Rearing carp (*Cyprinus carpio*) in different light: mini-review

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Abstract. Common carp (*Cyprinus carpio* Linnaeus, 1759) is one of the common fish species grown in aquaculture of many countries. This paper presents a review of publications on the effect of the light factor on carp. According to most studies, embryonic development improves in conditions of low intensity light, while long photoperiod has a positive effect on growth. Daylight lengthening also accelerates the maturation of females. Illumination and spectrum of light in certain optimal limits can cause positive effect on carp at different stages of development. Such modes of illumination and spectrum caused improvement of the physiological and biochemical state of fish and food conversion efficiency. Diurnal rhythm and behavior also show a photoperiodic dependence. Some preliminary recommendations on the illumination for carp in conditions of industrial fish farming are given in conclusion.

Key words: common carp, *Cyprinus carpio*, light, growth, development, physiology, behavior, reproduction.

Introduction. Common carp (*Cyprinus carpio* Linnaeus, 1759) belongs to the order Cypriniformes and the family Cyprinidae. This species lives in freshwater ecosystems such as rivers, lakes, and ponds (Barus et al 2001; Enache et al 2011; Artaev & Ruchin 2016). Due to its popularity and high ecological plasticity, it is currently common in many countries of the world, in some of them it is considered to be an invasive species (Koehn 2004; Clavero & Villero 2014; Froese & Pauly 2016). Following multiple translocations and introductions of domesticated and feral forms since Roman times, *C. carpio* is now present in 139 countries and islands worldwide (Froese & Pauly 2016), proving its reputation as 'the most successful colonizer of the world' (Vilizzi & Copp 2017).

Due to the hardiness of this fish species, its use in aquaculture has increased dramatically since the mid-1980s. In 2000, worldwide aquaculture produced 2,682,543 metric tonnes of carp at a value of U.S. $2.8 billion (Badiou et al 2011). In 2010, it ranked third (*Ctenopharyngodon idella* ranked first and *Hypophthalmichthys molitrix* second) in terms of worldwide finfish aquaculture production, contributing 9% of the world's total finfish aquaculture production, and Asia accounted for more than 90% of common carp's aquaculture production. China alone contributed 77% (2,462,346 tons) of the world's aquaculture production of common carp (3,216,203 tons) in 2009 (Rahman 2015). Of all fish species used in aquaculture, the common carp is the third most productive and valuable. Although aquaculture is the primary reason that the common carp was introduced to Europe, Asia, and the Middle East it is also a prized sport fish in many European countries such as France and England where they are commonly stocked in sport fishing ponds (Mohapatra & Patra 2014; Rahman 2015; Wang et al 2015).

Currently, there is a beneficial interaction between biotechnology and aquaculture. The first is conceived as a set of techniques used or applied to living organisms aimed at modifying or manufacturing a product for use or consumption. Aquaculture is defined as the production of aquatic organisms under controlled systems with technological applications that allow managing population densities higher than the natural ones, optimizing culture management; in other words, an intensive aquaculture. Biotechnology and aquaculture have made significant progress over the last decades (Díaz & Neira 2005). In the fishing complex of many countries, industrial fish farming, i.e. intensive aquaculture, occupies an important place. The usage of industrial technologies in fish farming allows to obtain eco-friendly products with the economical use of land and water resources and still achieve a high yield of fish. In addition, these products are available throughout the year, whereas the traditional fishery is very seasonal.

In fully controlled conditions, one of the environmental factors required for fish rearing is light. Light is a complex external and ecological factor whose components include color spectrum (quality), intensity (quantity) and photoperiod (periodicity). An aquatic environment has peculiar and extremely variable characteristics. Moreover, "receptivity" of fish to light changes profoundly from one species to another and, within the same species, from one developmental stage to another (Boeuf & Le Bail 1999; Boeuf & Falcon 2001). The carp is one of the most important species in aquaculture, known for its rapid growth and high tolerance to environment conditions. For carp aquaculture, we need to know the conditions that can be used when growing it in pools. In this review, we want to understand whether light is necessary for growing carp.

