EFEITO DA ILUMINAÇÃO NO CRESCIMENTO E COMPORTAMENTO DE DUAS ESPÉCIES DE PEIXE CARPA (*CARASSIUS GIBELIO* E *C. CARASSIUS*)EFFECT OF ILLUMINATION ON GROWTH AND BEHAVIOR OF TWO CARP FISH SPECIES (*CARASSIUS GIBELIO* AND *C. CARASSIUS*)ВЛИЯНИЕ ОСВЕЩЕННОСТИ НА РОСТ И ПОВЕДЕНИЕ ДВУХ ВИДОВ КАРПОВЫХ РЫБ (*CARASSIUS GIBELIO* AND *C. CARASSIUS*)

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RESUMO

A luz é um dos fatores ambientais mais importantes que influenciam muitas reações fisiológicas, bioquímicas e comportamentais dos organismos aquáticos. Neste trabalho, experimentos foram conduzidos para estudar como a iluminação influencia no crescimento de juvenis de duas espécies de peixes carpa (*Carassius gibelio* e *Carassius carassius*). Os experimentos foram realizados em aquários e bandejas de gradiente de luz foram utilizadas para controlar a luminosidade. Aproximadamente 20 a 25 peixes foram colocados em cada aquário, 3 a 4 indivíduos foram colocados em bandejas. Os peixes foram alimentados à saturação três vezes ao dia. Tipos ideais de iluminação foram identificados para o crescimento de ambas as espécies. Entre 200 a 930 lx é a iluminação ideal para o juvenil *Carassius gibelio*. E, 230 a 500 lx a iluminação é ideal para o juvenil *Carassius carassius*. Alta iluminação e escuridão total influenciaram negativamente o crescimento de ambas as espécies. Uma iluminação muito alta diminuiu consideravelmente a taxa de crescimento. Sobrevivência em todos os casos foi de 100%. A atividade motora do juvenil *Carassius gibelio* em gradiente de luz foi maior que na iluminação de equilíbrio. O número de movimentos de vetor, a distância média de movimento e o caminho total dos peixes no gradiente de luz excedem os valores correspondentes no controle na iluminação de balanceamento. Quando não havia comida, as zonas eleitas do juvenil *Carassius gibelio* foram deslocadas para uma iluminação mais alta. Quando a comida estava ausente por meia hora, os juvenis optaram por uma zona com a iluminação de 600 lux (o tempo total de permanência foi de 15,8 minutos por 1 h). Quando faltaram duas horas, os juvenis escolheram uma zona com iluminação de 1000 lux (17,3 minutos), e quando esta se ausentou por 24 horas, os juvenis escolheram uma zona com a iluminação de 1000-1200 lux (28,5 minutos). O estudo discutiu o efeito da luz no crescimento, e no comportamento de duas espécies de peixes.

Palavras-chave: Luz, iluminação, *Carassius gibelio*, *Carassius carassius*, crescimento, comportamento, atividade motora.

ABSTRACT

Light is one of the most important environmental factors that influence many physiological, biochemical and behavioral reactions of aquatic organisms. In this work, experiments were conducted to study how illumination influences on the growth of juveniles of two carp fish species (*Carassius gibelio* and *Carassius carassius*). In this work, experiments. The experiments were carried out in aquariums and trays with a light gradient. Twenty-five fish were placed in each aquarium, three-four individuals were placed in trays. Fish were fed to saturation three times a day. Optimal types of illumination were identified for the growth of both species. 200–930 lx is optimal for juvenile *Carassius gibelio*. 230–500 lx is optimal for juvenile *Carassius carassius*. High illumination and total darkness negatively influenced the growth of both species. Very high illumination considerably slowed the growth rate. Survival in all cases was at 100%. Motor activity of juvenile *Carassius gibelio* in light-gradient conditions was higher than in balancing illumination. The number of vector movements, the average distance of movement and the total path of fish in the light gradient exceed the corresponding values in control in balancing illumination. When there was no food, the elected zones of the juvenile *Carassius gibelio* were shifted toward higher illumination. When the food was absent for half an hour, the juveniles chose a zone with the illumination of 600 lux (total time of stay was 15.8 minutes for 1 h). When it

was absent for two hours, the juveniles chose a zone with the illumination of 1000 lux (17.3 minutes), and when it was absent for 24 hours, juveniles chose a zone with the illumination of 1000–1200 lux (28.5 minutes). The study discusses the effect of light on growth, the behavior of two species of fish.

