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The Correction of the Physiological Status of Carp *Cyprinus carpio* by Natural Chemical Signals

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Abstract—The study of the effect of isolation and starvation in juvenile carp *Cyprinus carpio* showed different changes in their physiological state. The isolation of fish causes stress but the starvation of isolated fish does not increase stress and even slightly decreases it. The differences determined under isolation and starvation manifest themselves in typical changes in biochemical parameters of superficial mucus in carp and the indices of physiological status of fish. External metabolites produced by carp contain substances, which have signal importance and inform the individuals of this species about the presence of the school and physiological status of other individuals (their stress and satiety). The metabolites inform isolated fish of the presence of the fish group and, thus, correct stress state that appears in the tendency for normalization of the biochemical parameters. The perception of metabolites, produced by a group of fish donors, is accompanied by biochemical changes in isolates. Observed effects suggest the effect on biochemical status of fish isolates of external metabolites produced by carp of different physiological state and their differentiated perception by recipients. External metabolites of fish can participate in protective-adaptive reactions of the organisms.

The effects of some natural chemical signals are known to cause the changes in physiological status of fish. Sexual pheromones possess the primary effect and stimulate the development of sexual glands in fish providing in such way the synchronization of spawning (Sorensen, 1992). The chemical signals of danger, alarm pheromone in carp, and stress pheromone and alarm kairomone (the smell of predatory fish) cause not only behavior and protective responses (Malyukina *et al.*, 1977), but also significant metabolic changes (Lebedeva *et al.*, 1991 and 1994). The character of these changes attests to stress development and the appearance of hemoglobin in skin mucus of fish is a sign of this (Lebedeva and Golovkina, 1987).

The present study was aimed at the investigation of the possibility in correcting the physiological status of carp *Cyprinus carpio* caused by isolation or starvation by means of natural chemical signals, regulating food, and social behavior of fish.

MATERIALS AND METHODS

Carp yearlings of a mean weight 20 g were the study subjects. The experiments were carried out at a water temperature from 18.5 to 21°C. A total of 60 fish were used in the experiments. The external metabolites (EM) of carp, obtained during the holding of five individuals in the 50 l aquarium for one day, were used as chemical stimuli. The external metabolites obtained from fish, which were fed once a day *ad libidum* by frozen midge larvae of Chironomidae, were labelled EMs. The external metabolites obtained from yearlings kept in similar conditions, but not received food during 10 days, were labelled EMh. Freshly prepared 0.1 g/l water extract of midge larvae, which was diluted to 0.001 g/l before giving it to the experimental fish, served as a food chemical stimulus. The mixture of EMh and midge extract solution, in which the ratio between both stimulus solutions was 1:1, was also used as a chemical stimulus.

In the first series of the experiments, biochemical parameters of mucus were determined every day for 15 days in nourished fish kept in a group in a common aquarium. The holding conditions were similar to those in fish that were EMs donors.

The series from 2 to 4 were carried out with carp held individually in 10-l aquariums with porous filters and forced water aeration. Half of the water in the aquariums was replaced every day with pure, freshly settled water or with a solution of one of the chemical stimuli.

In the second series of the experiments, pure, freshly settled water was used during the first 15 days for the partial replacement of water in the aquariums with single fish fed every day by frozen midge larvae *ad libidum.* The individuals maintained in a group serve as the control. After 15 days, experimental fish were divided into two groups. Pure water was added during the subsequent 10 days to the first group and EMs was added to the second group (experimental). Biochemical parameters of mucus were determined every 24 h in fish from control and experimental groups.

In the third series of the experiments, experimental fish were not fed for 10 days. Pure water was used for partial replacing of aquarium water during this period and the solution of midge extract, EMh, or their mixture was added to the aquariums on the 10th day. The determination of chemical composition of mucus was performed every 24 h after giving the stimulus solution. Intact hungry isolates were the control.