Embryonic development. The embryonic development of fish occurs in a wide variety of conditions, for example: at great depths, in the pelagial, on the ground, on the leaves of plants and in other very diverse conditions. There is evidence that the embryonic development of fish has a certain dependence on the light factor and that embryogenesis in this case can be significantly transformed. It should be said that light has a positive effect under certain parameters, beyond which it begins to inhibit the development of species (Kwain & McCauley 1978; Yang & Yang 2004; Chernyaev 2007; Ruchin 2016). Bădiliţă et al (2010) studied the embryonic development of carp when exposed to light in three different ways: natural light, total constant darkness and constant light (at 36 lux). It showed that during first 60 hours after fertilization, there was no significant difference between the development of embryos in any variant. However, by 83 hours after fertilization, the larvae hatched in the variants with natural light and round-the-clock illumination, while in complete darkness only 10% of embryos were in the hatching stage. We could conclude that, in carp embryos, the incubation period in all three variants was of 72 hours for 60-100% of the embryos. Yet, in total darkness, 10% of the embryos doubled their hatching period, but with lethal effects. In continuous light, the embryos hatched earlier than in natural light. At the end of the experiment, in these two variants, the hatching rate was of 100%, and in the third variant, it was of 90%.

The survival rate of carp eggs during the period of embryonic development with illumination of 80-100 lux was 15-20% higher than under illumination of 2-6 lux. The duration of the incubation of eggs in the dark made 100-103 h, whereas at an illumination of 80-100 lux it made only 84-87 h. At the same time, the larvae that switched to active feeding were larger and more mobile than the larvae grown in the dark (Kryuchkov & Kasimov 1978). The embryonic development of carp accelerated in the light (Korovina et al 1965).

Thus, the effect of light on the early stages of carp development is manifested to a large extent. This is due to crucial role of the visual analyzer in the formation of behavioral and defensive reactions of carp larvae. This is precisely the reason for the pronounced positive phototaxis of larvae before hatching.

Growth. Different ratio of light and dark can both suppress and stimulate fish growth depending on the ecological features of the species (Boeuf & Le Bail 1999). For example, Siberian sturgeon *Acipenser baerii* (Ruchin 2007b), sterlet *Acipenser ruthenus* (Azarin et al 2014), Atlantic salmon *Salmo salar* (Saunders et al 1989), Prussian carp *Carassius gibelio* (Ruchin et al 2005), Chinese sleeper *Percottus glenii* (Ruchin et al 2005), common bleak *Alburnus alburnus* (Ruchin et al 2005), sunbleak *Leucaspius delineates* (Ruchin et al 2005), guppy *Poecilia reticulata* (Ruchin et al 2005), Nile tilapia *Oreochromis niloticus* (El-Sayed & Kawanna 2004) grow better with an increased light period. While other species (*Clarias gariepinus, Brachymystax lenok, Rhamdia quelen*) grow much better in conditions of complete round-the-clock darkness (Piaia et al 1999; Mustapha et al 2012; Liu et al 2015). At the same time, photoperiod does not have a significant impact on growth of seahorse *Hippocampus reidi* and Mexican cichlid *Cichlasoma beani* (Aragon-Flores et al 2017; Hora et al 2017).

We studied carp fingerlings of different mass and their growth depending on the photoperiod (Ruchin et al 2005). The experiments showed that all groups of fish grew best with round-the-clock illumination. In the dark growth rate decreased significantly (by 20-30%). During three-month experiment with carp fingerlings, reared under different photoperiod regimes, Danişman-Yağci & Yiğit (2009) found out that up to day 45 there was no difference between groups of fish. By day 60, however, a significant difference in growth between the continuous photoperiod and the other ones (12L:12D, 16L:8D) has been observed. Similar results were obtained by Iranian scientists (Ghomi et al 2011): carps reared for 4 weeks with a photoperiod of 16L:8D showed higher growth rate than in other variants. After 8 and 12 weeks, the weight of carp with photoperiods 16L:8D and 12L:12D was already the same and exceeded the weight of fish kept under eight-hour illumination (Hisar et al 2005). The process of growing carp of different ages in pools with a closed water supply cycle showed that the best growth rates can be obtained in conditions of 20-hour light and 4-hour dark period (Vlasov 1991, 1996, 1997).

There are also opposite results: Meske (1981) did not reveal any significant differences in the growth rate of this species neither in the dark nor in the light. This author conducted an experiment on carp yearlings contained in two different photoperiods: 0L:24D and 9L:15D (Meske 1985). The report indicates that differences in the growth of the specimens were not observed. However, according to the table given by the author, carp mortality was higher in conditions of round-the-clock darkness. In addition, in the dark, feed consumption also increased significantly, which indicates an increase in growth energy expenditure. He also conducted a series of experiments on large carps weighing 1070 g (Meske 1983), reared in groups of 10 individuals in 400-liter pools for 139 days. No significant effect of a different photoperiod was revealed. However, weight gain was somewhat higher in conditions of round-the-clock illumination. Serbian scientists (Marković et al 2006) obtained the same results in their experiments. In complete darkness carp grew better than in the 12- and 24-hour illumination, its average food intake was 118.65 g per day, and average weight made 210 g at the beginning of the experiment and 328 g at the end. It was noted that the average ichthyomass increased by 118 g.