Key words: *light, illumination, Carassius gibelio, Carassius carassius, growth, behavior, motor activity.*

АННОТАЦИЯ

Свет является одним из важнейших экологических факторов, которые воздействуют на многие физиологические, биохимические и поведенческие реакции гидробионтов. Провели эксперименты по изучению роста молоди двух видов карповых рыб (*Carassius gibelio* и *Carassius carassius*) под воздействием освещенности. Опыты проводили в аквариумах и светогradientных лотках. В каждый аквариум помещали по 20-25 рыб, в лотки – по 3-4 особи. Рыб кормили 3 раза в сутки до насыщения. Были выявлены оптимальные для роста видов диапазоны освещенности. Для молоди *Carassius gibelio* составлял 200–930 лк, для молоди *Carassius carassius* – 230–500 лк. Общим для обоих видов было достаточно негативное влияние как высокой освещенности, так и полной темноты для роста. При этом очень высокая освещенность также сильно снижала скорость роста. Выживаемость во всех случаях была на уровне 100%. Двигательная активность молоди *Carassius gibelio* в светогradientных условиях выше, чем при равномерной освещенности. Число векторных перемещений, средняя дальность перемещений и суммарный путь рыб превышает в светогradientе соответствующие значения в контроле при равномерном освещении. При отсутствии пищи избираемые зоны сеголеток *Carassius gibelio* смещались в сторону увеличения освещенности. При отсутствии корма в течение 0.5 часа молодь избирала зону с освещенностью 600 лк (суммарное время пребывания 15.8 мин за 1 ч), в течение 2 ч – 1000 лк (17.3 мин), в течение 24 ч – 1000–1200 лк (28.5 мин). Обсуждается влияние освещенности на рост, поведение двух видов рыб.

Ключевые слова: *свет, освещённость, Carassius gibelio, Carassius carassius, рост, поведение, двигательная активность*

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1. INTRODUCTION

According to researches by Boeuf & Le Bail (1999), Ruchin (2004, 2019b), Marchesan *et al.* (2005), Niven & Laughlin (2008), the light creates the necessary conditions for the existence of many aquatic organisms, gives them the opportunity to navigate the environment. Illumination among all abiotic factors varies in the most extensive limits. As Kuznetsov & Ruchin (2001), Bashinskiy *et al.* (2019) proved, it varies depending on the depth, on the qualities of the aquatic environment, on the location of the sun above the horizon, and on cloudiness conditions. This light and photoperiod are the natural backgrounds for most fish species. If it changes, behavioral and physiological reactions also change (Boeuf & Le Bail, 1999; Ruchin *et al.*, 2005; Ruchin, 2006, 2007; Villamizar *et al.*, 2011; Vowles & Kemp, 2012; Beier, 2017; Echevarría, González, 2018).

Growth processes are one of the main physiological fish indicators, which are sensitive to the slightest changes in a particular environmental factor. For example, a small water illumination is necessary for incubating caviar (Bucking *et al.*, 2013; Ruchin, 2016; Prokešová *et al.*, 2017), for rearing larvae and juvenile *Salmo salar*, *Acipenser baerii*, *Cyprinus carpio*, *Poecilia reticulata*, *Brachymystax lenok* (Wallace *et al.*, 1988; Ruchin, 2001b, 2008, 2019a; Liu *et al.*, 2012). Wallace *et al.*, (1988), Person-Le Ruyet *et al.* (1991), Jirsa *et al.* (2009), Aragón-Flores *et al.*, (2017) suppose that an increase in the growth rate of *Cichlasoma beani*, *Scophthalmus maximus*, *Atractoscion nobilis*, *Salvelinus alpinus* is observed at more significant illumination levels. The purpose of this study is to determine the growth and behavior of two crucians species (*Carassius gibelio* and *Carassius carassius*) under experimental conditions.

2. MATERIALS AND METHODS

We caught fish yearlings in natural waters. In advance, we had been acclimating the fish to laboratory conditions for 30 days (round-the-clock lighting and a constant temperature of 20°C). We placed 20-25 same size individuals in each experimental aquarium. At the same time, we carried out three identical series of experiments (fig 1A). We did not register the fish death during the experiment in any experimental aquarium. During the experiment, the juveniles were kept in 40 l aquariums with a controlled temperature of

20°C. The duration of the experiments was 20-30 days. We measured the fish weight at the end of the experiments with an accuracy of 1 mg.

Fluorescent lamps illuminated aquariums. They were placed at 50 cm from the water surface. They created light. We fed fish with live food (*Chironomus* sp. larvae, *Tubifex* sp.) to satiate three times a day.

