent than wind or solar energy [2]. Steadfastness of the wave energy flow allows its direct and reliable integration into energy-transmission systems. Wave energy is profitable because waves offer energy with much greater density in comparison to other renewable sources, which allows collection of more power out of a smaller surface [3].

The possibility of extracting energy from sea waves intrigued people for centuries. Although, the first concepts date back about a 100 years, viable technologies for energy extraction/collection have been proposed only within the last 30-40 years. The reason is that waves are manifestation of random, irregular and non-linear processes, which hampers the extraction of energy [4]. Therefore, knowledge of the local wave climate is an essential aspect of the assessment of wave energy potential.

The wave energy resource can be defined in different ways: *theoretical resource* is the actual hydrodynamic power contained in the waves; *technical resource* is the power that can be produced by Wave Energy Converters (WECs); *accessible resource* is the power that can be produced in an area/region by a WEC [5]. Calculating the capacity of the global energy system [1] comes up with the figure $E_W = 3.4 \times 10^{20} \text{ J yr}^{-1}$ for wave energy potential. This corresponds to 9.79 TW in terms of theoretical global (gross) wave power. Later on, [5] provided a new estimate of 3.702 TW, which is limited to deep water off the coastlines except for coastlines of the Baltic and the Mediterranean Sea. The coastlines of internal seas were *a priori* excluded due to the very low wave power potential ($\leq 5 \text{ kW m}^{-1}$ of the wave front) making it practically unusable. Thus, excluding low-energy coastlines as well as locations, which may experience ice coverage, the above estimation dropped drastically to 2.985 TW in comparison to [1]. According to [6], world electricity generation was 24255 TWh in 2015 that corresponds to yearly averaged power of 2.769 TW, meaning that the theoretical global wave power resources slightly exceed the world consumption of electricity for 2015.

The main goal of this paper is to evaluate theoretical wave power resource along the Bulgarian Black Sea coast by employing the recent knowledge about the wave climate. This is considered of key importance for the strategic planning of the Bulgarian energy sector development.

Wave climate is a unique combination of mezo-scale processes in the atmospheric-ocean boundary layer and influence of the local geomorphic settings. It often exhibits significant short term, monthly, seasonal, and inter-annual variation. Climate can be evaluated on the basis of systematic and continuous measurements, application of numerical models or joint use of both approaches. The result is a series of representative data on the sea states. Long-term *in situ* wave measurements are rare in the Black Sea, which makes them inapplicable

for obtaining of representative climatic characteristics. The same largely applies to satellite (altimetry) measurements, which have been actively used in the last few decades. They suffer partial coverage and not sufficiently high for estimation of local wind and wave climate resolution, particularly near the coast [7]. Since the amount of wave energy that can be collected by contemporary WECs varies depending on location and weather conditions, the most effective method for assessment of energy potential is reconstruction of the past wave climate. Usually, it is done by means of wave modelling forced with historical data of atmospheric fields - wind and atmospheric pressure that is by hindcasting. Notable example is the study of wave climate in the North Atlantic [8]. Such an assessment for the western Black Sea was done in [9, 10, 11, 12]. These studies reveal western and southwestern shelf of the Black Sea as particularly perspective in terms of wave energy potential.

STUDY AREA

Figure 1. Scheme of the study and location of points for which area theoretical wave power resource were estimated

The study area comprises the shallow shelf and coastal zone along the Bulgarian Black Sea seaside. The theoretical wave power resource are estimated for twenty points indicated in Fig. 1. They are almost evenly distributed to from a strip along the coastline at off-shore distances varying between 2 and 10 km with water depths in the range of 20 to 70 m (Table 1). Except for points 14 and 19, all other points are located in transitional waters.

In the western Black Sea, considerable seasonal variability is the most marked feature of wind and wave climate. In general, the wind regime depends on the atmospheric circulation pattern over the Eastern Europe. During the storm season, the most relevant configuration is determined by the mutual position, displacement and resulting interactions between the Mediterranean cyclones and the Eastern European (Siberian) anticyclone [13].

In the study area winds from the eastern quarter are predominant. In the southern parts, eastern winds prevail over the north-eastern one, while in the northern shelf area the influence of the south-eastern winds is considerable due to the larger fetch [9]. Following wind pattern, high waves most frequently come from N, NE, E and SE (Fig. 1).

Table 1. List of investigated locations with their off-shore distance (L_{off}) as well as key wave properties such as significant wave height (H_s) maxima, wave energy period (T_E) maxima, wave length (λ) corresponding to the given T_E , and the ratio of water depth to deep water limit (d/DWL). The table provides information on theoretical wave power (P_w) means and maxima, total wave energy (E_w) and their seasonal (SV) and monthly (MV) variability.

Point		L_{off}	$\text{Ma} \times H_s$	$\text{Ma} \times T_E$	λ	d/DWL	$P_w \text{ [kW m}^{-1}\text{]}$		$E_w \text{ [MWhm}^{-1}\text{]}$	SV	MV
No	Location	[km]	[m]	[s]	[m]	-	mean	max	mean	-	-
1	Durankulak	2.5	6.15	8.1	104	0.62	1.16	89.66	10.16	0.92	1.22
2	Shabla	2.5	6.20	8.2	105	0.63	1.17	90.39	10.24	0.92	1.22
3	Tyulenovo	4.0	6.07	8.0	103	0.72	1.15	88.94	10.07	0.92	1.22
4	Rusalka	2.5	5.90	7.6	90	0.73	1.11	86.02	9.74	0.92	1.22
5	Kaliakra	9.0	2.96	7.0	77	0.83	0.21	14.01	1.88	1.00	1.00
6	Balchik	8.0	3.03	6.7	69	0.58	0.22	16.45	1.93	0.65	0.82
7	Golden sands	4.0	3.66	7.3	83	0.51	0.30	27.40	2.67	0.36	0.69
8	Sunny day	6.0	4.48	7.1	80	0.58	0.61	50.60	5.32	0.63	0.95
9	Pasha dere	4.5	4.98	7.2	80	0.60	0.65	54.34	5.71	0.89	1.26
10	Shkorpilovtsi	3.0	5.45	7.4	85	0.68	0.77	61.23	6.74	1.02	1.36
11	Byala	3.0	5.84	7.5	88	0.73	1.10	85.15	9.65	0.92	1.22
12	Obzor	3.5	6.17	8.0	99	0.71	1.29	92.09	11.27	1.09	1.36
13	Emine	7.0	6.25	8.1	100	0.80	1.30	93.29	11.42	1.09	1.36

14	Nesebar	5.0	2.69	5.5	47	1.11	0.14	12.61	1.23	0.94	1.14
15	Pomorie	10.5	5.60	8.0	99	0.55	0.89	72.07	7.76	0.88	1.26
16	Kavatsite	5.0	6.15	8.2	105	0.78	1.34	106.41	11.72	1.06	1.37
17	Primorsko	7.0	6.17	8.1	103	0.99	1.56	131.37	13.69	1.14	1.46
18	Tsarevo	7.5	6.46	8.3	106	0.91	1.81	140.12	15.83	1.18	1.51
19	Sinemorets	6.5	6.82	8.4	109	1.30	2.02	140.12	17.69	1.21	1.51
20	Rezovo	3.0	6.86	8.5	110	0.91	2.03	140.95	17.80	1.21	1.51

DATA AND METHODOLOGY

Waves are generated by wind blowing over the sea surface. As long as the waves propagate slower than the wind speed just above the waves, there is an energy transfer from the wind to the waves. Both air pressure differences between the upwind and the lee side of a wave crest and wind friction on the water surface, producing shear stress, cause the growth of the waves [14]. Sea state properties have a random nature. The waves in a sea state may differ in shape, height, frequency, and direction of propagation. Hence, wind waves can be described as a stochastic process, in combination with the physics governing their generation, growth, propagation and decay. For description of the wave climate in a certain area, temporal, directional and spectral characteristics are used, which are preconditioned by the wave spectrum of the individual sea states.

For the purposes of the present study, past wind wave climate was estimated by means of hindcasting spanning a time period of 59 years (1948-2006) using the wind fields obtained with REMO regional atmospheric model forced with NCEP reanalysis at 0.5° resolution [15]. Wind wave properties were obtained by numerical modelling of wave conditions on the western Black Sea shelf. To this end, a coupled system of third generation spectral wave models WAM-SWAN was employed, in which the WAM wave model was set up to cover the entire Black Sea domain in order to provide boundary conditions for the nested SWAN wave model. The SWAN Cycle III model, version 40.91 [16], was set up for wave simulations in the western shelf area at a horizontal resolution of about 3 km. SWAN was run in the third-generation mode accounting for the following deep and shallow water processes: generation by wind; dissipation by whitecapping, bottom friction and depth-induced breaking; and non-linear wave-wave interaction (quadruplets and triads). Details on the models set-up and validation can be found in [9, 17]. The availability of long-term numerical simulations allowed for extraction multi-annual time series of various wave properties, which were statistically processed.

Herein, theoretical wave power resource was computed using the spectral output of the numerical wave model as energy transport per unit of the wave crest length and given in kW m⁻¹ as follows [16]:

$$(1) \quad P_w = \rho g \int_0^{2\pi} \int_{\sigma_{min}}^{\sigma_{max}} c_g S(\sigma, \theta) d\sigma d\theta$$

where ρ is sea water density; g – acceleration of gravity; $S(\sigma, \theta)$ – directional wave variance density spectrum; c_g – wave group velocity; σ – wave frequency; θ – direction of propagation of spectral components.

The evaluation the wave energy potential is further based on the wave climate assessment in terms of significant wave height (H_s) and wave energy period (T_E). For this purpose the continuous wave time series were divided into two-dimensional clusters, as each of them covers H_s and T_E bands with discretization of 20 cm (starting at 30 cm, since smaller waves are considered still sea state) and 0.5 s, respectively. Thus, each cluster represents regimes with different wave energy potential. Mean annual P_w was estimated for each wave cluster.

Additionally, probability of occurrence for waves falling in each (H_s - T_E) cluster was determined as well as duration in hours of wave regimes within a statistical year. Statistical year is an engineering concept according to which the whole data temporal coverage is squeezed to duration of a year in a way that the action of waves in a cluster takes place during certain amount of hours depending on their frequency of occurrence. Thus, the total wave energy E_w was obtained.

Temporal variability of wind climate at each point is characterized in terms of seasonal variability (SV) and monthly variability (MV) of wave power resource. The lower the values of these indices the more stable the wave power potential and the more appropriate a site is for location of WEC. MV and SV are defined as follows [10]:

$$(2) \quad MV = \frac{P_{max,M} - P_{min,M}}{P_{year}} \text{ [kW m}^{-1}\text{]}$$

$$(3) \quad SV = \frac{P_{max,S} - P_{min,S}}{P_{year}} \text{ [kW m}^{-1}\text{]}$$

where $P_{max,M}/P_{max,S}$ and $P_{min,M}/P_{min,S}$ are the mean wave power in the most and less energetic month/season in a statistical sense, while P_{year} is the mean annual estimate of the wave power.

RESULTS AND DISCUSSION

Main role in determination of the spatial distribution pattern of wave energy plays wind and wave climate features. Detailed information about theoretical wave power resource and its seasonal and monthly variation for all selected locations is presented in Table 1. Wave power resources vary in broad range from 0.14 to 2.03 kW m⁻¹ (for means) and from 12.61 to 140.95 kW m⁻¹ (for maxima). This fact indicates the large spatial variability of theoretical wave power in Bulgarian Black Sea territorial waters. The same is valid for the total wave energy, which theoretical quantity ranges between 1.23 and 17.80 MWh m⁻¹.

Results show that the most and the less energetic seasons over the investigated period were winter and summer, respectively. Winter season includes December, January and February, while summer months are June, July and August. The most energetic month is January and the less energetic one is June. Prevailing, values of $P_{max,S} - P_{min,S}$ and $P_{max,M} - P_{min,M}$ considerably surpass P_{year} . As a result, seasonal and monthly variability indices are greater than one, which suggest large inter-seasonal and intra-annual variability of wave energy (Table 1). In addition, it is noticed that the wave power maxima exceeds the means 70-90 times. These circumstances lower significantly the accessibility to wave energy resources and hampers their reliable integration into energy-transmission systems due to unproductive capital investment costs and low efficiency of WECs operation.

Information about the distribution of theoretical wave power resources by significant wave height bands, is presented in Table 2 and Fig. 2. For almost all locations the most energetic wave band is $1 \leq H_s < 2$ m. The energy content in this band varies from 24 to more than 40% (point 9). The exceptions are five points for which the theoretical wave power is less than 0.5 kW m⁻¹ (points 5-7, 8 and 14). The reason is they are situated in sheltered areas with pronounced shoaling, which determines marked wave transformation relatively far from the shore.

Table 2. Theoretical wave power distribution in % of the total theoretical resources for each investigated location by significant wave height bands. The maximum contents are indicated in bold.

Points		Significant wave height bands [m]					
No	Location	0.2-1	1-2	2-3	3-4	4-5	> 5
1	Durankulak	20.1	34.1	22.2	13.0	7.1	3.5
2	Shabla	20.7	33.8	22.1	12.9	7.0	3.4
3	Tyulenovo	25.6	37.2	20.1	10.3	6.1	0.7
4	Rusalka	25.6	37.2	20.1	10.3	6.1	0.7
5	Kaliakra	67.9	29.3	2.8			
6	Balchik	69.3	27.8	2.9			
7	Golden sands	59.9	32.2	6.6	1.3		
8	Sunny day	41.6	38.6	13.3	6.6		
9	Pasha dere	37.9	40.3	16.6	5.2		
10	Shkorpilovtsi	32.7	38.9	17.8	8.5	2.1	
11	Byala	25.6	37.2	20.1	10.3	6.1	0.7
12	Obzor	22.4	36.3	21.7	12.9	5.7	1.0
13	Emine	22.4	36.3	21.7	12.9	5.7	1.0
14	Nesebar	72.9	24.1	3.0			
15	Pomorie	28.6	37.8	20.4	10.0	3.2	
16	Kavatsite	20.7	33.8	22.1	12.9	7.0	3.4
17	Primorsko	17.7	31.7	22.5	14.8	8.0	5.2
18	Tsarevo	16.1	30.0	22.3	15.5	9.2	7.0
19	Sinemorets	14.7	28.7	22.3	16.6	11.0	6.8
20	Rezovo	14.7	28.7	22.3	16.6	11.0	6.8

The maximum wave energy content in bands of $H_s \geq 3$ m is 34.4% for the most southern point of the strip and decreases irregularly northward. As a whole, the amount of wave power contained in the bands of $H_s < 3$ m is 16.37 kW m⁻¹ and in those of $H_s \geq 3$ m – 4.7 kW m⁻¹, i.e. 3.4 times lower. Fig. 2 reveals the large spatial variability of the mean wave power expressed in well-pronounced alteration along the shore. The highest potential is marked in the endmost northern (1-4), central (9-13) and southern (15-20) parts of the study area, which are exposed to the winds with the largest fetch and persistence – those of the eastern quarter (Fig. 2). This allows for full development of wave field and low rate of wave transformation even close to the shore, in particular to the south.

Figure 2. Mean wave power in [kW m^{-1}] by significant wave height bands.

In between them, lower energy potential areas stretch, which are confined predominantly within Varna and Burgas bays and the adjacent areas but are also sheltered by jugged out capes such as Kaliakra and Emine as well as by Pomorie peninsula. This highlights the importance of the local geomorphic settings such as shelf width and depth, shoaling conditions and coastal slope, which may considerably influence the wave field transformation, e.g. by refraction or bottom friction. In the above cases, waves start their transformation relatively far from the shore and as a result waves arrive at the selected locations already smaller in height and with lower energy potential. This is valid in particular for points 5-7 and 14-15. These results conform very well with findings about the wave exposure of the Bulgarian Black Sea coast [18].

Based on the mean P_W and the distance between selected points, as well as assuming linear variation of mean wave power, the annual theoretical wave power potential along the strip formed by these points was estimated to reach 2,187.7 GWh [19]. According to statistical data [20], these resources are comparable to the average monthly net electricity consumption of 2,912.4 GWh in Bulgaria for 2018.

CONCLUSIONS

This study gives an insight into theoretical wave power resources and its spatial distribution pattern along the Bulgarian Black Sea coast. To this end, wave hindcast data spanning nearly 60-yr period were modelled and statistically processed in order to obtain estimates of mean wave power and total wave energy at twenty locations situated in transitional waters. Results shows that mean wave power varies in broad range from 0.14 to 2.03 kW m^{-1} , while the total wave energy quantity ranges between 1.23 and 17.80 MWh m^{-1} . A large spatial variability of the mean wave power is observed, which is defined by distinct alteration of wave energy potential along the shore. The highest potential is marked in the endmost northern, central and southern parts of the study area. Main role in determination of the spatial variability pattern play wind and wave climate but nonetheless the local geomorphic settings such as shelf width and depth, shoaling conditions and coastal slope, which may considerably influence the wave field transformation and subsequent energy dissipation. The study asserts that the energy, which could be eventually obtained from waves (given that it is accessible) on annual basis, would cover just about the monthly net electricity consumption in Bulgaria.

REFERENCES

- [1] H.T. Odum. Handbook of eMergy Evaluation: eMergy of Global Processes, University of Florida, Environmental Engineering Sciences, Center for Environmental Policy, 2000.
- [2] M.J. Tucker and E.G. Pitt. Waves in ocean engineering. New York: Elsevier, 2001.
- [3] T. W Thorpe. A Brief Review of Wave Energy, Report ETSU-R120. Department of Trade and Industry, 1999.
- [4] M. Özger, A. Altunkaynak and Z. Sen. Stochastic wave energy calculation formulation. Renewable Energy, vol. 29 (10), 2004, pp. 1747–1756.
- [5] G. Mørk, S. Barstow, A. Kabuth and M. Pontes. Assessing the global wave energy potential. Proc. of 29th Int. Conf. on Ocean, Offshore Mechanics and Arctic Engineering OMAE'2010, 2010.
- [6] International Energy Agency. Key World Energy Statistics. IEA Publications, Chiriat, 2017.

- [7] S. Vignudelli, P. Cipollini, L. Roblou, F. Lyard, G. Gasparini, G. M. R. Manzella and M. Astraldi. Improved satellite altimetry in coastal systems: case study of the Corsica Channel (Mediterranean Sea), *Geophys. Res. Lett.*, vol. 32, 2005.
- [8] H. Günther, W. Rosenthal, M. Stawarz, J. C. Carretero, M. Gomez, I. Lozano, O. Serrano and M. Reistad. The wave climate of the Northeast Atlantic over the period 1955-1994: The WASA wave hindcast. *Global Atmos. Oc. System*, vol. 6, 1998, pp. 121-164.
- [9] N. Valchev, I. Davidan, Z. Belberov, A. Palazov and N. Valcheva. Hindcasting and assessment of the western Black sea wind and wave climate, *J. of Environmental protection and ecology*, vol.11 (2), 2010, pp. 1001-1012.
- [10] L. Rusu, D. Ganea and E. Mereuta. A joint evaluation of wave and wind energy resources in the Black Sea based on 20-year hindcast information. *Energy Exploration & Exploitation*, vol. 36(2), 2018, pp. 335-351.
- [11] A. Akpınar. Assessment of wind power potential along the south western Black Sea coasts. *Sakarya University Journal of Science*, vol. 20 (3), 2016, pp. 573-589.
- [12] A. Akpınar, B. Bingölbali and G.Ph. van Vledder. Long-term analysis of wave power potential in the Black Sea based on 31-year SWAN simulations. *Ocean Eng.*, vol. 130, 2017, pp. 482-497.
- [13] A.I. Sorkina, (Ed.). *Climatic Handbook of the Black Sea*. Gidrometeoizdat, Moscow, 1974 (in Russian).
- [14] L.H. Holthuijsen. *Waves in oceanic and coastal waters*. Cambridge University Press, 2007.
- [15] F. Feser, R. Weisse and H. von Storch. Multidecadal atmospheric modelling for Europe yields multi-purpose data, *EOS*, vol. 82, 2001, pp. 305-310.
- [16] The SWAN Team. *SWAN User Manual*. Delft University of Technology, 2013.
- [17] Z. Cherneva, N. Andreeva, P. Pilar, N. Valchev, P. Petrova and C. G. Soares. Validation of the WAMC4 model for the Black Sea. *Coast. Eng.*, vol. 55, 2008, pp. 881-893.
- [18] N. Valchev, N. Andreeva and B. Prodanov. Study on wave exposure of Bulgarian Black Sea coast, *Proc. of 12th Int. Conf. on Marine Science and Technology BLACK SEA'2014*, 2014, pp. 175-182.
- [19] D. Markov, R. Velichkova, I. Simova and N. Valchev. Evaluation of theoretical and accessible wave power resources along the Bulgarian littoral (Western Black Sea) (In print).
- [20] National Statistical Institute, Production and deliveries of electricity for 2018, URL: http://www.nsi.bg/sites/default/files/files/data/timeseries/Energy-1.4.Electricity_en.xls, accessed on 19.08.2018.

COASTAL FLOODING HAZARD ASSESSMENT AT VULNERABLE LOCATIONS ALONG VARNA REGIONAL COAST

Petya EFTIMOVA*, Nikolay VALCHEV*, Nataliya ANDREEVA*, Bogdan PRODANOV*, Lyubomir DIMITROV*

* Institute of Oceanology – BAS, Varna, Bulgaria

Abstract. The flooding hazard assessment presented was part of the second phase of the Coastal Risk Assessment Framework (CRAF) developed within the FP7 RISC-KIT Project (Resilience-Increasing Strategies for Coasts – toolkit). Three potentially vulnerable coastal locations (hotspots) along Varna regional coast (Bulgarian Black Sea coast) were examined. The assessment was done through offline coupling of open-source process-based nearshore storm impact model XBeach and LISFLOOD-FP overland flood model. ‘Response approach’ was adopted to assess the probabilistic distribution of the flood hazard, considering 20, 50 and 100 years return periods. XBeach was employed to simulate 75 storm events at the selected hotspots in 1D mode. Series of maximum flood depth and maximum depth-velocity along predefined cross-shore transects and overtopping discharges at fixed point positions were post-processed and analyzed. LISFLOOD model was fed with overtopping volumes to calculate the intensity and extent of the hinterland flooding for the given probabilities. XBeach and LISFLOOD models’ output was combined to map the maximum flood depth and maximum depth-velocity spatial distribution.

Keywords: flooding hazard, CRAF, XBeach model, LISFLOOD-FP model, hazard maps.

INTRODUCTION

Storm induced flooding is one of the most significant threats that the coastal communities face. It is expected to gain even more importance in the light of the climate change. Therefore, the adequate assessment of this hazard could increase the capability of mitigation of environmental and socio-economic impacts. In order to cope with the consequences of such unfavorable events coastal managers and stakeholders should have information about the possible hazard extremes.

This study focuses on the coastal flooding hazard assessment caused by extreme storms on a regional scale to delineate the hazard extents and assess hazard intensities at the most vulnerable spots of the coastal area. The goal of the study was to assess the flooding hazard on these sites and to prepare maps of maximum flood depths and maximum flood-velocity for events of defined return periods for further use in vulnerability assessment. It was accomplished during the second phase of the Coastal Risk Assessment Framework (CRAF) [1, 2] developed within the FP7 RISC-KIT Project (Resilience-Increasing Strategies for Coasts – toolkit) [3] (<http://www.risckit.eu>).

The assessment was implemented on potentially vulnerable coastal sectors located at Varna regional coast, Bulgarian Black Sea coast. The potential candidates called “hotspot” were selected during the initial screening phase of CRAF where the coastal risks were evaluated at regional level [4, 5]. Even if the study was performed at regional scale, the presented study covers only hotspots within Varna municipality.

Sequence of hydrodynamic and morphodynamic numerical models were used to accurately estimate the hydrodynamics in the nearshore area followed by modeling of the onshore inundation in terms of distribution of the overtopping water volumes. The response approach was applied in the study [6]. It is focused on creating of time series of the onshore impact rather than on the deep water boundary conditions. It allows calculation of the hazard extreme probability distribution induced by a variety of combinations of waves and surges. Thus, the forcing time series were used to calculate series of the onshore hazard parameters of interest (flood depth, depth-velocity and overtopping discharges in this case) and subsequently be fitted to extreme value probability distribution. The considered return periods (TR) within the extreme value analysis were 20, 50 and 100 years.