Table 1 shows results of various authors who studied the effect of photoperiod on carp growth. Perhaps, such contradictory results can be explained by an incorrectly chosen season or feeding method, as it is often reflected in the research results.

Table 1

The effect of photoperiod on carp growth according to different authors

Age groups	*Photoperiod light:darkness (h)*	*Time of the year*	*Authors*
Larvae	Not detected	–	Meske (1985)
Larvae	24:0	Summer	Vlasov (1991)
Fingerlings	Not detected	–	Meske (1981)
Fingerlings	24:0	Summer-autumn	Ruchin et al (2005)
Fingerlings	24:0	February-May	Danışman-Yağcı & Yiğit (2009)
Fingerlings	Not detected	–	Yamamoto et al (2001)
Fingerlings	0:24	February-March	Marković et al (2006)
Fingerlings	16:8 and 12:12	–	Ghomi et al (2011)
Fingerlings	16:8 and 12:12	–	Hisar et al (2005)
Yearlings	20:4	Summer	Vlasov (1996, 1997)
2 year-olds	24:0	–	Okumoto et al (1989)
2 year-olds	Not detected	–	Meske (1983)

In addition to photoperiod, the growth of many fish is also significantly affected by illumination. Moreover, its parameters and the optimal range for the fish growth are specific to each species. For example, the larvae of sea bass *Dicentrarchus labrax* and Atlantic cod *Gadus morhua*, fingerlings *Poecilia reticulata* grow better with a significant amount of illumination at the level of 1000-4000 lux (Barahona-Fernandes 1979; Puvanendran & Brown 2002; Ruchin & Kuznetsov 2003), whereas for the growth of other species (*Acipenser baerii, Megalobrama amblycephala*), minimum illumination at levels 100-500 lux is enough (Ruchin 2008; Tian et al 2015).

During two experiments conducted in the rearing rooms, there was an attempt to rear carp in different light conditions. However, significant difference in fish growth, depending on the intensity of light, has not been revealed (Enache et al 2012). In the experiments performed by Meske (1985), almost identical growth rates of larvae were observed in the dark with nine-hour illumination. Apparently, these results can be explained by not quite correct method of experiment. Thus, feeding of fish with brine shrimp nauplii in the mode characterized as “constant absence of light” (darkness) was carried out with the lights on. After larvae finished eating, the light was turned off again. So, with the above experimental set up, the role of eyesight in the feeding process of larvae is excluded. He also conducted a series of experiments on carp yearlings weighing 162 g (Meske 1983), which in groups of 30 specimens were placed in 400-liter pools for 106 days in different light conditions from 600 to 1,800 lux. As in the case of exposure to a photoperiod, this author also did not reveal a significant difference in the growth of carp. However, a somewhat noticeable weight gain was recorded at 1200 lux illumination.

Our experiments on carp larvae (Ruchin 2001b) showed that the highest growth rate is observed at illumination of 1700 and 12200 lux with a maximum growth rate at 4200 lux. In the works of Tkhor (1981) and Vlasov (1985, 1991) with a large number of larvae, the positive effect of bright light (8-20 thousand lux) on growth was obvious. Larvae grown in 200-liter units and 500-liter pools grew much better with high light intensity. Moreover, they were distinguished by low mortality rates and higher viability (Vlasov 1985). The survival rate of carp larvae at the age of 1-20 days is highest at illumination of 20-30 lux, the lowest in the dark and at illumination of 120-130 lux (Kryuchkov & Kasimov 1978).

Similar results were obtained in experiments on carp fingerlings with an average initial mass of 0.46-2.58 g (Ruchin 2001b). The optimum illumination for growth was 4200 lux, however, in the variants with the illumination level of 1300 and 2200 lux, the growth rate did not differ statistically. With an illuminance of 8400 lux, the growth rate decreased more significantly than with low illumination (16.1 and 11.5% lower, respectively, compared to the 4200 lux mode). Yearlings with an average weight of 3.8-4.1 g grew faster in the mode of 1300 lux. In our opinion, the decrease of optimal for growth illuminance with age is associated with the transfer of fingerlings to feeding on benthic organisms and, accordingly, to a more near-bottom lifestyle. In complete darkness, juveniles grew much worse than in other variants (Ruchin 2001b).