In the fourth series of the experiments, the starvation period of single fish was 20 days. After this time, EMs was added to the aquariums and the biochemical parameters of mucus were determined after 2, 24, and 48 hours. Normally, fed isolates were a control. The concentrations of hemoglobin, bilirubin, urobilinogen, protein, ketones, specific weight, and pH value were determined in fish mucus in vitro by an express method with reagents immobilized in solid carrier in multilayer color film (*Ames*, USA) (Lebedeva and Golovkina, 1990). A mean value of these parameters was calculated by 10 estimations, the total number of which comprised about 2500. Statistical analysis of the results was carried out with the non-parametric Mann-Whitney test (U).

RESULTS

Biochemical parameters of mucus in intact fish under a held group (first series)

Bilirubin, urobilinogen, and nitrites were not found in the mucus of nourished fish regularly kept in a group. The pH and specific weight of mucus were of 7.0 and 1.012 g/cm^3 respectively and these parameters did not change during the whole period of observation. The fluctuations of hemoglobin, protein, and ketone concentrations in fish mucus were observed in a chronic experiment (Fig. 1) and the tendency for a decrease in protein concentrations from 1.3 to 0.8 g/l was observed during this period. Hemoglobin concentrations in intact fish had no such character of changes and ranged from 100 to 160 μg/l.

The effect of isolation and EMs (second series)

Maximum biochemical changes in mucus in fish under isolation were found in hemoglobin concentrations. These concentrations in isolates were 2.5 times higher than in carp kept in a group. Hemoglobin concentrations ranged within 180–300 μg/l (Fig. 2a). A sharp increase in hemoglobin in mucus occurred in the first days of isolation then its concentrations stabilized at new level. Protein and ketone concentrations were more stable in isolates than in fish kept in a group (Figs. 2b, 2c).

Biochemical changes in the isolates of fish were corrected by external metabolites from the fish group. When EMs were offered to experimental fish, hemoglobin concentrations in their mucus decreased in the first 3 days of the experiment by 57, 44, and 37%, respectively, in comparison with the control isolates (Fig. 3a). The trend for an increase in hemoglobin concentrations in fish remained in subsequent days and its concentrations were similar to those in carp isolates by the end of the experiment. Ketone concentrations in isolates had a tendency to increase under the effect of EMs (Fig. 3b). Protein concentrations in experimental fish were somewhat higher than in the control ones during all 10 days of the experiment (Fig. 3c).

The effect of starvation and EMh (third series)

The offering of EMh midge extract or their mixture to isolates (not received food during 10 days) caused the decrease in hemoglobin concentrations in mucus by 76, 56, and 44%, respectively, and an increase in protein concentrations in fish mucus by 27, 73, and 15%, respectively, after 24 h. Ketone concentrations decreased by 30% only under the effect of EMh (table).

The effect of starvation and EMs (fourth series)

Long starvation of isolates (during 20 days) caused changes in the biochemical parameters in mucus (Fig. 4). Concentrations of protein and hemoglobin decreased and concentrations of ketones increased. Hemoglobin concentrations in mucus of isolates increased under the effect of EMs to 164% after 2 h (table), but decreased to 122% during the two subsequent days. The effect of EMs caused the increase in

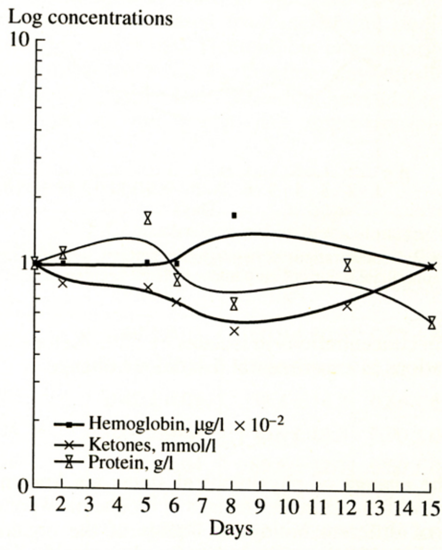

Fig. 1. Concentrations of hemoglobin, ketones, and protein in superficial mucus of carp under group keeping of fish.

