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REVIEW

Bioindication using Fish and its Role in an Integrated Assessment of the Condition of Coastal Ecosystems: a Review

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Coastal ecosystems located near cities, industrial and agricultural facilities are under significant anthropogenic influence. The complexity of modern anthropogenic impact on coastal ecosystems does not always make it possible to determine the quantitative content of all pollutants. The traditional methods used make it possible to assess physical and chemical indicators, but they do not provide a comprehensive assessment of the impact on the biological system. The use of bioindication methods that reflect the response of aquatic organisms to the complex influence of the environment is extremely relevant. Fish are a large group of vertebrates and inhabit a wide range of ecosystems where they are exposed to many different aquatic pollutants. In bioindication studies, both morphophysiological and biochemical indicators of fish are widely used. The use of morphophysiological indicators makes it possible to assess the impact of environmental factors on the organism, as well as the specifics of its adaptation to environmental changes. Due to the development of biochemistry and molecular biology, such new techniques appear that make it possible to determine the impact of an environmental factor at those stages when changes occur at the cellular, membrane and molecular levels, and do it before this impact leads to irreversible pathological processes. The use of bioindication methods, that reflect the reaction of biota to the entire complex of negative environmental influences, is a relevant and promising method. The review examines in detail modern bioindication methods based on determining the morphophysiological and biochemical parameters of fish, and also assesses the role of the bioindicator approach in a comprehensive assessment of the state of the environment.

Key words: bioindication, biomarkers, coastal ecosystem, complex pollution, fish, stress

At all times human activities had a profound impact on the life of coastal ecosystems located near the cities, industrial and agricultural facilities. An aquatic ecosystem, like any other, is in balance with environmental factors and has a complex system of mobile biological connections that are disrupted under the influence of various anthropogenic factors (Volkova *et al.*, 2018).

As a result of anthropogenic activities, wastewater, runoff from agricultural land and water transport enter the sea, various toxicants accumulate in bottom sediments, the physical and chemical properties of soil water change, as a result of which there is a negative effect on living organisms. Hydrobionts absorb pollutants and accumulate them, that causes intoxication and reorganization of metabolic processes (Rudneva *et al.*, 2016a; Malakhova *et al.*, 2018; Skuratovskaya *et al.*, 2020).

Monitoring of the marine coastal region (as part of the overall global monitoring system) is an important area of scientific and practical activity. It is necessary to have an integrated approach to study the characteristics of coastal regions and for settlement of the existing problems.

The complexity of modern anthropogenic impact on marine coastal ecosystems does not always make it possible to determine the quantitative content of all pollutants. Even special highly sensitive and expensive analytical methods do not always allow the determination of effective low concentrations of xenobiotics. In addition, many biologically active substances are unstable and disintegrate in a short time after interaction with a biological target.

The biological method for assessing the state of ecosystem components makes it possible to solve problems that cannot be solved using other research methods. Bioindication (gr. bios - life, lat. indico - determine, indicate) refers to the determination of biologically significant loads based on the reactions of living organisms and their communities to them, as well as assessment of the quality of the environment based on the state of its biota.

Biodiagnostic indicators reflect the organism's response to various influencing factors and have a biological meaning. Bioindication in natural communities often provides the only opportunity to obtain information about the influence of environmental parameters and their interactions. Thus, biological monitoring does not replace physicochemical methods for studying the state of the environment, but it makes it possible more accurate prediction of the changes in the environment caused by human activity (Volkova *et al.*, 2018). Various international organizations have recommended the use of biodiagnostic methods that reflect the response of living organisms to the entire complex of negative influences of the environment as a whole (Chesnokova *et al.*, 2020). The main goal and task of bioindication is the search and development of methods and criteria that adequately reflect the level of anthropogenic impacts.

Special methods for determining pollution come down for assessment of the degree of change in the morphometric, physiological and biochemical parameters of the biota. Living bioindicator organisms can serve as «biosensors» of ecosystem pollution.

It is necessary to have a system for a comprehensive assessment of the ecological state, which includes an analysis of abiotic factors and the effects of action on living organisms (Filenko and Chuiko, 2017). On the one hand, the system of comprehensive assessment of the ecological state of water areas is based on the concept of connecting the dose of an influencing stress factor with the level of severity of the response of organisms, and on the other hand, the cause-and-effect relationships of biological responses at different levels of biological organization (Chuiko and Klimova, 2018).

Various indicators of hydrobionts, such as size-weight, morphophysiological, biochemical and other characteristics, can be used as biomarkers. It is quite obvious that the processes that have been occurred in the body of aquatic organisms under the influence of unfavorable factors can be characterized only with the comprehensive use of biomarkers of different levels (Rudneva, 2016).

In order to detect early metabolic changes in the body of aquatic organisms, molecular biomarkers are used. They make it possible to determine the mechanisms of influence of negative environmental factors in a complex

and identify the features of structural and functional changes when adaptive and compensatory mechanisms are activated. They help to determine existing risks, and carry out environmental protection measures in due time. (Skuratovskaya *et al.*, 2020; Chesnokova *et al.*, 2020; Luk'yanova and Korchagin, 2017; Kroon *et al.*, 2017; Rudneva *et al.*, 2016a).

