Environmental Impacts of Aquaculture

Contents

Post-workshop summary of impacts 1
ELICITATION RECORD – Part 1 7
ELICITATION RECORD – Part 2: Outcome 1 18
ELICITATION RECORD – Part 2: Outcome 2 22

Post-workshop summary of impacts

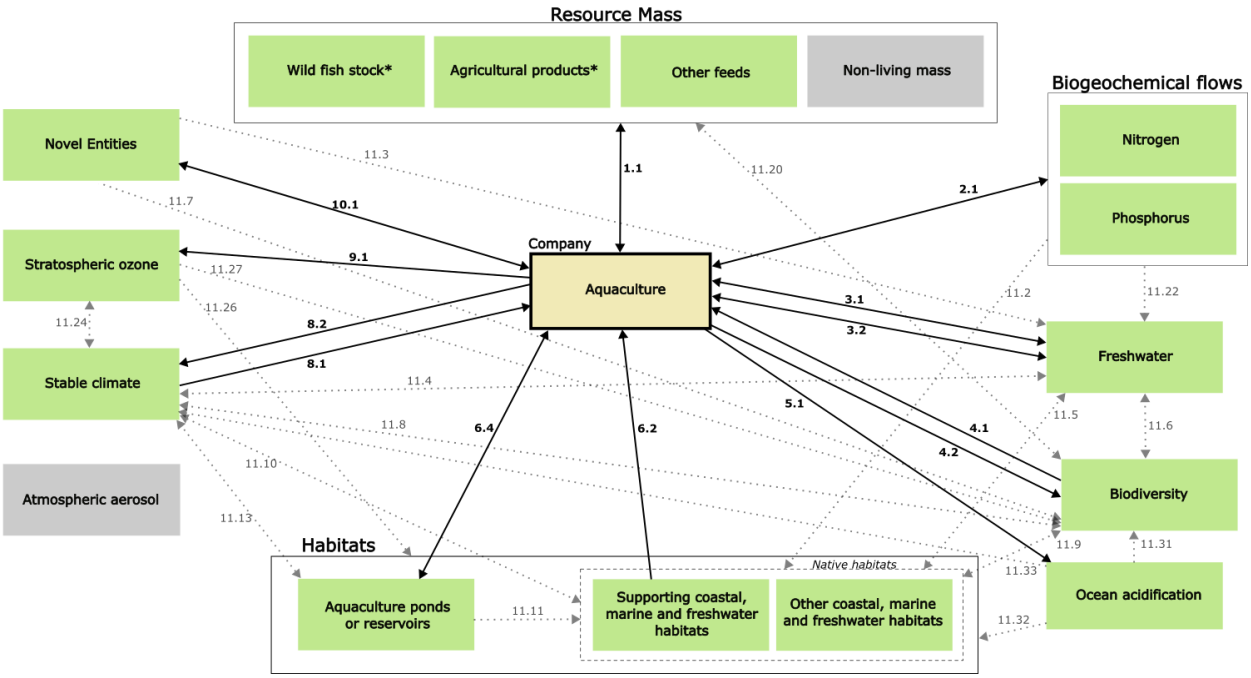

Figure 1. Conceptual systems diagram showing potential interactions between a company (yellow box) and various environmental dimensions. Dimensions are based on processes captured by the planetary boundaries framework, with the addition of natural resources. Solid lines represent direct impacts and/or dependencies of the company on various environmental dimensions. Dashed lines represent interactions between environmental dimensions. Viewed together, solid, and dashed lines represent the indirect impacts and dependencies of the company. Numbers refer to Tables 2 and 3 in this document. Boxes are shaded depending on if mechanistic links (i.e. arrows) are present (green) or not (grey).

Table 1. Direct environmental impacts and dependencies of aquaculture sector, shown as solid lines in figure 2. Links between a company operating in this industry, and the different environmental dimensions, are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

