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ECOLOGICAL PHYSIOLOGY
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The Impact of Short-Term Fluctuations of Temperature on the Production Indices of Aquatic Animals: *Oreochromis niloticus* (L.) and *Pistia stratiotes* (L.)

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Abstract—Short-term small periodic fluctuations of temperature within the range of ecological valence are favorable for Nile tilapia *Oreochromis niloticus* L. and water lettuce *Pistia stratiotes* L. At alternate thermal regimes, the specific growth rate is higher, production and energetic indices are better, the efficiency of food utilization for growth is higher, and the expense of oxygen on gaining the mass unit of a fish body is lower when compared to the optimal for constant thermal regimes of growth. During temperature fluctuations, the mineralization rate of dissolved and suspended organic matter increases.

Key words: Nile tilapia *Oreochromis niloticus* L.; water lettuce *Pistia stratiotes* L.; periodic fluctuations of temperature, growth, energetic, and production indices.

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INTRODUCTION

Temperature is one of the most important ecological factors controlling and determining all the main vital processes in poikilotherm aquatic organisms, fishes in particular [3]. A massive body of data on the impact of temperature on various aspects of vital functions in fish and other aquatic organisms has been accumulated. Most often, studies on the influence of temperature on aquatic organisms are performed at constant temperatures forecasted as optimal. At the same time, in natural conditions, variable temperatures are more realistic. Seasonal and diurnal fluctuations of temperature are observed in waterbodies. The amplitude of the latter in moderate latitudes may reach 10–20°C [13]. Diurnal changes of temperature in the subtropic waterbodies reach 3–7°C in spring and autumn; the differences in the temperature of the surface and near-bottom water layers reach 3–4°C [29].

Recently, studies on the algae and aquatic macrophytes [21–23, 43], protozoans [6], rotifers [24], crustaceans [5, 26, 42], mollusks [21, 39], holothurians [32, 33], fish [7–9, 15, 16, 18, 19, 30, 37, 44], and amphibians [14] revealed that certain temperature fluctuations positively affect growth, energetics, the physiological state, and production parameters in aquatic organisms. It was shown that periodic fluctuations of temperature within the range of the ecological norm considerably accelerate the growth rate in fish, amphibians, and invertebrates; decrease the intensity of their respiration and expense of oxygen for an increase in body weight; and increase the efficiency of food utilization for growth. Periodic fluctuations in temperature optimize growth, energetic metabolism, and reproduction in algae and higher aquatic plants. It was noted that the highest metabolic effect in fish is observed at alternate thermal regimes at more frequent fluctuations in temperature with an amplitude of 1–3°C [9].

The goal of this study is to clarify the specific features of growth, energetics, and production indices in Nile tilapia *Oreochromis niloticus* (L.) and macrophyte water lettuce *Pistia stratiotes* (L.) at joint propagation in enclosed recirculation systems in conditions of constant and alternate thermal regimes with short-term periodic temperature fluctuations.

MATERIAL AND METHODS

Juvenile Nile tilapia and water lettuce were raised at constant and alternate temperatures in experimental recirculation devices. Each device consisted of two blocks. Juvenile Nile tilapias (3 to 14 g body weight) were obtained from the laboratory of the All-Russian Scientific Research Institute of Pond Fishery (Rybnoye, Moscow oblast). Water lettuce was raised in laboratory. Nile tilapia and water lettuce were selected as model subjects because these species have similar geographic ranges, a close diapason of temperature optimum, high growth and development rates, they are tolerant to water pollution, and they are important in aquaculture [36, 38, 40, 41].

In the experiments, the water from 40 l tanks with fish was pumped into tanks (volume 10 l, bottom are 600 cm^2) with water lettuce. Then the water was returned to fish. That means the nutrients entering the

Table 1. Stocking density and parameters of the physicochemical parameters during experiments