The relevance of issues related to nature protection has led to improvement of diagnostic methods for assessement of the state of ecosystems, thereby it determines the prospects for expanding the bioindication method.

The presence of a large number of publications indicates the potential and successful use of ichthyofauna as an indicator of the state of aquatic ecosystems. Fish integrate the adverse effects of a complex of different influences. They have quite significant sizes and life expectancy, resistance to sublethal effects of various substances, and can be used to predict various impacts on aquatic ecosystems.

SELECTION OF BIOINDICATORS: HISTORY AND PRESENT

The presence and state of the bioindicators as organisms, as well as their communities, can be evidence of the occurrence of certain processes or the presence of certain pollutants in the environment. The history of observations of living objects as an indicator that characterizes the state of the environment goes back to the deep past. People have been using living creatures as sensitive indicators of environmental pollution since ancient times.

Even before the advent of hydrobiology as a separate science, there were made many attempts to study the inhabitants of the aquatic environment. In 1674, the Dutch naturalist Antonie van Leeuwenhoek described Spirogyra and the effect of wind on it (Egerton, 2006). In 1826, the Swiss scientist De Candolle made the first scientific description of the algae bloom process. In 1838, in his famous work, the German naturalist Christian Ehrenberg for the first time depicted and described in detail many lower algae, rotifers and protozoa (Ehrenberg, 1838). Detailed studies of planktonic organisms date back to 1845 and are associated with the name of the Danish biologist Otto Muller. The German scientist Johann Müller was the first to use a fine-mesh net to catch plankton (Otis, 2007).

Researchers have been thoroughly investigated the usage of aquatic organisms as indicators of water quality and studying responses to various adverse impacts. For example, it was found that vorticellas may indicate ooze contamination (Reynoldson, 1942).

At the beginning of the 20th century, the biodiagnostics began to develop intensively. At that time, «bioindication» meant the determination the presence/absence of a particular phenomenon, notation according to the yes/no principle. In modern conditions, the development of theoretical foundations and methodology for analyzing the response of biological systems to complex influences is considered one of the priority tasks of bioindication.

Currently, bioindicators (biomarkers) mean not only the organisms themselves, but also biological test systems, that are based on the lower levels of organization of biomatter: biological molecules, cellular structures, cells. Modern biochemical techniques have made it possible to develop test systems that determine the impact of an environmental factor at stages characterized by changes at the molecular, membrane, cellular levels (before the pathological processes become irreversible). Biochemical monitoring based on such test systems has found wide application in ecotoxicological analysis.

Indicative biomarkers are the components of the protective immune and antioxidant systems. Their reorganization allows to determine the state of the organism under the influence of unfavorable factors (Winston and Giulio, 1991). Biochemical parameters are the fastest and most sensitive to damaging factors. During a long stay of an organism in unfavorable conditions, changes occur at higher levels of organization, up to the population level. Studies have shown that in fish from polluted waters, the structure of cells and tissues disruptes due to the development of pathological processes and the accumulation of toxicants (Dorohova and Novoselova, 2010; Hinton and Lauren, 1990; Lang *et al.*, 2006).

There are a large number of bioindicators used to study water quality. They demonstrate a variety of reactions to water pollution: death, changes in the type and rate of reproduction, migration to more favorable conditions, accumulation of pollutants in tissues. A single species,

several species, or the entire aquatic ecosystem as a whole can act as a bioindicator. Being in water - their natural habitat - they truly indicate the hydroecological state of water bodies. At the same time, feedback is also noted: the purity of a water body depends on the functional activity of the community of organisms in it. This leads to the formation of a vicious circle: the state of the ecosystem depends on the quality of the water, and the quality of the water itself depends on the state of the ecosystem.

Like any method, bioindication has certain limitations (Chuiko and Klimova, 2018), such as the necessity to involve specialists; it should also be noted that bioindicators are in some cases unable to identify the main cause of changes occurring under the combined influence of a large number of factors, and adequate universal scales for measuring the level of responses have not been developed yet (Kotegov, 2007).

The biodiagnostic method is used in the study of systems of various ranks. Levels of bioindication are distinguished in accordance with the organizational level of biological systems: intracellular reactions (physiological, biochemical), organism's reactions, population-dynamic changes, changes in natural communities, biogeocenotic level, landscape changes.

The advantage of bioindication is the ability to reduce the use of complex analytical methods. Bioindicators integrate biologically significant effects of pollution and make it possible to determine the rate of changes, zones of accumulation of pollutants, and also predict the degree of danger of substances or their combinations for biota.

The importance of the indicator is determined by the ecological tolerance of a biological system; the organism has the ability to maintain homeostasis within the tolerance zone. A factor that goes beyond these limits is stressful, that leads to a response of the organism that differs in intensity and duration. The nature of the response depends on the species and specifies its indicator value (Melekhova. *et al.*, 2007).