In recent years, the processes of fish growth and development under the influence of different colors of illumination have been actively studied (see review: Ruchin 2020). In some experiments (Karakatsouli et al 2010; Nasir & Farner 2017), red-yellow light had a positive effect on carp growth. Detailed research was conducted by Karakatsouli et al (2010). With a low stocking density in the tank, the growth rate of carp fingerlings during the experiment was higher in red light. Fish reared under red and white light showed higher body weight compared to fish reared under blue light. Significant density effects were apparent after 17 days of rearing, whereas light colour effects appeared after 101 days. Interestingly, in the last 15 days of rearing, a significant interaction between the two factors was detected, revealing that red light effect was more evident when fish were kept under low density. Growth was reduced at high density for red and white light and it was not significantly reduced for blue light. In addition, with intensive illumination, positive effect of red light on growth was enhanced. Thus, the authors argue that carp, which is a benthic species, inhabiting turbid waters with a predominance of red rays in the water due to suspended matter, should be less stressed and grow fast exactly when illuminated with red light.

We should also note that in studies of Nasir & Farner (2017), the growth rate of juvenile carp in blue light was not very different from the growth rate in red light (2.830

and 2.897, respectively). In studies of Imanpoor et al (2011) and Eslamloo et al (2015), were discovered that the red light also had a negative effect on carp growth. However, in the experiments of these authors, the highest growth rates of fish were recorded under white light.

However, we (Ruchin et al 2002; Ruchin 2004a) obtained the opposite results in our experiments. We found out that the optimal mode for growing fingerlings of up to 4.5 g is green illumination, which significantly increases growth rate compared to control (white light). Growth rate also increased with blue light and blue illumination. Mehrdad et al (2013) studied the effect of three colors (blue, green and red) on the growth of larvae weighing 0.0402 g for two months. In this case, the larvae were fed twice a day with specialized food. Blue light caused the highest growth rate, unlike other options. At the same time, all groups had the same survival rate. We believe that the differences in the results we (Ruchin et al 2002; Mehrdad et al 2013) and other authors (Papoutsoglou et al 2000; Karakatsouli et al 2010; Nasir & Farner 2017) obtained, can be attributed to the different feeding technology during experiments. Usually, when grown in tanks, fish is fed with dry feed. We used sludge worms *Tubifex tubifex* (Annelida, Naididae) and the Chironomidae (Diptera) larvae, which are brown-red and contrasting in green and blue light (Ruchin et al 2002). It is possible that in these conditions carp consumed more feed and grew faster. Bairwa et al (2017b) received similar results, in which green and blue light accelerated the growth of carp. It was also shown that carp growth can be improved with a certain oscillations of illumination and light spectrum (Ruchin 2000, 2001a; Konstantinov et al 2003). Carp fry grew better under short-term irradiation with UV light. The calcium content in their muscles was increased (Rusanov 1974).

Papoutsoglou et al (2000) reared carp in tanks with walls of different color. They described that the body weight of common carp maintained under yellow light was higher than fish held under black and green light. At the same time, blue and green light had negative effect. White-adapted carp showed the highest specific growth rate and the lowest food conversion ratio, whereas black-adapted fish exhibited the opposite pattern. Prolonged rearing for 56 days of carp fingerlings in tanks of different colors, showed that the growth rate of fingerlings is higher in blue tanks (Ebrahimi 2011).

Daily respiratory and nutritional rhythms, feed conversion ratio. It is well known that carp larvae are planktonophagous, and then juveniles transfer to feeding on benthic organisms in the bottom layer of water. This is confirmed both by observations in nature and under growing conditions in tanks (Rahman et al 2008; Jurajda et al 2016).

Like many physiological processes, feeding is also a rhythmic process for fish. Rahman & Meyer (2009) had a thorough study of the daily feeding activity of carp in tanks under different feeding conditions. Fish behaviours were compared among three treatments: tanks with plankton only, tanks with plankton and benthic macroinvertebrates and tanks with plankton, benthic macroinvertebrates and artificial feed. Overall *C. carpio* grazed more frequently during daytime than at night and exhibited the reverse pattern for non-eeding swimming behaviour. Fish dispersed to graze individually during daytime but schooled at night and did not display any agonistic behaviours. In tanks containing plankton only, fish grazed in the water column, whereas when benthic macroinvertebrates were present, they spent more time near the tank bottom. Resting behaviour was only seen in tanks with artificial feed and even then was rare. Thus, the activity of carp is diurnal and rather labile. It may vary to a certain extent depending on the feed objects. Yamamoto et al (2001) reported that shortening of light phase during the feeding trial affected feed intake of carp.