No.	Category	Sub-category	Impact, Dependency or Both	Description of Mechanisms	References
1.1	Resource mass	Living biomass	Both	Use of living biomass as inputs. Feed includes agricultural products, wild-caught fish, re-circulated farmed fish, fish oil, or algae. Another input is wild-caught seed. Negative impacts include those of fishery and agricultural sectors.	1, 2, W
2.1	Biogeochemical flows	-	Both	Aquaculture production is dependent on biogeochemical flows. In addition, effluent discharge from fed aquaculture systems can cause nutrient pollution and disrupt biogeochemical cycles. The highest N and P emissions occur in farmed marine and diadromous fishes, milkfish and fed carp. Non-fed groups like seaweeds and bivalves and unfed, unfertilized finfish systems extract N and P, leading to negative emissions. Impacts on biogeochemical cycling and habitats are context-dependent, e.g. whether the environment is nutrient-rich or nutrient-poor.	3
3.1	Freshwater	-	Both	Freshwater aquaculture production uses surface and groundwater. In some systems, on-farm evaporative losses account for over 60% of water use for freshwater species (with the rest mainly feed production, captured in 'feed'). (Note that unfed mariculture requires little to no freshwater.) Construction of channels for water supply and drainage, pumping of brackish waters inland results in hydrological changes and deterioration of water quality. Brackish water seeps from aquaculture ponds into groundwater supplies, diminishing water quality with flow-on effects to other habitats (e.g. rice paddies, mangroves). Industrial aquaculture systems use a lot of groundwater, with negative impacts on groundwater, e.g. in China and Southeast Asia.	1, 2, 3, W
3.2	Freshwater	-	Both	Dependency of freshwater aquaculture production on good water quality. Fish processing could have positive or negative effects on water quality, e.g. filter feeding fish can improve water quality. However, wastes can diminish water quality, including nutrients and disease.	1, W

4.1	Biodiversity	-	Dependency	Dependencies based on biodiversity, e.g. genetic material, bioremediation	1
4.2	Biodiversity	-	Impact	Impacts on biodiversity, e.g. negative interactions with mammals, turtles and birds, disease and parasite spread, by-catch from fishing, invasive species introductions	1, 4, 3
5.1	Ocean acidification	-	Impact	Emissions of CO_2 from aquaculture production increase the acidity of surface seawater	5
6.2	Habitats	Supporting habitats	Dependency	Dependencies on supporting habitats, e.g. filtration, buffering and erosion control, and flood and storm protection.	1
6.4	Habitats	Appropriated habitats	Both	Use of space for ponds, reservoirs. This leads to major negative impacts on freshwater, coastal and marine habitats, e.g. clearing of mangroves	1
8.1	Stable climate	-	Dependency	Climate regulation, e.g. currents, winds, temperatures, humidity	1
8.2	Stable climate	-	Impact	GHG emissions e.g. methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). One mechanism is through energy use and depends on consumption and emissions intensity of energy. Microbial nitrification and denitrification in aquaculture systems releases N_2O, a powerful greenhouse gas.	6, 7
9.1	Stratospheric ozone	-	Impact	Microbial nitrification and denitrification in aquaculture systems releases N_2O, which is the dominant ozone-depleting substance emitted in the 21st century. It decomposes in the stratosphere to form nitrogen oxides (NO_x), which catalyze ozone destruction.	7, 24
10.1	Novel entities	-	Both	Inputs and releases of novel entities, e.g. genetically modified organisms are an input that can become genetic pollution due to escapes. A large number of chemicals are used in aquaculture, such as hormones, pesticides, anaesthetics, disinfectants and feed additives present in effluent discharge. Heavy metals enter the marine environment from antifoulant paints or as constituents of fish food, including copper, zinc, iron, manganese and others. Metals can bioaccumulate in the organisms, leading to food safety problems and affecting the company itself. Plastic and microplastic pollution is another source of pollution from gear. Microplastics also pose a risk to open aquaculture systems, especially filter feeders.	8, 9, 10, W

Table 2. Interactions between environmental processes relevant to aquaculture sector, shown as dashed lines in figure 1. Links are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

No.	Categories	Description of Mechanisms	References
11.2	Biogeochemical flows, Habitats (Native)	Nutrient emissions cause marine and freshwater eutrophication, e.g. due to feed waste	3, 11
11.3	Freshwater, Novel entities	Novel entities may increase toxicity in freshwater systems. Disinfectants and pesticides are some of the most hazardous compounds due to their high toxicity to non-target organisms and/or potential for bioaccumulation, potentially affecting functioning of adjacent ecosystems.	12
11.4	Freshwater, Stable climate	Interactions between climate and hydrological cycle. Climate change has driven detectable changes in the global water cycle, including intensification of both heavy precipitation events and droughts, when those occur.	13
11.5	Freshwater, Habitats (Native habitats)	Interactions between native habitats and water cycle and quality, e.g. Pumping groundwater to ponds, or brackish waters inland, causes hydrological changes and can lead to siltation and saltwater intrusion of habitats such as rice paddies and mangroves.	2
11.6	Freshwater, Biodiversity	Mutual interactions between hydrologic services and biodiversity. Sufficient water flow beneficial for proper ecosystem functioning, e.g. positive impact on spawning and breeding grounds, satisfactory diadromous fish migration. Plant roots and microbial communities provide phyto- and bioremediation, removing particles, pathogens, nutrients and chemicals from water and improving water quality.	14, 15
11.7	Biodiversity, Novel entities	Impact of novel entities on biodiversity, e.g. genetic pollution from escapes, and pesticides have toxic effects on non-target species and ecosystem function	8, 12
11.8	Biodiversity, Stable climate	Climate change and biodiversity loss are mutually reinforcing; resolving either issue requires consideration of the other, e.g. climate change increasingly alters ecosystems and organisms, and is a key driver of biodiversity loss.	16
11.9	Biodiversity, Habitats (Native)	Interactions between native habitats and biodiversity, e.g. spatial patterns of fish biodiversity is strongly associated with forest cover in some rivers. Conversion of primary old-growth forests to secondary habitats may cause loss of multiple animal-mediated ecosystem services. Predation on salmon by bears is an important ecosystem process and can determine nutrient cycling through terrestrial or aquatic pathways.	17, 18, 19