STUDY SITE

Varna regional coast is located on the western Black Sea coast (Fig. 1). It stretches from cape Ekrene (north) to cape St. Atanas (south), including Varna bay. The regional coastline is complex with an approximate length of about 70 km. Considerable part of the coast, especially in Varna Bay, is heavily human modified by construction of breakwaters, groynes, dams and revetments. The northern part of the regional coast down to cape St. George is presented by cliffs and beach bodies of different dimensions. The northern coast of Varna Bay is entirely protected by coastal defense structures. As a result, several beaches were formed that alternate with rocky revetments. In the most inner part of Varna bay lays a sandy spit – low-lying area cut by two artificial navigable canals connecting Varna Bay to Varna Lake (Fig. 4). In this area locates the largest in Bulgaria

transport and port agglomeration – Varna-Beloslav-Devnya industrial complex. Southward of cape Galata up to cape Paletsa the

coast is presented by a sequence of small narrow beaches obstructed by rocky deposits backed by cliff of various height. The longest (13 km) and widest beach along the Bulgarian Black Sea coast – Kamchia – Shkorpilovtsi stretches between cape Paletsa and cape Cherni nos including the Kamchia river mouth. The biggest dune complex at the Bulgarian Black Sea coast is located within this area. To the southward end of the site, between cape Cherni nos and cape St. Atanas, several narrow beaches are located backed by cliffs and limited by rocky capes.

Three groups of receptors are determined within identified potentially vulnerable sectors: 1) natural beaches, 2) man modified beaches and 3) artificial coasts. The present study deals with sites from man modified beach and artificial coast groups as the three of the potentially most vulnerable coastal sectors are Kabakum Beach, Varna ‘hotspot’ and Varna ‘artificial’ island (Fig. 1).

Kabakum Beach (Fig. 2 and pointed out with A in Fig. 1) is located in the open coast of northern part of Varna region. It is a steep sandy beach limited by low rocky cliff at north and by a groyne at south. There is a promenade along the rear line of the beach and low wall protecting the hillside landward. Varna hotspot (pointed out with B in Fig. 1, Fig. 2) is in the inner part of Varna Bay and includes three sectors defined within CRAF phase I: Varna groynes beaches, Varna central beach and Varna breakwater.

Figure 1. Study site. Varna regional coast. (Grey rhombs denote wave and surge boundary condition data points)

Kabakum beach and Varna central beach are presented by relatively long sandy beaches, of varying widths as being narrow in their northern part and wider to the south, subject to anthropogenic pressure due to presence of coastal protection structures causing sediment supply shortage.

Figure 2. Kabakum Beach (left) and Varna ‘hotspot’ (right): cross-shore profiles are denoted by grey lines and overtopping discharge output points by black dots).

The so called “Varna island” (pointed out with C in Fig. 1, Fig. 3), a remnant of the low-laying Varna sandy spit, is situated between two artificially created navigable canals connecting Varna bay and port area with Varna Lake. The island area is protected from the sea by an armoured forehead consisting of stone revetment and a low wall. The area comprises buildings, technical networks and facilities for industrial purposes.

Figure 3. Varna ‘artificial’ island; (cross-shore profiles are denoted by grey lines and overtopping discharge output points by black dots).

DATA AND METHODS

The main coastal hazard considered in this study is coastal flooding. Generally, coastal flooding is caused by a combination of high water levels (storm surges plus high tides) and wave action. Since the Black Sea is considered a basin of weak tides, only storm surge and waves were taken into account.

The methodology of the hazard assessment in use consists of the following main steps: definition of extreme storm events at 20 m depth in front of the study areas; selection of cross-shore profiles along the coastal stretches of interest up to 20 m depth and up to 10-20 m elevation in shoreward direction; simulation of storm events along the selected profiles; definition of hazard extents and intensities (flood-depths, depth-velocities and overtopping discharges) in probabilistic terms; simulation of flooding distribution inland in probabilistic terms; compilation of flood-depth and depth-velocity maps based on combined model results.

The prevailing coastal setting – beaches of various width with fast-rising slopes backed by promenade representing part of a narrow low-laying strip – did not allow the application of LISFLOOD model solely to correctly obtain the inundation pattern. This necessitated combination of XBeach and LISFLOOD-FP models’ output in order to assess properly flood depth and depth-velocity spatial distribution. For this purpose, a methodology for post-processing of XBeach output had to be developed to represent the hazard on the beach in probabilistic terms.

Morphological setting

The coast of Varna region has a variety of morphological settings. According to the morphodynamic classification of Wright and Short [7], beaches along Varna regional coast are predominantly intermediate (with presence of longshore bar-trough) but there are also dissipative beaches, as those in the vicinity of Kamchia river, and reflective beaches exposed to high wave energy or located in areas with sediment supply shortage (due to disruption of long-shore sediment transport). There are variety of coastal structures that influence the natural behavior of beaches as groynes, revetments, dams and a breakwater.

Digital surface model with 1 m horizontal resolution based on topography data from aerophotogrammetric surveys (10 cm resolution) carried out in 2014 (Varna central beach) and in 2015 (Kabakum beach), complemented by bathymetry data of 20 m horizontal resolution from surveys carried out during 2011-2014 was used in the study [8]. Sediment grain size data (D50) used in the study date from 2015 field surveys.

Extreme event definition

Wave properties time series for the individual storm events were extracted from wave hindcast data covering 57-year period (1949-2006) obtained by means of nested WAM-SWAN wave model train [9]. Corresponding water level series at the hotspots’ boundary were achieved by hydrodynamic simulations using

Delft3D FLOW model [10]. Selected boundary condition points for extraction of wave climate time series and surge time series are shown in Fig. 1.

Peak over threshold (POT) analysis was used to identify the individual coastal storms using threshold of 2 m for significant wave height, which should be exceeded for a time-span longer than 18 hours [11]. After analysis, 75 storm events were selected and series of significant wave height, peak wave period, mean wave direction and surge level were prepared to simulate each storm.

Storm wave and surge data statistics at the external boundary points are summarized in Table 1 for each study site. Significant wave heights are in the range of 2 - 4.8 m, peak wave periods – 5.1 - 10.9 s and mean wave direction vary between NE and ESE. The calculated surge level is in the range of 0.08 m to 0.31 m.

Table 1. Summary of wave and surge boundary conditions.

Point No (Fig. 1)	Point depth, m	Study area	Minimum/ maximum value	H_p , m	T_p , s	Direction, deg N	Surge level, m	Duration, hours
1	23	Kabakum	min max	2.0 4.2	5.1 10.9	47 106	0.09 0.33	8 126
3	22	Varna	min max	2.0 4.8	5.6 10.8	43 108	0.10 0.36	11 139

Numerical models

As mentioned above due to diverse characteristics of the coastline and coastal morphological features as well as the presence of coastal protection structures, it is necessary a combined use of two numerical models in order to assess the flooding hazard. This was done through off-line coupling of open-source process-based nearshore storm impact model XBeach [12, 13] and the overland flood model LISFLOOD-FP [14, 15].

Hazard assessment methodology

Since Varna regional coast comprises different coastal types, the cross-shore transects were selected considering the coastline contour, beach topography and alongshore coastal setting variability. Thus, the distances between modelled transects varies between 29 m and 145 m. All profiles were extended up to 20 m depth at the sea boundary, as well as landward to cover elevations up to 10-20m inland.

XBeach model was applied in non-hydrostatic mode on cross-shore profiles along the hotspots' shoreline fed with JONSWAP wave spectra series. Morphological acceleration factor of 5 was used for all simulations where morphological response was calculated. The influence of coastal defense structures was taken into account using the non-erodible layer option in the XBeach model. Different mean sediment diameters (D_{50}), ranging from 0.26 mm to 1.6 mm, were used for each profile, thus representing the local sediment features. The sediment transport calculation is included except at Varna artificial island.

XBeach implementation

XBeach was applied on: 13 profiles at Kabakum beach (Fig. 2), 47 profiles at Varna hotspot (Fig. 2) and 3 profiles at the artificial island (Fig. 3). After simulation of all selected storms, series of maximum flood depths and maximum depth-velocities along the profiles were extracted for every storm hour. Additionally, maximum overtopping discharges at initially predefined output points were extracted as boundary conditions for LISFLOOD-FP simulations. The cross-shore profiles used for simulations (grey lines) and the overtopping discharge points (black dots) are denoted in Fig. 2 and Fig. 3.

Concerning the flood depth and depth-velocity, the maximum distance between the initial shoreline and the position of maximum flood extent (i.e. up to flood depth = 0.05 m and up to depth-velocity = 0.01 m²/s) along each profile for every storm event were calculated. Additionally, the flood depth and depth-velocity maxima at the initial shoreline position for each storm were extracted for post processing.

The total distance for the maximum flood depth and depth-velocity hazard parameters for the individual storm event was calculated as the sum of distances of all profiles using Eqn. 1:

$$(1) \quad Dist_{tot} = \sum_{i=1}^n Dist_i$$

where n is the number of profiles. Subsequently, the individual profile contribution for every storm was calculated through the equation:

$$(2) \quad \alpha_i = Dist_i / Dist_{tot}$$

The maximum values of flood depths and depth-velocities at the shoreline were processed in similar manner. Thus, series of total distances and total hazard parameters values at the shoreline for all simulated storms were formed. All the series were subjected to extreme values analysis to be fit to Generalized Pareto probability distribution function. Inverse cumulative distribution function was used to obtain total distances with return values corresponding to 20, 50 and 100 years.

Subsequently, the profile locations delineating the maximum flood extent were calculated for the selected TR. This was done, using the total distances (flood depth and depth-velocity) calculated for storm events with the defined TR and individual profile contribution value (Eqn. 1 and Eqn. 2). Then, polygons defined by initial shoreline points and points delineating the extent of maximum flood depth and maximum depth-velocity parameters were formed for every study location.

The maximum flood depth and maximum depth-velocity spatial distribution was calculated through two-dimensional interpolation. The final hazard distributions were incorporated into LISFLOOD-FP output grids. The maximum overtopping discharge volumes series extracted from XBeach output were post-processed for further use in LISFLOOD-FP. The total overtopping discharge volume for the particular storm event was calculated as the sum of volumes of all profiles using Eqn. 3:

$$(3) \quad Vol_{tot} = \sum_{i=1}^n Vol_i$$

where n is the number of profiles. Subsequently, the individual profile contribution for every storm was calculated through the equation:

$$(4) \quad \alpha_i = Vol_i / Vol_{tot}$$

The total maximum overtopping discharge volumes (Eqn. 3) were fit to Generalized Pareto probability distribution function. Inverse cumulative distribution function was used to find total volumes with return values corresponding to 20, 50 and 100 years.

LISFLOOD-FP implementation

The model was applied on the three coastal sectors using digital surface model with 1 m resolution (Kabakum Beach and Varna artificial island) and 2 m resolution (Varna hotspot). The model was run in acceleration mode, with infiltration coefficient of 0.00001, Manning's n value for spatially uniform floodplain set to 0.06, and initial time step value of 10 s. The already calculated overtopping discharge volumes were fed into LISFLOOD-FP model to calculate the hinterland flooding. The water volume discharges were distributed along the seaward boundary (delineated by dark grey line in Fig. 2 and Fig. 3) created through connection of the XBeach discharge output points, according to the profile contribution (Eqn. 4). After simulations, grid files and maps of maximum flood depth and maximum depth-velocity for the whole event were generated using post-processing of the flood model output. Finally, XBeach and LISFLOOD-FP models' results were combined in order to obtain flood depth and depth-velocity maps for TR 20, 50 and 100 years. Further on, only results relevant for TR50 are discussed.

RESULTS AND DISCUSSION

The flooding hazard assessment at Kabakum Beach, Varna hotspot and Varna artificial island are presented in Fig. 4, Fig.5 and Fig.6, respectively. At Kabakum beach the flooding reaches up to the protecting wall situated behind the promenade. The area that is mostly endangered is located in the northern part of the beach which is not protected by wall and a big parking area is located. There, the elevations change smoothly allowing for the water to reach the inner part of the parking area and the areas in the vicinity of the hotel building and tourist facilities.

Figure 4. Hazard maps (TR50) at Kabakum beach – maximum flood depth (left) and maximum depth-velocity (right).

According to the results for Varna 'hotspot' simulations (Fig. 5), at the Varna groynes beaches and Varna central beach areas, the flood reaches up to the lower parts the cliff slope, flooding the entire beach and

the promenade built behind. The most negatively affected area is the northern part of Varna central beach where the beach is narrowest. Besides, due to presence of buildings on the central part of the beach, making it narrower (about 6 to 10 m), the maximum depth-velocity in the whole ‘hotspot’ is calculated for this location. Concerning Varna breakwater, the most endangered area is located in the northern part where the breakwater protection by rocks and tetrapodes is weakest. In the central part of the breakwater the flood reaches up to the half-width of the area, while concerning the southern part, the whole width of the breakwater is flooded.

It should be mentioned that for the profiles where sediment transport is taken into account, there are quite high values of depth-velocity and flood depth calculated at the initial shoreline position due erosion during the storm with subsequent depth increase.

Figure 5. Hazard maps for TR50 at Varna ‘hotspot’ – maximum flood depth (left) and maximum depth-velocity (right).

Regarding the maps of maximum flood depths and maximum flood-velocity at the ‘island’ (Fig. 6), they are a result from the water redistribution of the overtopping discharge volumes simulated by LISFLOOD-FP solely. The maximums of flood depth and depth – velocity values are smaller than those in the previous cases, since here there is no wave action involved.

Figure 6. Hazard maps for TR50 at Varna artificial island – maximum flood depth (left) and maximum depth-velocity (right).

The presented outputs and analysis were further used for vulnerability assessment as in the case of application of INDRA (Integrated Disruption Assessment) model [16] in order to determine the most vulnerable coastal hotspot [17].

CONCLUSIONS

The study presented the process of flooding hazard assessment at potentially vulnerable coastal locations of Varna regional coast. The methodology includes use of a sequence of numerical models through offline coupling of open-source process-based nearshore storm impact model XBeach and the overland flood model LISFLOOD-FP complemented by output and input data post-processing. The goal of the study was to assess the flooding hazard on Kabakum beach Varna ‘hotspot’ and Varna ‘artificial island’ and to prepare maps

and grids of maximum flood depths and maximum flood-velocity for events of defined return periods (20, 50 and 100 years) for further vulnerability assessment.

The methodology is quite complex and demands representative data describing geomorphological settings, presence of coastal structures, long-term spatial and temporal variability of hydraulic boundary conditions (surges and waves). Nevertheless, it was proven that it is a useful practical tool for flooding hazard assessment at regional scale using the non-exhaustive one dimensional XBeach modeling coupled with the two dimensional flood plain modelling in probabilistic terms. A possible drawback is the somewhat complicated applicability is in case of complex coastlines.

ACKNOWLEDGEMENTS

This work was supported by the European Community's 7th Framework Programme through the grant to RISC-KIT (Resilience-increasing Strategies for Coasts – Toolkit), contract no. 603458.

REFERENCES

- [1] [1] O. Ferreira, Viavattene C., Jimenez J.A., Bolle A., Neves Das L., Plomaritis T., McCall R., Van Dongeren A.R. Storm-induced risk assessment: evaluation of two tools at the regional and hotspot scale, *Coastal Engineering*, vol.134, 2018, p.241-253.
- [2] [2] C. Viavattene, J.A. Jiménez, O. Ferreira, S. Priest, D. Owen, R. McCall. Selecting coastal hotspots to storm impacts at the regional scale: a Coastal Risk Assessment Framework. *Coastal Engineering*, 2018, vol.134, p. 33 – 47.
- [3] [3] A. van Dongeren, Ciavola, P., Martinez, G., Viavattene, C., Bogaard, T., Ferreira, O., Higgins and R. McCall. Introduction to RISC-KIT: Resilience-increasing strategies for coasts. *Coastal Engineering*, vol.134, 2018, p.2-9.
- [4] [4] P. Eftimova, N. Valchev, N. Andreeva, B. Prodanov and L. Dimitrov. Calculation of maximum wave run-up at Varna regional coast (Western Black Sea) using empirical models. *Proceedings of the 35th International Conference on Coastal Engineering*, 2017, DOI:<https://doi.org/10.9753/icce.v35.management.17>
- [5] [5] N. Andreeva, N. Valchev, B. Prodanov, P. Eftimova, I. Kotsev and L. Dimitrov. Assessment of coastal receptors' exposure and their vulnerability to flood hazard along Varna regional coast. *Proceedings of the 35th International Conference on Coastal Engineering*, 2017, DOI:<https://doi.org/10.9753/icce.v35.management.8>;
- [6] [6] N.J., R Garrity, Battalio, P.J. Hawkes and D. Roupe. Evaluation of the event and response approaches to estimate the 100-year coastal flood for Pacific coast sheltered waters, *Proceeding of the 30th ICCE, ASCE*, 2006, pp. 1651-1663.
- [7] [7] L.D. Wright, and A.D. Short. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology*, Elsevier, 56, 9, 1984, 3–118.
- [8] [8] B. Prodanov, B. *Seabed mapping of the Bulgarian continental shelf in front of the Avren Plateau coastal area for habitat classification*. Ph.D. thesis, 2017, 163 pp. (in Bulgarian).
- [9] [9] N. Valchev N., Trifonova E. and N. Andreeva. Past and recent trends in the western Black Sea storminess, *Nat. Hazards Earth Syst. Sci.*, vol. 12, 2012, pp. 1–17,
- [10] [10] Deltares. *Delft3D-FLOW, User Manual*, 2014, p. 710.
- [11] [11] N. Valchev, N., N. Andreeva, P. Eftimova, B. Prodanov and I. Kotsev. Assessment of vulnerability to storm induced flood hazard along diverse coastline settings, *Proceedings of 3rd European Conf. on Flood Risk Management, FLOODrisk*, 2016, E3S Web of Conferences 7 10002.
- [12] [12] D. Roelvink, A. Reniers, A. van Dongeren, J. van Thiel de Vries, R. McCall and J. Lescinski. Modelling storm impacts on beaches, dunes and barrier islands, *Coastal Engineering*, 2009, vol.56, p.1133-1152.
- [13] [13] Deltares. *XBeach Technical Reference: Kingsday Release. Model description and reference guide to functionalities*, 2015, p.141.
- [14] [14] P. Bates and A.De Roo, A simple raster-based model for floodplain inundation. *Journal of Hydrology*, vol.236, 2000, pp. 54-77.
- [15] [15] P. Bates, M. Trigg, J. Neal and A. Dabrowa. *LISFLOOD-FP User Manual Code release 5.9.6*, 2013, p.49.
- [16] [16] C. Viavattene, S.Priest, D.Owen, D.Parker , P.Micou, and S. Ly. INDRA model: for a better assessment of coastal events disruptions. In: *Proceedings of the ISCRAM 2016 Conference – Rio de Janeiro, Brazil*, 2017, p. 9.
- [17] [17] N. Andreeva, P. Eftimova, N. Valchev, B. Prodanov. Assessment of flood-driven direct impacts on coastal receptors along Varna municipality seaside. *Proc. of the 14th Int. Conf. on Marine Sciences and Technologies 'Black Sea 2018'*, October 10th - 12th, 2018, Varna, Bulgaria.

ASSESSMENT OF FLOOD-DRIVEN DIRECT IMPACTS ON COASTAL RECEPTORS ALONG VARNA MUNICIPALITY SEASIDE

Nataliya ANDREEVA*, Petya EFTIMOVA*, Nikolay VALCHEV* and Bogdan PRODANOV*

* Institute of Oceanology “F. Nansen” – BAS, Varna, Bulgaria

Abstract. Assessment of flood-driven direct impacts on coastal receptors along Varna municipality seaside is performed making use of the coastal INtegrated DisRUption Assessment (INDRA) model developed as a risk assessment tool within RISC-KIT, FP7 EU project. The considered coastal receptors encompass the built environment located within coastal sectors previously selected as potential hotspots, i.e. areas with highest risk to flooding and include Kabakum beach, Varna beach & Varna port wall and ‘Ostrova’ industrial zone. Herein, the direct impacts are regarded as losses resulting from a direct exposure of receptors to flooding hazard: damages to properties and building collapse. The losses are expressed as a function of hazard intensities, receptors’ location, elevation and vulnerability by means of depth-damage curves and building collapse matrix, thus defining their level of exposure. Results reveal that flood-driven impacts primarily depend on combination of hazard extents and intensities, and receptors susceptibility due to their socio-economic function.

Keywords: Black Sea, coastal receptors, direct impacts, flooding hazard, risk assessment

INTRODUCTION

Coastal areas are highly dynamic and complex multi-function systems, which include a wide number of socio-economic activities like urbanization, tourism and recreation, industrial production, port activities and shipping, agriculture etc. Storm surge-driven flooding is regarded as a major natural hazard, endangering human life, occupation and built environment associated with coastal socio-economics, causing extensive damage, business disruption and economic losses [1]. Such circumstances pose the need of risk-oriented comprehensive analyses to assess the potential threat of coastal flooding and related impacts and damages. Therefore, the present study is focused on assessment of flood-driven impacts on coastal receptors, making use of coastal INtegrated DisRUption Assessment (INDRA) model developed as a risk assessment tool within Coastal Risk Assessment Framework (CRAF) [2], FP7 RISC-KIT project [3]. During implementation of CRAF Phase 1 [4] along Varna regional coast, three potentially vulnerable coastal sectors ‘hotspots’, i.e. areas with highest risk to flooding were identified at Varna municipality coast, namely *Kabakum beach*, *Varna beach & Varna port wall* and ‘*Ostrova*’ industrial zone [5]. The objective of CRAF Phase 2 was to assess and rank the identified hotspots by means of detailed risk analysis done by jointly performing a hazard assessment and an impact evaluation on different categories of receptors (*built environment, population, businesses, ecosystems, transport and utilities*), using INDRA model [6] at a regional scale [7, 8]. Since, the model has the ability to assess impacts at receptors level, i.e. direct exposure, the aim of the study is evaluation of flood-driven direct impacts on the built environment (private and business) within aforementioned vulnerable coastal sectors.

STUDY AREA AND SELECTED HOTSPOTS

The study site comprises the coast of Varna municipality (western Black Sea), as it stretches from cape Ekrene to the southern municipality border, including Varna Bay (Fig. 1). Northward, between capes Ekrene and St. George the coast is marked by cliffs and beach bodies of different dimensions, and is predominantly occupied by several large and smaller seaside resorts with national and international importance: ‘Golden sands’, Holiday Club ‘Riviera’, ‘Chayka’, ‘Sunny day’ Co., ‘St. Constantine & St. Helena’, and ‘Euxinograd’. The area also comprises villa zones mixed with family and smaller hotel complexes. For the most part, the northern arm of Varna Bay (Fig. 1) is protected by coastal defense structures – concrete groynes with rocky revetment in-between, which resulted in formation of several beaches. Some of these beaches are located within the city limits as the area is shaped as a seaside promenade with small beach bars and restaurants. In the most inner curve of Varna Bay lays a sandy spit – low-lying area cut by two artificial navigable canals shaping an island area called ‘Ostrova’ industrial zone, a center for industry and commercial activities relevant to shipbuilding and repair, cargo and oil storage, transportation and distribution. The area also holds the premises and infrastructures of port of Varna, protected by sea wall.

As mentioned previously three hotspots were selected for risk analysis: *Kabakum beach*, located in the area of international seaside resorts, and *Varna beach & Port wall* and *Industrial zone ‘Ostrova’* situated within the inner

Figure 1. Location of vulnerable coastal sectors 'hotspots' along Varna municipality coast

curve of Varna Bay (Fig. 1). The activities within the first two hotspots are relevant to seaside tourism and recreation, which predetermines the nature of the built environment potentially exposed to flood-driven direct impacts due to high sea levels, storm surge and accompanying wave attacks. Herein, the built environment within the beach area is mainly presented by small beach bars and restaurants, while larger restaurants, small to large hotels, rest houses, etc. are located predominantly right beyond the beach, farther inland or in some cases on higher ground, which decreases their exposure. As for the *Industrial zone 'Ostrova'* the exposed area is occupied by premises and relevant infrastructure of shipbuilding and ship-repair companies; cargo and oil terminals; cargo and industrial goods warehouses, and oil/fuel storage tanks.

DATA AND METHODS

Direct impacts assessment by INDRA model

The INDRA model was designed for ranking of previously identified hotspots, considering intermediate risk assessment of coastal hazards (such as flooding & erosion) by analysis of impacts on coastal receptors in a comparative manner on a regional scale [2, 6]. It assess the shock of events by estimating the impact on directly exposed to hazard receptors of different vulnerability, as well as the potential ripple effects during an event in order to assess the 'indirect impacts', which occur outside the hazard area and/or continue after the event for various categories of receptors.

The potential impacts are expressed in terms of uniform 'impact indicators', which independently score the indirect impacts on these categories, assessing disruption and recovery of the receptors. For the final hotspot ranking the model also provides methods for weighting the 'impact indicators' according to the preferences of end users, using a *Multi-Criteria Analysis*. As mentioned previously, the impact assessment process provides a regional assessment of various impacts, as the regional scale is necessary in order to reveal the relative impact and compare hotspots. To this end, initially the impact is calculated at receptors level, i.e. direct exposure and, then, converted into wider disruption impacts, i.e. indirect and systemic.

