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# Effect of Illuminance Oscillations on Growth of Juveniles of Some Fish Species and Brown Frog (*Rana temporaria*) Larvae

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**Abstract**—Influence of changing illuminance on the growth of fish juveniles and grass frog tadpoles was investigated. The maximum growth rate of all the species is observed under conditions of illuminance oscillations about certain values. For the fish growth, the regimes with 12- and 24-hour oscillations are the best. In the optimal varying regimes, the lower lethal oxygen level declines. Change of the darkness (0 lx) to bright light decreases the growth rate of fishes. Similar results are obtained in experiments with grass frog larvae.

Numerous studies have revealed versatile influence of light on fishes and amphibians. Light affects the growth, haematological indices, locomotor activity, feeding, and respiration of fishes (Oswald, 1978; Esavkin, 1980; Casterlin and Reynolds, 1980; Nagarajan and Gopal, 1983; Alimov, 1994). Also, illumination exerts influence upon the growth, development, intensity of respiration and metabolism, and behavior of amphibians (Beskrovnyi, 1952; Manteifel, 1977; Kaufman, 1979; Richards and Lehman, 1980; Sytina and Nikolskaya, 1984).

In all the papers cited above the state of animals was estimated under some constant illumination conditions. However, light is a very changeable factor of the environment. During the short periods of morning and evening twilight, the illuminance value changes by a factor of tens of millions. In natural reservoirs, the angle of sunlight incidence and various particles suspended in water exert strong influence on the illuminance (Kazakov and Melnikova, 1982). Thus, the illuminance varies over a wide range during day and season. Therefore, the changeable, rather than static, light conditions are normal for the vital activity of animals. This formulation of the problem is rightful, because the recently obtained data demonstrate clearly that periodic oscillations of temperature, salinity, pH, and oxygen concentration in water improve markedly the growth, energetics, and physiological state of fishes (Konstantinov and Zdanovich, 1986; Konstantinov, 1988; Konstantinov and Martynova, 1990; Konstantinov *et al.*, 1995), with the general tolerance of organism to the influence of adverse factors increasing (Konstantinov and Sholokhov, 1993). However, there is no published information concerning the effect of illuminance oscillations on the growth of fishes and amphibians.

## MATERIALS AND METHODS

In order to make up for the above-mentioned deficiency, experiments on the influence of astatic illumination on the growth of juveniles were carried out with three species of fishes: carp, *Cyprinus carpio* L.; common wild goldfish, *Carassius auratus gibelio* (Bloch); and Amur sleeper, *Percottus glehni* Dybowski. In parallel, similar experiments were conducted with larvae of grass frog (*Rana temporaria* L.) representing another group of vertebrate hydrobionts. The investigations were repeated twice in 1997–1998 at the laboratory of Zoological Department of the Mordovian State University. The animals were kept in 20-l aquariums with temperature maintained at 24 ± 1°C and forced aeration. LB fluorescent lamps were used as source of light, since they warm up in operation only slightly and produce a sufficiently strong light flux. Light intensity was measured at the water surface with a U-116 luxmeter. Five to twenty fish specimens and 60 frog larvae at the 39th stage were placed in each aquarium. The fishes were fed on live tubificids, and the frog larvae, on nettle leaves and boiled yolk, constituting a satisfying ration. The duration of the tests with fishes was 10 days, and that with frog larvae, till the end of metamorphosis. The specific growth rate of fishes was calculated following Schmalhausen (1935). For tadpoles, the body length without tail, weight, and stage of development were determined following