Growth parameters were calculated as Equation 1:

$$\text{Specific growth rate (SGR, \%day}^{-1}\text{)} = \frac{[(\ln W_f - \ln W_i)/t] \times 100}{\text{Specific growth rate (SGR, \%day}^{-1}\text{)}} = \frac{[(\ln W_f - \ln W_i)/t] \times 100}{\text{(Eq. 1)}}$$

For experiments on the arbitrary choice of light intensity (light-reflecting behavior) by the juvenile *C. gibelio*, we used organic glass gradient trays 150*15*15 cm, divided by transparent semi-partitions into 10 communicating compartments. There was a light gradient from 300 lx at the beginning of the tray to 1200 lx at the end (fig. 1B). The illumination in the control group corresponded to the average value in the experimental tray (750 lx). We conducted observations in the morning at a temperature of 24°C. We placed there 3-4 fed yearlings weighing 10–14 g. We watched one fish for 10-20 min a day. The experiments were repeated 10 times. We also conducted research on well-fed and hungry individuals. We investigated the options: 1 - well-fed, 2, 3, and 4, respectively, 0.5, 2, and 24 hours after the food's withdrawal.

Based on statistical data processing, we calculated the average duration of a single fish stay in a particular compartment (τ , sec), the swims' number in each compartment (n) and the total time of fish stay in each compartment ($\sum \tau$, min). All values were reduced to one hour (Ruchin, 2001a). The swimming distance from the beginning of the movement to the turn in the opposite direction was called "single-vector" and was designated as S_v . We calculated the duration of the continuous single-vector displacement (τ_v , sec) because the motion in the gradient is discrete. Moreover, we noted the total number of single-vector displacements (N). Knowing their average length (S_v), we calculated the total path traversed by fish per hour as well as calculated the speed of movements (S_v / τ_v), the total time of movements and the total time of fish delays in the compartments. According to Konstantinov & Zdanovich (1993), the using of these indicators makes it possible to characterize the fish behavior in gradient conditions more differentiated.

Data between treatments and sampling times were compared by analysis of variance (ANOVA).

3. RESULTS AND DISCUSSION:

Figure 2 shows that the highest growth rate of juvenile *C. gibelio* was observed at a low illumination intensity of 200–930 lx. In the first experiment, juveniles' specific growth rate with an initial mass of 0.42g in the 200lx illumination was 8.37%. In the variant in 930 lx illumination, growth was slightly lower (statistically insignificant). However, when the illumination intensity increased to 5400 lx or decreased to 65 lx, the growth decreased (statistically significant ($p < 0.05$)). The low growth rate was recorded in the conditions of around the clock darkness (0 lx). We obtained similar results on larger specimens in other experiments. The high growth rate of *C. gibelio* was in the 800lx illumination. The lowest growth rate was in the absence of light or in very high light (99% confidence).

In experiments conducted on juvenile *C. carassius*, the growth rate was higher in 230–500 lx illumination. It decreased with decreasing or increasing light intensity (Fig. 3). The highest growth rate was registered in the 470–500 lx modes. In the 230lx illumination, the growth rate decreased, but this decrease was not statistically significant. A decrease in illumination to 15 lx and 0 lx slows the growth rate by 14–17% ($p < 0.05$). Growth rates slowed down by 30–42% in high illumination of 2,000 lx and 8,000 lx ($p < 0.05$).

Studying the behavior of *C. gibelio* in different light conditions, we identified a number of dependencies (Tables 1, 2). The well-fed individuals stayed in the zones with the illumination of 300–600 lx (Table 1). However, in the absence of food, the elected zones shifted towards increasing illumination. In the absence of food for 0.5 hours, juveniles chose a zone with an illumination of 600 lx (total stay time was 15.8 min), for 2 h – 1000 lx (17.3 min), for 24 h – 1000–1200 lx (swim frequency was 61–63 times and the total stay duration was 28.5 min per 1 h).

The frequency (108 sec) and stay duration (11.7 sec) were highest in the compartment with the 400 lx illumination. Table 2 shows that in the control in uniform illumination, the juveniles moved without a definite pattern, but they were permanently delayed in the last compartments. In other words, in the control “edge” effect appeared. This effect was not registered in light gradient conditions.

The data were statistically processed using a standard method with Student's Test.

The motor activity of juveniles in light-gradient conditions was higher than the motor activity in control. The number of vector displacements differed by 23%. The average range of movement by 7%, the total path by 31% in the light gradient exceeded the corresponding values in control in balancing illumination. Thus, the fish motor activity increased due to the increase in the range of movement and swimming speed in a gradient field. Analysis of juveniles' behavior in the gradient field shows that the preferential zones vary depending on the period of lack of food: the preferential movement zone shifts towards higher illumination values

4. DISCUSSION

In the literature, there is information about the effect of light on the goldfish *C. auratus* closely related to these species. The juveniles rapidly grew in the 3–85 lx illumination (Wei *et al.*, 2019). However, Baite *et al.* (2010) conducted a 60-day experiment to study the effect of light intensity (0, 2000, 4000, and 6000 lx) on juveniles' growth and survival of the same species. They found that high levels of lighting had no effect on growth. It was the same in all three options. At the same time, the complete absence of light (0 lx) had an adverse effect on growth rates. The authors concluded that the 2000 lx illumination is optimal for the growth and favorable physiological state of goldfish.