Having said that, the present study assesses only flood-driven direct impacts on the built environment (private and business properties) across the identified hotspots, without further examination of indirect and disruption impacts. Herein, the direct impacts were regarded as losses resulting from a direct exposure of receptors to flooding hazard: inundation damages to properties and building collapse. The losses were expressed as a function of hazard intensities and extents, receptors' geographic location, elevation, characteristics and vulnerability by means of relevant vulnerability indicators [9], thus defining their level of exposure. Such combined evaluation was performed within INDRA model by making use of georeferenced information in *Geographic Information Systems* format on hazard intensities and extents, and receptors position, elevation and characteristics, as well as details on preliminary defined 4 hazard thresholds. The latter were necessary for 5-leveled scale of impacts (*None, Low, Medium, High, Very High*), reflecting each receptor's susceptibility to inundation damage or collapse [6]. As stated in [10] 'the availability of data on land use or for different vulnerability components is variable and a key source of uncertainty' and in order to 'maintain a degree of transparency and an opportunity to improve the assessment, a Data Quality Score (DQS) is included in the CRAF approach. It consists of scoring between 1 and 5 the different input data: from 1 (Data available and of sufficient quality) to 5 (No data available, based on multiple assumptions)' [2].

Hazard assessment background

Flooding hazard was assessed through coupled use of morphodynamic model XBeach 1D [11] and LISFLOOD-FP [12] inundation model at the three potentially vulnerable coastal sectors. 'Response approach' [13] was adopted to assess the probabilistic distribution of the flood hazard, aiming at 20, 50 and 100 years return periods. To this end, 75 storm events were selected for simulations with XBeach 1D model. Wave and water level time series for these events were extracted from 57 years-long SWAN and Delft3D hindcast data set [5]. The morphodynamic model was applied along multiple predefined cross-shore transects in non-hydrostatic mode. Series of flood depths fd and flood depth-velocities fdv along these transects, as well as the overtopping discharges at fixed positions were post-processed and analyzed. The LISFLOOD-FP model was then fed with overtopping volumes to calculate the intensity and extent of the hinterland flooding for considered return periods. Subsequently, both models' outputs were combined to map flood depths and flood depth-velocities spatial distribution at the studied locations and saved as polygon shape files. Detailed study is presented in [14].

Receptors' land use

For direct impacts evaluation it was necessary to obtain data on geographic location, elevation and characteristics of each receptor within the area of identified hotspots (Fig. 1). To this end, the land use area for each receptor was digitized from orthophoto images with spatial resolution of 0.8 m taken in December 2013 and Google satellite images. Information on receptors elevation and characteristics (receptors' category and building material) were identified by field surveys and Wikimapia. Thus, for INDRA modelling, data available as polygon shape files were converted into point shape files by calculating the centroid for each polygon and a single Land Use shape file was created. DQS: 2.

Vulnerability indicators

The category of built environment considers the direct damage to private and business buildings, including building collapse. Damage to this category is possible to occur in many ways, such as from floodwaters entering properties and building structures suffering from wave forces and erosion. The duration of flooding is also essential since the longer the duration the higher the damages due to increased drying times and higher clean-up costs.

Flood Depth-Damage vulnerability indicator [9]. The assessment of direct, physical flood losses to the built environment is commonly expressed by Depth-Damage (D-D) functions or curves, which provide the anticipated monetary value or percentage of loss at a given depth inside the property [15]. There are two sources for uncertainties within application of such curves coming from: 1) availability only of national level D-D curves, which may not be able to represent accurately regional or local conditions, and 2) uncertainties related to damage estimation data [16, 17]. Due to lack of vulnerability curves, reflecting local conditions, national D-D curves, which provide susceptibility (sensitivity) expressed as a percentage of the total value of the assets [18], were used to define four hazard thresholds for identified types of receptors. The actual determination of thresholds was done taking into account the inflection points of the curves and nature of function growth. This allowed assignment of the five-scale impacts. Threshold values are listed in Table 1. The setting of DQS to 3 was assigned because the proposed curves are borrowed from different international sources as part of them are an analytical remaking of statistically averaged observations, while others are modelled and partially readjusted to local conditions, according to contemporary levels of vulnerability of different receptors in Bulgaria [18].

Building collapse vulnerability indicator. In addition to floodwaters entering the properties, the impact of coastal events usually involves action of wave forces, where the structural integrity of a building might be compromised, leading to a partial or total collapse. Waves may impact significantly the structure of certain buildings due to their repetitive loading and related breaking wave pressure. Destructive pressures could even be caused by wave heights less than 0.9 m [19]. To assess potential collapse of directly exposed buildings an indicator developed in [9] and adopted from [20] was applied. Methodology focuses on building materials (timber-framed: anchored or unanchored, masonry, concrete and brick buildings) and using the parameter Flood depth-velocity fdv [m^2/s] = Flood depth fd [m] x Flow velocity v [m/s], provides a Damage matrix. It suggests what values of fdv would cause inundation damage, partial or total collapse, depending on the building material. Threshold values are presented in Table 1. DQS: 4.

For *Flood Depth-Damage* vulnerability indicator the *Very High* category relates to building collapse impacts, but these are usually not represented by D-D curves and a value of 9999 was attributed to Threshold 4 (Table 1). For receptors *Car Parks*, *Oil Tanks* and *Water Sport Attractions* (a public pool and 'Rolbata' water slide at Varna hotspot), only the first threshold was defined, which determines a single level of impact (*Low*). This is due to the fact, that for the first two receptors, even for $fd > 5$ m the D-D curves show percentage of susceptibility less than 5 %, and for *Water Sport Attractions* this value is less than 14 %. That is why 9999 values were set for the remaining three thresholds. On the other hand, for *Building Collapse* indicator the value 9999 was attributed to Thresholds 1-2, since values of $fdv < 3 m^2/s$ are associated with inundation damage and not collapse.

Table 1. Built environment receptors' types identified across considered hotspots and assigned threshold values for Flood-Depth Damage and Building Collapse vulnerability indicators

Receptors	Hazard intensity	Threshold 1	Threshold 2	Threshold 3	Threshold 4
Beach Bars & Restaurants	fd [m]	0	0.15	0.5	9999
	fdv [m ² /s]	9999	9999	3	7
Hotels & Restaurants*	fd [m]	0	0.25	1.25	0
Low Height Residential Properties *	fd [m]	0	0.25	1	9999
Retail*	fd [m]	0	0.25	0.5	9999
Administrative Buildings*	fd [m]	0	0.35	1	9999
Car Parks, Water Sport Attractions*, Oil Tanks*	fd [m]	0	9999	9999	9999
Oil Tanks Buildings*	fd [m]	0	0.15	0.5	9999
Warehouses for Industrial Goods*	fd [m]	0	1.75	9999	9999
Shipbuilding Industry*	fd [m]	0	0.4	9999	9999
Plastic Production*	fd [m]	0	0.4	1.75	9999

* Building collapse vulnerability indicator was also applied to these categories with the same thresholds values as for receptors 'Beach Bars & Restaurants'

RESULTS AND DISCUSSION

Before analysis of INDRA modelling results it is needed to make some remarks and comments on flood extents and intensities represented by parameters: *flood depth* and *flood depth-velocity*, which are essential to assessment of direct impacts on built environment. For hotspots *Kabakum beach* and *Varna beach & Port wall* due to the nature of their geomorphic and man-made settings, and partially due to the hazard assessment methodology in use, the flood extents are focused predominantly within the beach areas and seaward surface of the port wall. That is why for all return periods flood extents do not widen and only hazard intensities increase (Table 2). The rapid growth of fd and fdv with each return period is associated with small flooded area, beach bottom slopes and receptors' location relative to the shoreline. Presence of fdv values larger than 3 m²/s suggest potential partial building collapse, while $fdv > 7$ m²/s – potential total building collapse. On the contrary, the area of the industrial zone 'Ostrova' is a human-modified low-laying flat land of a former sandy spit, which despite of its fortified forehead is prone to storm surge driven flooding. Combination of these circumstances and the method used for flood estimation resulted in increase of flood extents with each return period. Hazard intensities increase as well, but in a different manner in comparison to the first two hotspots (Table 2). Due to milder surface slopes and bigger area maximum flood depths are smaller (max $fd = 2.1$ m for RP 100 years) and depth-velocities are significantly lower, as even for RP 100 years maximum $fdv = 0.3$ m²/s.

Table 2. Flood hazard intensities value ranges at the affected receptors within the three hotspots for return periods (RP) of 20, 50 and 100 years.

Hotspot name	Kabakum beach			Varna beach & Port wall			Industrial zone 'Ostrova'		
	RP 20	RP 50	RP 100	RP 20	RP 50	RP 100	RP 20	RP 50	RP 100
fd [m]	0.2-2.8	0.8-2.89	0.3-3.1	0.007-1.2	0.08-4.1	0.13-4.2	0.05-0.9	0.093-1.6	0.02-2.1
fdv [m ² /s]	1.1-11.7	0.78-11.9	1-13.7	0.01-12.9	0.01-13.6	0.2-13.9	0.0002-0.04	0.0003-0.11	0.0001-0.3

INDRA modelling results on flood-driven direct impacts are presented in Figs. 2-3. Fig. 2 gives a notion of affected types of receptors, as well as their numbers and levels of vulnerability for both considered indicators across the three hotspots for return periods of 20, 50 and 100 years. Additionally, Fig. 3 presents distribution only of number of affected receptors and their levels of vulnerability for all hotspots and all return periods. As can be seen from Fig. 2 of all 12 types of receptors (Table 1) only 8 types are found to be under direct impact and these fall into land use categories *Business* (Tourism and Industry & Commerce) and *Other* (Car Parks). It was established that no households are under direct threat of flooding, since for Varna beach & Port wall hotspot they are located on a much higher ground, at Kabakum beach they are potentially exposed, but not affected due to narrow flood extents, and there are no households in the industrial zone 'Ostrova'.

Figure 2. Distribution of numbers of affected types of receptors and their levels of flood depth-damage vulnerability (upper panel) and building collapse vulnerability (lower panel) across hotspots candidates Kabakum beach, Varna beach & Port wall and Industrial zone 'Ostrova' for all considered Return Periods (PR) 20, 50 and 100 years. Abbreviations for different types of receptors are: BBR – Beach Bars & Restaurants, CP – Car Parks, WSA – Water Sport Attractions, OT – Oil Tanks, OTB – Oil Tanks Buildings, SBI – Shipbuilding Industry, PP – Plastic Production, WH – Ware Houses for industrial goods

At Kabakum beach the types of affected receptors are only *Beach Bars & Restaurants* and *Car Parks* (Fig. 2, 4), the reason being the narrow flood extent and location of BBRs' premises within the beach area. On this account, the Total Number (TN) of affected receptors is somewhat limited and not changing considerably with each return period, i.e. TN grows in a following sequence 9-16-16 for the three RP. For the same reason, *High* and *Very High* levels of Flood Depth-Damage (FDD) vulnerability are observed for most of the receptors, and it can be seen that the larger the return periods the higher the vulnerability of the same receptors. Having in mind construction type and building materials of these BBRs: wood framed (anchored), timber and sheet iron, results show that the affected receptors are highly prone to partial and total building collapse.

Special feature of *Varna beach & Port wall* hotspot is that it occupies a long narrow stretch of Varna Bay coast (Fig. 1, 4) and all receptors are concentrated within and along this area. It consists of a port wall, an elongated concrete/stone coast protective structure with receptors situated behind it, and several relatively narrow sandy beaches in-between the port wall and Y-shaped groynes, all these backed by seaside city promenade and steep cliff slopes. Affected receptor types are *Beach Bars & Restaurants*, *Water Sport Attractions* ('Rolbata' water slide) and *Car Parks*. To the north of the port wall, BBRs are located predominantly within the premises of old Varna Sea Baths, a brick masonry buildings, which itself are constructed within the beach area and thus directly exposed to wave impacts. Farther north, the BBRs are situated beyond the promenade, which provides a certain degree of safety. *Car Parks* are present behind the port wall and at the northern part of the hotspot (Fig. 1, 4). Herein, the TN sequence of impacted receptors is 33-35-37, but almost one third (15) of them are *Car Parks*, which have very low vulnerability for both indicators (Fig. 2). Same level of vulnerability has 'Rolbata' water slide, but for return period of 100 years it might be subjected to partial collapse. Modelling results show that almost half of the affected BBRs have *Medium* level of FDD vulnerability, as this level is decreasing with each return period on the account of FDD vulnerability increase towards *High* and *Very High* levels for the same receptors. The effect of building materials on the structural integrity of buildings is well observed on the case of this hotspot, since only 2-2-4 receptors has the potential to be partially destructed and 2-3-3 might experience total collapse, in contrast to the numbers at Kabakum beach.

At industrial zone ‘Ostrova’ affected receptors are: *Oil Tanks* (OT), *Buildings* related to *Oil Tanks* (OTB), premises of *Shipbuilding Industry* (SBI), *Plastic Production* (PP) and *Ware Houses* for industrial goods (WH) (Fig. 2, 4). Of all impacted receptors, the largest number goes to *Oil Tanks*, but they initially have very low FDD vulnerability (Table 1) due to their construction and building materials. Moreover, their Building Collapse vulnerability is also low because of very low *flood depth-velocities* for all return periods (Table 2). The receptors, which are the most endangered in this case are brick masonry buildings servicing the oil tanks, as their TN sequence of impact grow like 6-11-12 with each return period, reaching *Medium* to *High* FDD vulnerability. For the rest of the receptors FDD vulnerability does not exceed *Medium* level. According to results presented in Table 2, i.e. very low *fdv* values, all receptors at the industrial zone ‘Ostrova’ are prone to inundation damages only and not partial or total building collapse.

Figure 3. Distribution of numbers of affected receptors, regardless of their type, and their levels of flood depth-damage vulnerability (left panel) and building collapse vulnerability (right panel) across hotspots candidates Kabakum beach, Varna beach & Port wall and Industrial zone ‘Ostrova’ for all considered Return Periods (PR) of 20, 50 and 100 years

For all receptors the average value of *fd* for Threshold 2 is ≈ 0.43 m (Table 1) and flood depths above this value are expected to cause substantial damage to all properties. Thus, during analysis based on results from Fig. 3 the *Medium* level of FDD vulnerability was taken into account as well. Having this in mind, even though business properties at *Kabakum beach* with *High* and *Very High* vulnerabilities are more than at *Varna beach & Port wall* hotspot, in Varna the total number of impacted receptors with *Medium* and higher vulnerabilities is larger. On the other hand, results show that in the view of vulnerability to potential property collapse *Kabakum beach* is more susceptible in comparison with Varna hotspot. Finally, for the third hotspot there are no *Very High* levels of FDD vulnerability and only inundation damages are expected with regard to building collapse.

On the example of 50 years return period Fig. 4 presents visualization of flood depths distribution, location of affected types of receptors and their flood depth-damage vulnerability for the selected hotspots. Flood depth intervals are defined making use of *Jenks natural breaks optimization*, a method for data classification [21]. The return period of 50 years was chosen as one of the main return periods in the temporal scale of large and significant hazard events posing a threat to population.

CONCLUSIONS

A coastal INtegrated DisRuption Assessment (INDRA) model, a risk assessment tool, was applied at three predefined coastal sectors (hotspots) along Varna municipality seaside and used to assess the flood-driven direct impacts on built environment, encompassing business and private properties. Direct impacts were regarded as potential damages due to inundation and building collapse, resulting from direct exposure of receptors to flooding hazard. The damage assessment was performed using various information on receptors and their susceptibility by means of two vulnerability indicators.

Modelling results reveal that flood-driven impacts primarily depend on combination of hazard intensities and extents, and receptors susceptibility due to their socio-economic function. It was found that only

premises related to businesses, like tourism and commerce, are under direct threat but not households. Very high vulnerability (exposure) to flood damage and building collapse are established for receptors at *Kabakum beach* and *Varna beach*, as these within Varna hotspot are more susceptible to flooding, while those at *Kabakum beach* are more likely to suffer destructive inundations leading to partial and total collapse of more than half of the affected buildings. As for industrial zone 'Ostrova', regardless of the large number of impacted receptors, results showed that they are subjected only to inundation damage, as *High* vulnerability levels are found only for one type.

Figure 4. Visualization of flood depths distribution, location of affected types of receptors and their flood depth-damage vulnerability for hotspot candidates along Varna municipality coast for 50 years return period; levels of vulnerability in color: Grey – None, Green – Low, Yellow – Medium, Orange – High, Red – Very High

Having in mind the complexity of the model and variety and volume of the data in use, it could be concluded that the model demonstrated very good ability to predict flood-driven direct impacts on built environment, as the quality of results could be improved upon enhancement of quality of input data, especially those related to vulnerability of receptors by tailoring D-D curves adequately reflecting local conditions. Further research suggests employment of full INDRA model potential, which means assessment of indirect impacts and eventual ranking of hotspots' vulnerability to flooding.

ACKNOWLEDGEMENTS

The study was developed within and funded by the European Community's 7th Framework Program research project "Resilience-Increasing Strategies for Coasts – toolKIT" (RISC-KIT), GA no. 603458, and by the Scientific Research Fund affiliated to Ministry of Education and Science, Bulgaria, contract Д01-188.

REFERENCES

- [1] J. Birkmann. *Measuring vulnerability to natural hazards: towards disaster resilient societies*. United Nation University Press, 2006.
- [2] C. Viavattene, J.A. Jiménez, O. Ferreira, S. Priest, D. Owen and R. McCall. Selecting coastal hotspots to storm impacts at the regional scale: a Coastal Risk Assessment Framework. *Coastal Engineering*, Vol. 134, 2018, pp. 33-47.
- [3] A. Van Dongeren, P. Ciavola, C. Viavattene, S. De Kleermaeker, G. Martinez, O. Ferreira, C. Costa and R. McCall. RISC-KIT: Resilience-Increasing Strategies for Coasts – toolKIT. In: Green, A.N. and Cooper, J.A.G. (eds.), *Proc. of the 13th Int. Coastal Symposium (Durban, South Africa)*, *Journal of Coastal Research*, SI. 70, 2014, pp. 366-371.
- [4] O. Ferreira, C. Viavattene, J. Jimenes, A. Bole, T. Plomaritis, S. Costas and S. Smets. CRAF Phase 1, a framework to identify coastal hotspots to storm impacts, 3rd European Conference on Flood Risk Management FLOODrisk 2016, E3S Web of Conferences 7, 10002, 2016.
- [5] N. Valchev, N. Andreeva, P. Eftimova, B. Prodanov and I. Kotsev. Assessment of vulnerability to storm induced flood hazard along diverse coastline settings, 3rd European Conference on Flood Risk Management FLOODrisk 2016, E3S Web of Conferences 7, 10002, 2016.
- [6] C. Viavattene, S.J. Priest, D. Owen, D.J. Parker, P. Micou and S. Ly. INDRA model: for a better assessment of coastal events disruptions. *Proc. of 13th Int. Conf. Inf. Syst. Cris. Res. Manag. (ISCRAM)*, Session: Planning, Foresight and Risk Analysis, 2016.
- [7] N. Andreeva, P. Eftimova, N. Valchev and B. Prodanov. Coastal flooding impact evaluation using an Integrated Disruption Assessment (INDRA) model for Varna region, Western Black Sea. *EGU General Assembly 2017, Geophysical Research Abstracts*, Vol. 19, EGU2017-18671, poster, 2017.
- [8] P. Eftimova, N. Valchev and N. Andreeva. Coastal flooding hazard assessment on potentially vulnerable coastal sectors at Varna regional coast. *EGU General Assembly 2017, Geophysical Research Abstracts*, Vol. 19, EGU2017-19114, poster, 2017.
- [9] C. Viavattene, A.P. Micou, D.J. Owen, S. Priest and D.J. Parker. *Library of Coastal Vulnerability Indicators*. RISC-KIT Project Report, Flood Hazard Research Center (FHRC), Middlesex University, 2015.
- [10] C. Viavattene, S. Priest, D. Parker and D. Owen. D. From theory to practice: Can we really value coastal flood impacts? *Proc. of the 6th Int. Conf. on Flood Management (ICFM6)*, PAP014681, 2014.
- [11] D. Roelvink, A. Reniers, A. van Dongeren, J. van Thiel de Vries, R. McCall and J. Lescinski. Modelling storm impacts on beaches, dunes and barrier islands, *Coastal Engineering*, vol. 56, 2009, pp. 1133-1152.
- [12] P.D. Bates. *The LISFLOOD-FP flood inundation model*. Software, University of Bristol, UK, 2013.
- [13] N.J. Garrity, R. Battalio, P.J. Hawkes and D. Roupe. Evaluation of the event and response approaches to estimate the 100-year coastal flood for Pacific coast sheltered waters. *Proc. 30th Int. Conf. on Coastal Engineering (ICCE)*, ASCE, 2006, pp. 1651-1663.
- [14] P. Eftimova, N. Valchev, N. Andreeva, B. Prodanov and L. Dimitrov. Coastal flooding hazard assessment at vulnerable locations along Varna regional coast. *Proc. of the 14th Int. Conf. on Marine Sciences and Technologies 'Black Sea 2018'*, October 10th - 12th, 2018, Varna, Bulgaria.
- [15] E.C. Penning-Rowsell, S. Priest, D. Parker, J. Morris, S. Tunstall, C. Viavattene, J. Chatterton and D. Owen. *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal*, Routledge, Taylor & Francis, London, UK, 2013.
- [16] H. De Moel and J. Aerts. Effect of uncertainty in land use, damage models and inundation depth on flood damage estimates. *Natural Hazards*, vol. 58 (1), 2011, pp. 407-425.
- [17] B. Jongman, H. Kreibich, H. Apel, J.I. Barredo, P.D. Bates, L. Feyen, A. Gericke, J. Neal, J.C.J.H. Aerts and P.J. Ward. Comparative flood damage model assessment: towards a European approach. *Natural Hazards and Earth System Science*, vol. 12 (12), 2012, pp. 3733-3752.
- [18] D. Dimitrov, I. Nyagolov, S. Balabanova, N. Lisev, G. Koshinchanov, A. Korcheva, Y. Marinski, L. Pashova, D. Grozdev, V. Vasilev, V. Bozhilov and N. Tsvetkova. Methods for assessment of flood hazard and flood risk, according to requirements of the EU Floods Directive 2007/60: Final Report, Black Sea Basin Directorate, Contract No D-30-62, 2013, p. 357 (In Bulgarian).
- [19] *Recommended Residential Construction for Coastal Areas: Building on Strong and Safe Foundations*. FEMA P-550, Second Edition, December 2009.
- [20] T. Karvonen, A. Hepojoki, H.-K. Huhta and A. Louhio. The use of physical models in dam-break analysis. *RESCDAM Final Report*, Helsinki University, Finland, 2000.
- [21] G. Jenks. The Data Model Concept in Statistical Mapping. *International Yearbook of Cartography* 7, 1967, pp. 186–190.

COMPARATIVE STUDY OF NUMERICAL SIMULATION OF COASTAL FLOODING IN URBAN & ESTUARINE AREAS

J.N. Pan^{*}, V. Penchev^{**}, J.S. Zhang^{*}, F. Penchev^{**}, M.J. Xiong^{*}, D. Dragancheva^{***}, S. Shukrieva^{**},
D.T. Wang^{*}, J.H. Wang^{*}

^{*} Nanjing Hydraulic Research Institute, PR of China

^{**} Black Sea Danube Association for Research and Development, Bulgaria

^{***} Bulgarian Ship Hydrodynamics Centre, IMST – BAS, Bulgaria

Abstract: Two different approaches for numerical simulation of coastal flooding in urban & estuarine area have been carried out within the framework of a bilateral research project supported by the National Science Fund of Bulgaria and the Ministry of Science & Technologies of the PR of China.

A high resolution digital elevation model has been established for the Asparuhovo - Karantina area in Varna, Bulgaria, located at Black Sea coast. The area is considered with high risk of flooding, being at low elevation above the sea-level, with the presence of a small river (gully) in the neighborhood. A MIKE FLOOD approach was used by Bulgarian team to simulate inundations in the considered area under example scenarios with expertly formulated data for compound flooding: coastal flood (storm surge) in combination with pluvial/flash flood (heavy rainfall in the urban area), and river overflow due to excessive rainfall over an extended period.

Concurrently a SWASH model has been elaborated by the Chinese team to study coastal flooding for the same geographical area, for the same scenarios for water levels and wind-wave climate conditions. Simulation results of wave transformation in coastal area obtained by SWASH model indicate that, the shoaling effect near shore and wave run-up and breaking in the swash zone may aggravate the flooding disaster on the beach, especially when a severe storm generate intense water level rise.

Key words: Digital elevation model, field measurement data, numerical modeling

INTRODUCTION (Background and Objective of the Study)

Since centuries, protection of coastal communities against floods was one of the key stones for the development of human civilizations. Today, this is still a key issue for the entire world. The urban population of the world has grown rapidly from 746 million in 1950 to 3.9 billion in 2014, expected to surpass six billion by 2045 - a sizeable challenge for urban water management. Climate change impacts affect cities significantly — increased flood risks, increased frequency/severity of extreme events (floods, droughts, storms, heat waves, etc.). The increase in extreme weather events and flooding in particular has serious potential consequences for human health, livelihoods and assets.