Individual taxa, ecological groups, physiologically similar organisms (for example, with the same type of nutrition), and size groups are used for bioindication of water pollution. Water body are characterized by the abundance of species the inhabitants, the complexity of their interaction with each other and with the environment, that was the reason for the appearance of variety of methods for assessment of the state of natural waters.

BIOINDICATION USING FISH

To obtain an integral assessment of the state of the ecosystem, it is convenient to use fish as a bioindicator. Specialists of the national aquatic toxicology have accumulated significant material on the effects of certain substances on the fish. The presence of a large number of publications indicates the potential and successful use of ichthyofauna as an indicator of the state of aquatic ecosystems (Fig. 1).

An important tool for bioindication of the ecological state of coastal waters is the assessment of various biochemical indicators of fish, that help to identify the mechanisms of influence of a set of factors on certain parts of metabolism, that identify the main strategy of structural and functional changes in the organism in the process of adaptation to unfavorable life conditions (Malakhova *et al.*, 2020).

In the trophic system of water body, fish are located at the upper level. The ability of effective metabolization and elimination of the toxicants determines the degree of resistance of the organism in conditions of intense pollution. Pathological changes in the organism serve as a criterion for the degree of toxicity of the aquatic environment, assessment of cumulative effects, which allows us to form an idea of the potential danger of pollutants.

In the 1970s, methods for the pathophysiological study of fish became widespread. Currently, the effects of various toxicants on the fish, as well as numerous biochemical, physiological and morphological disorders that arise as a result of such exposure, have been widely studied.

The preference of choice of the bioindicator species, preference is given to bottom representatives, as sensitive indicators of water pollution, whose structural and functional characteristics are a promising element of a water pollution monitoring system. Benthic organisms are most susceptible to the effects of chemical pollution. Due to the supply of toxic substances from bottom water layers and soil, their content in the food sources of benthic

organisms is increased. Benthic forms are often predators and are characterized by a sedentary lifestyle, resulting in the accumulation of pollutants leading to the development of oxidative stress, damage to cells, organs and tissues, and functional disorders (Rudneva *et al.*, 2016b; Sole *et al.*, 2009).

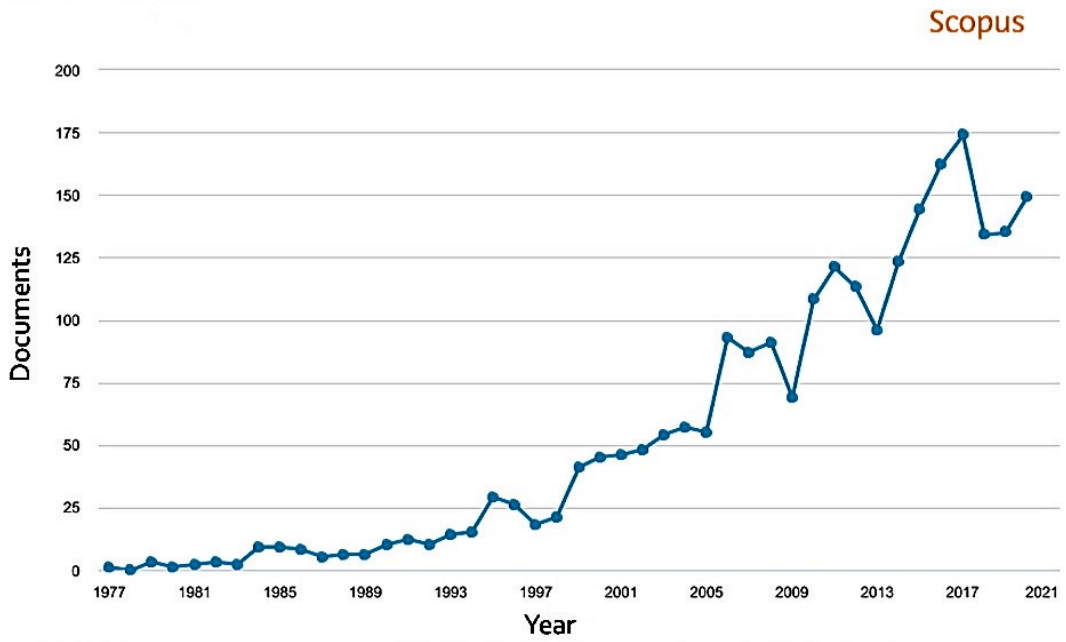

Figure. 1. Dynamics of the number of publications related to issues of biomonitoring and ichthyofauna (search results in the Scopus database upon request *TITLE-ABS-KEY (fish AND biomonitoring))*

The scorpionfish *Scorpaena porcus* L. is a biomonitor species, a typical representative of the coastal bottom ichthyofauna of the Black Sea from the scorpionfish family (Scorpaenidae). Among the Black Sea fish, the scorpionfish is widely used as a bioindicator for assessing the ecological state of water areas (Rudneva, 2016).