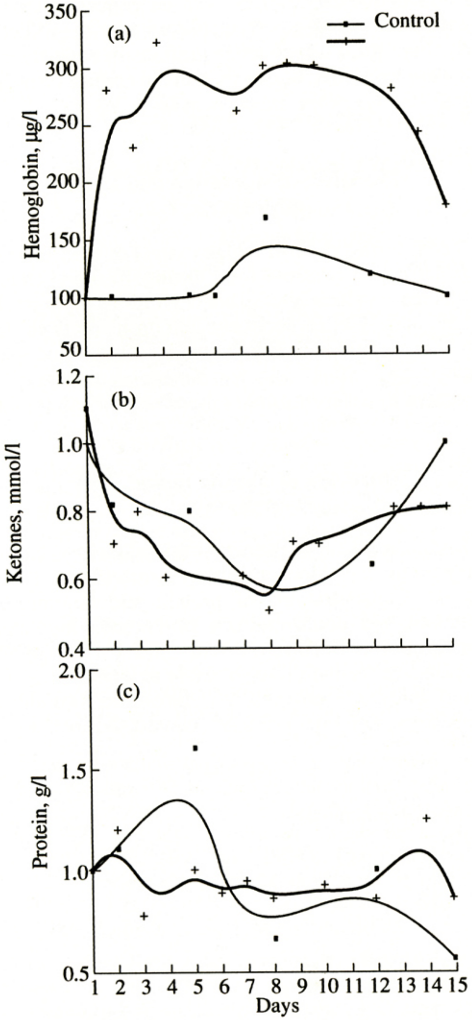

Fig. 2. Concentrations of hemoglobin, ketones, and protein in superficial mucus of carp under isolated keeping of fish.

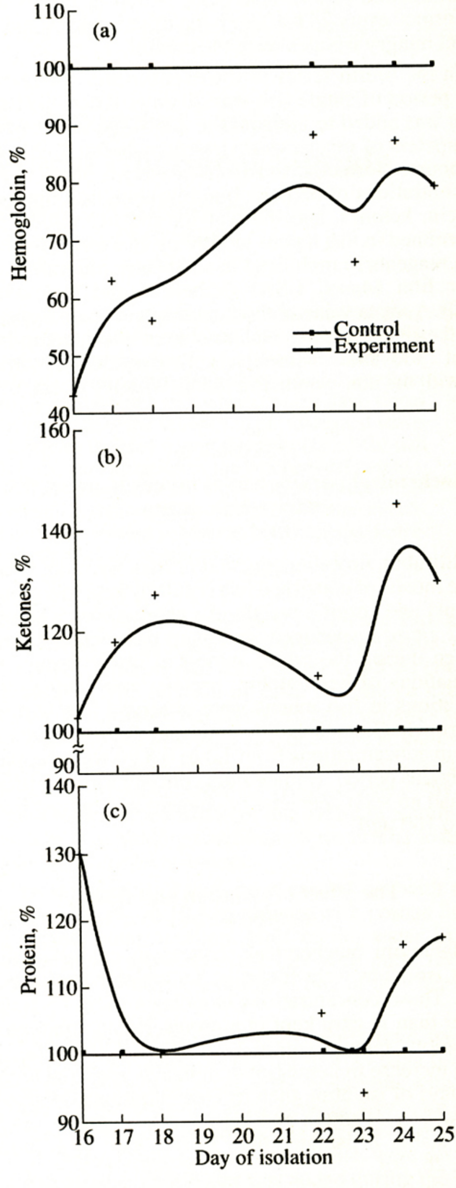

Fig. 3. Effect of external metabolites of carp (under group keeping) on concentrations of hemoglobin, ketones, and protein in superficial mucus of isolated carp individuals.

protein concentrations in isolates by 52%. Ketone concentrations in experimental fish did not change.