Observations of feeding habits in water bodies show that carp feeds during the day and night with certain peaks that occur in the morning and early evening hours (Rahman et al 2008). In pools with natural photoperiodicity, carp consumes feed most intensively from 4^{00} to 7^{00} and from 13^{00} to 19^{00} hours (Vlasov 1991). When kept in fish ponds on warm waters, 3 maxima of food activity were observed: at 13^{00}, 19^{00} and 23^{00} hours (Amelyutin 1985). When grown in the cultivation cages, juvenile carp feed consumption was the highest between 8^{00}-10^{00} hours and 20^{00}-24^{00} hours. When kept in cages in cooling ponds, 3 peaks of feeding activity were observed: at 13^{00}, 19^{00} and 23^{00}

hours (Amelyutin 1985). Feed consumption of carp juveniles in rearing channels was the highest between 8^{00}-10^{00} hours and 20^{00}-24^{00} hours. However, this rhythm could shift or even disappear depending on daily fluctuations in temperature and oxygen content in water (Lavrovski & Grin 1982). It was also noted that the feeding rhythm of carp, kept in pools, can shift depending on the time of switching on the light (Vlasov 1991).

According to Zaitseva (1981) fingerlings of carp in maturation ponds feed around the clock. Feed consumption was the most intensive during evening and nighttime. In June, 3 peaks of food consumption were noted: at 3^{00}, 17^{00} and 21^{00} hours. In ponds, peak of plankton consumption by carp larvae was observed during the daytime (Matlak & Matlak 1976).

Studies of food consumption intensity under experimental conditions showed that with 0 lux this parameter increases (Ruchin 2001b). At low growth rates and large amounts of feed consumed, the ratio of growth to diet during the experiment is small, and, consequently, food conversion ratio within constant darkness is much worse. In general, intensive feed intake leads to slow (comparing to received rations) growths and as a result somewhat larger estimates of the energy balance of juveniles are observed. Obviously, this increase in rations can be explained by a decrease in the digestibility of feed with its abundant consumption, as noted in the goldfish *Carassius auratus* (Davies 1963). The increase in juvenile growth under optimal illumination while reducing the intensity of feeding indicates an increase in the efficiency of food intake for growth (Ruchin 2001b). During the 12L:12D photoperiod, which proved to be the most effective for carp rearing, the efficiency of food ratio increased (Ghomi et al 2011). Rearing larvae showed that optimal for growth light regimes also have a positive effect on feed conversion ratio (Vlasov 1985).

In complete darkness, oxygen consumption by carp fingerlings was 18% lower (Ruchin 2002). Any other light regimes did not have any significant effect on the breathing of fingerlings. A similar effect was recorded in experiments on fingerlings of an ecologically similar species of goldfish (Ruchin 2005). Experiments with carp larvae by Vlasov (1991) showed that due to the increase in light intensity from 0 to 20 thousand lux, the intensity of their respiration also increases from 284 to 437 mg O_2 / kg * h.

When the light level oscillates, the respiration rate of juvenile carp also increases. In variants with high level of illumination (8400-9000 lux), the intensity of respiration increases (Ruchin 2001b). The total consumption of feed and oxygen in variable light modes increased slightly compared to the control. At the same time, the experimental fish grew faster, and the intensity of their respiration decreased, which indicates a decrease in the relative energy expenditure under the influence of illumination fluctuations. Thus, the consumption of oxygen per unit weight gain in the most favorable fluctuant modes decreased by 21.0-39.5% (average 27.2%) as compared to the constant mode of illumination. The food conversion ratio under experimental conditions exceeded that observed at constant illumination by 1.30 times (Ruchin 2002). On the other hand, Vinberg & Khartova (1953) did not reveal any significant difference between the oxygen consumption of carp fingerlings by day and night.

Simultaneously with the study of carp growth in conditions of different outdoor illumination colors we (Ruchin 2004b) determined the intensity of food consumption and the efficiency of its conversion to growth. In the most favorable regimes for juveniles, daily rations slightly increased. This was obvious in both short and long-term experiments. Food coefficients, and, respectively, feed conversion ratio, significantly increased. Thus, it was proved that against the background of a small increase in daily rations while the growth of carp increased significantly under green illumination, efficiency of feed conversion to growth increased by 30-35%.