Parameter	No. of experiment		
	1	2	3
Content in water:			
oxygen, % of saturation	80–90	80–90	80–90
$N\text{-}NH_4$, mg/l	1.5–2.2	1.3–2.6	1.2–2.6
$N\text{-}NO_3$, mg/l	5.5–10.5	5.0–15.0	10.0–16.0
Water turnover rate, l/h	60	60	80
pH	7.2–7.6	6.9–7.3	6.6–7.2
Illumination, lx	3000	3000	3000
Density of stocking fish, g/l:			
beginning of experiment	1.12–1.20	1.10–1.28	3.05–3.41
end of experiment	1.85–2.01	3.34–5.21	7.33–8.86

water with fish excreta served as a source of nutrition for water lettuce. Throughout the whole experimental period, the water was added in aquaria only at the volumes compensating losses for evaporation (≤5% a day). The water in the fish tanks was constantly aerated. In the tanks with constant temperatures (24, 26, 28, 30°C; trial 1) its level was maintained using a thermoregulator with a precision of ±0.5°C. At alternate thermal regimes (26 ± 2 and 28 ± 2°C; trials 2 and 3, respectively) sinusoidal fluctuations of temperature were run automatically in a 3-h period using recording potentiometer KSP-4 equipped with a thermoregulator. The fish were fed Tetra Pond dry food (31% protein, 5% lipids, 2% carbohydrates) at a daily ration of 3% of their body weight. Fish were fed by automatic feeders every 4 h. Throughout all the experiments, the oxygen content (oxygen meter Oxi330i, WTW), ammonium and nitrate nitrogen levels (ion meter Anion–7010, Infraspak–Analit), and pH values (Hi98127, Hanna) were monitored. The fish stocking density and dynamics of monitored parameters are shown in Table 1.

The fish were weighed individually using digital scales with a precision of 0.01 g prior to the experiment and every following 11–13 days. The mean daily body-weight gain and specific growth rate were assessed using the equation $C_w = [(\ln W_2 - \ln W_1)/t] \times 100\%$, where W_1 and W_2 stand for mean body weights (g) at the beginning and end of the experiment, respectively; t is the duration of the experiment, days. In order to assess the efficiency of food utilization for growth, the feeding coefficient was calculated as the proportion of the weight of food consumed for the experimental period to body-weight gain. The intensity of fish respiration was measured using the "interrupted current" technique [12], with an Oxi330i oxygen meter with a precision of 0.01 mg/l O_2. Three to five fish were put in 2.75 l respirometers and the intensities of their respiration were determine in 5–7 replicates every 11–13 days during the experiments with constant and alternate temperature regimes. For further calculations, the intensity of fish respiration was taken as mean for any thermal regime. The oxygen expense for a gain of 1 g body weight in tilapia was also assessed.

Prior to the experiments, each tanks for growing water lettuce was stocked with 15 g of the plant wet biomass. Recirculation devices were illuminated by luminescent bulbs (40 Wt) from top all day long. At the end of experiments, the weight of plants at each thermal regime was measured and the daily weight gain and specific growth rate by wet mass were assessed. To assess the rate of fish and plant production in the recirculation devices at constant and alternate thermal regimes, the values of daily P/B coefficient were calculated as the proportion of weight gain in each organism to its mean biomass for the experimental period.

At each experiment with constant and alternate thermal regimes, the rates of destruction of organic matter were determined using the oxygen method [4]. The dark exposure time of test vials was 4 h. The destruction was calculated as mean values at the beginning, middle, and end of the experiment per water volume in the tank.

The data were processed statistically with the Statistica 6 software package using Student's test.

RESULTS

Prior to the experiments aimed at a comparative study of the growth and metabolism in Nile tilapia at a constant and alternate thermal regimes, a test was carried out in order to find the optimal temperature for fish growth. During this test, juvenile tilapias were raised at constant temperatures (Table 2).

With a rise in temperature from 24 to 28°C in juvenile tilapia of two size groups with mean initial body weights of 4.3 and 12.3 g, the values of the specific growth rate, mean daily body weight gain, and daily P/B coefficient regularly increased while the feeding

Table 2. Growth rate, production indices, and efficiency of food utilization for growth in juvenile Nile tilapia at constant thermal regimes (experiment 1, duration 10 days, $n = 12$)

Thermal regime, °C	Growth rate, % g/day	Weight gain, g/day	Daily P/B coefficient	Food coefficient
24	6.53 / 2.72	0.376 / 0.517	0.063 / 0.029	0.74 / 1.24
26	8.32 / 3.21	0.505 / 0.610	0.078 / 0.035	0.55 / 1.06
28	8.37 / 4.02	0.577 / 0.803	0.078 / 0.046	0.48 / 0.80
30	8.29 / 3.98	0.566 / 0.720	0.077 / 0.042	0.49 / 0.89

Note: Mean initial body weight: (top) 4.3 g; (bottom) 12.3 g; (n) number of fish in experiment.