11.10	Habitats (Native), Stable climate	Interactions between native habitats and climate regulation, e.g. sufficient native habitat in critical carbon-rich ecosystems would provide substantial benefits for climate mitigation.	16
11.11	Habitats (Appropriated), Habitats (Native)	Creation of ponds or reservoirs leads to negative impacts on coastal and marine habitats, e.g. destruction of mangroves and wetlands in construction of aquaculture ponds, aquaculture can cause conversion of cropland leading to salinization of soil and water	2, 20
11.13	Habitats (Appropriated), Stable climate	Interactions between appropriated habitats and climate regulation, e.g. climate regulation provides favourable conditions for aquaculture ponds and reservoirs. Estimated hazards for freshwater aquaculture under a high-emissions scenario are 'high' or 'very high'. Fed marine and brackish aquaculture also face risks from sea level rise and cycles.	21
11.20	Living biomass, Biodiversity	Interactions between living biomass and biodiversity – extraction of biomass affects ecosystem structure and function. These are largely captured within the diagrams for other sectors (Fisheries, Agriculture); in addition, extraction of wild algae could also have an impact on marine ecosystems, including changes in primary production, habitat disruption, fragmentation, food-web alterations, bycatch of non-target species.	22
11.22	Biogeochemical flows, Freshwater	Flows of biogeochemical effluents pollute freshwater resources, degrading water quality, e.g. effluents from fish farming pollute water bodies	8, 11
11.24	Stable climate, Stratospheric ozone	Complex interactions between GHGs and ozone-depleting substances. Some substances, like N_2O, are both GHGs and ozone-depleting substances. However, other GHGs reduce the effectiveness of N_2O in destroying ozone (CO_2, CH_4).	23, 24
11.26	Stratospheric ozone, Habitats	Stratospheric ozone depletion leads to increased solar UVB radiation, causing DNA damage in plants	25
11.27	Stratospheric ozone, Biodiversity	Stratospheric ozone depletion leads to increased solar UVB radiation, causing DNA damage in fauna, such as marine Antarctic organisms.	26
11.31	Ocean acidification, Biodiversity	Many marine organisms are highly sensitive to changes to ocean CO_2 chemistry, especially those using carbonate ions to form calcium carbonate shells or structures. Ocean acidification could be deleterious to such organisms, which would constitute a major disturbance to marine ecosystems with highly uncertain impacts. Marine plankton are also vulnerable.	5

11.32	Ocean acidification, Habitats (Coastal, marine and freshwater)	Ocean acidification may have serious impacts on coral and other reef communities.	5
11.33	Ocean acidification, Climate	Oceans remove a large proportion of anthropogenic CO_2, but acidification threatens the ability of oceans to continue to function as a carbon sink.	5