It is important to determine the age of individuals (based on scales, bones and otoliths). There are differences in the response to the effects of substances in different age groups, as well as the severity of the studied parameters.

For indicator assessment of the physiological state of fish, biometric data, blood parameters and functional activity of vital hematopoietic organs are used. As the internal environment of the organism, blood quickly reacts to changes in factors affecting the state of the fish. Hematological indicators make it possible to determine both changes in the health of fish during acute diseases and toxicosis, and their stress state during chronic diseases. Quantitative and morphological hematological analysis makes it possible to determine the characteristic properties of metabolism at different stages of development and under different conditions of existence of the organism. For the more profound study of the state of the organism, it is necessary to study physiological processes and the immune system; one of the methods for physiological and immunological assessment of the state of aquatic organisms (with intravital sampling of blood and hemolymph) is described in detail in (Pronina and Koryagina, 2017). Thus, in conditions of changing environmental factors, a comprehensive analysis makes it possible to assess and monitor the physiological state of the body.

Morphophysiological parameters of hydrobionts as biomarkers of the quality of the aquatic environment.

Pollution of the aquatic environment causes increased work of the vital organs of fish that ensure exchange with the environment (gills, liver, kidneys). The intensification of the function of a particular organ is accompanied by an

increase in their weight. Therefore, changes in the weight of organs during their functional restructuring can serve as a sensitive indicator of deterioration in the quality of the environment. There was developed a method for morphophysiological indication of the relative weight of organs (Moiseenko, 2000).

The use of morphophysiological indicators makes it possible to assess the impact of environmental factors on the organism, as well as the features of its adaptation to environmental changes. The essence of the method is based on the variability of individual morphophysiological characteristics, one can judge the physiological state of the organism. According to the theory of Academician S.S. Schwartz, the weight of an organ is a morphological feature, but the size of organs such as the liver or kidneys so clearly reflects the physiological state of animals that it becomes possible to use them as a physiological indicator (Shvarts *et al.*, 1968). Having the morphophysiological indication method as the basis for the manifestation of adaptive reactions allows us to get an accurate idea of the functioning of the organism and its adaptation to certain life conditions.

The size of organs is related to the size of the organism, therefore, the method of morphophysiological indicators uses such parameters as total length, total weight and somatic weight (weight without organs) (Bozhko, 1969).

Indices of aquatic organisms' organs are used among the morphophysiological indicators in bioindication studies. It is known that the indices of fish organs reflect their physiological status and can characterize the effects of stress. The value of the indices largely depends on various factors: living conditions, the presence of chemicals in the environment, infectious diseases. A clear relationship has been established between the level of pollution and indices of fish organs, characterizing the state of both the individuals themselves and their habitat (Dzyubuk and Klyukina, 2010; Zhidenko, 2008; Rudneva, 2016).

The study of *Gymnocephalus cernuus* (L) populations from various water bodies using the method of morphophysiological indicators made it possible to assess and predict the state of the species' populations under changeable environmental conditions (Dzyubuk and Klyukina, 2014).

The liver index is widely used in ichthyomonitoring as a sensitive indicator for assessing the condition of fish and their habitat (Dzyubuk and Klyukina, 2010; Zhidenko, 2008; Rudneva, 2016).

In aquatic toxicology, an informative indicator of the condition of fish is the index of the immunocompetent organ - the spleen. A study of this parameter for Black Sea fish showed that this index less depends on gender, as well as the season of the year, however, a downward trend was noted for the benthic ichthyofauna, which is influenced by chronic pollution. The spleen index is also successfully used in acute and subacute experiments on fish (Kuzminova, 2008; Lapirova, 2011). According to various sources, the physiological adaptation of aquatic organisms is influenced by both endogenous and exogenous factors - water temperature, food availability, reproductive cycles and environmental pollution (Chelyadina *et al.*, 2019; Rouane-Hacene *et al.*, 2015; Lagade *et al.*, 2015).

Biochemical parameters of hydrobionts as biomarkers of the quality of the aquatic environment.

We use various biochemical indicators to detect the earliest changes in the metabolism of aquatic organisms. They indicate the presence of a pollutant and its effect on organisms (Pronina and Koryagina, 2017). Currently, there have been developed such complexes of biomarkers that characterize certain aspects of toxicant metabolism. They indicate the effect at the molecular and cellular levels (Chesnokova *et al.*, 2020; Fonseca *et al.*, 2011; Kroon *et al.*, 2017; Rudneva *et al.*, 2016a; Serafim *et al.*, 2012).

Such parameters as protein concentration, indicators of antioxidant protection and oxidative stress, and many others are widely used as molecular biomarkers.

It is important that during the monitoring programs biochemical blood parameters mainly reflect the state of health of the organism and quickly respond to the action of various unfavorable factors (Rudneva *et al.*, 2016b).