DISCUSSION

The change of physiological status are known to appear in animals in the changes of biochemical parameters of different biological liquids of the organism (Natochin, 1984), particularly of such a specific liquid as superficial mucus. The changes of physiological status in fish can be adequately assessed by the changes in sodium and potassium concentrations and their ratio (Lebedeva *et al.*, 1988, 1989) and concentrations of hemoglobin, ketones, and protein in mucus (Lebedeva *et al.*, 1993). We succeeded in determining the appearance of hemoglobin in mucus in fish under stress in many of the studied fish species, both peaceful and predatory, salt-water and fresh-water, and in *Cyprinus carpio, Hypophthalmichthys molitrix, Ctenopharyngodon idella, Clarias lazero, Mugil soiuy, Sebastes marinus, Misgurnus fossilis, Gymnocephalus cernuus*, and *Tinca tinca*, (Lebedeva *et al.*, 1998). It is shown that hemoglobin concentration under stress varies proportionally to the intensity of stress development (Lebedeva and Golovkina, 1987, 1989) and correlates with fish excitability. High excitability of silver carp to the effect of a stress factor is accompanied by biochemical changes, which significantly exceed those in carp. The range of biochemical changes in silver carp under stress exceed the changes of significant parameters by 10 times (Lebedeva *et al.*, 1991). All these facts confirm the existence of the species specificity in metabolic response in fish under the effects of stress factors and allow us to consider hemoglobin concentrations in mucus to be a good stress indicator. The development of this syndrome is accompanied by the changes of ketone and protein concentrations in mucus. The biochemical changes under stress are directed at the adaptation of an organism to new conditions and simultaneously reflect these conditions and serve as the indicator of the syndrome. Every biochemical parameter serving the stress criterion has its own features.

Our experiments demonstrated that isolation caused significant changes of metabolism in carp, which are similar to those observed under stress. Protein and ketone concentrations in isolates by the end of the experiment exceeded those in fish kept in a group. Distinct similarity in the character of ketone and protein changes (decrease of concentrations) was found in the latter. A significant increase of hemoglobin concentrations in mucus of fish kept individually in comparison with fish kept in a group suggests the development of stress syndrome in isolates. These changes occur quickly, at least a day after fish isolation (i.e., the stress under isolation develops in carp during first two days).

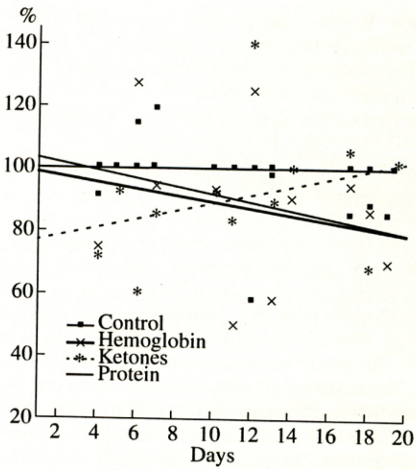

Fig. 4. Effect of starvation and isolation on concentrations of hemoglobin, ketones, and protein in superficial mucus of carp.

Short handling is inevitable in the procedure of mucus sampling for the determination its biochemical composition. The stress effects of handling can be ignored because all fish, both controlled and experimental, were subjected to this procedure. Fishes were not subjected to the effects of other manipulation stress, particularly, to those connected with the relocation procedure. It should be noted that the fish-recipient and fish-donor of external metabolites were in the same physiological status, namely, decreased food excitability (fed regularly and in full value). Hemoglobin concentrations in isolates increased during the first three days of isolation then stabilized at the level exceeding hemoglobin concentrations in the group fish approximately by

The effect of natural chemical signal substances on isolated carp individuals during starvation

Object	Effect	Time of the effect, h	Concentrations of biochemical parameters		
			ketones, mmol/l	hemoglobin, μg/l	protein, g/l
Control, satiated isolates			0.60 ± 0.03	160.0 ± 10.5	0.52 ± 0.04
Hungry isolates	10 days, adding the EM from a hungry group		0.55 ± 0.04	140.0 ± 9.4	0.47 ± 0.03
		24	0.42 ± 0.08	38.4 ± 14.3	0.66 ± 0.07
	midge extract	24	0.60 ± 0.06	70.0 ± 15.8	0.90 ± 0.08
	summary effect	24	0.60 ± 0.04	89.6 ± 12.1	0.60 ± 0.06
Hungry isolates	20 days, adding of EM from satiated groups		0.60 ± 0.04	112.0 ± 8.1	0.44 ± 0.02
		2	0.53 ± 0.06	262.4 ± 24.9	0.79 ± 0.07
		24	0.53 ± 0.04	196.8 ± 12.5	0.52 ± 0.04
		48	0.53 ± 0.04	195.2 ± 10.7	0.49 ± 0.05