References

1. Natural Capital Finance Alliance, ENCORE (Exploring Natural Capital Opportunities, Risks and Exposure), https://encore.naturalcapital.finance/en (2022).
2. Páez-Osuna, F. The Environmental Impact of Shrimp Aquaculture: Causes, Effects, and Mitigating Alternatives. *Environ Manage* **28**, 131–140 (2001).
3. Gephart, J. A. *et al*. Environmental performance of blue foods. *Nature* **597**, 360–365 (2021).
4. Tacon, A. G. J., Metian, M., Turchini, G. M. & De Silva, S. S. Responsible Aquaculture and Trophic Level Implications to Global Fish Supply. *Rev Fish Sci* **18**, 94–105 (2009).
5. Rockström, J. *et al.* Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecol Soc* **14**, (2009).
6. Yuan, J. *et al*. Rapid growth in greenhouse gas emissions from the adoption of industrial-scale aquaculture. *Nat Clim Chang* **9**, 318–322 (2019).
7. Hu, Z., Lee, J. W., Chandran, K., Kim, S. & Khanal, S. K. Nitrous Oxide (N_2O) Emission from Aquaculture: A Review. *Environ Sci Technol* **46**, 6470–6480 (2012).
8. Diana, J. S. Aquaculture Production and Biodiversity Conservation. *BioScience* **59**, 27–38 (2009).
9. Burridge, L., Weis, J. S., Cabello, F., Pizarro, J. & Bostick, K. Chemical use in salmon aquaculture: A review of current practices and possible environmental effects. *Aquaculture* **306**, 7–23 (2010).
10. Liang, P. *et al.* Role of mariculture in the loading and speciation of mercury at the coast of the East China Sea. *Environ Pollut* **218**, 1037–1044 (2016).
11. Islam, Md. S. Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis towards model development. *Mar Pollut Bull* **50**, 48–61 (2005).
12. Rico, A. *et al.* Use of chemicals and biological products in Asian aquaculture and their potential environmental risks: a critical review. *Rev Aquacult* **4**, 75–93 (2012).
13. Douville, H. *et al.* Water Cycle Changes. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V. et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1055–1210, doi:10.1017/9781009157896.010 (2021).
14. Brauman, K. A., Daily, G. C., Duarte, T. K. & Mooney, H. A. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annu Rev Environ Resour* **32**, 67–98 (2007).
15. Rytwinski, T., Taylor, J. J., Bennett, J. R., Smokorowski, K. E. & Cooke, S. J. What are the impacts of flow regime changes on fish productivity in temperate regions? A systematic map protocol. *Environ Evid* **6**, 13 (2017).
16. Pörtner, H. O. *et al.* Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change, IPBES secretariat, Bonn, Germany, doi:10.5281/zenodo.4659158 (2021).

17. Arantes, C. C. *et al.* Relationships between forest cover and fish diversity in the Amazon River floodplain. *J Appl Ecol* **55**, 386–395 (2018).

18. Albrecht, J. *et al.* Correlated loss of ecosystem services in coupled mutualistic networks. *Nat Commun* **5**, 3810 (2014).

19. Quinn, T. P., Carlson, S. M., Gende, S. M. & Rich, Jr., H. B. Transportation of Pacific salmon carcasses from streams to riparian forests by bears. *Can J Zool* **87**, 195–203 (2009).

20. Primavera, J. H., Asian, S. & Development, F. Socio-economic impacts of shrimp culture. *Aquac Res* 815–827 (1997).

21. Tigchelaar, M. *et al.* Compound climate risks threaten aquatic food system benefits. *Nat Food* **2**, 673–682 (2021).

22. Lotze, H. K., Milewski, I., Fast, J., Kay, L. & Worm, B. Ecosystem-based management of seaweed harvesting. *Bot Mar* **62**, 395–409 (2019).

23. Revell, L. E., Tummon, F., Salawitch, R. J., Stenke, A. & Peter, T. The changing ozone depletion potential of N_2O in a future climate. *Geophys Res Lett* **42**, 10,047-10,055 (2015).

24. Ravishankara, A. R., Daniel, J. S. & Portmann, R. W. Nitrous Oxide (N_20): The Dominant Ozone-Depleting Substance Emitted in the 21st Century. *Science* 326, 123–125 (2009).

25. Rousseaux, M. C. et al. Ozone depletion and UVB radiation: Impact on plant DNA damage in southern South America. *PNAS* **96**, 15310–15315 (1999).

26. Weiler, S. & Penhale, P. Ultraviolet Radiation in Antarctica: Measurements and Biological Effects, Volume 62. vol. 62 (American Geophysical Union, 1994).

ELICITATION RECORD – Part 1

The Workshop Context

Elicitation title	Essential Environmental Impact Variables
Workshop	Aquaculture
Date	11 November 2022
Part 1 start time	9:00

Attendance and roles	Facilitator, Note taker, Experts 1, 2, 3, and 4
Purpose of elicitation	1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables. 2. Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
This record	Participants are aware that this elicitation will be conducted using an adapted Sheffield Elicitation Framework, and that this document, including attachments, will form a record of the session.
Orientation and training	Participants received a pre-workshop participant brief.
Participants' expertise	Expert 1 *Expertise:* Sustainability of aquaculture and fisheries. Working more local scale. Expert 2 *Expertise:* PhD focused on eco certifications for aquaculture and fisheries. Both production and consumption side. More recent interest in mid-value chain actors and corporations and how they use sustainability information. Broad view on systems. Additional in-depth fieldwork expertise. Shrimp systems in Southeast Asia. Has known expert 1 for many years.