Blood plasma proteins perform many functions in the organism; the level of total protein is one of the most

important laboratory indicators. The concentration of total serum protein in the blood of fish sensitively reflects the characteristics of the functional state of the organism and is very changeable under the influence of various factors, at the same time, the amplitude of such variability can be quite large. The protein content in the blood serum of fish is used to determine the level of physiological state during infection with parasites and fish poisoning with toxicants (as a rapid test) (Andreeva, 2012).

The tissues of aquatic organisms are often analyzed for the content of various xenobiotics for diagnostic purposes. Such xenobiotics can cause significant metabolic disorders and damage to the most important biomolecules. In this case we can analyse the degree of such disorders, the adaptive or toxic response of the organism to the quality of the environment using the special biochemical parameters (biomarkers) (Rudneva *et al.*, 2011).

It is a necessary step to study the activity of conjugation enzymes in the tissues of organisms for understanding the nature of various pathologies caused by xenobiotics. We use biological test systems . They are based on the study of detoxification enzymes in tissues.

Enzymes are widely used as biomarkers of environmental pollution by various pollutants, as well as indicators of oxidative stress in living organisms. They participate in the binding and inactivation of a wide range of xenobiotics. (Gallagher *et al.*, 2001).

The presence of xenobiotics in the environment triggers a complex mechanism of their detoxification, that results in the formation of ROS, which have the ability to damage biological molecules. The organism's protective antioxidant system is aimed at inactivating free radicals and toxic products of their metabolism (Menshchikova and Zenkov, 1993).

Complex water pollution causes oxidative stress in the tissues of organisms, accompanied by an imbalance of prooxidant-antioxidant processes. The responses of the main antioxidant enzymes express the response of nonspecific defense systems to the action of unfavorable factors and, therefore, can characterize the quality of the environment and its suitability for habitation (Rudneva *et al.*, 2011).

Antioxidant enzymes include superoxide dismutase (SOD), catalase (CAT), peroxidase and glutathione-dependent enzymes.

Thus, the antioxidant defense system, including enzymes and low molecular weight compounds, ensures the integrity and stability of all living organisms. The study of these parameters is becoming increasingly important due to the increasing anthropogenic impact on the aquatic environment, which mobilizes the protective functions of the organism in order to adapt to living conditions. This gives grounds to use these indicators to assess the state of the organism under the influence of various unfavorable factors.

Under normal conditions, the oxidant/antioxidant system has a balanced ratio of components at a relatively low level. Under the influence of certain environmental factors, including pollutants, the balance in the system is disrupted, which can ultimately lead to pathological disorders in the organism and its death. In aquatic ecotoxicology, biomarkers of the state of oxidative stress (SOS) are actively studied in aquatic organisms (Klimova *et al.*, 2017; Binelli *et al.*, 2015) in order to assess their functional state and for biodiagnostics of the state of the aquatic environment. SOS biomarkers of aquatic organisms demonstrate a clear response to all the main currently known types of pollutants: heavy metals, polychlorinated biphenyls, dioxins, polycyclic aromatic hydrocarbons, organochlorine pesticides, pharmacological drugs, etc.

It can be assumed that a shift in the prooxidant-antioxidant balance is one of the first nonspecific stages in the development of the stress response and can serve as a biologically important change in the internal environment of the cell that triggers other protective mechanisms.

Such pollutants that constantly enter the marine environment, petroleum products, heavy metals and pesticides pose a significant danger.

Intoxication with petroleum hydrocarbon products stimulates oxidative stress in the organism, causing a response from the antioxidant enzymatic system. An increase in the activity of SOD, CAT, glutathione-s-transferase and lipid peroxidation was found in Nile tilapia *Oreochromis niloticus* being exposed to crude oil (Gad, 2011). Also, there was noted an increase in the activity of

SOD and CAT in the presence of petroleum products in the environment, that indicates the tandem nature of these enzymes, that provide the first line of defense during oxidative stress (Sturve *et al.*, 2006).

According to available data, heavy metals contribute to the intensification of free radical oxidation processes and, as a consequence, the induction of the organism's defense systems (Golovanova, 2008).

There was revealed an increase in the activity of antioxidant defense systems under exposure to pollutants of various chemical natures (Ozkan *et al.*, 2017). Taking into account previously mentioned information the parameters of the antioxidant system and indicators of oxidative modification of proteins and lipid peroxidation are effective biomarkers of the condition of aquatic organisms and the quality of their habitat.

Another important direction is the study of the influence of toxic substances on the activity of aminotransferases in fish tissues. Alanine aminotransferase and aspartate aminotransferase are important for living organisms (Kori-Siakpere *et al.*, 2010). The level of activity of these enzymes changes in the presence of xenobiotics in the fish, and can be used to assess the pollution of water bodies with various toxic substances.

Distinguished by their significant susceptibility to the action of natural and anthropogenically caused factors, these enzymes take part in the responses of both the body as a whole and the liver as the main organ of xenobiotic detoxification to changes in the state of the external environment (Jung *et al.*, 2008; Kori-Siakpere *et al.*, 2010; Oluah, 1999). The effect of heavy metals on the activity of these enzymes in various organs and tissues of fish is being actively studied. Scientists are interested in studying the effect of plant toxins (saponins, cyanides, alkaloids, etc.) on the state of the ichthyofauna (Gabriel *et al.*, 2009).