Physiological rhythms and behavior. One of the specific features of light as an environmental factor is that the regular dynamics of illumination conditions plays an important role in the regulation of the fish daily rhythms. Along with the photoperiod, the intensity of respiration and activity can be influenced by light intensity, since it acts as a peculiar factor-signal for physiological processes of fish (De Silva et al 1986; Imsland et al 1995; Ruchin 2007a, 2008; 2019; Setyawan et al 2018).

Zhigin & Korenkov (1991) studied daily rhythms of oxygen consumption and release of ammonium nitrogen done by carp in a closed-cycle water supply system. With natural light, the highest oxygen consumption and nitrogen excretion was observed in the daytime with a maximum at 16^{00} hours. In conditions of round-the-clock darkness or constant illumination, this rhythm was maintained. However, with inverting the diurnal rhythms of illumination, breathing rhythms also rearrange.

Olifan (1940) identified 3 peaks of oxygen consumption by carp larvae at the age of 1-3 days (at 5^{00}-6^{00}, 11^{00}-13^{00} and 17^{00}-19^{00} h) and 3 minima (at 7^{00}-9^{00}, 15^{00}-17^{00} and 22^{00}-24^{00} h). Carp specimens of different ages manifest certain daily rhythm, which is individual in every case (Vinberg & Khartova 1953). The night decrease in oxygen consumption was also detected in other experiments (Hamada & Maeda 1983; Vlasov 1991).

In other studies (Chakraborty et al 1992), carp weighing 79.8 g consumed oxygen most intensively at 12:12 alternation of light and dark (152 mg O_2 / kg * h), while round-the-clock darkness or light suppressed respiration. Breathing rhythm under conditions of around-the-clock illumination and constant darkness also changed, though no significant peaks could be traced. In adult carp adapted to artificial photoperiod 12:12, maximum respiratory intensity was observed after the light was switched on (Chakraborty et al 1992). At the same time, in carp larvae in this mode, the difference between the maximum and minimum reached 40 mg O_2 / kg * h (Vlasov 1991), and under illumination from 70 to 20 thousand lx only 26-36 mg O_2 / kg * h. The latter case can be explained, on the one hand, by insufficient sampling (not hourly), and on the other, by peculiarities of larval development. A detailed study was carried out in the experiment of carp wintering in special wintering basins (Vologdin & Beloborodova 1985). A decrease in illumination led to same decrease in oxygen consumption by the yearlings. At the same time, the consumption of energetic substances (glycogen) in darkened conditions occurred at a slower rate than with greater illumination.

The simple diel cycle of rising and setting of the sun imposes on the behaviour and activity of fish a dramatic, overriding set of predictable constraints. As a direct result, many kinds of behaviour and the species that engage in them follow characteristic convergent patterns that transcend geographic and taxonomic boundaries (Helfman 1986). It is well known, that under natural conditions carp moves within the water during the day (Devine & Shiozawa 1984). In Spain they observed carp behavior in a pond for 19 months using telemetry. The activity of carp and their use of depth displayed low seasonality compared with abiotic factors. However, carp exhibited diel vertical migration patterns, mostly in the warm season, shifting from deep positions near the reservoir bottom during the night (with decreased activity) to shallow waters during the day (Benito et al 2015).

Juveniles of carp at the age of 12 months are most active during the day in conditions of complete darkness, whereas with round-the-clock illumination, activity is reduced. In the latter case, peaks and decreases in activity were not observed, i.e. activity during the day remains the same. Under the conditions of a natural photoperiod, the maximum activity peak is observed at 6^{00} hours, the second smaller peak — at 19^{00} hours, the minimum activity was detected at 11^{00}-16^{00} and 2^{00} hours. In the natural light mode and round-the-clock darkness, the daily cycle of the locomotor activity of carp yearlings was obvious both in the upper and in the lower layers of water (Kryuchkov et al 1989).

Klimov & Ogurtsov (1981) studied the behavior of carp larvae when incubating eggs in special devices. It showed that when the device was darkened the migration of carp prelarvae increased by 2-4 times, and the greatest intensity of the migration is achieved within complete darkening. Under gradient conditions at the age of 5 days, the larvae prefer a zone of low illumination, at the age of 10-15 days they choose zones with higher illumination (Kryuchkov & Kasimov 1978), while juveniles of carp at the age of 35-50 days prefer illumination of 2-10 lux (Orudzhev 1973).