Flooding in coastal urban areas (urban flooding) can be caused by high intensity rainfall, or storm surge floods, or river floods, or wave action in coastal zone, or the most dangerous combination of these events, whereby the city sewage system and draining canals do not have the necessary capacity to drain away the amounts of water that are falling. Typical examples of urban flooding were catastrophic flash floods in Bulgarian cities of Varna/Asparuhovo and Dobrich, in June 2014, with casualties' loss of human life, and huge damage of infrastructure and properties. This requires the study of hydrodynamic processes in very complex terrain conditions (coastal zone with urban infrastructure). "Composite modelling" or "Hybrid modelling" is one approach widely used over the past few decades to achieve a reliable forecast of inundation in floodplain areas at different scenarios. The "Composite Modelling" integrates physical modelling, numerical simulations, and verification with field measurement data. This present-date research approach can combine the main strengths of prototype data, physical and numerical modeling and this way to improve modeling and design. These elements of composite modeling can essentially complement each other – physical model provides verification data for numerical models; model simulations provide the continuum information to bridge the gaps in field data, etc. Thus increasing quality of the study results at the same cost or obtaining the same quality at reduced cost and/or reducing uncertainty at the same cost, since uncertainty reduction is also quality issue. Following the principles of composite modelling, physical and numerical modelling can improve further and broaden their range of applicability, [1].

The objective of the present study is to test and discuss two different approaches and techniques for numerical simulation (as element of composite modeling) of coastal flooding in urban and estuarine area. It should be pointed out that the greatest advantages of numerical modelling are its low cost compared with physical model tests, different options that it offers, possibility to repeat many times the simulation, lack of scale effects and of course extraction of data of all kinds by “virtual” probes without interfere with the flow. In any case the numerical model needs to be calibrated using sufficient reliable field data, [2].

The paper contains brief description of used numerical tools (MIKE21/MIKE FLOOD, and SWASH) and presents some example results obtained during numerical simulations of flood in the selected coastal area.

CASE STUDY AREA (MODELED AREA)

The two numerical approaches for simulation of coastal flooding have been tested for the conditions of an urbanized coastal area Asparuhovo - Karantina near Varna, Bulgaria, (Fig. 1). It is located in the southern part of Varna Bay on the western coast of the Black Sea (a closed sea, with negligible tidal variations).

Figure 1. Case Study Area near Varna, Bulgaria

This is a residential area that includes a sandy beach and a small river (gulley) in the southeast part of the beach. The residential area behind the beach is considered with high risk of flooding, being at low elevation above the sea-level. The numerical model also includes the fishing harbor to be built in the area.

MODELS AND RESULTS

MIKE 21 approach

MIKE 21 was developed by DHI (Danish Hydraulic Institute) and designed for 2D free surface modelling of flow and waves, sediment transport and environmental processes for estuarine and coastal applications. From wide range of models in MIKE Software family, released during more than 30 years, numerical models MIKE FLOOD, MIKE21 SW and MIKE21 BW were used in this study.

MIKE FLOOD is flexible software with the possibility to integrate 1D (MIKE 11 and/or MIKE URBAN) and 2D (MIKE 21 FM) models and perform more complex hydrodynamic simulations by different combinations between the 1D and 2D model.

MIKE 21 SW (Spectral wave) is a state-of-the-art third generation spectral wind-wave model that simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas. It includes two different formulations: A fully spectral formulation and a directional decoupled formulation. The first formulation is based on the wave action conservation equation and the second one is based on a parameterization of the wave action conservation equation. MIKE 21 SW is mainly used for simultaneous wave analysis on regional and local scale. A coarse mesh and large time steps are employed for the regional scale, while a high resolution boundary and depth-adaptive mesh is used for the shallow water areas.

Several data sets were combined in the process of the generation of the unstructured computational mesh for the simulations with MIKE 21 SW of Asparuhovo - Karantina beach area. The generated meshes are illustrated on Fig. 2 (a, b).

Figure 2. Unstructured flexible mesh for MIKE SW simulations:
a) Varna bay; b) Asparuhovo beach area and fishing harbor Karantina

A MIKE SW model was applied to evaluate waves entering shallow water, and provide boundary conditions for a MIKE 21 BW (Boussinesq Wave) model to study wave diffraction/transformation in the nearshore zone and in the harbor area.

The numerical model simulation results from MIKE21 SW model were compared with water level (storm surge) and wave data for the shallow water and wave breaking zone of the Asparuhovo beach area provided from Institute of Oceanology-BAS.

On the basis of the numerical bathymetry and the prepared meshes for the SW model, an additional numerical model has been set up with a larger resolution for the Karantina area. In order to construct the final model for the simulations of combined flooding including spill of the river combined with rising sea level driven by a storm. The described high resolution model (DEM) in the area of the river, harbor and beach is illustrated on Fig. 3.

Figure 3. 3D Visualization of the Digital Elevation Model (DEM) of the Asparuhovo beach and residential area, including sea bathymetry, sand beach, roads, buildings, fishing harbor and a small river

Digital Elevation Model (DEM) of Karantina area was created with a spatial resolution of 1 x 1 m in plan, and 15 cm in vertical on the base of data from hydrographic measurements and terrain scanning integrated in a GIS environment, and used to generate a 3D surface map on the base of standard triangulation techniques.

A MIKE FLOOD model was used to study riverine flow in the small river (1D approach), followed by a 2D MIKE 21 FM model, integrating both sea level elevation (coastal flooding) and the fluvial flood (river overflow). The calculation mesh comprises of 500 000 finite elements. Bed resistance is varying in the domain, higher values close to the beach and lower values offshore.

For numerical simulation of the inundation in the case study area a gradual increase in the mean sea level was simulated to levels typical of extreme meteorological events with a very long return period, and which

levels are quite significant in terms of beach flooding and overtopping the planned new harbor and coastal infrastructure.

A combination with multi-year river discharge was added to try to estimate compound flooding. Results of the simulations in the high-resolution DEM of the study area are illustrated on Figure 4.

Figure 4. Example results of calibration tests by MIKE FLOOD model of compound coastal & fluvial flooding in Asparuhovo - Karantina area (Sea level rise and high water coming from the small river)

SWASH approach

SWASH is an operational public domain code for simulating wave fields, rapidly varied flows and transport phenomena in 1D, 2D or 3Ds in coastal waters. The governing equations are the nonlinear shallow water equations including non-hydrostatic pressure. SWASH provides a general basis for describing complex changes to rapidly varied flows typically found in coastal flooding and wave transformation in both surf and swash zones due to nonlinear wave-wave interactions, interaction of waves with currents, and wave breaking as well as run-up at the shoreline.

A SWASH model has been elaborated by the Chinese team to study coastal flooding for the same geographical area, for the same scenarios for water levels and wind-wave climate conditions. SWASH is referred to a non-hydrostatic wave-flow model aimed to simulate wave transformation in coastal area.

The model domain is 1500m×1000m shown in Fig. 5. A uniform grid of 1500×1000 cells ($dx = dy = 1.0$ m) and 1 vertical layer is employed. The northern boundary uses weakly reflective boundary condition to generate irregular waves of JONSWAP spectrum and the spectrum parameters are $H_s=3.0$ m, $T_{mean}=8.8$ s, $Dir=76$ deg. These parameters are calculated by a three-nested SWAN model.

Figure 5. Schematic view of SWASH model domain

At the western and eastern boundaries, sponge layers with width of 300 m are applied to absorb short wave energy. At the southern boundary, discharge per unit width in the river upstream with a linear time-varying increase from 0 at the initial time step to $7 \text{ m}^3/\text{s}/\text{m}$ at the end of simulation is given. The still water level in the domain is set to be 0.5 m initially and rise up slowly to 1.2 m at the end of simulation to describe the large-scale storm surge set-up during extreme event. Figure 6 shows wave transformation and inland inundation scenario along the Asparuhovo - Karantina coast during the simulation period of 20 min.

Figure 6. Detailed results after 20 min. simulation period of flooding by SWASH in Asparuhovo - Karantina coast

11 “virtual” wave gauges are set in study area, (Fig. 7), to investigate the time series properties in the Asparuhovo - Karantina coastal area. P0~P5 is located at initial still water depth of -1.2 m, 0.5 m, 1.5 m, 3.5 m, 5.0 m and 6.0 m, respectively, aiming to explore the wave transformation properties from offshore to the swash zone. E1 is located at the estuary and R1, R2 are located in the upstream river. They are used to look up the interactions between the storm run-off from inland and extreme waves from seas in the estuary area.

Figure 7. Locations of “virtual” wave gauges for extracting a time series results

Figure 8 shows the time series of significant wave height H_s at point P5, P2 and P0. Waves at P5 are common waves in relatively deeper waters larger than 5.0 m. With the approaching coast, the bottom friction and wave breaking effects start to play a dominant role in gradually decreasing of wave height – from 1.66 m at P5 to 0.96 m at P1. As shown from the time series at P2 the nonlinearity increases in shallow waters and shapes of wave crests become steeper and wave troughs become more flat compared the shape of deep water wave. It should be noticed that, P0 is located at the swash zone, where the breaking waves swash up-and-down with violent turbulence and rotational flows. As shown in the “gauge” P0 in Fig. 8, located at the swash zone on the

beach, the wave uprush height can reach up to +1.5 m above the still water level. That means that large waves can aggravate the coastal disaster in the Asparuhovo - Karantina area and deserves prominent attentions.

Figure 8. Time series at points P5, P2 and P0

Figure 9. Time series at points E1, R1 and R2 in the river

Located at the estuary, the surface elevation of E1 mainly performs to be irregular wave motions with slight mean level variations. That means, under the wave and discharge conditions of this case, waves from open seas control the estuary dynamics rather than the run-off from inland.

Located in the upstream river, R1 and R2 possess similar features of surface variations, both performing to be rising curves loaded by short wave vibrations. The elevation rises from 0.5 m to 1.7 m at R1 and from 0.5 m to 2.0 m at R2. Closer to the estuary, waves can go upstream to R1 all the time but become large evidently near the 11st minute, when local water level rises to about +1.4 m. While, located further upstream, waves from estuary can hardly arrive at R2 until the 13rd minute, when local water level rises to +1.9 m.

SWASH model results show that, storm surge and wave set-up can push the waterline forward 40 meters to the backshore, approaching the front of coastal buildings, (Fig. 6, right snapshot). Meanwhile, large waves may aggravate the flooding disaster that the wave uprush can reach to +1.5 m above the still water level on the beach and impact the buildings, (Fig. 8). Upstream discharges make inland inundations over the streets and plain with a flooding area of about 1500 m². Surface elevations in the river perform to be gradually set-up curves mainly controlled by upstream discharge. While, the water level in estuary area is mainly affected by the waves in the shore.

CONCLUSIONS

Within this study, the use of various numerical tools for simulation of flooding and inundation in residential coastal areas has been investigated, and demonstrated in this paper for a case area of Asparuhovo-Karantina, near Varna, Bulgaria.

One approach use MIKE21 (MIKE FLOOD) numerical tools for simulation of inundation in areas with complex topography and bathymetry. The results obtained for the case area are in good correspondence with the provided statistical & field observation data that gives reason to use this approach when developing coastal flood protection projects.

Another approach has been demonstrated to simulate compound coastal flood by wave transformation in coastal area using SWASH model. Results indicate that, the shoaling effect near shore and wave run-up and wave breaking in the swash zone may aggravate the flooding disaster on the beach, especially when a severe storm generate intense water level rise.

The results obtained by the two approaches are comparable. They have demonstrated the applicability of the chosen approaches for forecasting of flood inundation, as well as for flood mapping and flood risk assessment in urbanized coastal and estuarine areas. This encourages authors for further research and improvement of the demonstrated approaches.

Further research will be focused on the composite modeling approach that will include use of the selected numerical tools in combination with large-scale physical modeling test, and field observation data for detailed calibration and verification of the numerical simulation results.

ACKNOWLEDGEMENTS

The authors express their sincere acknowledgment to National Science Fund of Bulgaria and the Ministry of Science and Technology of the People's Republic of China for their financial support of this study within the framework of the Agreement for Bilateral Scientific Cooperation (Contract DNTS/01/12/2016).

REFERENCES

1. Sutherland, J., & Barfuss, S. L., Composite Modelling: Combing Physical and Numerical Models, 34th IAHR World Congress. Brisbane, Australia: HR Wallingford, 2011
2. Vyzikas T., Application of numerical models and codes, WP3 BP Report, MERiFIC Project, University of Plymouth, Feb. 2014, www.merific.eu

MAPPING SEABED HABITATS IN EMODNET - THE BLACK SEA CASE

Valentina Doncheva*, Valentina Todorova* Nikolay Valchev* Adrian Teaca**, Mihaela Muresan**, Jacques Populus***, Mickaël Vasquez***, Eleonora Manca****

*-Institute of Oceanology –BAS, Varna, Bulgaria

** - GEOECOMAR, Constatna, Romania

***-Ifremer, France

**** -JNCC, United Kingdom

Abstract: EMODnet Seabed Habitats has developed, improved and gradually increased the coverage of a broad-scale seabed habitat map for Europe's seas, also known as EUSeaMap. The first Black Sea physical habitats map was created as a part of EUSeaMap Phase II. The habitats are classified according to the EUNIS (Version 2007-11) habitats classification, and also as MSFD “Benthic Broad Habitat Types”(as defined in the Commission Decision 17 May 2017). Statistical analyses were used to define the thresholds of biologically relevant physical and chemical parameters, which were then used to model the habitats boundaries. The ongoing Phase III of EMODnet Seabed Habitats will deliver maps to the highest resolution possible, taking account of the best-resolution data coming from other Lots (for example, Lot 1 Geology), accessing ground truthing data, and boosting the existing library of digital habitat maps. MSFD Benthic Broad Habitat types map is a new product made available that is especially suitable to inform against the MSFD criteria D1.6 - Habitat condition and D6.1 - Physical damage.

Keywords. Black Sea, EMODNet, EUSeaMap, maps, seabed habitats

Introduction

The European Marine Observation and Data Network (EMODnet) is a network of organisations supported by the EU's integrated maritime policy (www.emodnet.eu). The main purpose of EMODnet is to reveal fragmented and hidden marine data resources and to make these available to individuals and organisations, and to facilitate investment in sustainable coastal and offshore activities through improved access to quality-assured, standardised and harmonised marine data.

Seabed Habitats theme was initiated in EMODnet Phase I (2009-2013) through the EUSeaMap project, which aims to produce a broad-scale predictive seabed habitat map covering all European Seas in a consistent way. In its first phase (2009–2013) over two million square kilometres of European seabed were mapped, across four regions: the Baltic Sea, Greater North Sea, Celtic Seas and Western Mediterranean Sea (Fig.1). The Black Sea was encompassed by Phase II (2013-2016) of the project that involved the regional partners GeoEcoMar, IO-BAS and METU. Phase II delivered full coverage of a broad-scale physical habitat map for all European seas with resolution 250 m.

In the current Phase III (2017-2020) the broad-scale map is being updated and improved with the highest resolution possible (100 m or better), and further extended to cover the Barents Sea (Fig.1). New in Phase III is the collation and dissemination of point habitat data from surveys and selected single habitat model outputs from across Europe. The habitats are classified according to the EUNIS (Version 2007-11) habitats classification, and also as MSFD “Benthic Broad Habitat Types”(as defined in the Commission Decision 17 May 2017) [1].

Methodology and data

The approach to model a predictive physical habitats map includes the steps:

1. Acquire the best-available spatial data for several environmental variables, organised and harmonised into raster images. The principal input layers are the type of seabed substrate and the biological zones. Depending on the basin, layers of hydrodynamic energy levels, salinity and/or oxygen regime are also produced.
2. Combine by ‘layering’ the data in GIS to create a combined output describing the habitat.
3. Confidence assessment scores are provided along with maps to inform users on their reliability and data quality [1], [2].

Figure 1. Overview of the EUSeaMap broad-scale map coverage in Phase I and Phase II, and areas to be covered in Phase III.

The use of raster mode in Phase II leads to the loss of some of the detail contained by the seabed substrate polygon layers provided by EMODnet Geology. Therefore, Phase III will test a new polygon-based approach [3].

Black Sea primary data

The basic input layers for bathymetry and seabed substrates were provided by EMODNet Bathymetry and EMODNet Geology Lots, respectively. Additional data was provided by the Black Sea partners (IO-BAS, GeoEcoMar and METU) in the Seabed Habitats Lot.

Wave energy was used in the Black Sea to differentiate infralittoral from shallow circalittoral zones on soft bottoms, the boundary between them defined as the maximum depth at which seabed is no longer affected by stormy waves. In EUSeaMap II the coarse resolution of the model *Kassandra* was deemed inappropriate for broadscale habitat mapping. During Phase III IO-BAS developed a long-term wave hindcast in the western part at 3 km resolution and two small areas at resolution around 400m. ISPRA post-processed 11 years of data to evaluate the 90th percentile of wave energy at the bottom of the 3 km resolution area. ISPRA decided to provide a new evaluation of the sea bottom wave energy at high resolution using EMODnet Bathymetry and the available high resolution winds. The resolution of the total new domain of Black Sea is 1/64, and two nested areas have also been processed, the resolution of which is 1/128 (i.e. around 1 km) and the union of which covers all the Black Sea. The available data covers the period 2016-2018.

Temperature data was used in the Black Sea to distinguish shallow circalittoral from deep circalittoral zone. Oxygen was used in the Black Sea to differentiate deep circalittoral from suboxic zone. During Phase II, data on temperature and oxic-suboxic boundary was provided by METU. Phase III will probably use Copernicus CMEMS product named “Black Sea biochemistry hindcast”, which is a hindcast for various biochemical variables among which is “dissolved oxygen”. Simulated values of oxygen are annually averaged at the spatial resolution of 5 km, for 30 vertical levels in the water column over an 11-year time period. Another variable comprises oxygen values at the seafloor. Unfortunately, its spatial coverage is the north-western shelf only.

Effort was placed by Black Sea benthic experts in defining a pan Black Sea list of assemblages that could be portrayed at a broad scale and identifying the environmental variables that are likely to influence their distribution. This was done by checking literature and ground truth data for all identified assemblages and associated environmental parameters. A broad-scale Black Sea habitat list was prepared containing the known benthic assemblages occurring throughout the basin and the abiotic variables known to influence them.

A total of 5078 of macrozoobenthos sampling point data were collated for habitat map modelling of the Black Sea in Phase II. The highest percentage of data covered the Romanian and Ukrainian shelves (about 65%), while a serious gap was recorded for the eastern and southern part (less than 1% of samples at the Turkey coast). 547 benthos (IO – BAS and IBER) ground truth points covering the Bulgarian shelf were provided, which made possible a detailed statistical discriminatory analysis of habitats type of infra- and circalittoral zones [3], [4].

Modelling methods

To define the thresholds between the biological zones, the existing sample point data were used of those benthic communities considered as indicators of the biological zones.

Two general approaches were used in EUSeaMap II to set threshold between biological zones:

1. Optimal approach: fitting a logistic regression model with sample point data

A method was developed, which employs that approach for the prediction of the broad habitat descriptor classes that are considered in the marine section of EUNIS. Each habitat descriptor class for which were available point data of observed biology were modelled by fitting a GLM (Generalised Linear Model) using the unique environmental variable that explains the occurrence of the habitat descriptor class.

The GLM was fitted with presence/absence sample point data. Presence data are observed occurrences of species/communities that occur specifically in the modelled habitat descriptor class, while absence data are observed occurrences of species/communities that occur specifically in the neighbouring habitat descriptor class. GML was fitted in the Black Sea for the prediction of the shallow circalittoral at its lower boundary with deep circalittoral. The presence of the shallow circalittoral is driven by temperature. Dots are observed occurrences of species/communities that occur specifically in the shallow circalittoral (top of the graph, where $y=1$) and in the deep circalittoral (bottom, where $y=0$) –Fig.2 [3], [4].

Figure 2. GLM curve fitted in the Black Sea for the prediction of the shallow circalittoral at its lower boundary with deep circalittoral

The Receiver Operating Characteristic (ROC) curve [5] was used to identify the cut-off (threshold) probability value that is employed to transform probability values in discrete presence/absence values: above this value the habitat descriptor class is predicted as present and below it is predicted as absent (Fig.3).

Figure 3. ROC curve for bathymetric values of boundary between infra-circalittoral on soft bottom (after [6]).

2. Alternative approach: using threshold values and fuzzy classifiers

When no presence/absence point data is available the alternative to the logistic regression modelling method for the prediction of a habitat descriptor class occurrence along a gradient of a physical parameter is to use a fuzzy classifier. In abscissa are the variable values (e.g. temperature). In ordinate is the probability of occurrence for the habitat descriptor class.

In-between is a simple straight line, whose slope a and intercept b , a cut-off probability value has to be worked out. It is the probability value above which the habitat descriptor class will be classified as present and below which it will be classified as absent.

The cut-off probability value is subsequently used to classify the probability layer into presence of the habitat descriptor class.

Phase II results

Infralittoral - shallow circalittoral boundary on soft bottoms

On soft bottoms the wave energy is considered the biologically relevant physical factor that drives the distinction between the infralittoral and shallow circalittoral zones. Considering the lack of appropriate wave data, bathymetry was used as a proxy. For each sample point of indicator zoobenthos community of infralittoral or shallow circalittoral, depth values were extracted from the EMODnet Bathymetry DTM. According to the fuzzy classifier -20 m was estimated as the soft bottom threshold (Table 1).

Infralittoral - Shallow circalittoral boundary on hard bottoms

On hard bottoms the limit between the infralittoral and the circalittoral is marked by the end of the domination of photophilic macroalgae caused primarily by decreasing light availability. As above, due to lack of sufficient light data, bathymetry was used as a proxy. From the distribution of depth values for the points of infralittoral and circalittoral communities according to the fuzzy classifier - 14 m was assessed as the hard bottom threshold (Table 1).

Shallow circalittoral - Deep Circalittoral

In the Black Sea the circalittoral on soft bottoms was divided in shallow and deep circalittoral, and the limit between those two zones was defined as the maximum depth at which seabed is affected by temperature seasonal variations. For each occurrence of indicator community a value of temperature was extracted from the temperature grid climatology. A GLM was fitted with those values and a ROC analysis was performed in order to determine the cut-off value. As a result, equivalent of a temperature of 9.0°C was estimated (Table 1) [4].

Table 1. Thresholds used for biozones in the Black sea

	Threshold	Fuzzy thresholds to add/substract (m)
Infralittoral/circalittoral Hard bottoms	Depth=14m	4
Infralittoral/Shallow circalittoral Soft bottoms	Depth=20m	10
Shallow circalittoral/Deep circalittoral	Temperature=9°C	NA because GLM method

Confidence

The confidence assessment method follows a consistent structure and method for all regions. The assessment consists of a hierarchy of confidence assessments that cover confidence in the quality of the input layers and uncertainties associated with threshold values used to categorise these layers.

Each assessment is given as a rating of high (H), moderate (M) or low (L) confidence to ensure consistency across data types and regions, and, in most cases, reflect the lack of detail available to produce a more detailed assessment. These are combined into a single final value of confidence in the habitat type.

Created confidence maps of the Black Sea habitat maps were of low and moderate confidence: biozone and oxygen maps were predominately of moderate confidence, substrate was of moderate confidence for whole Black Sea and low for the Bulgarian part. The overall confidence in the predicted habitat map in the Black Sea is as whole moderate and low in Bulgarian part due to substrate map confidence.

Phase III developments

A meeting took place in April 2018 at IO-BAS (Varna, Bulgaria), the objective of which was to assess the broad-scale habitat map which was produced in 2016 as part of EMODnet Phase II and brainstorm on solutions to the identified issues. A key output of the meeting was a revised version of the broad-scale habitat classification for the Black Sea. An updated list of these habitats was provided along with their definition in terms of seabed substrate and abiotic variables, and the acknowledged benthic assemblages hosted by these habitats. A revised version of a correlation table between benthic broad MSFD habitats and the broad habitat types used in EMODnet broad-scale seabed habitat maps was also developed.

As a result, a revised map of the Black Sea broad-scale seabed habitat map was created and will be published soon (Fig. 4). This map will be updated to include the latest seabed substrate map provided by EMODnet Geology at the scale 1:100 000 [3].

New database was developed during Phase III. IO-BAS provided additional ground truthing data points in unified for the project format.

During Phase III total of 257 maps were collated by the 12 partners, six of them provided by IO available to download at www.emodnet-seabedhabitats.eu/access-data/download-data/.

Figure 4. Update of the Black Sea broad-scale seabed habitat map.