Determination of cholinesterase activity under various exposures is a convenient and rapid test for assessing the toxicity of many chemical compounds (Rudneva *et al.*, 2016b; Gad, 2009; Rudneva *et al.*, 2016a). Research data indicate a decrease in cholinesterase activity (as a result of enzyme inhibition by toxicants) in the tissues of fish from areas with high levels of pollution (Gad, 2009; Rudneva *et al.*, 2016a).

Studies conducted on fish indicate that cholinesterase activity in tissues can be used as biomarkers in ichthyomonitoring of water bodies contaminated with pesticides (Kovyrshina and Rudneva, 2014).

One of the works (Nemova and Vysotskaya, 2004) describes a unified integrated approach or indicator system of biochemical indicators, that takes into account modern environmental and biochemical paradigms and contains various internal controls that increase the reliability of the data obtained with a small specimen. A comprehensive system of tests has been developed, that takes into account the ecological and taxonomic variability of objects, the stages of their ontogenesis, the necessity to use different tissue organs in analyzes, the use of various controls, as well as the development and use of field biochemistry methods.

Work (Mashukova *et al.*, 2019) provides examples of the use of modern biophysical and biochemical methods in monitoring the coastal waters of Sevastopol. The presented materials indicate that the choice of the type of bioindicator and the methods used for the assessment of the state of marine ecosystems is determined by the monitoring tasks and the research environment.

The use of fish blood biomarkers to assess the condition of coastal marine waters was the subject of a study (Rudneva *et al.*, 2008), that examined the content of toxic elements Zn, Cu, Hg, Pb, Cd and As in the tissues of Black Sea fish, as well as their impact on the activity of key antioxidant enzymes in the blood. It has been established that copper content has the greatest effect on enzyme activity.

There was studied the influence of the content of toxic elements (Zn, Cu, As, Pb, Hg, Cd) in the muscles of Black Sea fish on the concentration of modified forms of proteins and medium molecular peptides in serum was studied (Rudneva *et al.*, 2011).

In the study (Moiseenko *et al.*, 2005), to assess the geochemical background and anthropogenic load on the bioaccumulation of trace elements in the body of fish, a comparative description of the content of a number of trace elements (Ni, Cu, Sr, Al, Zn, Co, Mn, Pb, Cd, Hg, As) in the body of fish is presented, and the patterns of their accumulation depending on their content in water are

considered. The main disorders associated with the accumulation of microelements in the organs and tissues of fish are identified.

Many works are devoted to the study of the characteristics of the accumulation of chemical elements by fish, including heavy metals (Lapin *et al.*, 2016; Lukyanova, 2001).

The effect of pollution on the parameters of oxidative stress in fish was studied in (Shaida *et al.*, 2015), the results of it demonstrate the presence of oxidative stress in the liver of fish caught in a contaminated area. One of the potential methods for assessing the level of oxidative stress in individuals is the chemiluminescence method (Vladimirov, 2001).

In work (Rudneva *et al.*, 2005), the morphophysiological and biochemical parameters of the scorpionfish living in two bays with high anthropogenic load, located in the area of Sevastopol, were studied. The was revealed the influence of natural and anthropogenic factors on the size, weight, age and sex composition of both populations. There was found out the relationship between the concentration of organochlorine pollutants in bay water, the accumulation of these compounds in the liver and gonads of fish, the activity of antioxidant enzymes in the blood and the fractional composition of serum proteins. There was considered the possibility to use the scorpionfish as a biomonitor species when analyzing the ecological situation in the coastal waters of the Black Sea.

In (Dorohova and Novoselova, 2010), researchers analyzed the parameters of the liver index, endogenous intoxication and activity of liver aminotransferases of *Scorpaena porcus* from Sevastopol bays with different levels of anthropogenic load. The research results showed certain differences in the liver responses of male and female fish to the level of anthropogenic pollution. The conducted studies allow us to conclude that the ecological state of the habitat significantly affects metabolic processes in the liver. The variability of abiotic and biotic factors in combination with anthropogenic load causes an increase in the variability of the liver index, changes in the activity of aminotransferases and activation of endogenous intoxication processes.

The study (Rudneva, 2012) examined the antioxidant defense of marine fish and its relationship with their ecological status. The results showed that the antioxidant status of fish correlated with their phylogenetic position, trophic strategies, feeding behavior, environmental variables, swimming activity, etc.

The work (Lushchak, 2016) described oxidative stress in fish caused by pollutants. In many cases, the harmful effects of pollutants are associated with the induction of oxidative stress. Therefore, deciphering the molecular mechanisms leading to such pollution and the response of organisms may prevent or minimize the deleterious effects of oxidative stress.