	Expert 3 *Expertise:* Based in Shanghai, sustainable development of aquaculture systems. China is biggest producer of aquaculture - 60% of global. Expertise covers a lot of different aquaculture farming systems and their different environmental impacts. Expert 4 *Expertise:* Works with LCA but also modelling, environmental assessment of aquaculture, also aquaculture trade. On advisory board for different carbon footprint tools. Experts 3 and 4 did their PhD in the same project.
Declarations of interests	No competing interests
Strengths and weaknesses	Expert 1 *Strengths*: All different farmed systems. Both environmental and how it links to people. Social aspects. Expert 2 *Strengths:* Food systems, eco certification for aquaculture and fisheries, mid-value chain actors and corporations, systems, fieldwork especially shrimp systems in Southeast Asia. Broad perspective *Weaknesses:* Not a core expert in aquaculture systems and impact categories Expert 3 *Strengths:* China, environmental impacts of various farming systems Expert 4 *Strengths:* LCA and modelling, environmental assessment of aquaculture. Trade. Industry considerations. Carbon footprint tools.
Evidence	*Clarifying question asked:* (Expert 1) • I agree with the purpose and need to formalise how you report sustainability, not for corporations to pick what they want to report • First comment: how do you define environmental impact? What we have identified is more like 'potential' environmental impact. More like stressors that could lead to

	impact. Greenhouse gas emissions are not impact in itself, they will cause impacts in future. Same as waste. And depends what type and where. • You say 'indirect impact' but maybe it is a stressor with potential to cause impact. This is important to clarify. • Environmental and potential impacts of resource use. Difficult to stay in silo without connecting to people. Question is how it'll be used. Together with other indicators? Or should everything related to aquaculture be in the end product? Also including the social aspect? You always land in interlinked system. Difficult to put environmental glasses and stay there. You should not stop there. • Final comment: you can go to different initiatives where they try to identify what they consider important for aquaculture. You land same place- ASC, Monterey. The core ones are there. But you can't make general for aquaculture. Systems are so different you'll have discussion for each type. ASC has done it, for each system. If you aim for general list for indicators and some kind of benchmark, it will be very difficult because diversity so great. *Answer:* (Facilitator) • What you call potential for impact is what we call impact, acknowledging that it depends on location and whether well-managed. The fact that there could be impact if not well managed. Those things that could never cause impact will be excluded. • The importance of location and context specificity – we will push that because we see in all sectors. In contrast to disclosure work done by corporations – broad numbers on a company level. One of the main things from our work is that doesn't make any sense to have one number at HQ level, you need to know the specific locations. We can come back to it. • Social – of course, always intertwined. But we drew the line for 3 reasons. One is practical - need some limits to what we're doing. Two – to capture full breadth of social side, need many more experts and we (the author/coordinating team) are not as strong (in expertise) in this area of impacts. Three – in the TNFD there is a focus on the E in ESG. Realisation to do more than climate, so our work aims to broaden that, but not just add a few things that are easy. • Diversity – this is interesting. I would like to get out of discussion later to see – is it possible to have the same

	impact categories across aquaculture systems? Would like to gain insight. *Clarifying question asked:* (Expert 2) Are indicators for reporting the end goal of this workshop? *Answer:* (Facilitator) • For this workshop, no. From this workshop we want a good idea of what the impacts are, systems perspective, including prioritisation. Afterwards, we will distil what is reportable. Input would be useful but don't want to fall into trap of feasibility. That's where the other processes are going. Opened in paper that there might be placeholder variables where we know it's not feasible at the moment but needs to be considered because it is important. *Clarifying comments* (Expert 1): • In the beginning [of the participation brief] you do not discuss feed. It comes back in diagram in resources. It is important to ask if you are sourcing in sustainable ways. • Important: are we using these resources in an equitable way? This is as important or more important than sustainable way. We are moving toward equity in the conversation. • Carbon so much in focus – if you have ambition to report on GHG in general, you can develop systems so low in emissions because connected to energy grids. But miss property of system. Could be a huge energy consumer but 'fix' it by different things. We have finite resources and energy production, a ceiling. *Answer* (Facilitator): • To clarify on feed – we can discuss. But we have other workshops for mapping the impacts from feed production, we don't have to go into e.g. emissions from fishing boat. <u>Expert 1:</u> • Feed is the biggest question for aquaculture development. If you leave it out, you leave out impact on nutrients and carbon. <u>Facilitator:</u>