**Table 1.** Growth rate and lower lethal oxygen level of fish juveniles in astatic illuminance conditions

| Illumination regime, lx | Oscillation period, h | Fish weight, g | | Specific growth rate, % per 24 h | Ratio of specific growth rates in control and experiment | Lower lethal oxygen level, mg $O_2$/liter |
|---|---|---|---|---|---|---|
| | | initial | final | | | |
| Carp | | | | | | |
| Test 1 ($n$ = 5) | | | | | | |
| 4200 | – | 1.84 ± 0.17 | 3.21 ± 0.31 | 5.56 | 1.00 | – |
| 3000–5400 | 24 | 1.84 ± 0.17 | 3.38 ± 0.41 | 6.08 | 1.09 | – |
| 2200–6200 | 24 | 1.84 ± 0.17 | 3.41 ± 0.18 | 6.17 | 1.11 | – |
| 700–7700 | 24 | 1.84 ± 0.17 | 3.70 ± 0.33 | 6.98 | 1.25 | – |
| 0–8400 | 24 | 1.84 ± 0.17 | 3.19 ± 0.36 | 5.50 | 0.99 | – |
| Test 2 ($n$ = 5) | | | | | | |
| 4200 | – | 1.20 ± 0.15 | 2.44 ± 0.29 | 7.10 | 1.00 | 0.99 |
| 700–7700 | 12 | 1.20 ± 0.15 | 2.69 ± 0.43 | 8.07 | 1.14 | 0.81 |
| 700–7700 | 24 | 1.20 ± 0.15 | 2.71 ± 0.33 | 8.15 | 1.15 | 0.82 |
| 700–7700 | 48 | 1.20 ± 0.15 | 2.56 ± 0.45 | 7.58 | 1.07 | 0.89 |
| Test 3 ($n$ = 10) | | | | | | |
| 4000 | – | 1.94 ± 0.17 | 3.35 ± 0.35 | 5.16 | 1.00 | – |
| 3050–4950 | 24 | 1.94 ± 0.17 | 3.41 ± 0.44 | 5.64 | 1.09 | – |
| 2150–5850 | 24 | 1.94 ± 0.17 | 3.45 ± 0.24 | 5.75 | 1.11 | – |
| 450–7550 | 24 | 1.94 ± 0.17 | 3.59 ± 0.32 | 6.15 | 1.19 | – |
| 0–8000 | 24 | 1.94 ± 0.17 | 3.39 ± 0.39 | 5.58 | 1.08 | – |
| Common wild goldfish | | | | | | |
| Test 1 ($n$ = 10) | | | | | | |
| 800 | – | 2.60 ± 0.15 | 3.67 ± 0.24 | 3.45 | 1.00 | – |
| 600–1000 | 24 | 2.60 ± 0.15 | 3.80 ± 0.23 | 3.80 | 1.10 | – |
| 450–1150 | 24 | 2.60 ± 0.15 | 3.85 ± 0.27 | 3.93 | 1.14 | – |
| 230–1370 | 24 | 2.60 ± 0.15 | 4.05 ± 0.17 | 4.44 | 1.29 | – |
| 0–1600 | 24 | 2.60 ± 0.15 | 3.52 ± 0.26 | 3.03 | 0.88 | – |
| Test 2 ($n$ = 5) | | | | | | |
| 800 | – | 2.86 ± 0.22 | 3.88 ± 0.25 | 3.05 | 1.00 | 1.07 |
| 200–1400 | 12 | 2.86 ± 0.22 | 4.23 ± 0.25 | 3.91 | 1.28 | 0.86 |
| 200–1400 | 24 | 2.86 ± 0.22 | 4.35 ± 0.29 | 4.19 | 1.37 | 0.79 |
| 200–1400 | 48 | 2.86 ± 0.22 | 4.13 ± 0.33 | 3.67 | 1.20 | 0.86 |
| Test 3 ($n$ = 5) | | | | | | |
| 800 | – | 1.89 ± 0.06 | 3.08 ± 0.24 | 4.89 | 1.00 | – |
| 600–1000 | 24 | 1.89 ± 0.06 | 3.65 ± 0.29 | 6.59 | 1.35 | – |
| 400–1200 | 24 | 1.89 ± 0.06 | 3.76 ± 0.17 | 6.88 | 1.41 | – |
| 200–1400 | 24 | 1.89 ± 0.06 | 3.80 ± 0.21 | 6.99 | 1.43 | – |
| 0–1600 | 24 | 1.89 ± 0.06 | 2.65 ± 0.20 | 3.38 | 0.69 | – |
| Amur sleeper | | | | | | |
| Test 1 ($n$ = 20) | | | | | | |
| 800 | – | 0.29 ± 0.04 | 0.48 ± 0.06 | 5.04 | 1.00 | – |