Table 3. Growth, energetic, and production indices in juvenile Nile tilapia at constant and alternate thermal regimes

Parameter	Temperature, °C							
	24	26	28	26 ± 2	26	28	30	28 ± 2
	Experiment 2				Experiment 3			
Duration of experiment, days	21	21	21	21	24	24	24	24
Number of fish, specs.	12	12	12	12	10	10	10	10
Initial mean body weight of fish, g (±*m*)	3.94 ± 0.38	3.68 ± 0.23	4.16 ± 0.28	4.27 ± 0.18	13.65 ± 0.79	12.21 ± 1.00	12.51 ± 1.02	12.51 ± 0.90
Final mean body weight of fish, g	11.14 ± 0.93**	13.58 ± 0.76*	16.07 ± 0.72	17.38 ± 0.67	29.35 ± 1.47	32.08 ± 2.88	31.38 ± 2.68	35.46 ± 2.69
Fish body weight gain for the experiment, g	86.4	118.8	142.9	157.3	157.0	198.7	188.7	229.5
Body weight gain, g/day	0.34	0.47	0.57	0.62	0.65	0.83	0.78	0.96
Growth rate, % g/day	4.94	6.22	6.43	6.68	3.19	4.02	3.83	4.36
Daily *P/B* coefficient	0.047	0.055	0.056	0.057	0.030	0.037	0.036	0.040
Amount of food consumed for experiment, g	70.5	70.5	70.5	70.5	155	58	157	173
Food coefficient	0.81	0.59	0.49	0.45	0.98	0.80	0.83	0.75
Intensity of respiration, mg O_2/(g · h)	0.472 ± 0.004**	0.565 ± 0.008*	0.687 ± 0.005**	0.526 ± 0.005	0.431 ± 0.002**	0.452 ± 0.006**	0.485 ± 0.002**	0.317 ± 0.003
Amount of oxygen consumed by fish for experiment, g	21.78	29.48	42.03	34.44	53.37	57.55	61.19	43.83
Oxygen expenditure for gain of body weight unit, g	0.252	0.248	0.294	0.219	0.340	0.290	0.325	0.191

* $p < 0.05$, ** $p < 0.01$ – level of significant differences of results from those in alternate temperature regimes in each experiment.

coefficient decreased. At a further rise in temperature from 28 to 30°C, growth was inconsiderably retarded and the weight gain and *P/B* coefficient decreased. The latter was due to the fact that the increasing energy demand approached the gain of energy with food. These data indicate that a constant temperature close to 28°C is optimal for the growth and efficiency of food conversion at relevant conditions of feeding. Our data conform well to the data published earlier [31, 34, 35].

The experimental data on the growth rate, energetics, and production parameters of juvenile Nile tilapia at constant and alternate temperatures are shown in Table 3. At the alternate thermal regimes, all registered parameters in Nile tilapia differ considerably from those observed at constant temperatures. At the 26 ± 2 and 28 ± 2°C alternate regimes, the growth rates in juvenile tilapia were, on average, 1.08 and 1.09 times higher, respectively, than at a constant temperature at the values equal to the mean and upper limits of its oscillation. Compared to the constant optimal for the

Table 4. Growth and production parameters in water lettuce at constant and alternate thermal regimes

Thermal regime, °C	Parameter		
	Growth rate, wet weight, % g/day	Weight gain, g/day	Daily P/B coefficient
24	13.88	3.52	0.128
26	16.31	4.57	0.147
28	19.46	6.22	0.169
30	21.10	7.23	0.179
26 ± 2	17.69	5.25	0.157
28 ± 2	20.95	7.15	0.178

growth temperature optimum of 28°C, the growth rate in tilapia at the alternate regime was 1.06 times higher. A pairwise comparison of specific growth rates in fish at various time periods of the experiments revealed a high statistical significance of differences in the values at alternate and constant temperatures ($p < 0.05$).

Mean daily values of the body-weight gain in tilapia at the studied alternate thermal regimes were, on average, 20% ($p < 0.01$) and 16% ($p < 0.05$) higher than those observed at constant temperatures equal to the mean and upper limits for the cycle of temperature fluctuation, respectively; compared to temperature of 28°C, the values were 11% ($p < 0.05$) higher. The values of the daily P/B coefficient at temperatures of 26 ± 2°C and 28 ± 2°C were on average 1.06, 1.07, and 1.05 times higher than at respective constant temperatures ($p < 0.05$).