	• Let's come back to it *Clarifying question asked:* (Expert 2) • DPSIR – alternative way to frame it? We are maybe discussing pressures. Useful way to categorise. • Expert 1: If you stop at identifying stressors, then you need to know where it is, need to know about the system. Need to also know about status. *Clarifying question asked:* (Expert 3) • Title is impact variables. But I think it is about indicators. We had similar project to develop sustainable consumption indicators. All these variables are part of indicators. • Environment not enough – need to consider social, economic. Like food safety is important for many consumers. Safety more important than environment. • Just farming sector or whole value chain? Many more impacts. Fishmeal: not a key issue. Fresh fish more damaging than fishmeal. The latter from South America. To transport pelagic fish – don't want subsidies for consumption in other parts of world. Direct and indirect impact in table – water, resources. Both have freshwater use, biodiversity. Maybe we could have one table and have direct and indirect together. *Response* (Facilitator): • Feed will be an important discussion point, let's come back to it. Social – it is important. Full value chain. We understand it is very big, but didn't seem feasible to do everything in one project, boundaries somewhere. • Expert 3: Direct impacts? • Facilitator: More from the production. We are starting here, final product will be influenced by production. • Expert 4: Of course we have variable production systems. Not all depend on feeds. • On biodiversity, used in a complicated way. We use a few indicators, but all these will impact biodiversity. Almost like a higher and more overarching problem of the other impacts. • Expert 1: Comment by Expert 3 is important – where to put boundary and value chain. Say upstream. If you talk of feed. GHG impacts, mainly from feed. Freshwater impacts, mainly from feed. Such an important aspect. Expert 4 mentioned

	that some don't use feed. Then, what is the end product from nutritional perspective. Compare output. Is it nutritionally rich? • Facilitator: Feed may be one of the greatest ones. That's something that can come out of the workshop. • Expert 1: compared to fishery discussion. There it might be easier to identify direct impacts. Aquaculture is about agriculture, fishery, and its own thing. Makes it more difficult to identify what is at forefront. • Expert 3: Maybe we can think about major inputs and outputs of these production systems? And impacts from those. *Clarifying question* (Expert 1): • Have you searched for different types of reporting for companies? Like the Fair initiative? How they focused on various sustainability domains. How does it look today, and then what do we need for version 2. • Also intro text is about the PBs. How is it considered today, how should it be considered in future? Aquaculture will not impact the boundaries at global scale. But more regional, local. Much like many other. PB more like framework to identify important aspects. *Response* (Facilitator): • Facilitator: Have looked at some of these initiatives. Some are very sector specific. But one of the reasons the standardisation is happening is that companies are overwhelmed and don't know how to navigate so many different ones. • Expert 1: We heard Norwegian salmon farmers say they are the most sustainable food system in world. Due to carbon footprint. And not sourcing soy from Brazil and unsustainable fish in feed. • Facilitator : Exactly the point – certain indicators/ways of reporting that will be set in motion. Things will tell us little. Also relative numbers – impossible to compare. • Expert 1: Agree. On the diversity of systems and difference Asia and west. The use of trash fish. Asia is so big needs to be included. The frameworks are European and don't mention trash fish. You want to influence farmers in both West and East.

	• Expert 4: Then you would need certification. Also, when you work with companies, people are convinced that they are doing the right thing. People get so caught up with what they're doing good, forget what they're doing bad. Abalone farm had a closed life cycle. We did LCA, they used a lot of coal power that was horrible. Every farm has its issue. • Expert 1: You said you've been doing review. We want to know about what is being suggested to report. • Facilitator: But where I want to start: what can be the impacts. Often path dependency and based on feasibility, want to go away from, think outside the box. Then later can see if it matches. But if doesn't match, should highlight what was missed. Danger of that route. • Expert 2: good approach. Would be good to see afterwards. *Clarifying question* (Expert 2): • With reporting, who is main recipient? General public, financers, companies? *Response* (Facilitator): • Now, sustainability reporting is voluntary, bias toward bigger companies. Resources and pressure. Push for standardisation and to make mandatory. The hope it will become more like financial report – comparable. As part of annual report, have to disclose environmental aspects. For investors, who don't know how to invest sustainably. • Expert 2: Is there any process more from EU level? • Facilitator: That is happening. • Expert 1: EU is seeking to push for these lights to indicate (traffic light idea). • Note taker: There are a number of EU regulations coming into play. *Clarifying questions* • Expert 2: Are we supposed to be coloured by the discussion in our elicitation? • Facilitator: Do say what you want to say • Expert 2: Might change, not because of pressure, more learning.