**Table 1** (Contd.)

| Illumination regime, lx | Oscillation period, h | Fish weight, g | | Specific growth rate, % per 24 h | Ratio of specific growth rates in control and experiment | Lower lethal oxygen level, mg $O_2$/liter |
|---|---|---|---|---|---|---|
| | | initial | final | | | |
| 700–900 | 24 | 0.29 ± 0.04 | 0.49 ± 0.05 | 5.25 | 1.05 | – |
| 400–1200 | 24 | 0.29 ± 0.04 | 0.54 ± 0.06 | 6.22 | 1.23 | – |
| 200–1400 | 24 | 0.29 ± 0.04 | 0.59 ± 0.05 | 7.10 | 1.41 | – |
| 0–1600 | 24 | 0.29 ± 0.04 | 0.41 ± 0.07 | 3.47 | 0.69 | – |
| Test 2 ($n$ = 10) | | | | | | |
| 800 | – | 0.40 ± 0.05 | 0.65 ± 0.07 | 4.85 | 1.00 | 0.45 |
| 700–900 | 24 | 0.40 ± 0.05 | 0.66 ± 0.06 | 5.01 | 1.03 | 0.42 |
| 400–1200 | 24 | 0.40 ± 0.05 | 0.74 ± 0.06 | 6.15 | 1.27 | 0.40 |
| 200–1400 | 24 | 0.40 ± 0.05 | 0.85 ± 0.05 | 7.54 | 1.55 | 0.37 |
| 0–1600 | 24 | 0.40 ± 0.05 | 0.58 ± 0.07 | 3.71 | 0.76 | 0.47 |
| Test 3 ($n$ = 10) | | | | | | |
| 800 | – | 0.44 ± 0.06 | 0.62 ± 0.06 | 3.43 | 1.00 | 0.38 |
| 200–1400 | 12 | 0.44 ± 0.06 | 0.78 ± 0.06 | 5.73 | 1.67 | 0.27 |
| 200–1400 | 24 | 0.44 ± 0.06 | 0.79 ± 0.05 | 5.85 | 1.71 | 0.27 |
| 200–1400 | 48 | 0.44 ± 0.06 | 0.68 ± 0.06 | 4.35 | 1.27 | 0.29 |
| Test 4 ($n$ = 12) | | | | | | |
| 800 | – | 0.19 ± 0.02 | 0.32 ± 0.05 | 5.22 | 1.00 | 0.81 |
| 600–1000 | 24 | 0.19 ± 0.02 | 0.38 ± 0.04 | 6.94 | 1.33 | 0.72 |
| 430–1170 | 24 | 0.19 ± 0.02 | 0.40 ± 0.04 | 7.45 | 1.43 | 0.64 |
| 250–1350 | 24 | 0.19 ± 0.02 | 0.41 ± 0.03 | 7.70 | 1.47 | 0.60 |
| 0–1600 | 24 | 0.19 ± 0.02 | 0.31 ± 0.04 | 4.90 | 0.94 | 0.77 |

Dabagyan and Sleptsova (1975). After completion of some experiments, the critical level of oxygen concentration for the grown fish juveniles was measured. To do this, fish specimens were placed in respirometers, and after their death, the oxygen concentration was determined using the Winkler method. Statistical processing was done using standard procedures, with the use of the method of paired comparisons (Lakin, 1990).

## RESULTS AND DISCUSSION

In preliminary tests, the optimal constant illuminance conditions were determined for the species under study. The level of 4200 lx was found to be the optimal for carp juveniles, which is somewhat lower than the values reported in the literature (Vlasov, 1991). Most likely this is associated with the use of larger specimens in our experiments, whereas the tests in the cited work were made on larvae. Maximum increments of goldfish and sleeper were registered for illuminance of 800 lx. The control level of 2400 lx was chosen for grass frog tadpoles, since larvae develop in the surface water layers at relatively high illuminance (Bannikov *et al.*, 1971). In the following sets of tests the illuminance was varied about these constant values.

The results of experiments showed that the growth of fish juveniles considerably accelerates in the case of illuminance oscillations within certain limits (Table 1). Increments of juveniles gradually increased with increasing amplitude of illuminance variation. Under the most favorable astatic conditions, the growth rate of carp was 26% higher, and that of goldfish, 29% higher than that at the constant optimum ($p < 0.05$). The effect of growth rate increase was even more pronounced in Amur sleeper: the specific growth rate was 1.41 times as high as the control value ($p < 0.01$). This effect was observed in all the tests. At maximum am-

**Table 2.** Influence of diel illuminance oscillations on growth and development of *Rana temporaria* L. tadpoles

| Illumination regime, lx | Mortality during the test, % | Time from hatching, days | Length, mm | Weight, mg | Coefficient of variation | | Stage of development |
|---|---|---|---|---|---|---|---|
| | | | | | in length | in weight | |
| 2400, control | 6.7 | 15 | 9.0 ± 0.1 | 111.0 ± 4.4 | 8.70 | 29.55 | 40–44 |
| | | 26 | 13.4 ± 0.2 | 291.3 ± 9.8 | 13.40 | 25.28 | 42–48 |
| 1800–3000 | 6.7 | 15 | 9.3 ± 0.1 | 104.6 ± 4.3 | 10.03 | 28.50 | 40–45 |
| | | 26 | 14.1 ± 0.2 | 303.1 ± 9.1 | 12.59 | 22.38 | 42–48 |
| 1000–3800 | 5.0 | 15 | 9.6 ± 0.1 | 108.6 ± 4.0 | 8.87 | 28.43 | 40–45 |
| | | 26 | 14.0 ± 0.2 | 319.1 ± 9.3 | 12.14 | 21.69 | 42–49 |
| 600–4200 | 2.7 | 15 | 10.0 ± 0.1 | 126.6 ± 4.2 | 7.56 | 24.85 | 41–46 |
| | | 26 | 14.8 ± 0.2 | 325.3 ± 8.9 | 11.86 | 20.30 | 43–49 |

plitudes of illuminance oscillations (from “darkness,” 0 lx, up to bright light) the growth rate of fishes decreased. This is likely to result from the strongly negative influence of constant darkness, observed in preliminary tests.