Physiological and biochemical aspects. Physiological and biochemical parameters of fish are very pliant. The variability of the external environment, age, ecological specificity of living conditions – all this causes a certain imprint on the functioning of fish organism. Along with this, some physiological parameters of the organism (in particular, the indices of blood, biochemical and morphophysiological indices, which are most sensitive to the environmental changes) can shift.

Somatotropin is one of the most well-known growth-stimulating hormones. Numerous factors, which can affect its secretion in the carp pituitary and activity, are described in detail in the paper by Peter & Marchant (1995). According to Sautin & Romanenko (1982), the somatotropic function of the carp pituitary gland responds to changes in the photoperiod in as little as 12 days. It is likely that this is the long-term effect of changes in the photoperiod. This is how the difference in growth of experimental groups subjected to additional coverage after 60 days is explained (Danışman-Yağcı & Yiğit 2009). It is assumed that acclimatization to rearing conditions under photoperiodic regimes could require several weeks. This result is consistent with other studies conducted on other fish (Okumoto et al 1989; Perez-Sanchez et al 1994; Koskela et al 1997). In other experiments, opposite results were obtained. The introduction of exogenous growth hormone against the background of an increased photoperiod did not affect the growth of carp (Adelman 1977).

Another hormone that is involved in photoperiodic reactions and is of great importance in the life processes of fish is melatonin (Ekström & Meissl 1997). An in vitro study of the melatonin release from the pineal gland of common carp originating from France, found a similar profile to the current study. The melatonin level showed a clear similarity to the type B, with melatonin release from the pineal that increased gradually until a peak around mid-dark phase (Bolliet et al 1996). The profiles, observed in these studies, are in contrast to other findings in common carp. Kezuka et al (1988) found a profile more similar to type C, with a rapid increase in plasma melatonin after lights off, and the high levels were maintained during the darkphase. When the lights were on, the level returned to daytime levels.

Some observations indicate that photoperiod constitutes a particularly relevant modulator in the neuroendocrine cascade that activates of prolactin transcription in the carp. Plasma thyroxin hormone T_4 levels were significantly higher in the groups exposed to 8 or 12 hours of light than in the group exposed to 16. Plasma T_4 levels significantly dropped with time in all three photoperiods. At 12 weeks, weight gain dropped 4.78%, 7.57%, and 8.72% while plasma T_4 dropped 12.1%, 15.8%, and 66.9% in the 8L:16D, 12L:12D, and 16L:8D photoperiods, respectively (Hisar et al 2005). There were other experiments to study thyroxin concentration in carp plasma at different photoperiods. Two groups of fish were subject to a 3-mo treatment that consisted of 8 h of light followed by 16 h of darkness and 16 h of light followed by 8 h of darkness at 25^oC. No significant changes were recorded between the two groups at the beginning of the study. After 3 months, the triiodothyronine and levels of copper, zinc, iron, magnesium, manganese as well as the growth rates of fish in the long-time exposure period were significantly higher than those in the short-time exposure (Ayik et al 2005).

When experimental combinations of long and short photoperiods with 10°C and 20°C environmental temperatures were studied, only a short photoperiod (8L:16D) in summer-acclimatized carp acclimated to a winter temperature (10°C) markedly depressed of prolactin gene expression (Figueroa et al 1997).

The concentrations of stress indicators (cortisol and glucose) were significantly higher in yellow, red and for control fish group. Total protein, globulin protein, lysozyme activity and respiratory burst activity was significantly higher ($p < 0.05$) in blue and green exposed fish groups whereas, yellow and red exposed fish recorded decline in this parameters after 60 days. These studies have shown that red and yellow light have a stressful effect, while green and blue illumination have a positive effect on carp and stimulate its growth (Bairwa et al 2017b).

The activity of enzymes in the intestines of fish under the influence of serotonin and cholecystokinin in conditions of light deprivation signifiantly increases, especially the activity of peptidases of the mucosa under the action of Cu (Kuz'mina & Kulivatskaya 2018).