	• Facilitator: Say what you thought initially then we can change later. • Expert 3: Maybe we can identify the different systems and combine together – ponds, which is partially closed, open water (there are three). Extractive – molluscs. • Facilitator: from my point of view what would be useful is, when you look at the diagram and tables, identify which systems it is relevant to. Relates to Expert 1's points as to whether we can have general ones. • Expert 3: The differences are major. Mainly open or closed water systems. • Expert 2: Looking at box figure. The numbers skip, boxes grey, asterisks. • Facilitator and note taker: Relates to other sectors and whole project. Wanted to avoid duplication. • Expert 4: Reflecting on categories. They are quantifiable. We are better at quantifying things. Easier to report. E.g. Biodiversity more complicated. Might be things very relevant we don't see because not quantifying. Also issue with planetary boundaries. • Facilitator: Good point and relates to feasibility. Don't be limited by quantifiable nature, still bring up. • Expert 4: Tendency corporations, decision makers, to want everything to be quantifiable. Easier decision making. Worker wellbeing. But should we quantify? • Facilitator: There will be some variables we come up with that will be more descriptive. E.g. for Fisheries, gear type. Here it might be something that is 'type of system', such as Expert 3 mentioned. • Expert 4: Companies don't give us information we need • Facilitator: Want to limit additional calculations companies do, that create black box, don't know methods. More about 'what are you doing', translation is for other entities. Might be more important: where, inputs, outputs, what are you doing. Rather than 'put 4 species at risk'. • Expert 1: What you describe now, companies. What they do/don't do. Economically – dig deep to find out different costs. Should do for environmental externalities. But don't to spend energy, money on environment. How they function. Capture fisheries – if you can link method/gear type to environmental pressures/impacts. That is one level. E.g. trawling – you can say detrimental. But difference if trawled 100 years. As you say in the text the context is so important. Farm reporting land use where building new hatcheries,

	allocating land. Depending on if they use native forest vs. junkyard, very different. • Finally on the difference between systems. Relating to non-living mass. The benefits of one being low in infrastructure (mussels, seaweed) vs. other on land with cement. The benefits of being low in that dependency. On wild fish stock – the fish used as a resource, it is from farming itself re-circulated. You have algae there, but very minor right now.
Structuring	The variables were not elaborated or rephrased at this stage.
Definitions	1. Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured. 2. Assessment of which are the *greatest* impacts on nature, meaning that impacts have either 1) a large globally cumulative impact, or 2) impacts are more locally incurred but are the largest for individual firms.

Part 1 end time	10.12
Attachments	

ELICITATION RECORD – Part 2: Outcome 1

Eliciting Expert Knowledge on Qualitative Outcomes

Elicitation title	Essential Environmental Impact Variables
Workshop	Aquaculture
Date	11 November 2022
Outcome	1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables. Specify if any impacts are missed, should be rewritten/rephrased or removed.
Anonymity	Experts are identified as Experts 1, 2, 3 and 4 (aligned across all elicitation records).
Start time	9:00

Definition	Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured.
Evidence	A participant brief was provided in advance, containing a background review and evidence.
Individual elicitation	**Missed –** <u>Expert 1:</u> Non-living mass – benefits of one system being low in infrastructure (mussels, seaweed), vs. the other on land with cement On resource mass, you should have a perspective on by-products, because we could better utilise by-products, which is important due to trade-offs. <u>Expert 2:</u> Groundwater use – in China and Southeast Asia, some systems use a lot of groundwater – industrial systems. This is very bad for groundwater. Fish processing byproducts, which can have positive effects. Filter feeding fish, silver carp in lakes and rivers can improve water quality

	Plastic and microplastic causes pollution is a major impact of aquaculture facilities on sea, from gear <u>Expert 2:</u> Resource use - would like to add consideration of how much food is produced. [Out of scope.] **Rewritten/rephrased –** <u>Expert 1:</u> On wild fish stock – actually the fish used as feed resource can be from farming itself re-circulated now. You include algae but it is very minor right now as feed You have GHG emissions, but I would put energy consumption per se. It should be captured if you need a large amount of energy to run a system. Disagreed with inclusion of 'supporting functions' in this exercise. Note that supporting habitats are very system-specific. Biogeochemical flows should have both impacts and dependencies Freshwater is really context dependent. For some, evaporation is a strong force. But a lot of the freshwater impact comes from feed. Some systems might use freshwater, but not cause an impact because they release it back out (Brackish water). Note that waste should include nutrients, carbon, disease, antibiotics. <u>Expert 4:</u> Novel Entities can be anything. Toxicity is important for many aquaculture systems, might want to highlight more specifically. Antibiotic use and resistance is a threat to human health and wellbeing. Are we including human health? If so, there are more impacts. Invasive species are important as one of 5 underlying drivers of biodiversity loss in Millennium Ecosystem report

	Note that the use of chemicals is about preventing disease, but there is diversity in phyla regarding immune responses. A shrimp can't be vaccinated, so you need antibiotics or clean water. <u>Expert 2:</u> There is not a double arrow between aquaculture and biogeochemical flows, suppose it is because water quality captured in freshwater box. But production systems could have a massive leakage of nutrients. Consider a double arrow there. Microplastics a stressor impacting open aquaculture systems, especially filter feeders. Feed includes fish oil **Removed –** None
Matches/ Mismatches	Agreement between Expert 1 and Expert 2 to have double arrow between aquaculture and biogeochemical flows Several refinements on different types of feed that should be included or de-prioritised. Expert 1 and Expert 3 both highlighted by-products. Disagreement on whether plastics are an impact, dependency or both (Experts 1,2 and 3). Other points were raised by individuals and the others did not disagree (e.g. Expert 1 raised infrastructure need and cement use for land-based systems).
Group discussion	On plastics, Expert 3 said that plastic and microplastic is a major impact of the sector. Expert 2 disagreed and said the increased abundance of them was more of a stressor impacting aquaculture systems, especially open systems and filter feeders. As there are uncertain effects on human health, this is more of an impact on the sector. Expert 1 agreed with Expert 2 that it could be a threat but argued we should not consider dependencies as it is too complicated for footprint thinking.