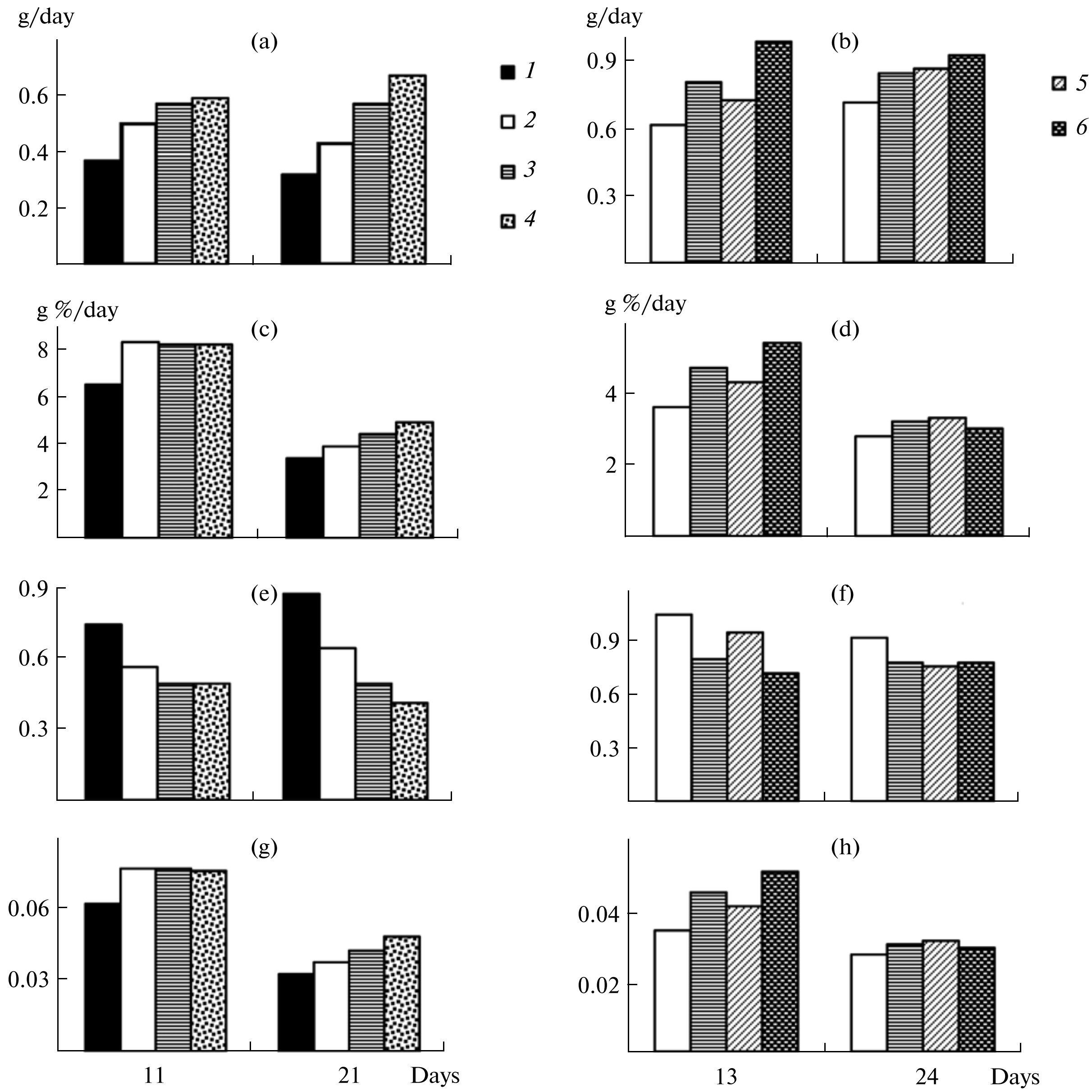
In the conditions of periodical temperature fluctuations, the efficiency of food utilization for growth in Nile tilapia was also much better than at constant temperatures. At a thermal regime of 26 ± 2°C, the values of the feeding coefficient were 24 and 8% lower than at 26 and 28°C; at 28 ± 2°C, they were 6 and 10%, respectively, lower than at 28 and 30°C ($p < 0.001$). The efficiency of food conversion in tilapia at alternate temperatures was on average 7% higher than in conditions of a constant temperature of 28°C optimal for growth ($p < 0.05$).