2.5 times. Ketone and protein concentrations in carp mucus under isolation also reached a new level of stability. The observed changes of the physiological status in carp under isolation can be considered as biochemical adaptive reactions to changed environmental conditions.

Carp do not belong to typical schooling fish, which are characterized by a high level of social association. We can consider that isolation can be even more stressful for the latter and cause sharp disturbances in many physiological and biochemical parameters. Isolation from a school causes a sharp increase in oxygen consumption (more than in 1.5 times) in minnow *Phoxinus phoxinus*. The combination of several single individuals into one group normalizes respiration (Malyukina, 1966). The isolation of schooling fish from one another can manifest itself in the decrease of mobility, suppression of the research activity, and longer acclimation to new conditions. In single individuals of *Pollachius virens*, adaptation to aquarium isolation and the beginning of feeding occurs three times slower than in fish kept in a group (Leshcheva and Zhuikov, 1989). Adaptation after capture and the placement in artificial conditions in such typical schooling fish as *Clupea harengus* occurs more slowly and less than in a school of experimental fish. Sometimes, individual isolation had such a significant suppressive effect that part of a fish died off some time later, yet had not begun to feed (Gerasimov, 1983). Schooling fish are more alert and fearful of being isolated or in small schools (Itazawa *et al.*, 1978). Returning to a school or providing visual contact with a school leads to normalization of the behavior of individuals (Radakov and Mochek, 1972). The biological significance of these changes is connected with the important role of school behavior for fish (Radakov, 1972). The isolation acts as a stress factor for schooling fish. Stress reaction in fish with a single mode of life is also observed under the changes of social status and the stress is caused by the artificial joining of individuals of the same species. The joining of even two individuals of rainbow trout *Oncorhynchus mykiss* in one aquarium caused a significant increase in the cortisole level in blood plasma and a decrease in the amount of circulating lymphocytes (Pottinger and Pickering, 1992). This is connected with establishment of the hierarchy between the individuals. The offering of EM from dominant, and especially from subdominant individuals, caused the development of stress even in single fish of this species (Petrauskene *et al.*, 1997). Consequently, every disturbance of normal social contacts in fish can cause the development of stress.

It was determined in the present study that biochemical changes caused by isolation can be corrected by offering EMs and EMh from fish. There are apparently substances in EM which possess the informative function for isolates. These chemical signal substances possess a sedative effect on individual carp under stress. EM has an especially significant effect at the beginning of the impact on isolates. However, regular (during 15 days) effects of metabolites on isolates do not normalize the studied parameters completely. The antistress effect of EM had not actually been observed by the end of the experiment. We are inclined to attribute such dynamics of the EM effect to the fact that a single impact of EM was not followed by the offering of other biologically significant signals (visual, seismosensory, etc.), which are typical for the school. The observed effect is in agreement with reflex theory.

We believe that the obtained results will be taken into consideration in the experimental works with carp and other species. The normalization of the physiological status did not occur even after 15 days of isolation. Stress in fish can be accompanied by all the symptoms signs of syndrome development.