	On disease, Expert 4 mentioned that chemicals and antibiotics are a response to disease. Expert 1 added that the disease issue depends on the system, and it has an impact on the wild. However, we don't know much about it, so it is a sleeping concern. On waste, Expert 1 said that waste is interesting because it relates to habitats. It includes nutrients, carbon, disease, antibiotics. Expert 2 said it was an interesting way to group those things, and includes a lot. It also includes invasive species. Expert 4 and Expert 2 focused on biosecurity / invasive species. Examples: Tilapia introduced through wastewater. Salmon on the West coast of the US and concerns it will become endemic. Movement of shrimp larvae. Disease introduced to many regions. Expert 1 added example of parasites (sea lice), and that there are many unknowns. Facilitator suggested all this relates to the movement of species. Expert 4 agreed and clarified that it relates to disease, biosecurity and genetic pollution. Expert 2 mentioned indicators will be difficult. Facilitator suggested it relates to location of species. Agreement from Expert 1.
Group elicitation	Missed or rephrased – see above as mentioned by individual experts Removed – none
Chosen outcome	See above
Discussion	Discussion was raised about planetary boundary framing, and system boundaries, e.g. whole value chain and social factors were seen as important. Social factors include food safety, human health (antibiotic resistance more social than environmental), development needs, equity considerations. Strong emphasis on importance of context and diversity of systems. Discussion around measurability and whether only quantifiable indicators are captured. Bigger issues relating to food systems – what is the nature of the food source (nutritionally), is the resource being shared equitably, what is the comparison with meat and plant-based products? (e.g. we should not feed food-grade inputs to fish)

End time	12:08
Attachments	

ELICITATION RECORD – Part 2: Outcome 2

Eliciting Expert Knowledge on Qualitative Outcomes

Elicitation title	Essential Environmental Impact Variables
Workshop	Aquaculture
Date	11 November 2022
Outcome	2. Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
Anonymity	Experts are identified as Experts 1, 2, 3 and 4 (aligned across all elicitation records).
Start time	9:00

Definition	Assessment of which are the *greatest* impacts on nature, meaning that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
Evidence	A participant brief was provided in advance, containing a background review and evidence.
Individual elicitation	<u>Expert 4:</u> For intensive systems: wild fish stocks through fishmeal, and agricultural products. For extensive systems: habitats, requiring land for farming or water area <u>Expert 3:</u> Feed is the most important source of environmental impacts Plastic and microplastic pollution a major impact of aquaculture facilities on the sea

	<u>Expert 2:</u> Feed, for the reasons mentioned by the others. LCA shows it is the main contributor across impact categories, including biodiversity. Resource use - would like to add consideration of how much food is produced. [Out of scope.] Habitat alteration – using ecologically important areas for aquaculture, especially in Asia but everywhere. Brackish water problematic. Mangrove and previously deforested areas. Expanding into ocean probably less problematic, but uncertain impacts. Possibly leakage and invasive species, but uncertain whether greatest. <u>Expert 1:</u> Feed – many interactions linked to feed Habitats (including through feed) Effluents – organic particulate matter, antibiotics, invasive species. (Also said: waste includes nutrients, carbon, disease, antibiotics.) What is not important: algae as a feed, parasites (e.g. sea lice) is an impact but not a key one. Lots of unknowns.
Matches/ Mismatches	Unanimous agreement on importance of feed. Wide agreement on habitats and waste (broad category).
Group discussion	On waste, Expert 1 said that waste is interesting because it relates to habitats. It includes nutrients, carbon, disease, antibiotics. Expert 2 said it was an interesting way to group those things and includes a lot. It also includes invasive species. Expert 3 and Expert 4 agreed that waste is as important as habitats and feed.
Group elicitation	**Feed** Due to high impact of fed production. **Habitats** For non-fed production, very important. Also one of the biggest impacts in some areas/species (e.g. shrimp and mangroves). **Waste** Wide definition to include effluents, chemicals, antibiotics and species movements (invasive but also movement of native between

	places). Connected to disease and 'novel entities'. Also impacts habitats.
Chosen outcome	See above.
Discussion	

End time	12:08
Attachments	