At short-term periodic fluctuations in temperature, the intensity of respiration in juvenile Nile tilapia was significantly lower ($p < 0.005–0.01$) than at constant temperatures. At the thermal regime 26 ± 2°C, the oxygen consumption values in tilapia were 1.07 and 1.31 times lower than at 26 and 28°C; at the regime 28 ± 2°C, they were 1.43 and 1.53 times lower than at 28 and 30°C respectively. At alternate temperatures, the intensity of respiration in fish was on average 27% ($p < 0.01$) lower than the stationary temperature optimum of 28°C. At alternate thermal regimes, oxygen expense per unit of body-weight gain for the whole experimental period decreased noticeably: on average by 23 and 33% compared to the constant temperatures corresponding to the mean and upper values at the alternate regimes. The oxygen expense per unit of body-weight gain was on average 30% lower ($p < 0.01$) at the fluctuating temperatures when compared to the temperature of 28°C.

The changes in production parameters, growth rate, and efficiency of food conversion in juvenile Nile tilapia during different periods of propagation at constant and alternate thermal regimes are shown in the figure. The optimization of fish metabolism at oscillating temperatures occurs quite quickly. By the first 11–13 days after the start of experiment, at alternate thermal regimes, the mean daily values of the body-weight gain, growth rate, and daily P/B coefficient were higher than their respective values at constant temperatures. At the same time, the food coefficient value decreased. During the following period of propagation, similar patterns of ratios of registered parameters in juvenile Nile tilapia at alternate and constant thermal regimes were observed. The studies have shown that a change in the intensity of the fish metabolism in alternate temperature conditions starts during the first hours and stabilizes after 1–2 days [9, 17].

A similar metabolic effect of the alternate temperature was also observed in water lettuce (Table 4). At a thermal regime of 26 ± 2°C, the growth rate, daily weight gain, and daily P/B coefficient are 1.08, 1.15, and 1.07 times higher than those observed at similar (in terms of sum heat) conditions with a constant temperature of 26°C. At such an alternate regime, when compared to the constant temperature of 28°C, the registered parameters were lower. At the alternate temperature of 28 ± 2°C, registered growth and production indices in water lettuce were 1.08, 1.15, and 1.05 times higher than at the constant thermal regime of 28°C and, in fact, were similar to those at a temperature of 30°C (close to the optimum temperature for this species [40]).

In the recirculation devices with an alternate thermal regime, the destruction rate of organic matter was much higher than at constant temperatures (Table 5). At the thermal regime 26 ± 2°C, the destruction of organic matter was 1.25, 1.20, and 1.16 times higher ($p < 0.01$) than at constant temperatures of 24, 26, and 28°C, respectively; at 28 ± 2°C, it was 1.41, 1.28, and 1.16 times higher ($p < 0.01$) than at 26, 28, and 30°C,



(a, b) Mean daily weight gain, (c, d) growth rate, (e, f) food coefficient, and (g, h) daily P/B coefficient in juvenile Nile tilapia during various stages of growth at constant and alternate thermal regimes: (a, c, e, g) experiment 2; (b, d, f, h) experiment 3; thermal regimes, °C: (*1*) 24; (*2*) 26; (*3*) 28; (*4*) 26 ± 2; (*5*) 30; (*6*) 28 ± 2; (abscissa) time from start of experiment.

respectively. Higher rates of destruction of organic matter at oscillating temperatures evidence an intensification of metabolic processes in microorganisms in these conditions. Similar data on the acceleration of the destruction rate at alternate thermal regimes were also obtained earlier [23].

DISCUSSION

According to the commonly accepted concept of ecology concerning the effects of abiotic environmental factors, certain values of a factor exist that most favorably affect a functioning organism. The diapason of values of an ecological factor meeting this case is treated as the optimum zone. Within this zone, the adaptive mechanisms are "switched off" and the energy is spent only for the fundamental vital processes, providing the maximal productivity of an organism. If abiotic factors deviate from the optimal values, the adaptive mechanisms are "switched on" and their functioning relates to a certain energy expenditure that rises the more the factor deviates from optimal values [28].