Uses and benefits

The data products created by EMODnet Seabed Habitats are made available to view and download for free through the portal at www.emodnet-seabedhabitats.eu.

EUSEaMap products have been used for assessing and reporting the status of European seas and potential cumulative impacts, designing ecologically coherent MPA networks, for regional mapping of ecosystem services and informing marine planning.

Potential benefits of broad-scale habitat maps are identified in the area of: MSFD assessment, benthic habitat monitoring, marine protected areas, species distribution modelling and marine planning [1].

The paper is based on EUSEaMap website and leaflets, EUSEaMap II final report [4], EUSEaMap III interim report (2017-2018) [3], and project meetings presentations [2], [6].

Acknowledgments

Information contained here has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (<http://www.emodnet-seabedhabitats.eu/>), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

REFERENCES

- [1] EUSeaMap: A broad-scale physical habitat map for European Seas, 2018. <http://www.emodnet-seabedhabitats.eu/resources/documents/>
- [2] Vasquez, M., 2013. Tutorials: creating a full coverage broad-scale map of the EUNIS classification habitat types. Departement DYNamique de l'Environnement Cotier Service Applications Geomatiques Ifremer
- [3] Seabed Habitats Interim Report EASME/EMFF/2016/1.3.1.2/Lot2/SI2.751208 EMODnet Thematic Lot n° 2 –Reporting Period: 05/05/2017 –04/05/2018, 57 p.
- [4] Populus, J., Vasquez, M., Albrecht, J., Manca, E., Agnesi, S., Al Hamdani, Z., Andersen, J., Annunziatellis, A., Bekkby, T., Bruschi, A., Doncheva, V., Drakopoulou Vivi, Duncan Graeme, Inghilesi Roberto, Kyriakidou Chara, Lalli Francesco, Lillis Helen, Mo Giulia, Muresan Mihaela, Salomidi Maria, Sakellariou Dimitris, Simboura Mika, Teaca Adrian, Tezcan Devrim, Todorova, V., Tunesi, L., 2017. EUSeaMap. A European broad-scale seabed habitat map. Ifremer, 174 p. <http://doi.org/10.13155/49975>
- [5] Pearce, J. and Ferrier, S., 2000. Evaluating the predictive performance of habitat models developed using logistic regression. *Ecological modelling*, 133(3), pp.225-245.
- [6] Vasquez, M., 2015. Black Sea Infralittoral – circalittoral classification. Bucharest Project Meeting Presentation.

APPROPRIATENESS AND AVAILABILITY OF THE *MNEMIOPSIS LEIDYI* AND *BEROE OVATA* DATA ON THE BLACK SEA

Elitsa STEFANOVA*, Violeta SLABAKOVA*, Kremena STEFANOVA*,
Volodymyr MYROSHNYCHENKO**, Ahmet KIDEYS**, Tamara
SHIGANOVA***

* Institute of Oceanology, Bulgarian Academy of Sciences, Varna, Bulgaria

** Institute of Marine Sciences, Middle East Technical University, Turkey

*** P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Russia

Abstract. The article is based on the results achieved in the framework of the EMODnet Sea Basin Checkpoint Lot 4: Black Sea project. It aimed to assess the basin scale monitoring systems on the basis of input data sets for 11 prescribed Challenges including Alien species (Challenge 11). The quality assessment based upon ISO and INSPIRE principles is subdivided into two categories “appropriateness” and “availability”. In term of the gelatinous zooplankton alien species five Targeted products (tables and digital maps) were produced which serve as basis for the input data sets adequacy assessment. The quality scores of the products are estimated as sufficient due to non-uniform coverage of the data in time and space.

Keywords: alien species, checkpoint, data base assessment

INTRODUCTION

Availability and accessibility of marine data, their cross-borders exchanges and multiple usage are hot topics. The aim of the EMODnet BlackSeaCheckpoint project has been to assess the quality and to identify the gaps of the monitoring data sets for the entire Black Sea towards eleven targeted applications or "Challenges" (Wind farm siting, Marine protected areas, Oil platforms leak, Climate, Coasts, Fisheries management, Fisheries impact, Eutrophication, River inputs, Bathymetry and Alien species) and to point out the steps for optimizing the monitoring systems in term of availability, operational reliability, efficiency, time consistency, space consistency etc.[1].

The alien species are important issue in the marine ecosystems and therefore they are one of the elements of the Marine Strategy Framework Directive (Descriptor 2). Penetration and introduction of non-native species in the Black Sea in some cases enriched the biodiversity but in the most of cases they have negative effect on the native populations (predation pressure, parasitism, competition etc.). Development of reliable indicators and thresholds for Good Environmental Status suggests using of all of the available data sets. Additionally the development of adequate indicators requires sufficient amount of data which should be assessed periodically.

The scope of Challenge 11 - Alien species has been: a) to identify sources of the alien species data in the Black Sea basin; b) to check the fitness for use of the current available datasets; c) to develop indicators which determine the impacts on ecosystem and economy and d) to indicate the gaps of the current monitoring systems.

The article presents the main results of the availability and the appropriateness assessment of the existing *Mnemiopsis leidyi* and *Beroe ovata* alien species data bases in the Black sea. The outcomes of the project are five Targeted Data Products (tables and digital maps) which include information about species name, family, year of introduction, reason for introduction, geographical area, impact on ecosystem and economy.

MATERIAL AND METHODS

For the availability assessment the following data sources were used:

- Black Sea *M. leidyi* database [2];
- project's databases (SESAME; ARENA; PERSEUS; Stock assessment of Black Sea Anchovy using acoustic method and establishing a monitoring model for National Fisheries Data Collection Program; NATO SfP-971818 ODBMS Black Sea Project [3]);
- Bulgarian National Monitoring Programme Database [4].

Only two databases (Black Sea Database created in framework of NATO SfP-971818 ODBMS Black Sea Project and Bulgarian National Monitoring Programme [3, 4]) have been found to be suitable for generation of the Targeted Data Products (TDPs) and appropriateness assessment.

Methodology

Detailed description of the assessment methodology is given in the Black Sea Checkpoint First and Second Data Adequacy Reports (DARs) [5, 6].

It provides quantitative and qualitative information on:

- how the input data sets are made available to Challenges (Availability Indicators). The potential input data sets and the availability indicators are estimated (Table 1);

- and what is the quality of the monitoring data for the Challenge products (Appropriateness Indicators). The calculation of appropriateness indicators has been done for the Data Product Specification (DPS), Upstream Data (UD) and Targeted Data Products (TDP) quality elements (Table 2).

Table 1. Availability indicators used for assessment of the input data sets [5].

Availability	
How are data made available to the challenges?	
Visibility	
Easily found	Can the data sets or series of datasets be found easily?
EU Inspire Catalogue service	Is the datasets referenced by a EU catalogue service or other bodies (private or public), national or international non EU services?
Accessibility	
Visibility of data policy	How visible is the data policy adopted by data providers?
Data policy	What is the data policy?
Pricing	What is the cost basis?
Data delivery mechanism	What services are available to the user to access data?
Readiness of format for use	How ready is the format for operational use?
Performance	
Responsiveness	

Table 2. Appropriateness quality elements used for assessment of the DPS, UD and TDPs [6].

Appropriateness	
What is the quality for challenges (products & data)?	
Appropriateness	
Spatial domain	Horizontal spatial coverage Horizontal resolution
Vertical domain	Vertical spatial coverage Vertical resolution
Temporal domain	Temporal coverage Temporal resolution
Thematic domain	Number of characteristics Thematic accuracy
Expert domain	Purpose Lineage Usage Credibility Temporal validity

The gaps of the monitoring system for the Black Sea are evaluated based on combination of the availability, appropriateness indicators and expert opinions.

The expert evaluation of the “fitness for purpose” of the Targeted Products and input data quality has been done according to the scale presented in Table 3.

Table 3. Targeted Products quality scores and their meaning [6]

SCORE	MEANING
1 EXCELLENT	completely meets the scope of the Targeted Product
2 VERY GOOD	meets more than 70% of the scope of the Targeted Product
3 GOOD	meets less than 50% of the scope of the Targeted Product
4 SUFFICIENT	does not adequately meet the scope but is a starting point
5 INADEQUATE	does not fulfill the scope and is not usable

Data processing

The data are subdivided into two Categories of characteristics (P02) - Zooplankton wet weight biomass and Zooplankton taxonomy-related abundance per unit volume of the water column. All available input datasets (meta data bases) are checked using eight “availability” indicators (Table 1). The indicators are classified based upon a three value range color scale: “red” meaning “not adequate”, “yellow” “partly adequate” and “green” “fully adequate” [5].

The data used for generation of the products which present the distribution of *M. leydyi* and *B. ovata* are quality assured (QA). The QA check include detection of stations with different names but the same geographic location; detection of stations with the same name but with different geographic locations. Afterward the values at stations with different names but the same geographic location are averaged; stations with the same name but in different geographic locations are renamed; the units are recalculated from ind/m³ and g/m³ to ind/m² and g/m² for representative visualization.

For assessment of *M. leydyi* impact on the ecosystem the original data are used without any transformations.

Inverse distance weighted (IDW) method [7] have been used to produce the digital maps of the alien species abundance and biomass distribution.

RESULTS AND DISCUSSION

The inventory process identifies seven data sources and 24 input data sets (Upstream Data) usable for the purpose of the availability assessment. Based on the application of the Availability Indicators (Table 1) it has been found that the unavailability and restrictions on the data sharing imposed by some projects makes the data “not adequate” or “partly adequate” for the next stage of the evaluation [4].

Two available data bases (6 UDs) are used for development of the following products:

BLACKSEA_CH11_Product_1 Table of *Mnemiopsis leidyi* alien species abundance and biomass distribution in the Black Sea [8]

The product is based on the data from 23 available datasets from the Black Sea Database created in framework of the NATO SfP-971818 ODBMS Black Sea Project [3] and the Bulgarian National Monitoring Programme [4]. The product includes two characteristics - abundance and biomass of the species. Both of them are equally important for the Targeted Product quality. Although the data are not evenly distributed in space and time the product is useful for visualization of the *M. leidyi* alien species distribution in the Black Sea (Fig. 1).

BLACKSEA_CH11_Product_2 Digital map of *Mnemiopsis leidyi* alien species abundance distribution in the Black Sea [9]

The product is based on data from 21 available datasets i.e. all mentioned above except two datasets where abundance data are missing. It is useful for assessing the species distribution in the Black Sea although the data are not evenly distributed in space and time (Fig. 2).

BLACKSEA_CH11_Product_3 Digital map of *Mnemiopsis leidyi* alien species biomass distribution in the Black Sea [10]

The product is based on the data from the same 23 datasets. It is useful for assessing the species biomass distribution in the Black Sea although the data are not evenly distributed in space and time (Fig. 3).

Fig. 1. Map of *Mnemiopsis leidyi* alien species abundance and biomass data distribution in the Black Sea (BLACKSEA_CH11_Product_1)

Fig. 2. Digital map of *Mnemiopsis leidyi* alien species abundance distribution in the Black Sea (BLACKSEA_CH11_Product_2)

BLACKSEA_CH11_Product_4 Table of *Beroe ovata* alien species abundance and biomass distribution in the Black Sea [11]

The table includes 15 available datasets from the Bulgarian National Monitoring Programme [4]. The data are not evenly distributed in space and time. The product does not adequately meet the scope to assess the species distribution on the entire Black Sea but is a starting point (Fig. 4).

BLACKSEA_CH11_Product_5 Table of *Mnemiopsis leidyi* alien species abundance and biomass distribution in the Black Sea as indicators for impact on the ecosystem and economy [12]

The table includes 24 available datasets with the original values (g/m^3 ; ind/m^3) from the Black Sea Database created in framework of the NATO SfP-971818 ODBMS Black Sea Project [3] and the Bulgarian National Monitoring Programme [4]. The both characteristics - abundance and biomass of the species are equally important for the Targeted Product quality. Being an invasive species but not only alien *Mnemiopsis* affects the ecosystem even with its presence in the environment. The publications of Vinogradov et al., 2005 and Shiganova et al., 2014 [13, 14] took thresholds for Good Environmental Status (GES) $< 4\text{g/m}^3$ (120 g/m^2) and $< 5\text{ ind/m}^3$ respectively. In concentration above these thresholds the species affects the ecosystem. The data modifications of Product 1 (data averaging) do not allow reliable assessment of this impact on the ecosystem.

Fig. 3. Digital map of *Mnemiopsis leidyi* alien species biomass distribution in the Black Sea (BLACKSEA_CH11_Product_3)

Fig. 4. Map of *Beroe ovata* alien species abundance and biomass data distribution in the Black Sea (BLACKSEA_CH11_Product_4)

Based on the expert opinion the quality elements which affect the quality of the *M. leidyi* alien species products (BLACKSEA_CH11_Product_1, BLACKSEA_CH11_Product_2, BLACKSEA_CH11_Product_3, BLACKSEA_CH11_Product_5) are:

- *Horizontal Spatial Coverage and Horizontal Resolution.* The data are insufficient in the Northern part of the basin;

- *Temporal Coverage and Temporal Resolution.* The data doesn't cover the whole period from the species settlement in 1982 till now. The databases would be more complete if they contain seasonal and annual data.

The limitations on the quality of the product due to the input dataset used (fitness for use) are:

- *Horizontal Spatial Coverage and Horizontal Resolution.* Each of used 23 UD's (21 UD's for Product 2) has different horizontal coverage and resolution which are not enough to present the species distribution in the entire Black Sea.

- *Temporal Coverage and Temporal Resolution.* The datasets cover relatively short time spans related to the monitoring campaigns.

The most important gaps in the input data sets are:

- Lack of long-term annual and seasonal data for the period from the species settlement till now.
- Sparse and unevenly distributed sampling stations reduce the reliability of the product.

The quality elements which affect the Product 4 quality are:

- *Horizontal Spatial Coverage and Horizontal Resolution.* The data covers only the Western part of the sea basin;

- *Temporal Coverage and Temporal Resolution*. The data doesn't cover the whole period from the species settlement in 1997 till now. The databases would be more complete if they contain seasonal and annual data.

The limitations on the quality of the product due to the input dataset used (fitness for use) are:

- *Horizontal Spatial Coverage and Horizontal Resolution*. Each of used 15 UD's has different horizontal coverage and resolution which are not enough to present the species distribution in the entire Black sea.

- *Temporal Coverage and Temporal Resolution*. The datasets cover relatively short time span related to monitoring campaigns.

The most important gaps in the input data sets are:

- Lack of long-term annual and seasonal data for the period from the species settlement till now.

- Sparse and unevenly distributed sampling stations reduce the reliability of the product.

The quality scores assigned by the CH 11 experts to the Targeted Products developed in order to evaluate the adequacy of the observational system at the Black Sea basin level is "sufficient"- does not adequately meet the scope but is a starting point (Table 3).

CONCLUSIONS

The species populations are dynamic systems with annual, seasonal and spatial variations. Our recommendations for the *M. leidyi* and *B. ovata* databases are in terms of the completeness - the data should be acquired in regular time intervals (seasonally) and with representative density of the stations net.

Other disadvantages of the existing datasets are the unavailability and restrictions on the data sharing imposed in frameworks of some projects.

In term of Product 5 new indicators should be proposed and tested.

Acknowledgments: The study presents the EMODnet Sea Basin Checkpoint Lot 4: Black Sea project results. Challenge 11 - Alien species was leaded by the Institute of Oceanology, Bulgarian Academy of Sciences, Bulgaria in partnership with the Institute of Marine Sciences, Middle East Technical University, Turkey and Shirshov Institute of Oceanology, Russian Academy of Sciences, Russia.

REFERENCES

- [1] <http://emodnet-blacksea.eu/>
- [2] V. Vladymyrov, A. Kideys, V. Myroshnychenko, D. Slipetsky, T. Shiganova, G. Abolmasova, F. Bingel, D. Tezcan, Y. Ak, B. Anninsky, L. Bat, G. Finenko, V. Gorbunov, M. Isinibilir, L. Kamburska, V. Mihneva, Z. Ozdemir, Z. Romanova, O. Sergeyeva, K. Stefanova, M. Xalvashi 2011. A basin-wide Black Sea Mnemiopsis leidyi database. Aquatic Invasions (2011) Volume 6, Issue 1: 115–122 [doi: 10.3391/ai.2011.1.15](https://doi.org/10.3391/ai.2011.1.15)
- [3] <http://sfp1.ims.metu.edu.tr/ODBMSDB/>
- [4] <http://bgodc.io-bas.bg/documents/>
- [5] http://emodnet-blacksea.eu/wp-content/uploads/2017/01/D15.2_First-DAR_v10.pdf
- [6] http://emodnet-blacksea.eu/wp-content/uploads/2018/04/D15.4_DAR2_v7_FINAL.pdf
- [7] G. Philip, D. Watson 1982. A Precise Method for Determining Contoured Surfaces. Australian Petroleum Exploration Association Journal 22: 205–212. Watson, D. F., and G. M. Philip. A Refinement
- [8] Institute of Oceanology - BAS (2017). BLACKSEA_CH11_Product_1 / Table of *Mnemiopsis leidyi* alien species abundance and biomass distribution in the Black sea. EMODnet Black Sea Checkpoint. [http://doi.org/10.12770/e43ca75d-e644-44cd-955f-1a5840b889cb](https://doi.org/10.12770/e43ca75d-e644-44cd-955f-1a5840b889cb)
- [9] Institute of Oceanology - BAS (2017). BLACKSEA_CH11_Product_2 / Digital map of *Mnemiopsis leidyi* alien species abundance distribution in the Black sea. EMODnet Black Sea Checkpoint. [http://doi.org/10.12770/82de7b15-f066-4615-a99c-cd80f4dd6995](https://doi.org/10.12770/82de7b15-f066-4615-a99c-cd80f4dd6995)
- [10] Institute of Oceanology - BAS (2017). BLACKSEA_CH11_Product_3 / Digital map of *Mnemiopsis leidyi* alien species biomass distribution in the Black sea. EMODnet Black Sea Checkpoint. [http://doi.org/10.12770/824cadd5-bb16-4c49-be16-356fe9090be0](https://doi.org/10.12770/824cadd5-bb16-4c49-be16-356fe9090be0)
- [11] Institute of Oceanology - BAS (2017). BLACKSEA_CH11_Product_4 / Table of *Beroe ovata* alien species abundance and biomass distribution in the Black sea. EMODnet Black Sea Checkpoint. [http://doi.org/10.12770/80965ab8-8bad-4ae4-b0e5-2ddc70672c70](https://doi.org/10.12770/80965ab8-8bad-4ae4-b0e5-2ddc70672c70)
- [12] Institute of Oceanology - BAS (2017). BLACKSEA_CH11_Product_5 / Table of *Mnemiopsis leidyi* alien species abundance and biomass distribution in the Black sea as indicators for impact on the ecosystem and economy. EMODnet Black Sea Checkpoint. [http://doi.org/10.12770/00f21daa-c781-4cd4-9130-2366f81e9e19](https://doi.org/10.12770/00f21daa-c781-4cd4-9130-2366f81e9e19)
- [13] M. Vinogradov, L. Lebedeva, G. Vinogradov, E. Musaeva, T. Lukasheva, D. Zasko, L. Anokhina, A. Sivkovich 2005. Monitoring of the Pelagic Communities of the Northeastern Part of the Black Sea in 2004: Macro- and Mesoplankton, Oceanology 45 (3), 356–367.
- [14] T. Shiganova, L. Legendre, A. Kazmin, P. Nival 2014. Interactions between invasive ctenophores in the Black Sea: assessment of control mechanisms based on long-term observations. Mar Ecol Prog Ser 507:111-123. doi.org/10.3354/meps10806

SATWEBMARE PRODUCTS AND SERVICES IN SUPPORT OF THE SUSTAINABLE MANAGEMENT OF THE BULGARIAN COASTAL ZONE

O. Kounchev, L. Pashova, L. Filchev, D. Kalagarski, V. Craciunescu, V. Galabov, E. Peneva, M. Ilieva, B. Srebrov, Z. Bibov

* Institute of Mathematics and Informatics – Bulgarian Academy of Sciences, Bulgaria,
<https://satwebmare.wordpress.com/>

Abstract. The coastal zones have important ecological, social, and economic impact on the human life and are undergoing the severe anthropogenic degradation that is happening against the backdrop of environmental alterations due to climate change. To address the challenges of present and future environmental changes in coastal areas, this article aims to represent a prototype of Web-based integrated system SatWebMare designed to provide through geo-portal innovative products and services for integrated coastal zone management of the Bulgarian coastal zone, inline with the nowadays concepts of Big Data. The SatWebMare prototype system will combine geo-database sets from different sources, which will be used for improving a spatial and temporal accuracy of modeling the air-land-sea interaction processes and their forecast. An overview of the system architecture consisting of three main modules will be presented. The SatWebMare geo-portal aims to provide an access to products and services with added-value information for ministries, agencies, local authorities, and other stakeholders in support of the integrated coastal zone management.

Keywords: Earth Observation, Bulgarian coastal zone, Geoportal, Open Source, Big Data

INTRODUCTION

The Black Sea coastal zones have important ecological, social, and economic impact on the human life and are undergoing the severe anthropogenic degradation that is happening against the backdrop of environmental alterations due to climate change. At the same time, Bulgarian coastal zone is exposed to wide variety of natural hazards, where their complex impact may cause negative social and economic consequences and environmental changes. A more responsible policy for sustainable integrated coastal zone management should lead to address the challenges of present and future environmental changes in these regions. To improve the understanding of such dangerous and destructive processes, a new knowledge and techniques are required. Remote sensing (RS) Earth observations (EO) are increasingly popular as a potential tool to aid in decision making for planning and management over large coastal areas. These powerful tools for making spatially detailed maps takes advantages of the spatial and temporal resolution of satellite, aerial, UAV and *in-situ* data contribute for understanding the complex land- and seascape processes. Efficient analysis and interpretation of diversity of EO can contribute to a better understanding of these environmental challenges.

This article aims to represent, in general, a project of establishing a prototype Web-based System Integrated with a Geo-portal (SatWebMare) that will provide innovative products and services to the end-users for maritime applications in the Black Sea coastal area. The nature of coastal ecosystems is a highly dynamic and heterogeneous, both in space and in time. One of the main challenges is developing the innovative products for Bulgarian coastal zone with substantially improved spatial and temporal accuracy using geodata sets from different sources. This system consists of a geo-database of EO products from ESA satellites (e.g., Sentinel, ENVISAT), UAV imagery, and data from *in-situ* observational networks. It comprises three main modules (Calculation Engines): Engine (1) Forecasting module (for atmospheric, wave, storm surge parameters); Engine (2) SpaceGeomagnet module; and Engine (3) Geohazard module. All computation and data analyses will be performed exploiting the resources of the High Performance Supercomputer AVITOHOL at the Institute of Information and Communication Technologies of the Bulgarian Academy of Sciences. Due to the large number of data sources and information services (not always easily and freely accessible), the achievement of the project objectives requires the application of the modern approaches of Big Data. The SatWebMare prototype system will provide an access to added-value information in supporting the decision-making process of different stakeholders and end-users.

ARCHITECTURAL SYSTEM OF THE SATWEBMARE PLATFORM

Developing of a System Concept and Architecture of an integrated SatWebMare system, including the Top-level Architecture, Data-Flow, System Deployment, and use-cases is the first stage of the project (Fig. 1). The SatWebMare system will be developed following a distributed architecture incorporating geospatial datasets from various sources (satellite and UAV images, *in-situ* data) and model outputs. The main components of the system are: i) Database management service; ii) Catalogue service; iii) Data delivery and portrayal service (GIS

server); iv) Software clients. It will serve as a working tool for the scientific community and the relevant decision makers. Architecture design will be driven by service-oriented architecture design principles, and use open standards from IETF, W3C, OASIS, ISO/TC 211, and Open Geospatial Consortium (OGC). To assure the interoperability with other ESA, GEOSS, INSPIRE or Copernicus applications/services/systems will be implemented in free and open-source software platforms mainly related to the system integration, data interoperability and visualisation. One of the main challenges to be overcome by the prototype SatWebMare platform is the very large quantity of EO and other type of data that is required to be accessed and fast analyzed in order to provide meaningful insight upon various environmental aspects related to the Bulgarian coastal zone. The volume of EO data is significant, and they practically are Big Data. However, SatWebMare platform will not replicate those datasets that can be accessed online through standard network services [1].