During the studies molecular biomarkers of anthropogenic pollution in the liver of the fish *Neogobius melanostomus*, there was revealed the dependence of the level of biotransformation enzymes and low-molecular antioxidants on the degree of pollution and the spectrum of xenobiotics. It is proposed to use liver biomarkers of *Neogobius melanostomus* to assess the state of fish under conditions of chronic exposure to persistent xenobiotics (Karapetyan *et al.*, 2011).

The work (Tsema, 2015) presents the results of studies of the physiological and biochemical parameters of *Neogobius melanostomus* from different water areas of the Sea of Azov during the spawning period. The negative impact of environmental pollution on the reproductive quality of spawners in some study areas has been shown.

A review (Van der Oost *et al.*, 2003) examined a wide range of bioaccumulation markers used to demonstrate the exposure to environmental contaminants with respect to their usefulness in environmental risk assessment. Fish bioaccumulation markers can be used to reveal the behavior of environmental pollutants in the aquatic environment, as bioconcentrators to identify certain substances and assess the impact on aquatic organisms. The impact of environmental pollutants on aquatic ecosystems can be examined to assess the following set of fish biomarkers can be examined: biotransformation enzymes (phases I and II), oxidative stress parameters, biotransformation products, stress proteins, metallothioneins, hematological, immunological, reproductive, endocrine, genotoxic, neuromuscular, physiological, histological and morphological parameters. Many of the biological measurements represent the only

way to integrate effects on a large number of individual and interacting processes in aquatic organisms. Moreover, biological and biochemical effects may link the bioavailability of the necessary compounds to their target organ concentrations and intrinsic toxicity.

Fish metalloproteinase as biomarkers of environmental pollution are considered in (Hauser-Davis *et al.*, 2012). Several proteomic studies have demonstrated the validity and value of using fish for the search and discovery of new biomarkers. The metallometric approach is at an early stage of development, but has already demonstrated great potential for use in the context of environmental monitoring.

A case study of fish health in ports explores the integration of multiple fish health biomarkers. To compare the interpretation of results based on individual biomarkers with interpretation based on multivariate analysis, a case study was conducted that examined the physiological states of two fish species collected from two ports located in Western Australia (Gagnon and Rawson, 2016).

Non-invasive methods for measuring the condition of fish (measuring the concentration of cortisol in the mucus on the skin of fish as a biomarker of the quality of the habitat) are discussed in (Carbajal *et al.*, 2019). Mucus cortisol levels have proven to be a good indicator of stress in individuals exposed to various stressors. The study's findings provide the first evidence that cortisol levels in skin mucus may be influenced by environmental quality.

Thus, numerous publications indicate the successful use of fish as indicators of the state of aquatic coastal ecosystems.

CONCLUSION

We can conclude that fish are convenient objects in research, the purpose of which is to establish the degree of influence of various factors on a living organism. Assessment of various biochemical indicators of fish (as representatives of aquatic organisms) is an important tool for bioindication of the ecological state of coastal waters and forms the basis of biochemical monitoring, which is currently widely used in environmental and toxicological analysis. The use of bioindication methods, reflecting the reaction of biota to the entire complex of negative environmental influences, is a relevant and potential method. An important task is to expand the bioindication direction in monitoring the state of coastal waters, the selection of bioindicator species and biomarkers by which the state of aquatic organisms and their habitat can be assessed.

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CONFLICT OF INTERESTS

The authors declare that they have no potential conflicts of interest.

REFERENCES

Andreeva I.M. (2012) Principles of organization of blood proteins and stabilization of the internal fluid environment of the fish body. *Materials of the Conf. Physiological, biochemical and molecular genetic mechanisms of adaptation of aquatic organisms*, 9-14. (in Russian)

Binelli A., Della Torre C., Magni S. and Parolini M. (2015) Does zebra mussel (*Dreissena polymorpha*) represent the freshwater counterpart of Mytilus in ecotoxicological studies? *Environmental Pollution*, 196, 386-403.

Bozhko A.M. (1969) Liver as a morphophysiological indicator of fish habitat conditions. *Scientific notes of the Leningrad Pedagogical Institute named after A.I. Herzen*, 422, 38-46. (in Russian)

Carbajal A., Soler P., Tallo-Parra O., Isasa M., Echevarria C., Lopez-Bejar M., Vinyoles and Towards D. (2019) Non-Invasive Methods in Measuring Fish Welfare: The Measurement of Cortisol Concentrations in Fish Skin Mucus as a Biomarker of Habitat Quality. *Animals (Basel)*, 9(11), 939.

Chelyadina N.S., Pospelova N.V. and Popov M.A. (2019) Comparative Characteristics of Indices to Assess the Quality of Mussel Production by an Example of

Cultivated *Mytilus galloprovincialis* (Crimea, the Black Sea). *Turkish Journal of Fisheries and Aquatic Sciences*, 19(9), 719-726.