In the wild, aquatic organisms always face fluctuations of abiotic environmental factors due to their seasonal and diurnal changes. Vertical and horizontal gradients of quantitative values of various environmental factors are, in fact, always present in natural waterbodies. When aquatic organisms actively move in waterbodies, as well as when they migrate vertically and horizontally, they are subject to fast, sometimes almost momentary, changes in temperature, waterborne oxygen content, pH, and other factors.

Temperature is truly one of the most important abiotic environmental factors. Temperature is extremely important ecologically since, on the one hand, aquatic organisms are quite sensitive to its changes and, on the other, the thermal conditions for the life of these animals are very variable. As an ecological factor, temperature influences the geographic and zonal distribution of aquatic organisms, rates, and patterns of dynamics of various vital processes (respiration, growth, and development particularly); temperature may also have signal importance [3].

For a long time the impact of thermal rhythms on the development and growth of poikilothermal organisms did not garner serious attention. However, V.V. Alpatov [1], D.N. Kashkarov [11], Odum [25], and A.S. Konstantinov [13] described the influence of temperature fluctuations on the processes of growth and development. It was stressed that the “extent” of temperature changes is very important in ecology. Summarizing the published data in his monograph, Odum [25, p. 269] wrote “The vitality of organisms that in the wild are usually subject to fluctuating temperatures is either suppressed fully or partially or retards under the impact of constant temperatures.” In conditions of fluctuating temperatures, the growth, development, and energetic metabolism are optimized and the physiological state of various groups of poikilotherm aquatic organisms becomes better.

In the ciliate *Paramecium caudatum* (Ehrenberg) at thermal regimes with a circadian rhythm of fluctuations with amplitudes of 6, 12, and 20°C, the rate of cleavage was 1.3–3.0 times higher than at an average constant temperature. At the diapason of diurnal fluctuations of temperature to 12°C, the number of degree hours necessary for one cleavage of ciliate decreased sharply [6]. The positive impact of alternate temperatures on the growth, reproduction, development, and energetics was also noted in rotifer *Euchlanis dilatata* (Ehrenberg) [24].

In *Daphnia magna* Straus in conditions of temperature fluctuations within the limits of the tolerant diapason, specific rates of linear and mass growth were accelerated, along with an increase in the absolute weight gain, rate of development, and real rates of population recruitment. In crustaceans living at alternate thermal regimes of 20 ± 2 and 20 ± 5°C, the duration of juvenile period was considerably decreased (by 27.5 and 11.6%, respectively) when compared to the animals living at a constant optimal temperature of 23°C; at the circadian thermal regimes of 23 ± 3°C, the duration dropped by 79% [5]. In amphipod *Gammarus lacustris* (G.O. Sars) in natural conditions, the growth rate is higher if the environmental temperature is more variable. At shallows where mean 3–4°C diurnal fluctuations of temperature were noted, specific rates of growth in the length and weight of amphipods were 18% higher than in ecotopes with less-pronounced (≤0.5°C) diurnal changes in temperature [26].

Table 5. Values of destruction of organic matter in recirculation systems at constant and alternate thermal regimes

Thermal regime, °C	Value of destruction, mg $O_2/(l \cdot day)$	
	Experiment 2	Experiment 3
24	9.15 ± 0.047	–
26	9.56 ± 0.07	7.47 ± 0.03
28	9.87 ± 0.09	8.23 ± 0.04
30	–	9.09 ± 0.03
26 ± 2	11.46 ± 0.07*	–
28 ± 2	–	10.55 ± 0.05*

* $p < 0.01$ compared to relevant constant thermal regimes.

The growth rate in freshwater shrimp *Leander modestus* (Heller) at the oscillating temperature was 23% higher than at the constant optimal temperature. At the same time, at an alternate thermal regime, the intensity of respiration in shrimps was 8% lower, resulting in an average 26% decrease in the energy expenditure per unit of body-weight growth [21]. Within the temperature tolerance diapason, the growth rate in shrimp *Fenneropenaeus chinensis* (Osbeck) was significantly higher at alternate thermal regimes than at constant temperatures equal to the mean temperature values in the cycle of fluctuations. For this species, the amplitude of fluctuations of ±2.0...2.2°C and ±1.4°C is considered optimal at mean temperatures of 25 and 31°C, respectively [42].

In mollusk *Pila* sp., cyclic fluctuations of temperature within the limits of 26 ± 3°C resulted in a 1.84 acceleration in the growth rate when compared to mollusks kept at a constant temperature close to optimal. At the narrower range of temperatures (26 ± 2°C), the effect on growth decreased to 20% [21].