Figure 1. Scheme of the SatWebMare prototype system

ENGINE MODULS OF THE SATWEBMARE PROTOTYPE SYSTEM

Engine 1, Forecast module aims to improve the marine meteorological forecasts provided to the maritime users. A configuration of the limited area weather forecast model is designed based on the Advanced Research version of the numerical weather prediction system ARW WRF (Weather Research and Forecast), configured to perform one-way nesting with two geographical domains. The first one covers the Balkan Peninsula domain with resolution of ~5 km, and the second is focusing on the area of interest, the Bulgarian part of the Black Sea with higher spatial resolution ~1 km. Consecutive steps will be implemented:

- Operational chain of data analysis (Fig. 2)

The first step is to establish the operational chain for the work in **Engine 1, Forecast module** for the box area bounded within the 41°-44.5°N and 27°-30°E and conduct a survey of the best initial and boundary conditions for the model. On a daily basis the external data for the global forecast are downloaded from the distributing US National Center for Environment Prediction (NCEP). The model domains configurations are run transferring information from the larger domain to the smaller and then numerical procedures for the preparation of the visual material and the data files needed for the wave module are run.

Figure 2. The operational chain to run the limited area model WRF

- Static boundary conditions:

It is well known that in the coastal areas it is very important to correctly represent the coastal line with as much details as possible. Thus, it is necessary to check and improve the land cover representation in the coastal zone. According to the publications, it is prominent to use the new product for land cover of Copernicus Land Monitoring Service, Corine Land Cover 2012 will be implemented within the Calculation Engine Forecast module as well as other data sources, i.e. USGS, Corinne, and MODIS-based. During the second step time varying initial and boundary conditions are defined.

- Time varying initial and boundary conditions:

The source of this information will be the Global Forecasting System with resolution of 0.25 deg (~25 km). The model is run 4 times daily with output every 3 hour. The basic variables needed are the 4D fields of the air atmospheric pressure, temperature, humidity, wind, geopotential, cloud cover. This is a free and reliable source of information provided for Global Forecast System (GFS) Model and Global Data Assimilation System (GDAS) Model (<http://www.nco.ncep.noaa.gov/pmb/products/gfs/>).

- Sub-grid physical parameterization:

The tuning and calibration of the WRF model are long and difficult processes. At the present, the literature survey revealed that for different seasons one should use different combinations of parametrization schemes for PBL and Microphysics. The best combinations of schemes will be chosen according to the published test results.

Preliminary tests with lower spatial resolution of the SWAN model of different parametrizations of the physics of the model including the cutting edge ST6 physics, according to the nowadays specifications, is already performed [2]. On the next stage of SatWebMare project a storm surge model with high spatial and temporal resolution will be implemented as well as analysis of the historical reconstruction of the Western Black Sea wave climate [3].

A local manifestation of geomagnetic activity along the Bulgarian coastal zone will be investigated within **Engine 2 Space-geomagnet module**. Data from the Intermagnet Geomagnetic Observatories /GO/ Panagyurishte (PAG), Bulgaria, Surlari (SUA), Romania and Odessa (ODE), Ukraine, absolute measurements during the last several years over the Bulgarian territory and in some repeat stations in the coastal zone, as well the European MagNetEgroup model will be used to compile a map of the geomagnetic declination for the region of interest. This map will be reduced to the modern Epoch to be used for practical purposes, as navigation in sea, air and land, as well as for adjustment of different devices as the various aircraft and vessels, vehicles and portable radio-locator devices. Some parameters of ionosphere conditions (e.g. TEC variations, local F2 critical frequencies) based on data provided from world Database centers and permanent GNSS stations in the Black Sea region will be determined within this Engine 1 module.

The data analysis performed within **Engine 3 Geohazard module** will contribute to develop wide-range monitoring of the potential endangered areas, detection of slow surface movements and delineation of destructive natural hazard events in the coastal zone of Bulgaria. The spatial knowledge about the natural and man-induced risks will increase in that way the landslides susceptibility assessment models, but will also improve the land management, market assessment, flood awareness and response, and insurance and defense of critical infrastructure. The resulting flood maps can be used in crisis management for taking of rescue decisions and for damages assessment in insurance. Suitable applications using Sentinel data for natural hazard monitoring will be elaborated, considering that the Bulgarian National program for disasters preparedness and risk mitigation is harmonized with the EU policy of natural hazard risk mitigation.

Within this **Engine 3** for monitoring the stability of a coastline (landslides and vertical crustal movements) and for carrying out a rapid pre- and post-storm assessments to quantify storm impacts along the Bulgarian coastal zone Unmanned Aerial Vehicle (UAV) will be used. It can be used to quickly survey potentially difficult and dangerous large sites with a very high level of detail. Other applications for UAV in coastal areas are for erosion monitoring, assessment of cliff stability, monitoring coastal vegetation and changes in land volume or coastline state. To achieve high spatial accuracies during UAV surveying, three approaches will be tested during the field campaigns:

- Combining UAV image data with Ground Control Points (GCPs) from the Bulgarian State geodetic network;
- Correcting position information by means of post-processing kinematic (PPK) systems;
- Correcting position information by means of real-time kinematic (RTK) systems using permanent GNSS sites in the Bulgarian coastal region.

A comparative review of optical and radar satellite images comprising the data archive since the beginning of 1990-ies and data from Copernicus initiative till now covering the western Black Sea area is presented in [4]. The preliminary analysis revealed that around 320 Sentinel-1 images from Ascending orbit No 058, around 290 images from Ascending orbit No 131, around 360 images from Descending orbit No 036 and around 225 images from Descending orbit No 109 could be used to determine the land surface deformation along the Western Black Sea coast. The Sentinel-2 mission acquires all coastal waters up to 20 km from the shore as well as all inner seas, which means that the whole of the Black Sea aquatory is covered. The Sentinel-2 and Sentinel-3 images acquired in the period since the launch of the satellite platform by 31 December 2017 at Open Data Hub of Copernicus for Bulgarian Black Sea coast are 2401 in total, where the images suitable for interpretation with a cloud cover of less than 10 % of the scene for Sentinel-2 are just 25. This can be explained with the specific sea meteorological conditions throughout the year. For Sentinel-3 the number of images (cloud-free strips) which fully or partially cover the Bulgarian Black Sea coast in the investigated period are 756. The data analysis will contribute to develop wide-range monitoring of the potential endangered areas, detection of slow surface movements and delineation of destructive natural hazard events along the Bulgarian coastal zone.

SATWEBMARE SOFTWARE SOLUTIONS

SatWebMare web-based platform will provide services based on OGC standards for data retrieval (WMS, WCS, WFS and server-side processing (WPS)). The platform is developed according to INSPIRE directive. The services were built upon open source solutions such as: GeoServer, OpenLayers, ZOO, PostgreSQL, GDAL, GRASS GIS. The prototype system can serve as main source of near real time information for decision making in emergency response and risk assessment, security operations in maritime, etc. The speed of the access to the services of the SatWebMare prototype system will practically depend on and is limited by all sources of data, incl. ESA services. Thus, if there is other real-time data sources in the Black Sea region, it would be possible to integrate them in the pipelines for a fast access to the outputs of the SatWebMare system. The main data sources are listed below.

- The Scientific Data Hub (SCI Hub) provides a Graphical User Interface to the full production of all Sentinels core products since opening of the data dissemination service in October 2014. Since the end of 2015, a complementary instance has been created (API Hub) supporting a scripting interface to access the latest products. The platform will use this scripting interface to transfer the data needed by a specific user processing request.

- Copernicus Marine Environment Monitoring Service and Copernicus Land Monitoring Service: Copernicus Marine Environment Monitoring Service is set to be operational for 6 years, starting with May 2015. CMEMS provides core information on the global ocean and 7 regional seas, including the Black Sea. Copernicus Land Monitoring Service, operational since July 2015, provides geographical information on land cover/land use and on variables related to vegetation state and the water cycle.

- Copernicus Reference Data Access represents the gate to Copernicus-relevant national and regional geospatial reference data. Geospatial reference data are a special category of in-situ data for Copernicus services,

providing a geographic framework to which other required in-situ data are referenced and maintained. Reference data are required by Copernicus services for creation, verification and validation of information products and services derived from satellite images.

The system SatWebMare will integrate functionally the Calculation Engines, relying upon cutting edge mathematical algorithms in the area of hydrodynamics which provide different forecasting parameters of the sea climate, geohazard parameters, etc. The algorithms required for data processing are already published in scientific journals and implementation for most of them are available in different open source packages (e.g.

Orfeo Toolbox, GRASS GIS). Free accessible data from ESA products and in situ measurements, which will be further processed by the three Calculation Engines, will be used for developing the useful products for end-users. Further, the system SatWebMare integrates a modern GIS geoportal which consumes the output of the Calculation Engines as well as other input data from third party sources, as WMS servers, Google Maps, Bing Maps, OpenStreetMap, etc. The GIS platform will use ISO/OGC standards, and provides the main output of the integrated system SatWebMare in a visual form. An integration of the SatWebMare platform into the ESA exploitation platform is presented on Fig. 3.

Figure 3. SatWebMare ESA exploitation platforms integration scenario.

CONCLUSIONS

The SatWebMare prototype system will supplement the already elaborated Romanian ESPOSS platform [1]. This platform aims at developing into a mature solution for handling big geospatial data for the Bulgarian coastal area. It shall provide new and interesting capabilities of interpreting and connecting various types of datasets in order to extract the most valuable information to be further used. The web-based platform will integrate existing data from different sources, which will be accessible to a wide range of users and stakeholders.

Its further integration of the SatWebMare system with the already existing technical exploitation platforms (TEPs) of ESA and Copernicus monitoring services DIAS is envisaged. The platform will provide to the users can access, among other geospatial data, to a wealth of satellite data coming from various sources and sensors of ESA, which are related to Bulgarian coastal area.

Acknowledgments: This research is supported by the ESA Contract Contract No: 4000124110/18/NL/SC. The information and views set out in this paper are those of the authors and do not necessarily reflect the official opinion of the ESA.

REFERENCES

- [1] F. Serban, V. Craciunescu, S. Constantinescu, S. Constantin. ESPOSS: Big Data infrastructure for the Black Sea region, Conference: Conference: Proc. of the Big Data from Space (BiDS'14) conference, Frascati, Italy, 2014, DOI: 10.13140/RG.2.1.1992.5849.
- [2] V. Galabov. Operational storm surge modelling in the Western Black Sea: one way coupling with a wave model. Bulgarian Journal of Meteorology and Hydrology., vol. 21, 2016, pp. 10-23V .
- [3] V. Galabov and H. Chervenkov. On the Winter Wave Climate of the Western Black Sea: The Changes during the Last 115 Years. Lecture Notes in Computer Science, 10665, 2018, pp. 466-473, DOI: 10.1007/978-3-319-73441-5_51.
- [4] M. Ilieva, L. Filchev, and L. Pashova. Preliminary analysis of Copernicus data for natural hazards monitoring of the Bulgarian Black Sea coastal zone, In: Proceedings, 7th International Conference on Cartography and GIS, 18-23 June 2018, Sozopol, Bulgaria, pp. 384-392, available at: [https://iccgis2018.cartography-gis.com/7ICCGIS_Proceedings/7_ICCGIS_2018%20\(43\).pdf](https://iccgis2018.cartography-gis.com/7ICCGIS_Proceedings/7_ICCGIS_2018%20(43).pdf)

APPLYING SEMANTIC APPROACH IN SEARCH OF OCEANOGRAPHIC DATA

Nurhan Hassanov*, Vasil Donev*, Atanas Palazov*

*Institute of Oceanology – Bulgarian Academy of Sciences

Abstract: The paper presents results from studies done in the course of preparation of doctoral thesis. It presents and analyzes some advanced methods of oceanographic data management and in particular possibilities for implementation of semantic approaches in heterogeneous data sets' analysis. The issues are examined both at theoretical and practical level outlining the major steps in implementing this so far uncommon for the particular scientific field approach.

Keywords: Oceanographic data, semantic analysis, semantic data search

INTRODUCTION

The continuously increasing volumes of available data from oceanographic studies pose new and serious problems both for the involved scientists and even more for any other interested parties (governmental, business, local, etc.). Practically it becomes impossible even for experienced scientists to keep up with the latest findings which cover more and more fields of interest. The issues related to the search of the necessary information now tend to move from purely quantitative (as commonly being in the past) to more qualitative in view of the expanding multidisciplinary nature of the contemporary primary oceanographic data. Taking into account that the newest trends in the information technologies move more to knowledge management rather than data or even information management it becomes clear that commonly accepted approaches so far tend to produce less benefits to the interested parties and hence threaten to turn a great deal of the incoming and even existing data sets into useless piles of data which besides the expenses for their production and storage start to generate unacceptable levels of information pollution or noise.

The issue became first evident and provoked different approaches for its resolution with the extensive use of the most common search engines well known to the general public. The different providers of information search services organize nowadays their work around complex and more often so far seeming exotic tools and technologies generally gravitating around what is understood nowadays as artificial intelligence (AI). A typical example for such transition in the information technologies is the extension of Google's search engine with the Knowledge Graph, a knowledge base used by Google and its services to enhance its search engine's results with information gathered from a variety of sources.

STATUS

There are several factors, directly linked to the nature of the oceanographic studies and data obtained through these that determine the current status of the scientific information preservation and hence the operation with and the use of it. These can be summarized as follows:

- the entrance into the global digital era caught the ocean sciences and in particular the information they have produced in fairly disintegrated status both geographically and institutionally
- resulting from this disintegration serious format and standardization problems were seen across the scientific communities and data centers that serviced them
- on the other hand, a clear striving for broadening of the intercommunity contacts and overcoming of the existing data integration issues was already evident which acted as catalyst for joining efforts in the field of data integration
- because of the mainly regional nature of the oceanographic studies, this scientific area faced the challenges of the new digital times without suitable common instruments for integration of the existing and/or currently obtained data unlike other scientific fields like quantum physics for instance; partially we may excuse this situation with some economic factors – the oceanology in its broader sense in much more directly practical science than other fields of science
- the traditional regionality of the studies, respectively the storage and the processing of the data were acting somewhat restrictive for the implementation of the new information processing technologies in the oceanology; here we have in mind first of all the data integration/search tools both for the raw data and/or for the research results
- the conservative local maintaining of the information pools pays a price and this is the difficult support of number of national information centers for technical and financial reasons

- and lastly to make the picture with data handling even worse, came the production of unseen until that time enormous volumes of raw data as a result of the falling of the prices of the mass oceanographic equipment and the almost total automation of the data gathering process. This phenomenon posed rather serious requirements both to the capacity of the existing national data centers and to their interoperability and abilities to cope with this avalanche of data and even more to search/analyze the data they hold.

The ocean science in its traditional appearance faced for the first time what is known as the “the big data phenomenon” and it became evident that it was not ready to cope with it. The practically neglectable cost of a unit of raw data shifted the research issues from data obtaining to data finding and the scientists and the society as a whole ended up with what is known as “information overflowing” or “information pollution”. Instead of making scientists’ job easier, the big data made it more difficult and sometime practically even impossible. Another reason for the big data issues regarding the oceanographic information was the fact that the commonly used data search techniques were not capable to deliver well filtered and logically structured results, both because of the largely increased volumes of information they had to process and because of their inability to logically analyze the stored data. We may add to this disadvantage also the interdisciplinarity of the data search imposed by the increasing complexity of the ocean studies.

The oceanographic data is both spatially determined and heterogenous in its complexity. These two factors defined its storage approach during the pre-information era i.e. through locally based centers in the form of libraries. Unfortunately, or may be unavoidably with the ascent of the digital society this approach was retained and led to the creation or transformation of the analogous existing data storages into new digital data centers organized similarly to the old-fashioned libraries. To be fair these were equipped with some modern features like automated search engines organized almost everywhere around keywords use and search parameters definition. As it could be expected, due to some of the reasons outlined above this approach showed its drawbacks very soon. The problems came mainly from the combined impact of the big data and the of the ever-increasing complexity of the research itself. Shortly, the scientists increasingly were looking to find existing knowledge rather than simple raw data. This however is more and more difficult to achieve with the present already digitized data storages. Actually, the issue goes beyond the pure science because in the globalized world and economy the span of the users of the oceanographic data/knowledge broadens, covering nowadays governmental, communal, private, business and other non-scientific users. The creation and use of new knowledge ceased to be predominantly monopoly of the scientific community only.

APPROACH

The problem with the management of vast amounts easily available information is not restricted to the oceanology in particular. It concerns every part of the human activities – private and official, personal and communal, scientific and popular. This was immediately reflected in the strategies for the software development. If by the early 90s the focus of the software industry was onto computers’ management through the quick development of the operational systems and the supporting software applications, just by the mid-90s the first globally working search engines came onto the front stage. All of these were organized around the triple: web crawling, indexing, searching. It is not a subject of this paper to deal in detail about the mechanisms through which the different search engines process the web available content, however almost all of them work on comparing search patterns with content occurring ones, possibly omitting this way the meaning of the search criteria. With such an approach the efficiency of the search greatly depends on the experience of the searcher and partially on the way the loader of the information has tagged it with the keywords. As mentioned above the shifting focus from data to knowledge search in the contemporary use of the net as ultimate source of information to multiple and differently oriented users requires more sophisticated approach to data analysis in the cause of the information search. The users needed tools that would combine the high speed of the pattern search with the capabilities provided by the already existing AI. This was given to the public through the implementation of the semantic search of data as part of the search process. The applying of the semantics as approach is often done through the construction of domain ontologies which formally describe knowledge as set of categories, properties, and relations between the concepts, data, and entities in the appropriate domains. Without going deeper into the knowledge presentation, we should only mention that one of the ways to achieve this is through the creation of so called knowledge graphs which formally implement the elements of the knowledge. As already mentioned a realization of this approach is the Google’s Knowledge Graph used by the company to enhance the search results obtained with its search engine. As far as there is no official description of Google’s solution and there is no way to understand how it produces the search results we shall analyze the features of the approach on the example of another similar and practically available tool, the GraphDB™, released and supported by Ontotext AD, a Bulgarian innovative company operating in the field of the semantic data technologies. A free fully functional version of the product is available on [1].

Before getting into the details of using this tool we should understand the fundamentals of the semantic data integration as they lay down the basis for a particular solution we aim for. The main instrument for the implementation of the semantic integration is the Semantic Web – a term introduced by Sir Tim Bernes-Lee in

2001 [2]. What is essential in the context of our study is the fact that the Semantic Web is an extension of the existing web which allows for providing software programs with machine readable definitions of all kinds of things and the relationships between them. In other words, we add additional data descriptors to otherwise existing data in the web which allow for its meaningful interpretation by the computers in a manner similar to the way humans process information in achieving their goals.

As the concept evolved into two important types of data which taken together implement the vision today which defines two major types of logically processable data, namely:

- **Linked Open Data** (LOD [9]) – structured data modeled as a graph and published in a way that allows interlinking across servers and easy interpretation of the semantics of the data by both people and machines. Today there are thousands of datasets published as LOD across different sectors – encyclopedia, geographic data, government data, scientific database and articles, entertainment, travelling, etc. In Life sciences alone, there are more than 100 scientific databases published as LOD [12]. Because of the linking, these datasets form a giant web of data or knowledge graph, which connects vast amount of descriptions of entities and concepts of general importance. For instance, there are several descriptions of Varna, e.g. one derived from Wikipedia¹ and another one in a global geographic database called Geonames². Linked open data includes factual data about concrete entities and concepts (e.g. *Varna*, *WW2* or the *Global warming theory*) and ontologies – semantic schemes that define classes of objects (e.g. *Person*, *Organization*, *Location* and *Document*) and type relationships (e.g. *parent of* or *manufacturer*) and attributes (*birth date* of a person or *population* of a geographic region).

- **Semantic metadata** – semantic tags added to regular webpages in order to better describe their meaning. For instance, the home page of the Bulgarian Institute for Oceanography can be semantically annotated with references to several appropriate concepts and entities, e.g. Varna, Academic Institution³ and Oceanography⁴. Such metadata makes it much easier to discover a web pages based on semantic criteria, without ambiguity – making sure than when searching for Paris (the capital of France) one will not get pages about Paris Hilton. To make sure the relationship between the subject of the page and the corresponding page or document are determined well, one have to use one of the structured data metadata schemes. The most popular such scheme today Schema.org [10] established by Google, Yahoo, Microsoft and Yandex. According to recent study [11] in 2015 30% of the webpages contain semantic metadata.

The Semantic Web concepts got rapid adoption for data and information managements. Today multiple organizations used Linked Data as mechanism to publish master data internally. Knowledge graph is nothing more than a knowledge base represented as Linked data. Semantic metadata is widely used to improve enterprise document search. Fundamental for the adoption of the Semantic Web vision was the development of set of standards in order to achieve meaningful interpretation by the computers in a manner similar to the way humans process information in achieving their goals: RDF (Resource Description Framework) – a simple language to describe objects and their relations in a graph; SPARQL which is a protocol and query language for RDF data; and Uniform Resource Identifier (URI) which is a string of characters designed for unambiguous identification of resources and extensibility via the URI scheme. The availability of such standards fostered the development of an ecosystems of different tools from various providers, e.g.: database engines that deal with RDF data (known as triple-stores), ontology editors, tagging tools that use text analysis to automatically generate semantic metadata, semantic search engines and more.

As evident from the above in the particular case of arranging the oceanographic data (which exist as at today in different forms and places) in order to produce effectively searchable data base what we need is to add/link to existing data units/sources appropriate descriptors that would allow the knowledge base search engine to effectively produce desired query results with a context meaning as close as possible to the meaning implemented in the query. The arrangement of this logic constructions is done in a form of RDF triples, that is a combination of three pieces of data – Subject – predicate (verb) – Object, the predicate showing the relationship between the subject and the object. Obviously with such construction of the knowledge description any relation of anything to other thing can be described. Apart from defining relationships, RDF triples also allow links between databases with structured data and documents that contain unstructured, free-flowing text. In this way, RDF triplestores, i.e. the stores organized around RDFs, connect entities from databases to documents that mention these entities. RDF triplestores may handle huge amounts of data, which improves the knowledge discovery and analytic capabilities of the organizations. What's more important is that triplestores are able to infer implicit facts out of the explicit statements. This feature becomes especially important in the light of the increasing multidisciplinary nature of the contemporary ocean studies. To put it another way – the computers with their search abilities become efficient extension of the human logical and analytical abilities. Triplestores

¹ <http://dbpedia.org/resource/Varna>

² <http://www.geonames.org/726050/varna.html>

³ http://dbpedia.org/resource/Academic_institution

⁴ <http://dbpedia.org/resource/Oceanography>

also facilitate many text analytics techniques such as extracting information from unstructured data and enriching content. By ‘learning’ the meaning as well as the context in which entities are used, machine learning algorithms can classify entities and disambiguate between them. The issue is essential and will be still such because of the inherited problem with the different meaning of the terms used by the scientists.

All of the above principles for efficient data search may be found in a combined form in practical solutions of semantic based knowledge search engines [3], [4], [5], [6]. It is important from the point of view of this paper to access what should be necessary to implement such semantic based integration/search tools in order to improve the results from the search for ocean related data. There are several technological challenges to be taken care of:

- *Oceanographic Knowledge Graph* – set up a knowledge graph appropriate for dealing with data and research findings related to Oceanography. This may include a various ontologies and datasets that are already publicly available. One such example would be the Geonames dataset, which already includes exhaustive information about all geographic features on Earth. Tagging Oceanographic data or research with entity identifiers (URIs) from Geonames would allow unambiguous analysis of the data and easy aggregation of data, because in Geonames there is information about the nesting of the different regions, e.g. that Varna is part of Republic of Bulgaria, the Black sea region, Eastern Europe, the Balkan Peninsula, etc.

- *Oceanographic Tagging Service* – set up text analysis tool or service which can analyze research results and tags them with the correct concepts in the Oceanographic Knowledge Graph. Many of today’s semantic annotation platforms allow customization of existing text analysis pipelines with respect to different knowledge graphs and types of documents.

- *Data integration service* – develop methodology and establish toolset which allows for integration of new data sources, e.g. raw results of oceanographic experiments, with the Oceanographic Knowledge Graph.

- *Semantic Search Service* – ecosystem of tools, which allows oceanographic research results, be it structured or unstructured, to be discovered and interpreted using the Oceanographic Knowledge Graph. There are two principle modes of operation of such service. The first option is to develop a meta-search engine, which re-writes the queries of the users, sends them to existing search engines, obtains results, which are transferred and consolidated in a way most appropriate for the target audience. The second option is to source content (e.g. by crawling websites, registering for data feeds or downloading dumps) which is analyzed and indexed locally. Both schemes have well known advantages and disadvantages. There are also hybrid approaches.

As mentioned in the beginning of the paper more or less the accumulated through the years oceanographic data exists in different formats (mostly) and in different geographically spread data stores/centers. All of these centers are organized under different architectures and have their own data processing interfaces which by rule do not look alike. In order to retrieve some information from any of these data repositories one should be well familiar with the main attributes related to the desired information, which when entered through the UI of the appropriate data storage system may (or may not) produce desired results. However, the knowledge about the metadata and the required by the appropriate data center request attributes would not be sufficient to produce the best possible result from the query should we are not familiar with the logic that stays behind the request UI. This is even more valid for non-professional/non-scientific users of such data stores and it makes the utilization of such data by non-experienced user practically impossible. The reason for which such arrangement would not operate and deliver desired results is that practically all of the data (especially the raw one) is in strictly structured form. And if such situation is unavoidable for the raw data in a sense, there is no reason that the unstructured information like papers, analytical reports, etc. should not be searchable in a looser manner, i.e. through its logical connection with other available information or similar to the way humans analyze and search for some information. This is where the semantic approach comes into use.