A study of the influence of different photoperiods revealed that the best regimes for growth are those with light oscillation with a period of 12 and 24 hours. The growth rate increased, respectively, 1.14 and 1.15 times in carp, 1.28 and 1.37 times in goldfish, and 1.67 and 1.71 times in sleeper, compared with the control ($p < 0.05$). Illuminance variation with 48-h period raised the increments, but the difference between the test and control mean values was not significant.

It is well known that the resistance to extreme disturbances and the physiological state of a fish are positively correlated. The first parameter characterizes the efficiency of adaptation-compensatory mechanisms and can serve as an indicator of improvement of environmental conditions (Luk’yanenko, 1987). From Table 1 follows that the lower oxygen level lethal for the fish diminishes, which in turn testifies to the more positive effect of astatic illumination on fish juveniles.

**Table 3.** Size characteristics of *Rana temporaria* L. underyearlings after the metamorphosis completion under conditions of astatic illumination

| Illumination regime, lx | Length, mm | Weight, mg | Coefficient of variation | |
|---|---|---|---|---|
| | | | in length | in weight |
| 2400, control | 12.9 ± 0.2 | 219.9 ± 13.3 | 6.60 | 26.27 |
| 1800–3000 | 13.6 ± 0.2 | 253.2 ± 9.7 | 5.48 | 21.09 |
| 1000–3800 | 13.8 ± 0.1 | 272.4 ± 10.6 | 5.46 | 22.69 |
| 600–4200 | 14.0 ± 0.1 | 288.0 ± 8.8 | 5.33 | 18.99 |

Similar results were obtained in a study of the growth and development of the grass frog tadpoles (Table 2). By the end of experiment, the test groups outran the control one in all investigated characteristics. The confidence probability of means’ difference is more than 95%. It should be noted that the survival in the control and in tests was just the same and constituted 93–98%. Along with making the growth rate higher, the illuminance oscillations markedly accelerated the larval development. In all measurements, the experimental specimens outran the control ones by 1–2 stages. Tadpoles passed all the developmental stages on the average in 39.6 days in control, and in 39.4, 36.9, and 34.1 days at illuminance oscillations within, respectively, 1800–3000, 1000–3800, and 600–4200 lx. The duration of tadpole development was much shorter than that observed in nature, being yet in agreement with the experimental results (Pyastolova and Ivanova, 1978; Lyapkov, 1986).

As is known, tadpoles of the grass frog are strongly pigmented and develop in upper water layers (Bannikov *et al.*, 1971), i.e. their growth is probably stimulated by light. Joung pointed to this circumstance as far back as 1883 (cited from Berkovich, 1954). However, other investigations showed the opposite effect (Irikhimovich, 1947), which is probably due to erroneous techniques of tests with metamorphizing tadpoles. Our experiments revealed that the rate of growth and development of grass frog larvae increases under illuminance oscillations, which in turn confirms the dependence of the parameters under study on light.

Underyearlings (= youngs of the current year) raised under variable illuminance were larger than the control specimens (Table 3). For example, at the maximum amplitude of light oscillations, underyearlings were

8.5% longer, and 31% heavier as compared with the control ($p < 0.05$). In all the varying regimes, a tendency toward decrease in the length-weight parameters variability in underyearlings with increasing oscillation amplitude is clearly pronounced, which indicates favorable growth conditions (Polyakov, 1975).

The effect of an increase in fish growth rate under astatic light conditions, revealed in this study, is similar to that caused by oscillations of temperature, salinity, pH, and oxygen concentration (Konstantinov and Zdanovich, 1986; Konstantinov, 1988; Konstantinov and Martynova, 1990; Konstantinov *et al.*, 1995). In the best of the varying regimes used, we observed growth rates much exceeding those recorded under the best constant conditions.

Improvement of the physiological state of fishes was observed along with the growth acceleration, as also in the case of oscillations of other factors (Konstantinov and Sholokhov, 1993). This indicates the nonspecificity of the influence exerted by variable illuminance on the fish growth, inasmuch as the described effect is manifested in a similar way in oscillations of other ecological factors. This conclusion is supported by the favorable effect of light oscillations on the growth and development, demonstrated experimentally for larvae of the grass frog representing another group of vertebrate hydrobionts. Presumably the optimization of the growth and development of living organisms under conditions of a periodic astatic character of environmental factors is a general biological property of both fishes and amphibians.

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