The growth rate in holothurian *Apostichopus japonicus* (Selenka) was considerably faster at diurnal fluctuations of temperature 15 ± 2 and 18 ± 2°C than at control constant temperatures of 15 and 18°C. At the same time, at alternate temperatures, the intensity of respiration in animals decreased [32, 33].

Astatic thermal conditions considerably influence aquatic plants as well. At sinusoidal fluctuations of temperatures of 27 ± 3°C with a 3 h period, as early as after 1 day following the start of temperature fluctuations, the number of cells of *Chlorella vulgaris* (Beyer) and *Scenedesmus quadricauda* (Breb.) were 1.56 and 1.17 times higher, respectively, than at an optimal stationary temperature of 27°C. By the end of the experiment, the numbers of algae were 1.81 and 1.25 times higher than in the control. Elodea *Elodea canadensis* (L. C. Rich.) responded to inconsiderable sinusoidal fluctuations of temperature in a similar manner. On average, by the 14th day of growth, its growth rate at a fluctuating thermal regime 26 ± 2°C was 36% higher than at 26°C. The intensities of photosynthesis in algae and elodea under an alternate thermal regime were 13–19% higher. As opposed to photosynthesis, the intensity of respiration in aquatic plants rose considerably at fluctuating temperatures [10].

The growth rate in macroscopic alga *Ulva pertusa* (L.) was significantly higher in conditions of circadian thermal regimes of 20 ± 2 and 20 ± 4°C when compared to the constant temperature of 20°C. It is accepted that a ±3.7°C amplitude of temperature fluctuations at the mean value of 20°C is optimal for the growth of alga. At alternate thermal regimes, considerable changes in the biochemical composition of *Ulva pertusa* thallomes were also observed: at alternate temperatures, the contents of chlorophyll, proteins, and carbohydrates were significantly higher than at constant temperatures [43].

Studies on more than 20 species of eurythermic and stenothermic fish revealed that, at alternate thermal regimes, the observed growth rates are always higher than at constant optimal temperatures. It was found that, in eurythermic fish species, within the limits of their ecological valence, the ±3...5°C amplitude of temperature fluctuations is most favorable for growth; in stenotherm species, the optimal amplitude is ±1...1.5°C. Along with an acceleration of the growth rate at oscillating temperatures, the intensity of fish respiration and the daily ration decrease, resulting in a sharp increase in the efficiency of food conversion and a decrease in the energy expenditure per unit of bodyweight gain. The optimization of the energy metabolism and growth in fish at an alternate thermal regime is accompanied by an improved physiological state of animals, an increase in their tolerance to extreme impacts of environmental factors, and a decline in their mortality rate. Periodic changes in the temperature cause considerable changes in the biochemical compositions of fish: the water content of the tissue decreases while the levels of lipids and proteins rise [7–10, 14, 16–20].

Fluctuating thermal regimes optimize the vitality in various groups of aquatic organisms. This presumably represents a general biological principle: the necessity of continuous breaks of homeostasis with further recovery due to the relevant adaptive mechanisms being triggered. Studies by H. Selye [27] and I.A. Arshavskii [2] have shown that the short-term impacts of weak and moderate stressors result in physiological stress (eustress) accompanied by an increase in the intensity of anabolic processes and a rise in the nonspecific resistance of an organism. Weak short-term stress impacts in natural conditions form the background of physiological stimuli positively influencing all vital processes.

CONCLUSIONS

Short-term periodic fluctuations of temperature within the limits of the stationary temperature optimum for Nile tilapia and water lettuce cause a significant increase in the growth rate and an improvement of the production and energetic parameters in aquatic organisms when compared to the parameters observed at constant thermal regimes optimal for growth. In conditions of an oscillating temperature, the efficiency of food conversion by tilapia increases over the stationary temperature optimum; the intensity of fish feeding and expenditure of oxygen per gain of body weigh unit decreases. The values of the daily P/B coefficient in tilapia and water lettuce at alternate thermal regimes are noticeably higher than in conditions of constant temperatures. The higher rate of destruction of organic matter in the water of recirculation devices with alternate thermal regimes indirectly indicates a higher abundance of bacterial plankton in these thermal conditions when compared to constant thermal regimes.

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