Behavioral responses in fish to food chemical signals are characterized by a high diversity of manifestations. At the beginning of a behavioral response to the smell of food in fish, the rhythm and amplitude of opercular motions increase, "the cough" and typical twitching motions of the fins are observed, and fish orientation changes, etc. (Jones, 1992). The phase of food excitement is quickly replaced by the proper food search reaction, which is closely correlated in fish with the mode of life, general strategy of food behavior, and development and participation of sensory systems in searching for prey (Pavlov and Kasumyan, 1998). The sensing of food causes aggravation of domination-subordination relationships in fish with expressed intragroup hierarchy (Kasumyan and Ponomarev, 1986). Numerous available data on the effect of food smell on fish deal with releaser characters of these signals. The data on primary effect of food chemical signals are very limited. The use of artificial forage with food chemical stimulators is known to cause a significant increase in the activity of digestive enzymes and increase in the rate of fish growth (Takeda and Takii, 1992). Our results demonstrate that the primary effect of food extracts appears also in the significant displacement of metabolic processes in fish under stress. The characteristic of these changes attests to the sedative effect of natural food chemical stimuli on fish. The realization of this effect is apparently based on the olfactory system, because there are many sense of smell signals for which the well expressed primary effect was determined: preovulatory sexual pheromones (Sorensen, 1992), natural signals (alarm pheromone, alarm kairomone) of danger (Malyukina *et al.*, 1977; Lebedeva and Chernyakov, 1978; Lebedeva and Golovkina, 1994), and chemical signals regulating intragroup hierarchy interactions of fish (Petrauskene *et al.*, 1997). The gustatory and general chemical sensitivity also takes place in the formation of food behavior of fish (Pavlov and Kasumyan, 1990). There are no available data on the lagged effect of chemical signals, perceived by these two chemosensory systems, regarding the physiological status of fish. The concentration of midge extract (0.001 g/l) used in this work exceeds the threshold of olfactory sensibility of carp, which was determined early to exist 10^{-4}–10^{-5} g/l (Kasumyan and Ponomarev, 1990). Olfactory deprivation causes the loss of the ability in carp fish to give a behavioral response to the smell of food (Kasumyan and Ponomarev, 1989).

It is known that starvation is widely distributed in fish as a physiological phenomenon. Starvation was shown to cause insignificant changes in the functioning of the main physiological systems in animals (Ugolev, 1961). For example, hemato-physiological parameters do not change in the course of adaptation to the absence of food (Vosilene *et al.*, 1999). However, protein concentrations in blood serum decrease under starvation and functional features of enzyme proteins in tissues are disturbed (Sorvachev, 1982). We determined earlier that undernourishment and change of the diet and long laboratory confinement cause the decrease in the total amount of proteins and changes of their qualitative composition in superficial mucus of minnow (Lebedeva and Burlakov, 1975).

The tendency for the decrease in hemoglobin and protein concentrations is observed under the starvation of carp isolates. This attests that starvation of these fish does not lead to an increase in stress. On the contrary, the tendency for some decrease is observed. Hence, we can assume that starvation is not a stress factor for fish. Insignificant changes in the metabolism in carp isolates under starvation agree with known data that the intensity of the metabolism does not increase under starvation (Sorvachev, 1982). It is known that hunger excitement is suppressed under neural (for example, stress) overstrain (Selye, 1950). We believe that the obtained results confirm this fact at the metabolic level.

It is shown that changes from the EMs offering are similar to stress changes and cause a short-term increase in hemoglobin concentration after only 2 h. Then this parameter decreases but complete normalization was not observed.

The differentiated metabolic response was observed in carp isolates when the "chemical outline" of the school of satiated and hungry fish was offered. EMh provide a normalizing effect on the metabolism in hungry isolates. The food extract also had a sedative effect on hungry isolates appearing in the decrease of hemoglobin concentration but slightly less. The impact of these stimuli was accompanied by the sedative effect on hungry fish stressed by the isolation. The hemoglobin concentration did not increase under the effect of these stimuli even after 24 h.