We studied the effect of photoperiod and light on carp blood under experimental conditions (Ruchin 2006). It showed that there is a certain dependence of the number of some formed elements, such as lymphocytes, monocytes and basophils on photoperiod. The proportion of lymphocytes regularly increased from 77.5% in continuous darkness to 89.0% under a 12L:12D cycle and to 82.3% under a 24L:0D cycle. An inverse pattern was observed for monocytes and basophils. Their proportion decreased to the minimum under a 12L:12D cycle and increased under a 24L:0D cycle although not to the extent observed in continuous darkness. The proportion of eosinophils was similar in all variants and varied from 4.0 to 6.2%. Hence, a physiological deterioration can be recognized in carp yearlings in the dark as well as their better physiological state in the 12L:12D, 8L:16D, and 24L:0D variants. The number of lymphocytes, basophils, neutrophils and eosinophils did not show a clear dependence on the illumination. From November to March, Bieniarz & Maslowska (1971) studied the effect of constant darkness, constant illumination and natural photoperiod on blood parameters (amount of red and white blood cells, hemoglobin contents, hematocrit, erythrocyte sedimentation rate) of two-year-old carp. The authors did not find any significant differences in the ratios of the parameters studied.

It is likely that regulatory processes during non-specific photobiostimulation depend on the dose and intensity of irradiation. For example, at high intensity of illumination, the process of rejection of allotransplant scales in carp is significantly accelerated than at low intensity (Balakhnin & Neborachek 1992).

Roh et al (2018) studied the effect of shortwave LED light, used in fish farming to reduce the number of pathogens, on the carp body. There were no clinically significant histopathological changes in the skin and eyes of fish exposed to 405 nm and 465 nm LED light for 12 hours a day during month.

Reproduction. Numerous studies report the use of artificial photoperiods to modify, among other, fish maturation time. One of the oldest reports was published by Hoover (1937) who applied it to speed up the sexual cycle of brook trout (*Salvelinus fontinalis*). In recent years, a significant amount of information on how changes in the photoperiod can both activate and inhibit the maturation of fish has been obtained (Kadmon et al 1985; Dubé & Portelance 1992; Mañanós et al 1997). A particularly significant number of studies relates to a popular aquaculture object, which is salmonids (Oppedal et al 1999; Wilkinson et al 2010; Imsland et al 2014). For instance, a significant advance of spawning in rainbow trout (*Oncorhynchus mykiss*) can be obtained with accelerated photoperiod regimes from 6 to 9 months (Bon et al 1997). Accelerated maturation of *Salmo salar* is observed in the 12L:12D cycle (Strand et al 2018). In contrast, a spawning delay can be achieved with a continuous light regime (Boulier & Billard 1984). Thus, manipulations with the photoperiod have the most diverse influence on the maturation of the fish grown in aquaculture.

Davies et al (1986a) reared adult carp at 12L: 12D and 16L: 8D phototeriods. Fish showed a continuous increase in the number of mature oocytes and an increase in body weight during the first 5-6 months (August-January). These changes became more significant after 9 months of keeping fish in such conditions. Fish ovulated one month earlier in conditions of 16-hour illumination than in conditions of 12-hour coverage. With combinations of different temperatures and photoperiods, it was shown that spawning occurs only in those fish that were kept under 16-hour lighting after they were moved from cold water to warmer one (Davies et al 1986b). In India, carp shows 2 peaks of reproductive activity, which are in spring and autumn (Chattopadhyay 2016a). Carp maturation can be accelerated by prolonged light period (Fouche et al 1985; Chattopadhyay 2016b).

During September, Bairwa et al (2017a) conducted research on the effect of LED light sources of different spectra on the reproductive performance of carp. The authors revealed an improvement in reproduction in green light, while in yellow and red light the maturation of the gonads was inhibited. It was found that the spectrum of light affects the quality of the egg cells, but does not affect their number.

Conclusions. In the natural environment, light is one of the main factors that regulate life processes. In fact, it is a factor-signal that triggers many adaptation mechanisms, physiological processes, regulates behavior and other vital functions. That is why it should be used for carp rearing. However, we should not forget about quite definite ranges of this factor, beyond which the effect of light may not have such a positive effect. For example, carp breeding directly depends on the ratio of the light and dark and the maturation of females is accelerated by longer photoperiod. For the development of carp eggs, before the transition of larvae to active feeding, necessary level of illumination makes 50-100 lux. Larvae can develop in pools or special devices with illumination up to 2000 lux. Then, the illumination should be reduced, but in total darkness the carp grows poorly. It should also be mentioned that when exposed to constant illumination, fish may be stressed, it is possible that they develop pathologies. For example, constant intense light (e.g., 20000-21000 lux) induces intense apoptosis of the photoreceptors and retinal regeneration in albino zebrafish (*Danio rerio*). Therefore, to determine the optimal rearing conditions in each specific case, an experimental study of a certain carp breed is necessary. Carp feeding is also recommended at a certain time of the day, which is chosen empirically.

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