Due to historical reasons the existing oceanographic data is stored and still processed for search in a non-semantic way. And while for the primary, raw data there might be some excuse and explanation for such approach nowadays, there is no such logic reason that this should be applied to the unstructured information, the more that it is the exactly this type of information that carries most of the knowledge content. Because of the more directly practical essence of the oceanology it may be expected that more and professionally differently specialized people shall be interested about the knowledge for the ocean environment. A great deal of these users are not supposed to be acquainted in depth for the specifics of the particular field of knowledge they are interested in. The straightforward solution for them is to have at disposal integration and search tools with well developed set of ontologies, which when applied in the appropriate search engines would produce meaningful results even from stored unstructured information. Once created such set of ontologies may be implemented in the structures of the appropriate data integration systems or interlinked with specially designed for semantic search engines. This is what the sample data search system looked at in this report offers.

GRAPHDB™ FEATURES

GraphDB™ is a semantic graph database that is capable of integrating heterogeneous data from many sources and making links between datasets. It focuses on the relationships between entities and is able to infer

new knowledge out of existing information. It is a powerful tool to use in relationship-centered analytics and knowledge discovery. In addition, the capability to handle massive datasets and the schema-less approach support the NoSQL semantic graph database usage in real-time big data analytics. Ontotext's GraphDB is able to use inference, that is, to infer new links out of existing explicit statements in the RDF triplestore. Inference enriches the graph database by creating new knowledge and gives organizations the ability to see all their data highly interlinked. GraphDB also includes several plug-ins which allow for specific types of indexing and analysis of the data. One such example is the geo-spatial plug-in that allows efficient handling of constraints based on geographic distance (e.g. "get all airports within 100 kilometers from Varna"). As explained earlier, this feature is particularly important for oceanographic data.

GraphDB is part of the Ontotext Platform which unites a range of tools in order to provide ecosystem of development of knowledge graphs, semantic annotation and search services. These can be summarized as follows: the GraphDB data base itself incorporating semantic indexes, consolidated entity profiles, linked open data and user behavior profiles; machine learning models for text analysis, disambiguation of entities, concept extraction and classification; APIs for text analysis, model training, search, recommendations, content management and concept profiles; tools used to build UIs for contextual authoring, enrichment monitoring, curation and quality assurance, template definition and other user applications. An advantage of the system is that it capabilities can be used in a cloud form as well. As for the stand-alone data base this option can be tried on a free basis [7].

To avoid accusation in narrow-mindedness we have made a brief analysis of the market available graph and RDF databases using for the purpose the results of a study completed by Bloor Research, one of Europe's leading IT research, analysis and consultancy organizations. Their 2016 comparative report [8], gives a detailed enough idea for the advantages and the disadvantages of the major products available as at the time of the analysis and how do they project in the light of the consumer intentions. The main conclusion from the report is that the difficulty for potential users is in identifying the type or range of use case for which each product is most suitable. Again, in the light of the above-mentioned study we may claim the sample RDF database, the GraphDB™, stands fairly well regarding its longevity, broad availability of ancillary tools (very strong feature in comparison to similar competitors) and unified solution both for database and text mining. The latter feature presents very serious options in respect of our specific effort for implementation of the information integration in the oceanology. In fact, this feature of the product would add to the most desired feature of an ideal oceanographic global data integration system – an ability to infer new knowledge rather than just provide access to some kind of raw/primary data.

CONCLUSION

The use of semantic technologies in the integration and search of oceanographic data is a challenge at the present moment. The reason for this is because there is a little to almost no work done on the creation of the domain ontologies as foundation stone beneath the semantic base system to service the needs of both scientists and other non-scientific entities (governmental, private, non-profit, business). The main advantages of so created semantic data base should be sought not that much in direction of search for primary data (this falls within the interest of a narrower group of ocean specialists) but rather as an opportunity to provide meaningful access to useful data for non-scientific entities. Not to be neglected as well is the fact that the semantic knowledge base operates much faster compared to traditional relation data bases.

REFERENCES

- [1] <https://ontotext.com/products/graphdb/>
- [2] Berners-Lee, Tim; James Hendler; Ora Lassila (2001). "The Semantic Web". Scientific American.
- [3] <http://www.evi.com/about/>
- [4] <http://ebiquity.umbc.edu/paper/html/id/317>
- [5] <https://state.com/>
- [6] <https://ontotext.com/products/ontotext-platform/>
- [7] <https://ontotext.com/products/cognitive-cloud/>
- [8] <http://go.pardot.com/e/45622/ATABASES-2016-Bloor-Report-pdf/4r7cds/1330342319>
- [9] https://en.wikipedia.org/wiki/Linked_data
- [10] <https://schema.org/>
- [11] <https://dws.informatik.uni-mannheim.de/en/news/singleview/detail/News/244-billion-quads-rdfa-microdata-and-microformat-data-published/>
- [12] <https://lod-cloud.net/clouds/life-sciences-lod.svg>

ONE-WAY SHORT BASELINE UNDERWATER POSITIONING SYSTEM

Konstantin Chterev

Institute of Oceanology – Varna, Bulgaria, Department of Marine Geology

Abstract. This paper proposes a novel underwater positioning system based on a modified short baseline acoustic concept with application to a cable operated underwater vehicles. The standard short baseline acoustic positioning systems use two-way communications between the surface vessel and the underwater vehicle/object, which adds complexity and unnecessary cost. One-way communication system – from the underwater vehicle to the surface vessel only - is designed and implemented. System components are tested for performance on board RV Mahanga in the summer of 2018. The results show adequate speed and accuracy for most underwater ROV activities.

Keywords: Navigation; marine robotics; positioning system; ROV; short baseline; underwater acoustics

Introduction

The Acoustic Positioning Systems (APS) are de-facto standard in tracking and navigation of underwater objects like ROVs, AUVs and divers. Other systems – GPS or Dead Reckoning are unsuitable due to the poor radio waves penetration in water or significant error accumulation in prolonged underwater missions. The APS fall broadly in three major categories – Long Base Line (LBL), Short Base Line (SBL) and Ultra Short Base Line (USBL) depending on the distance between the system acoustic components relative to the distance to the tracked object. Fig.1 visualises the theory of operation of the three systems.

Fig.1: The three major APS types

LBL. Three or more acoustic buoys are deployed in the area of interest. The distance between the buoys is larger or similar to the distance between the buoys and the tracked object. A transmitter, mounted on the object emits a signal, which is received by all the buoys. They reply accordingly and their replies are received back by the tracked object. The distances between the object and the buoys are calculated based on delays of the signal and the speed of sound in water. By simple triangulation the position of the tracked object is calculated in the reference frame of the buoys. The calculated position is then transmitted to the surface vessel

SBL. Similar to the LBL, but the acoustic transmitters/receivers are mounted on a vessel. The distances between the receivers are significantly smaller than the distance to the underwater object. A signal is emitted from a vessel mounted transmitter. The underwater object receives the signal and replies back. All the vessel receivers receive the reply. Based on the time delay, the distances between the object and the vessels receivers are calculated. By triangulation, the position is calculated in the reference frame of the vessel.

USBL. This system uses a single buoy with an array of receivers. The receivers are closely spaced (the distance is smaller than the wavelength) and register the phase of the acoustic wave, giving as an output a direction (azimuth and elevation angle) and distance to the object. Very often a depth sensor attached to the underwater object is used to provide the Z coordinate. The coordinates are calculated in the reference of the buoy.

With price range from tens to hundreds of thousand US dollars, most of the APS are out of reach for small R&D teams and academic researchers. The SBL is by far the cheapest and easy to implement, thus suitable for DIY. In this article, simple SBL APS, suitable for tethered ROVs is presented. System components are implemented and tested, the results are given in the relevant section.

SBL APS in details

Fig.2: Traditional SBL APS

The traditional SBL APS is based on a minimum two transponders (i.e. transmitter/receivers) and two hydrophones (receivers only). One of the transponders is attached to the vessel together with the two hydrophones, the other transponder is attached to the underwater object, in our case - the ROV. The vessel transponder emits a burst of pulses usually between 50 and 800 kHz with total length of a few hundred microseconds. The pulse packet arrives at the ROV after certain time, depending on the distance and the speed of sound in water. The ROV transponder detects the packet arrival and responds with emitting another pack, usually identical to the received one. The pack from the ROV is received by the vessel hydrophones and the precise timings to each hydrophone is recorded. This way the distance between each of the hydrophones and the ROV can be calculated and by simple triangulation the position of the ROV relatively to the vessel can be determined. The tracking precision depends mainly on the accuracy of the delay time detection. The positioning error can be estimated by the following formulas:

$$\begin{aligned} D_1 &= (T_{td} + E_{tt} + T_{rd1} + E_{tr}) c \\ D_2 &= (T_{td} + E_{tt} + T_{rd2} + E_{tr}) c \\ D_3 &= (T_{td} + E_{tt} + T_{rd3} + E_{tr}) c \end{aligned} \quad (1)$$

Where:

$D_{1,2,3}$ - distance between the ROV and the hydrophone 1,2,3

T_{td} - packet delay between the vessel and ROV

$T_{rd1,2,3}$ - packet delays between the ROV and the hydrophones 1,2,3

E_{tt} - time error in the detection of the transmitted packet by the ROV

E_{tr} - time error in the detection of the received packet by the Vessel

c - speed of sound in water

As we can see there are many measurement errors which, accumulated, take part in the triangulation calculation. The measurement errors usually follow a normal distribution and can be eliminated by a filter, like moving average filter. The efficiency of the filter depends on the frequency of the sampling, so estimation of this

parameter is important. The maximum sampling frequency is limited by the maximum distance between the vessel and the ROV. This is due to the fact that the next pulse pack cannot be emitted before the previous transmit/receive cycle is completed.

$$F_s = c / 2D \quad (2)$$

Where:

F_s - sampling frequency

D - Distance between the ROV and the vessel

If we have a tether 500 metres long ($D=500$), the maximum frequency will be approximately:

$$F_s = 1500 / (2 \cdot 500)$$

$$F_s = 1.5 \text{ Hz}$$

1.5 Hz is quite low frequency and as the moving average filter needs several samples to be able to eliminate measurement errors, the whole system response will be quite slow – in a range of few to more than ten seconds.

These two factors – slow system response and accumulated measurement errors are targeted and a modification of the traditional SBL APS is proposed in the next section.

One-way SBL APS

The proposed SBL APS is applicable to tethered ROVs and any other cable operated underwater equipment. The main difference to the traditional SBL APS is the absence of any transponders. A single transmitter is mounted on the underwater vehicle; three or more hydrophone receivers are mounted on the surface vessel. The synchronisation is achieved by routing the electrical pulse which drives the piezo transmitter through the cable powering the ROV to the APS electronics mounted on the vessel – Fig.3:

Fig. 3: Modified SBL APS

The ROV mounted transmitter generates and emits a pack of pulses on a regular basis, with frequency no greater than F_s . Simultaneously with the acoustic emission, the same electrical pulse pack is routed through the cable to the vessel where the APS records the precise time of the emission. After certain delay the acoustic signal arrives to the vessel hydrophones. Depending on the delays, the distance between the ROV and the hydrophones can be calculated by triangulation. Similar to the traditional SBL APS the equations are:

$$D_1 = (T_{rd1} + E_{tr}) c$$

$$\begin{aligned} D_2 &= (T_{rd2} + E_{tr}) c \\ D_3 &= (T_{rd3} + E_{tr}) c \end{aligned} \quad (3)$$

As we do not have the first transmission from the vessel to the ROV, we can see that we have half of the measurement errors comparing to the traditional SBL APS. Also, the maximum sampling frequency is doubled, as we have just half of the acoustic path, which allows much better filtering–

$$F_s = c / D \quad (4)$$

Implementation

The main challenge with this architecture is routing the electrical signal from the piezo driver through the ROV cable. Ideally, if the cable construction allows, we can use an unused dedicated twisted pair to transmit the signal. Unfortunately, this is rarely the case and most of the off-the-shelf ROVs do not have such option. The following approach is applicable to all tethered ROVs, provided the power is supplied to the underwater vehicle via the tether.

The power supply frequencies vary between a DC to a few hundred Hertz maximum. The APS frequencies are in the range of tens to few hundred kilohertz. They can be separated by a low pass and band pass filter as shown on the block diagram below – Fig.4.

Fig.4: Block diagram of the power supply and synchronisation circuit

There are few requirements to the circuit:

- The low pass filter must withstand the power voltage and current required for the ROV, in some cases up to several kilowatts.
- The bandpass filter must withstand the power voltage supplied to the ROV.
- The low pass and the bandpass filters must provide good separation between the power line frequency and the APS frequency.
- The circuit is split into two parts. One installed on the vessel, the other – on the ROV. Only the power wire pair is used from an existing tether.

The practical implementation can be done many different ways. One possible option is presented in Fig. 5.

Fig.5: Practical implementation of the power and synchronisation circuit

The schematic is drawn in LTspice simulation software, which gives the flexibility to simulate the system and check the signal levels. R1 represents the resistance of the cable, R3 - the resistance of the ROV power electronics, R6 represents the input impedance of the synchronisation detector circuit. The piezo transmitter is driven by 50% square waveform - Fig. 6.

Fig.6: Piezo transmitter voltage

The synchronisation detector circuit, after filtering, receives the pulse pack as shown on Fig.7:

Fig.7: Detector circuit input voltage

The peak to peak amplitude is around 10 volts which is plenty to be detected by a simple rectifier. The receiver circuit consists of minimum 3 hydrophones and envelope level detectors plus a forth separate channel for the synchronisation pulse pack. The forth channel is schematically identical to the first three, but the threshold level must be adjusted differently as the signal from the cable is much stronger than the received acoustic pulses. The detectors outputs are edge triggers to a processor unit, which calculates the delays between the synchronisation pulse and the hydrophone pulses. The length of the pulse pack must be negligible comparing to the required accuracy of positioning. The 250 microseconds as shown on the Fig.7 give theoretical maximum error of approximately 40cm.

Tests and results

A simple test on the research vessel Mahanga is performed to prove the concept. The self-oscillating piezo transmitter is attached to a fixed 10m cable with an anchor. The transmitter is put in open waters and a single hydrophone is attached to the hull. The transmitter to hydrophone distance is measured to be precisely 10 metres +/- 0.1m. The sampling frequency is chosen to be 10 Hz. 10 000 samples are generated and the acoustic delays are recorded. At the moment of the test the water temperature was 22 degrees Celsius, giving a speed of

sound in the Black Sea waters around 1530m/s. Two histograms are created, one with the raw data, one with the data filtered with a simple moving average filter with window of 10 samples – Fig.8:

Fig.8: A histogram of distances distribution

As expected, the measurements follow a normal distribution. Fig. 8b shows that a simple moving average filter puts all the measurements in a narrow window of about 0.2m. The maximum sampling frequency for a 500m tether from (4) is 3Hz, which, for 10 samples averaging window will create $10 \cdot 1/3 \sim 3$ s delay for an accurate measurement.

Conclusion

The proposed SBL APS demonstrates very good performance with accuracy of 0.2m for a single acoustic path measurement and around 3 seconds delay in the worst-case scenario of 500m tethered ROV. The component count is also minimised. No expensive transponders are used. Off the shelf 40 KHz cleaning transducer is used for a transmitter and 40 KHz off the shelf marinized piezo sensors are used for the hydrophones. The whole bill of materials is less than a \$200 for the transducers, detectors and processing board, which can be Raspberry PI or similar. The modified SBL APS is suitable for DIY enthusiasts, students and academics on a tight budget or in projects where high customisation is required and off the shelf APS cannot be used.

References

- [1] Jo~ao N. Pic~ao. Ultrashort Baseline Positioning System: Implementation and Tests at Sea. Instituto Superior T~ecnico, Lisboa, Portugal, 2009
- [2] P. H. Milne. Underwater Acoustic Positioning Systems. Gulf Publishing Company, 1983.
- [3] A. Alcocer, P. Oliveira, and A. Pascoal. Underwater Acoustic Positioning System Based On Buoys With GPS. Proceedings of the Eighth European Conference on Underwater Acoustics, 8th ECUA, June 2006.
- [4] Anuj Kumar, P.P.Pathak and N.Dass. A Study of Speed of Sound in Water. IOSR Journal of Applied Physics (IOSR-JAP) e-ISSN: 2278-4861. Volume 8, Issue 4 Ver. II (Jul. - Aug. 2016), PP 21-23.
- [5] Analog Devices. Moving Average Filters. The DSP Book, Chapter 15.
- [6] NIST/SEMATECH. e-Handbook of Statistical Methods, <http://www.itl.nist.gov/div898/handbook/>, 2018.
- [7] W. Stallings. Data and Computer Communications. Chapter 7, Prentice Hall, 2009.
- [8] Telemetry Standards, RCC Standard 106-17, Chapter 3 - Frequency Division Multiplexing Telemetry standards, July 2017

Black Sea 2018

MARINE EDUCATION

ESTABLISHMENT OF A BLUE CAREER CENTRE AS AN IMPORTANT LINK IN THE BLUE ECONOMY IN BULGARIA

Ilze ATANASOVA*, Rumen KISHEV**, Petar GEORGIEV***,

* Marine Cluster Bulgaria; ** BSHC - Varna; ***Technical University of Varna

Abstract. The paper presents partial results from the establishment of a regional Blue Career Centre (BCC) in the frame of project “Blue Career Centre of Eastern Mediterranean and Black Sea -MENTOR” funded by EASME/EMFF (Executive Agency for SMEs/ European Maritime and Fisheries Fund). The main objectives and activities of the BCC are explained in the light of the statistics for education and training in Bulgaria and in other partner countries. The activities of the future centre are considered, taking into account the latest international events and signed documents between the countries of the Black Sea region. The establishment of the BCC demonstrates the collaboration of regional marine clusters in reducing the skill gaps at Blue Growth sectors.

Keywords: blue career, blue growth, blue economy

INTRODUCTION

The European project “Blue Career Centre of Eastern Mediterranean and Black Sea (MENTOR)” is co-funded by the EASME, Grant Agreement EASME/EMFF/2016/1.2.1.2/06/SI2.749365-MENTOR. The partners in the projects are 7 institutions from 4 countries as follows: Cyprus - University of Cyprus; Maritime Institute of Eastern Mediterranean; Cyprus Chamber of Commerce and Industry; Greece - National Technical University of Athens; Agricultural University of Athens; Bulgaria - Marine Cluster Bulgaria; Romania - Constanta Maritime University.

The EU Blue Growth Strategy [1] identifies and ranks marine and maritime activities of the highest potential for future growth and jobs perspectives in the Mediterranean and the Black Sea regions. In order to achieve sustainable growth, the Blue Economy needs highly qualified and skilled professionals. The 2014 Communication from the Commission on “Innovation in the Blue Economy: realising the potential of our seas and oceans for jobs and growth” [2], pointed out that the shortage of skilled workforce is one of the main obstacles to the further development of the blue economy. To address this issue it is of crucial importance to bring industry and education /training providers together to promote and support the development of career opportunities in the blue economy.

The general objectives of MENTOR Project are as follows: [3]

- Set up a regional platform – Blue Career Centre – for dialogue between business stakeholders, education & training institutions, research organizations, regulators, the civic society;
- Work closely and actively in order to close the skills gap, make blue careers more attractive, and tackle unemployment;
- Focus on four Marine and Maritime Economic Activities (MEAs) of strategic importance in the East Mediterranean (EM) & Black Sea (BS) region: Maritime Transport (i.e. shipping, ports, shipbuilding and ship-repairs); Cruise Tourism; Marine Aquaculture (mainly in the EM); Offshore oil and gas.

For the achievement of the general objectives, a number of specific objectives have been set:

- Establishment of the Blue Career Centre (BCC) Secretariat in Cyprus with representations in Greece, Bulgaria and Romania, which may later extend to other countries in the area;
- Mapping of the provided maritime education and training in the EM and BS region, including availability of infrastructure;
- Development of re-training schemes for blue professionals in the maritime sector, fisheries and offshore oil and gas;
- Mentoring and career guidance to students (age 15-18) for the Blue sectors in schools in Cyprus, Greece, Bulgaria, and Romania;
- Re-train blue professionals in the maritime sector, cruise tourism, fishing tourism and ichthyotourism, and offshore oil and gas sectors;
- Establish introductory e-learning courses for the maritime transport sector, for offshore oil and gas sector, for marine aquaculture sector, cruise tourism and for fishing tourism and ichthyotourism;

- Sharing and pooling of resources, such as maritime simulators and possibly a training vessel from the EM & BS area;
- Organise Blue Career Fairs (Days) in the Eastern Mediterranean and Black Seas;
- Promote the mobility of students and staff within the region;
- Balance the demand and supply of maritime, aquaculture, cruise tourism and offshore oil and gas professionals in the region;
- Promote the harmonisation of Maritime Education and Training;
- Set an example and model for other sub-basins so that in the near future we can have a European Network of Blue Career Centres that will bring together all the stakeholders of the various European Marine and Maritime Clusters in the common effort to close the skills gap, tackle unemployment and make “blue careers” more attractive to the young people of Europe and its neighbourhood.

Against the background of the objectives of the MENTOR project, the paper deals with some alarming statistics related to the training and employment of young people. The next subchapters describe the essence of the established centre in Bulgaria and the prospects for the BCC in response to the challenges facing the Black Sea countries.

ALARMING STATISTICS

The target group of the MENTOR project includes young students (age 15-18), maritime sector employees and unemployed workers in blue or other sectors. The choice of this target group is based on some alarming statistics in Europe. The next subchapters include overview of some of the Eurostat statistics for the last few years with chart examples including data for the partner countries in MENTOR project.

Early leavers from education and training

The strategic framework for European cooperation in education and training (known as ET 2020) adopted a goal to be achieved by 2020, namely, that the share of early leavers from education and training in the EU-28 should be not more than 10 %. The highlights from Eurostat in this field are as follows [4]:

- 10.6 % of the 18-24 year olds in the EU in 2017 had completed at most a lower secondary education and were not in further education or training ('early leavers').
- 12.1 % of young men and 8.9 % of young women in 2017 in EU were early leavers from education and training.
- The proportion of early leavers from education and training in 2017 ranged from 3.1 % in Croatia to 18.6 % in Malta.

For the last five years (2012-2017) the overall share of early leavers from education and training fell in the EU-28 by 2.1 percentages. The largest reductions (in percentage point terms) for this were in Portugal, Spain and Greece, each reporting a fall in excess of 5.0 points. The biggest increases were recorded in Slovakia (up 4.0 percentage points) and the Czech Republic (1.2 points). Bulgaria and Romania reported increases of less than 1.0 points. Figure 1 presents the percentage of early leavers in a period of 10 years. For the last five years the figures in Greece and Cyprus are below the target for EU and for Bulgaria, especially for Romania they are above desired 10 %.

The proportion of early leavers in 2017 in the EU-28 was 3.2 percentage points higher for young men (12.1 %) than for young women (8.9 %). Almost all EU Member States reported a higher number for early leavers for young men than for young women. There were five exceptions, as the proportion of early leavers was lower for young men than for young women in Slovakia (1.8 percentage point difference), Bulgaria (1.5 points), Hungary (1.0 points) and Romania (0.1 percentage points difference). The dynamic for the relation between the men and women for the last 10 years is shown in Figure 2. For EU the relation is almost constant i.e. about 33% higher number of early leavers for young men. In Romania the numbers are almost equal and for Bulgaria, for the whole period the number of early leavers among young women is higher than that for young men. One can see a serious fluctuation in this relation for Cyprus.

Early leavers may face difficulties in the labour market. Figure 3 presents an analysis of whether these early leavers are employed or not: those not in employments may or may not want to work. The greatest number of employed early leavers was reported in Malta (13.9 %) and from partner countries – in Romania (9.4 %). The largest gender differences among the proportion of young people who were early leavers and not wanting to work for 2017 were recorded in Bulgaria (5.9 %), Romania (5.0 %) and Slovakia (3.6 %).

Figure 4 presents the data for the proportion of early leavers from education and training according to the degree of urbanisation, with regions classified as cities, towns and suburbs, or rural areas. The proportion for EU is in line with the benchmark set in the strategic framework (not more than 10 % by 2020). For several countries, including Bulgaria, Greece and Romania, the highest proportion of early leavers was reported in rural areas.