It was interesting to study a simultaneous combined effect of starvation and isolation (these factors are often observed in natural conditions) on carp. The absence of an additive effect in the case, when EMh and the food extract were offered to isolates, makes it possible to assume that these two stimuli induce similar metabolic reactions in the organism. Midge extract similar to EMh provides a correcting effect and causes a sharp decrease in hemoglobin concentration; i.e., EMh and extract (odor) of food provide a sedative effect in hungry fish stressed by isolation. Hungry and isolated fish responded in an opposite manner to the offering of EMs. This factor caused stress changes in hungry isolates. We cannot talk about the unambiguous effect of "chemical outline" of a school on isolates. It should be noted that the opposite effects of EMs and EMh are observed even at a metabolic level. Protein concentration in isolates is also normalized under the effect of EM from fish group and the ketone concentration in mucus did not change under the effect of EM from the fish group. This parameter attests to the metabolic changes and is connected first of all with disturbances in feeding. It was found earlier that the effect of biologically active compounds depends on the physiological state of the organism (Ashmarin and Kamenskaya, 1988).

Hence, the reaction of fish to EM is determined by the ratio of the physiological states of the donor and recipient. The effects of studied stimuli manifest themselves more clearly in isolates against the background of the changes under starvation. The correction of stress by EM in hungry individuals also increased in comparison with those fed regularly. Immature carp of the same age group (juveniles), similar weight and size, were used in the experiments that allowed us correctly to compare the determined effects of EM.

The great number of combinations of separate factors determines the environmental conditions and adaptive reactions to these factors are also characterized by significant diversity. We believe that the functional importance of EM in carp has an adaptive character. Vernadskii noted that "There is not any other connection amongst the living bodies of the planet and the environment than the biogenic migration of atoms organic substances, discharged by organisms during the process of their life activity into the environment, and are most important in biogenic migration of the substances" (Vernadskii, 1977).

The estimation of biochemical parameters in carp mucus makes it possible to determine the limits of these parameters, which represent the biochemical characteristics of the species. The latter well agrees with our results obtained earlier in the study of biochemical composition of mucus in carp from different regions. However, the monitoring of such biochemical parameters as hemoglobin, ketones, and protein showed some fluctuation of these parameters under the same conditions of chronic experiments.

The fluctuation of biochemical parameters, as it was shown earlier (Lebedeva and Golovkina, 1998), correlates with heliophysical factors, intensity of solar activity, and radio emission that allow by our opinion for an explanation in the fluctuations of biochemical parameters in long-term experiments. The observed fluctuations of biochemical parameters in intact fish can reflect the effects of endo- and exogenous factors on the physiological status of an organism. It is known that the response of an organism to environmental changes is formed at different levels of life. The observed biological rhythm of the changes and its synchronization with heliophysical rhythms can also reflect the normal physiological state of an organism. We observed the changes under the shifts in the physiological state that manifest themselves in correlation with the studied biochemical parameters with a value of heliophysical factors estimated on different days of the experiment. Determined shifts in the synchronization of biochemical and heliophysical rhythms can be the result of changes in the physiological status of an organism. Observed desynchronization of the rhythms can be connected with stress development and can be one of its indicators. The changes in physiological status can appear in the changes of the concentration range for biochemical components or in desynchronization of their rhythms with periodical fluctuations in environmental parameters.

Environmental factors and physiological status also provide a correcting effect on fish reaction towards the biogenic chemical stimuli (Pavlov and Kasumyan, 1990).

The idea of the environment obtains a specific meaning in the study of the environmental adaptability of the organisms and in the character of the resulting changes of in physiological processes in the organism. Heliophysical environmental effects and adaptability of organisms to them can serve one of the environmental characteristics. These effects can also be summed up by the effects of other environmental factors and affect the value of an organism response. Such investigations elucidate the characteristics of properties and the role of environmental factors, forecast on the basis of modeling of the environment its effects of physiological status of fish, and to find out causal interactions between these factors. "The determination the mechanisms of the variability and plasticity of the physiological status of an organism as a reflection of the biochemical process of adaptation to the conditions of the changing environment is an important task of ecological biochemistry" (Koval'skii, 1982). The study of the biochemical nature of adaptations to the effects of natural factors as well as determination of the mechanisms of reactions and causal interaction between these mechanisms and environmental factors is a promising trend, because "in the system environment-organism, deep metabolic connections are established in the latter with environmental factors" (Vernadskii, 1977).

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