In our experiments, we used typical representatives of the bottom ichthyofauna from low-flow reservoirs. According to Holopainen *et al.* (1988), Artaev & Ruchin (2016, 2017), they usually live on the bottom near the thickets of aquatic vegetation. They eat almost non-stop, however in the summer they meet mainly in the morning and evening, so fish are active in the early morning and late evening (Holopainen *et al.*, 1997; Kottelat & Freyhof, 2007; Radtke, 2011; Benito *et al.*, 2015). According to illumination's measurements in the fish habitat by Kuznetsov & Ruchin (2001), the level of light reaches less than 1500 lx during these hours. Apparently, this explains the optimal illumination zone for the species' growth. This range was 200–930 lx for juvenile *C. gibelio* and it was 230–500 lx for juvenile *C. carassius*. The negative effect of high light and total darkness for growth was common to both species. At the same time, very high illumination also greatly reduced the growth rate.

The study by Wei *et al.* (2019) shows that cortisol, glucose, and lactic acid are significantly increased in the blood plasma of juvenile goldfish in the illumination, which had a negative effect on fish growth. The appearance of cortisol and the metabolites indicates an organism's stress response to excessive light exposure (Mommensen *et al.*, 1999; Tian *et al.*, 2015).

Thus, the results of our experiments coincide with the biological features of the two species. Their growth is accelerated at low light levels. It is typical for other near-bottom fish species (Konstantinov *et al.*, 2003; Trippel & Neil, 2003; Trotter *et al.*, 2003; Han *et al.*, 2005; Strand *et al.*, 2007; Collett *et al.*, 2008; Wang *et al.*, 2013). Observation of the fish behavior in different light conditions confirms the results. Juveniles of goldfish chose such lighting conditions that were optimal for growth in aquariums.

5. CONCLUSIONS:

The obtained results confirm the need for appropriate intensity of illumination while growing the two carp fish species. The growth of juvenile *C. gibelio* improves in the 200–930 lx illumination. The growth of juvenile *C. carassius* is maximum in the 230-500 lx illumination. In the absence of light and at a very high light intensity, the growth rates of both species decreased significantly. The behavioral reaction of the juvenile *C. gibelio* corresponds to the results obtained in aquariums and shows the preferred areas of illumination.

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Figure 1. The scheme of the experiments: A – the first experiment (there is an aquarium with experimental fish, covered with a lid with a lamp that creates a certain illumination); B – the second experience (Side view and top view; it was described in the text).

Figure 2. The specific growth rate of *C. gibelio* of different initial mass in different illuminations (in the legend, the figure shows the initial mass of fish before the experiments, (mean SGR $\pm$ S.E.).

Figure 3. The specific growth rate of *C. carassius* of different initial mass in different illuminations (in the legend, the figure shows the initial mass of fish before the experiments, (mean SGR $\pm$ S.E.).

Table 1. The frequency of occurrence and the stay duration of the juvenile *C. gibelio* in various light zones

Control				Experiment			
Illumination, lx	n	τ , sec	$\Sigma\tau$	Illumination, lx	n	τ , sec	$\Sigma\tau$
750	12	42.0	8.4	300	75	10.6	13.2
750	32	9.9	5.3	400	108	11.7	21.1
750	31	12.6	6.5	500	85	10.3	14.6
750	33	9.4	5.2	600	55	6.9	6.3
750	53	10.2	9.0	700	25	4.8	2.0
750	50	9.1	7.6	800	18	4.0	1.2
750	30	8.6	4.3	900	9	4.7	0.7
750	21	10.9	3.8	1000	8	3.8	0.5
750	20	14.1	4.7	1100	5	3.6	0.3
750	10	31.2	5.2	1200	2	3.0	0.1

n – the number of swims in the zone per hour; τ - the average duration of a one-time stay in the zone, sec; $\Sigma\tau$ - the total duration of stay in the zone per hour.

Table 2. Indicators of the motor activity of young fish in light-gradient conditions (experiment) and under uniform illumination (control) *

Indicator	Control	Experiment
The number of vector displacements, (N)	183	225
Average distance vector displacement, cm (S_v)	22.8	24.3
Total path, m ($\Sigma S_v \cdot N$)	41.7	54.6
Average duration of vector displacement, sec (τ_v)	7.9	8.3
Travel speed, cm / sec (S_v / τ_v)	2.9	2.9
Total travel time, min	24	31.1
Total time of delays in the compartments, min	36	28.9

* - All values were equalized to one hour.