Figure 1. Percentage of early leavers for partner countries

Figure 2. Relations between the percentage of early leavers for young men and young women

Figure 3. Distribution of early leavers from education and training by labour status, 2017

Figure 4. Early leavers from education and training by degree of urbanisation, 2017

Figure 5. Employment, education and training status of young people, 19 – 24 year, 2017

Figure 6. Young people neither in employment nor in education or training (NEETs), 2017

Young people neither in employment nor in education or training (ET)

The Eurostat data [5] show that in the EU in 2017, 17.2 % of the 20-34 olds were neither in employment nor in education and training ('NEETs'). The proportion of young people neither in employment nor in education and training in 2017 ranged from 7.8 % in Sweden to 29.5 % in Italy. There were almost 16 million young people aged 20–34 who were neither in employment nor in education and training.

The distribution of 'NEETs' in three age subgroups (20-24; 25-29 and 30-34) for partner countries is presented in Figure 6. The figures for all countries are greater than those for EU and are about 20%. For Greece the percentage for 'NEET's' is higher – 22%, 32.2% and 31%.

Vocational education and training statistics

Vocational education and training, abbreviated as VET, is the training in skills and teaching of knowledge related to a specific trade, occupation or vocation in which the student or employee wishes to

participate. On this broad topic, attention is focused only on two aspects - the number of pupils included and the corresponding expenditure.

Figure 7. Share of students in vocational education programmes (upper secondary), 2015

Figure 8. Cost of CVT courses per participant, 2015

According to [6] in 2015, close to half (47.3 %) of all upper secondary (ISCED level 3) school pupils in the EU-28 followed vocational programmes, with the share for males 10% higher than that recorded for females. In half of the EU Member States, less than half of all upper secondary pupils were studying vocational programmes, with this share dropping below one quarter in Hungary (23.2 %) and lower still in Cyprus (15.6 %) and Malta (12.7 %). There were no vocational programmes at this education level in Ireland. By contrast, in Slovenia, the Netherlands, Slovakia and Austria more than two thirds of upper secondary pupils followed vocational programmes, with even higher shares —above 70.0 %— in Croatia, Finland and the Czech Republic, where a peak of 73.2 % was recorded. Figure 7 presents the number of upper secondary school pupils for partner countries compared with the average figures for EU-28,

The important topic in VET is Continuing Vocational Training (CVT) by enterprises. The Eurostat data [6] refers to education or training activities which are financed, at least in part, by enterprises; part financing could include, for example, the use of work time for the training activity; CVT can be provided either through dedicated courses or other forms of CVT, such as guided on-the-job training. In general, enterprises finance CVT in order to develop the competences and skills in the people they employ, hoping that this may contribute towards increasing competitiveness. A large majority of CVT is non-formal education or training, in other words, it is provided outside the formal education system.

The data on the cost of CVT courses for partner countries (as shown in Figure 8) has been converted to *purchasing power standards* (PPS). Purchasing power standards are an artificial currency which adjusts for price level differences between countries.

In 2015, the average expenditure on CVT courses by enterprises in the EU-28 was PPS 1418 per participant; note that each person is only counted once, regardless of how many courses they attend during a year and regardless of how long these courses were. The average expenditure per participant on CVT courses ranged from PPS 449 in the Czech Republic to PPS 3452 in Denmark. The expenditure for Greece is higher than the rest of the countries and for Bulgaria and Romania the figures are equal.

BLUE CAREER CENTRE OF EASTERN MEDITERRANEAN AND BLACK SEA

The Blue Career Centre (BCC) has planned a regional platform for dialogue between business stakeholders, education and training institutions, research organizations, policy makers, civil society as well as the EU and the Union for the Mediterranean. It will give the opportunity to increase employability by providing prospects for young jobseekers and support to businesses in finding eligible employees with proper qualifications.

The project consortium along with observers from neighboring non-EU countries, such as Egypt, Jordan, Lebanon and Turkey, will join forces in order to:

- Attract higher education graduates or persons with vocational/technical qualifications to maritime professions through targeted and innovative education and/or training initiatives (including career guidance);
- Offer mentoring and career guidance to students (age 15 - 18) for Key Blue Sectors in the region;
- Retrain and up-skill workers employed in other sectors and/or people currently unemployed for a job in the Blue Economy;

- Diversify and expand the skills of people currently employed in the Blue Economy to progress in their careers and/or to facilitate their mobility to other maritime jobs.
- A Blue Career Centre Secretariat will be established in Cyprus with representations in Greece, Bulgaria and Romania.

The proposed solution in the MENTOR project is in line with the latest international agreements on the Black Sea.

Burgas ministerial declaration

The European Maritime Day (EMD) was officially created on 20 May 2008. EMD is celebrated annually across Europe on 20 May to raise the visibility of maritime sectors and support an integrated approach to maritime affairs.

The EMD 2018 conference and exhibition took place on 31 May and 1 June 2018 in Burgas, Bulgaria, making it the first time for the Black Sea region. Ministers and representatives from Bulgaria, Georgia, Moldova, Romania, Russia, Turkey and Ukraine reaffirmed their commitment to working more closely with the endorsement of the Declaration towards a Common Maritime Agenda for the Black Sea.

This declaration called Burgas Ministerial Declaration [7] recognizes the potential of voluntary cooperation on:

- *Shipping, passenger and cruising lines to boost trade and the promotion of transport connectivity to develop business throughout the Black Sea basin;*
- *Maritime and coastal tourism in the Black Sea to spur cooperation for a sustainable Blue Economy, taking into account the cultural and environmental assets of the region;*
- *Marine science and maritime education and training as a good basis for cooperation and as key factors in improving and developing new skills in the Blue Economy;*
- *Marine research and innovation as a key priority for cooperation;*
- *Promoting maritime investment for a sustainable blue economy through planning tools;*
- *An improved marine environmental protection for developing a sustainable Blue Economy, and in particular coordination while addressing transboundary environmental challenges, such as plastic marine litter;*
- *Maritime and environmental observation and monitoring which will contribute to the sustainable use of marine resources and to the achievement of good environmental status.*

Researchers and scientists, representing lead institutes from all coastal countries and the Republic of Moldova, have developed a shared vision for a productive, healthy, resilient, sustainable and better valued Black Sea by 2030 (the Burgas Vision Paper [8]). In the document for education and capacity building, the parties agree on:

- *Supporting formal and informal learning, education, training and utilisation and transfer of technologies and knowledge for established and new marine and maritime-related jobs;*
- *Promoting educational and vocational youth mobility related to the blue economy among the countries in the region;*
- *Contributing to an enhanced science-policy dialogue in formulating coastal and marine policies and programmes;*
- *Empowering ocean-engaged citizens and policy-makers by providing high-level scientific output, contributing to a clean, plastic-free, healthy and productive Black Sea.*

Establishment of BCC Bulgaria

Following the ideas included in the MENTOR project and the documents and vision for development of the Black Sea region, on August 14, 2018 in Varna, a Blue Career Center (MENTOR) was established. The center is a non-profit organization. Founders and first members of the organization are Marine Cluster Bulgaria and several individuals.

The BCC (MENTOR) Bulgaria will be a link between the various actors in the blue economy of the country (Figure 9).

The objectives of the centre are as follows:

- Attracting young people for work and career development in the blue economy sectors and helping businesses in the blue economy to recruit and select human resources;
- Attracting graduates or persons with vocational/technical qualifications to maritime professions through targeted and innovative career development, education and/or training initiatives (including career guidance);

- Attracting the interest of the growing generation towards career development in the sectors of the blue economy;
- Diversification and expanding the skills of people working in the blue economy for their career development and / or to facilitate their mobility to other maritime activities and jobs.

Figure 9. Scheme of the network of BCC (MENTOR) Bulgaria and the actors in blue economy

CONCLUSIONS

The EU Blue Growth Strategy identifies and ranks marine and maritime activities of the highest potential for future growth and jobs perspectives in the Mediterranean and the Black Sea. In order to achieve sustainable growth the Blue Economy needs highly qualified and skilled professionals. Many Blue Sectors are experiencing difficulties in finding the eligible employees and expect that these difficulties will continue throughout the foreseeable future. The Eurostat statistics clearly show some problems.

At this stage four Key Blue sectors have been selected, being of strategic importance in the Eastern Mediterranean and Black Sea regions: Maritime Transport, Cruise Tourism, Marine Aquaculture and Offshore Oil and Gas.

The successful operation of the first Blue Career Centre for the Eastern Mediterranean and the Black Sea is expected to set an example and model for all other sub-basins. A European network of Blue Career Centres may eventually be established bringing together all the stakeholders of the various European Marine and Maritime Clusters in a common effort to close the skills gap, tackle unemployment and make “blue careers” more attractive to young people from Europe and its neighborhood.

ACKNOWLEDGEMENTS

This paper reports a work developed in the project “Blue Career Centre of Eastern Mediterranean and Black Sea (MENTOR)”, co-funded by the European Maritime and Fisheries Fund in the framework of the EASME call for Blue Careers in Europe, Grant Agreement EASME/EMFF/2016/1.2.1.2/06/SI2.749365-MENTOR.

REFERENCES

- [1] https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en
- [2] EESC (European Economic and Social Committee), 2014, TEN/554, Innovation in the Blue Economy TEN/554 – EESC-2014-03567-00-00-AC-TRA (EN) 2/8
- [3] Georgiou, G. Blue Career Centre of Eastern Mediterranean and Black Sea (MENTOR), Presentation KO Meeting, Brussels, 8.3.2017
- [4] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Early_leavers_from_education_and_training#Analysis_by_labour_status
- [5] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Statistics_on_young_people_neither_in_employment_nor_in_education_or_training#The_transition_from_education_to_work
- [6] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Vocational_education_and_training_statistics#Numbers_of_pupils
- [7] Burgas Ministerial Declaration. https://ec.europa.eu/maritimeaffairs/maritimeday/sites/mare-emd/files/burgas-ministerial-declaration_en.pdf
- [8] Burgas Vision Paper. A Blue Growth Initiative for Research and Innovation in the Black Sea. https://ec.europa.eu/maritimeaffairs/maritimeday/sites/mare-emd/files/burgas-vision-paper_en.pdf

PROFILE OF THE INNOVATION NEEDS OF *SME*'s FROM MARITIME SECTOR IN THE REGION FROM THE ADRIATIC-IONIAN SEAS TO THE BLACK SEA

Petar GEORGIEV*, Ilze ATANASOVA*, Martina ROSSI**, Carlo KRASKOVIC**,
Angelos KTORIS***

* Marine Cluster Bulgaria; ** Maritime Technology Cluster FVG S.c.a r.l, Italy; ***Maritime Institute of Eastern Mediterranean, Cyprus

Abstract. The paper presents the obtained results from the developed common methodology for collection of technology features and innovation needs of *SME*'s from maritime industry from six countries - Albania, Bulgaria, Croatia, Cyprus, Italy and Romania. The survey was carried out in the frame of Blue NET project, funded by the European Maritime and Fisheries Fund (EASME/EMFF/2015/1.2.1.7/01/SI2.735914). The results include profiles of surveyed companies, by size, activities and innovation needs. The ranking of innovation fields and needs emerged during the dialogue between experts, companies and clusters, enabling the identification of the innovation paths that can be considered as international trajectories on a long-term basis and that should capture the interest of policy makers and other local stakeholders

Keywords: Adriatic-Ionian Sea, Black Sea, Blue NET project, Innovation, *SME*

INTRODUCTION

The European project “Blue NET – Maritime Clusters Network for Blue Growth” is co-funded by the European Maritime and Fisheries Fund (EASME/EMFF/2015/1.2.1.7/01/SI2.735914). The partners in the projects are six institutions from different countries as follows: Maritime Technology Cluster FVG S.c.a r.l. (Italy- coordinator); Marine Cluster Bulgaria (Bulgaria); Maritime Institute of Eastern Mediterranean (Cyprus); Këshilli i Qarkut Shkodër (Albania); Union of Romanian inland ports (Romania); University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture (Croatia) [3].

The general objective is to enhance the *SME*'s capacity to develop networking among maritime clusters in the Mediterranean, in particular in the area from the Adriatic-Ionian Seas to the Black Sea. The aim is to diffuse innovation and achieve an added value in relation to the maritime policy of the target area. Project activities are implemented in the framework of Integrated Maritime Policy of the European Union and will allow:

- Exchange of good practices for cluster management and development of the business sector mainly for the *SME*s;
- Empowering maritime clusters and/or regional centres of competence to go blue-innovative;
- Enhanced intensive networking among the stakeholders in the involved countries.

The main activities during the projects are as follows:

- *State of the art of each country:* The first step of the action is an initial assessment of the “blue economy” sectors in each of the involved countries and identification of the stakeholders (enterprises, research institution and clusters) working in these sectors. In order to facilitate the exchange of information, a common web-based database will be developed to gather and manage stakeholders' features. The database will be a tool for further projects' activities but also available beyond the end of the project in order to become a long-term platform for exchange of information and identification of innovation projects opportunities among clusters.
- *Joint innovation path:* Based on previous outputs, a common methodology will be defined, to collect technology features and innovation needs from the maritime industry taking into consideration the different traits of involved clusters. To evaluate its efficiency, the common methodology will be implemented by partners by auditing at least three enterprises in each country to identify the technological development opportunities and possible mutual innovation paths. Based on the matching of the identified needs the joint innovation paths will be designed.
- *International World Café:* The organization of an international world cafe is intended as an opportunity for involved enterprises to compare innovation needs and identify possibilities of collaboration among them and with research actors. Besides enterprises the event will gather relevant experts and research institutions working in the blue economy.

- *Mutual learning conferences in every country*: The aim of mutual learning conferences is to disseminate among stakeholders the common methodology and its implementation results. The conferences will be organized by each partner in their country.

The paper presents the results from the development of a common methodology for collection of technology features and innovation needs from maritime industry taking into consideration the different traits of the involved clusters.

COMMON MARITIME SECTORS

The six partner countries involved have diverse maritime traditions, however, not all have available data to define the most relevant maritime sectors in terms of stakeholders, research and innovation activities. Starting with the classification of Maritime sectors provided by [1] the partners agreed in the identification of a 4 (out of 8) sectors meant that it will be more relevant in terms of national policy, research and companies. Table 1 below shows the sectors identified as relevant per country.

Table 1. Common maritime sectors

Maritime sector	ITALY	BULGARIA	CYPRUS	ALBANIA	ROMANIA	CROATIA
<u>Shipbuilding and boatbuilding</u> : design, construction, maintenance and reparation, fittings, plants and equipment	X	X		X	X	X
<u>Maritime transport</u> : deep-sea shipping, short sea-shipping, passenger ferry services, inland waterway transport, logistics linked to waterborne transport, port activity	X	X	X	X	X	X
<u>Energy and raw materials</u> : offshore oil and gas, offshore wind, ocean renewable energy, carbon capture and storage, aggregates mining, marine minerals mining, securing fresh water supply	X		X	X		X
<u>Leisure, working and living</u> : coastal tourism, yachting and marina services, cruise tourism	X	X	X	X		X

The document “Blue NET - State of the art of maritime sectors” provides all the details of the analysis performed by the partner countries during the project.

ANALYSIS OF INNOVATION NEEDS

Profile of the surveyed companies

To identify main innovation needs of the organizations that participated in the project, commonly agreed upon Questionnaires and Technological audits were performed. The goal of these audits is to assess the technological capability of the company, its capacity to innovate and its performance and innovation needs.

As a second step, these outcomes were reviewed and approved by experts selected according to the working plan of the project. The final stage of this process was validation and extension these innovation needs during the World Café meeting based on the actual needs of the participating companies, the expertise of the professionals and the facilitation of the discussion by the partners of the project.

As far as the project is focused to the SME, Figure 1 presents the criteria for definition of SME.

The developed questionnaire includes 13 questions. Companies in each country have been asked to indicate the sector in which they operate, their market orientation, the type of their customers and their main innovation needs. These needs are mostly derived from the market request. Indeed competitors’ and customers’ requests seem the most chosen answers, although in companies dealing with ships and/or ports management the regulatory constraints seem to be the main reason for innovation.

The total number of surveyed companies from each country and the carried out technological audits are presented in Table 2. The maritime sectors and corresponding fields activities included in the questionnaire are shown in Table 3.

The distribution of all 96 companies in SME categories is shown in **Error! Reference source not found**. Almost 60% of those are small and medium sized companies, 33% are micro and only 8% are classified

as a big company. Figure 3 presents the distribution of activities across the considered maritime sectors. Some companies have selected more than one maritime sector in the questionnaire.

Figure 1. The criteria for the SME definition

Table 2. Number of surveyed companies from countries

Country	No of Questionnaires	No of Technological Audits
Albania	18	5
Bulgaria	20	5
Croatia	13	5
Cyprus	13	2
Italy	21	7
Romania	11	4
TOTAL	96	28

Table 3. Maritime sectors and fields of activity

Shipbuilding and boatbuilding	Maritime transport	Energy and raw materials	Leisure, working and living
Design	Deep-sea shipping	Offshore oil and gas	Coastal tourism
Construction	Short sea-shipping	Offshore wind	Yachting and marina services
Maintenance and reparation	Passenger ferry services	Ocean renewable energy	Cruise tourism
Fittings (interiors, furnishing, finishing)	Inland waterway transport	Carbon capture and storage	
Plants and Systems	Logistics linked to waterborne transport	Aggregates mining	
Equipment	Port activity	Marine minerals mining	
		Securing fresh water supply

Figure 2. Distribution of company size

Figure 3. Distribution of company activities in sectors

Innovation fields

From the questionnaires and technological audits, a total number of 145 innovation needs were extracted grouped in 17 different innovation fields. The distribution of these needs among the maritime sectors is as follows: Shipbuilding and boatbuilding – 62; Maritime transport – 40; Energy and raw materials – 22 and Leisure, working and living – 21. From the total number of needs, 108 of them (75%) are grouped in 8 innovation fields that are expressed by 3 or more companies. Percentage distribution of the innovation needs for every one of the sectors is presented in Figure 4.

Figure 4. Summary of innovation needs in the surveyed maritime sectors: Shipbuilding and boatbuilding (top left), Maritime transport (top right), Energy and raw materials (bottom left) and Leisure, working and living.

The innovation fields have been verified with the companies during a special event – International World Café on June 2018, where thanks to the guidance of 5 international experts, some fine tuning has been done. The sharing of thoughts among companies and experts led to merging 2 fields and to adding more detail to the list of comprehensive needs (Figure 4).

The innovation fields and needs emerged during the dialogue between experts, companies and clusters, who enabled the identification of the following paths that can be considered as international trajectories on a long-term basis and that should capture the interest of policy makers and other local stakeholders:

- Efficient and optimized infrastructures;
- Smart design and manufacturing processes;
- Environmentally respectful, automated and integrated vessels and plants.

Possible networking

As further contribution to the innovation paths, the information included in the questionnaire concerning the innovations needs permits the development of a preliminary network for exchange of knowledge and experience and common work on innovation of mutual interest. Figure 5 presents a possible network of cooperation. The graph includes ID numbers instead of the names of the companies from the partner countries with technical audits.

Figure 5. Network for joint work for innovation in Blue NET project

Table 4. Innovation fields and detailed needs in considered maritime sectors

Innovation fields	Detailed needs	Maritime Sectors			
		Shipbuilding & boatbuilding	Maritime Transport	Energy and row material	Leisure working & living
Advanced infrastructure development	Process chain optimization, LNG/ CNG Infrastructure, Smart/ Electric Port, Crane Automation, Improved port and shipyard facilities	5	4	----	----
Advanced manufacturing technology	3D Scanning (including underwater) / Printing, Laser cutting, Modularity in shipbuilding/ boatbuilding, advance wet blasting machine, advance machine for metal processing	17	6	6	6
Software Development	Internet of Things, Design Software Tools and Add-ons, Big Data analytics, Integration Solutions, Digitalization of Ports, Software that will improve the work processes (logistics), Condition Monitoring System, Simulation software, CAD design software, Management software, Mobile applications, Marina management tools	15	12	----	9
Reduce Emission Technology	Scrubbers, LNG/ CNG Fuel, Hybrid Engines, Water Ballast Systems, Training courses for the protection of the environment.	3	4	----	----
Energy Efficiency System	Electric Propulsion, Engine Performance Monitoring and Optimization, Hybrid lubricants, Fuel efficiency methods, High- efficient batteries	----	3	----	----
Advanced Materials	Fiber reinforced plastic, Ceramic materials, Superlight materials, Carbon fiber resilient at high temperatures, recyclable materials, Bio - composites	7	----	3	----
Advance Automation System	Drone, USV, Artificial Intelligence , Virtual Reality, Robotics, Remote Control, Track System, Block Chain, Additive manufacturing, Improved dynamic, positioning systems (for dragging), CNC machines	4	----	4	----
		108			
		47%	27%	12%	14%

The connections inside the pentagram present possible common work based on the experience in the activities of one company and innovation needs in the same field of another, or based on mutual interest for innovation. For example, Case A (see Figure 5) presents cooperation among two companies in order for the first to meet the need of the second. The products/services provided by the company C1 from Croatia are electric machines, electric propulsion - synchronous machines with permanent magnets that can be motors as well as generators. At the same time the company B4 from Bulgaria in the questionnaire mentions that there is a need for Energy efficiency of their fleet. Such energy efficiency can be sought through introducing some electric machines and equipment.

Case B indicates potential cooperation of two companies to address their common need to upgrade their products/services. During the technological audit the company C2 from Croatia reported as innovation need durability and ageing of polymer and composite (Fibre reinforced plastic) materials for ship repairs and the company I2 from Italy reported as a need the development of new recyclable materials for composite production, new production processes for composite such as welding technologies and modular moulding and application of ICT in manufacturing processes.

CONCLUSIONS

It is relevant to be mentioned that, the needs expressed are more and more focused on the improvement of processes and consider always interconnection between means (vessels) and infrastructures, but also between design phases and manufacturing or operation and maintenance. In addition, we can see that if we refer to the nine technology trends mentioned as founding technologies for Industry 4.0 and expressed by Scalabre [4], all of them are emerging from the needs expressed by the companies interviewed. These technologies are: Big data and analytics; Autonomous robots; Simulation; Horizontal and vertical system integration; The industrial internet of things; Cybersecurity; The cloud; Additive manufacturing; Augmented reality.

At the time of the conclusion of the Blue NET project (summer 2018), not all the countries involved have a cluster management organization. Some of the territories involved do not have specific cluster policies and in some cases the bottom-up dialogue (from the companies to policy makers or from cluster representatives to policy makers) is still extremely hard. In some other cases a reliable system of information about the best way to exploit public support and funding opportunity is missing or managed by consultants not always aware about the business needs and processes in the sector.

The collaboration of Blue NET highlighted the huge potential that all the companies, if properly involved, could give in the definition of EU policies, overcoming the actual approach of some actors that still believe that they can only follow EU indications instead of also contributing for their definition.

The work on the joint innovation paths in the Blue NET has enabled:

- The establishment of a real and operative network among maritime clusters in the East Mediterranean and the Black Sea;
- The practical sharing of best practices among clusters and regional governments, experiences, reliable methodologies, methods to deal with companies and innovation topics and to act for the creation of international networks for innovation;
- The realization of the first tangible opportunity of involving a heterogeneous group of companies in a sharing activity dedicated to the future of the maritime sector, opening up to new contacts and collaboration opportunities.

In many of the technological audits, not depending on the Country, it comes out that most of the obstacles that the companies find in innovation are related to financing and the high cost of new technologies. Indeed it has been widely indicated that finance consultancy services are useful for the company growth. Another point broadly expressed as an obstacle in innovation is related to the qualification of personnel. The conclusion from these two points is that there is a lack of workers preparation on innovation and new technologies and a general unfamiliarity with the financing process. In any case, most of the interviewed companies have indicated their interest in innovation projects collaborating with other companies with both public and private financing.

ACKNOWLEDGEMENTS

This paper reports a work developed in the project Blue NET – Maritime Clusters Network for Blue Growth”, which was partially financed by the European Union, under the EASME, Grant Agreement EASME/EMFF/2015/1.2.1.7/01/SI2.735914.

REFERENCES

1. EUNETMAR, Study to support the development of sea-basin cooperation in the Mediterranean, Adriatic and Ionian, and Black Sea Analysis of Blue Growth needs and potential per country. Executive Summary, March 2014, CONTRACT NUMBER MARE/2012/07 - Ref. No 2
2. EU (2015). User guide to the SME Definition. PDF ISBN 978-92-79-45301-4 doi:10.2873/620234 ET-01-15-040-EN-N
3. <http://bluenet-project.eu/>
4. Scalabre, O. (2018). Embracing Industry 4.0—and Rediscovering Growth. The Boston Consulting Group. (<https://www.bcg.com/>)

VARNA SCIENTIFIC AND TECHNICAL UNIONS

FOURTEENTH INTERNATIONAL CONFERENCE ON MARINE SCIENCES AND TECHNOLOGIES

Computer layout by LARGO CITY Ltd. - DOBRICH
Total print: 40, Format 60/84/8
LARGO CITY Ltd. - DOBRICH
DESIGN, PRE-PRESS AND PRINTING

ISSN 1314 - 0957