Chesnokova I.I., Sigacheva T.B. and Skuratovskaya E.N. (2020) Comparative Analysis of Hepatic Biomarkers of Black Scorpionfish *Scorpaena porcus* Linnaeus, 1758 from Sevastopol Water Areas (the Black Sea) with Different Pollution Levels. *Water Resources*, 47, 486-490.

Chuiko G.M. and Klimova Ya.S. (2018) Parameters of oxidative stress state in freshwater and marine water bivalves as biomarkers of anthropogenic impact of water environments: comparative study. *Pollution of marine environment: ecological monitoring, bioassay, standardization*, 298-301. (in Russian)

Dorohova I.I. and Novoselova J.V. (2010) Peculiarities of morphophyisiological and biochemical parameters in scorpionfish liver inhabiting in bays with different anthropogenies influence. *Current problems of physiology and biochemistry of aquatic organisms,* 2, 44-48. (in Russian)

Dzyubuk I.M. and Klyukina E.A. (2010) The morphophysiological characteristics of ruffe from Lachta lip of Onego lake. *Current problems of physiology and biochemistry of aquatic organisms: Proc. of the III Int. Conf. and Young Scientists School*, 46-48. (in Russian)

Dzyubuk I.M. and Klyukina E.A. (2014). Morphophysiological analysis of ruffe (*Gymnocephalus cernuus* L.) local population near the Raantasaari island in lake Ladoga by variation statistics methods. *Bulletin of the Nizhny Novgorod University named after N.I. Lobachevsky,* 4(1), 214-221. (in Russian)

Egerton F.N. (2006) A History of the Ecological Sciences, P. 19: Leeuwenhoek's Microscopic Natural History. *Bull. of the Ecological Society of America*, 87, 47-58.

Ehrenberg C.G. (1838) Die Infusionsthierchen als vollkommene Organismen. Ein Blick in das tiefere organische Leben der Natur. L. Voss, Leipzig.

Filenko O.F. and Chuiko G.M. (2017) Aquatic ecotoxicology in Rissia: from past to present. *Transactions of the Institute for Biology of Inland Waters Russian Academy of Sciences*, 77(80), 124-142. (in Russian)

Fonseca V.F., França S., Serafim A., Company R., Lopes B., Bebianno M.J. and Cabral H.N. (2011) Multi-biomarker responses to estuarine habitat contamination in three fish species: *Dicentrarchus labrax, Solea senegalensis* and *Pomatoschistus microps*. *Aquat. Toxicol*., 102, 216-227.

Gabriel U.U., Obomanu F.G. and Oveh O.D. (2009) Enzymes in selected tissues of catfish hybrid exposed to aqueous extracts from *Lepidagathis alopecuroides* leaves. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 8(9), 856-864.

Gad N.S. (2009) Determination of glutathione related enzymes and cholinesterase activities in *Oreochromis niloticus* and *Clarias gariepinus* as bioindicator for pollution in Lake Manzala. *Global Veterinaria*, 3(1), 37-44.

Gad N.S. (2011) Oxidative stress and antioxidant enzymes in *Oreochromis niloticus* as biomarkers of exposure to crude oil pollution. *International Journal of Enviromental Science and Engineering*, 1, 49-58.

Gagnon M.M. and Rawson C.A. (2016) Integrating Multiple Biomarkers of Fish Health: A Case Study of Fish Health in Ports. *Archives of environmental contamination and toxicology*, 70(2), 192-203.

Gallagher E.P., Gross, T.S. and Sheehy K.M. (2001) Decreased glutathione-S-transferase expression and activity and altered sex steroids in Lake Apopka brown bull heads (*Ameiurus nebulosus*). *Aquat. Toxicol.*, 55(3–4), 223-237.

Golovanova I.L. (2008). Effects of heavy metals on the physiological and biochemical status of fishes and aquatic invertebrates. *Inland Water Biology*, 1(1), 99-108. (in Russian)

Hauser-Davis R.A., de Campos R.C. and Ziolli R.L. (2012) Fish metalloproteins as biomarkers of environmental contamination. *Rev. Environ. Contam. Toxicol*., 218, 101-123.

Hinton D.E. and Lauren D.J. (1990) Integrative histopathological approaches to detecting effects of

environmental stressors on fishes. *Am. Fisheries Soc. Symp.*, 8, 51-66.

Jung H., Kim S.-J., Lee T.-K. *et al.* (2008) Biomarker response in caged rockfish (*Sebases schlegeli*) from Masan Bay and Haegeumgang, South Korea. *Marine Pollution Bulletin*, 57(6-12), 599-606.

Karapetyan O.Sh., Tsema N.I. and Dudkin S.I. (2011) Molecular biomarkers of anthropogenic pollution in liver of the round goby, *Neogobius melanosotomus*, from the Taganrog Bay. *Problems of Fisheries*, 12, 747-759. (in Russian)

Klimova Y.S., Chuiko G.M., Gapeeva M.V. and Pesnya D.S. (2017) The Use of Oxidative Stress Parameters of Bivalve Mollusks *Dreissena polymorpha* (Pallas, 1771) as Biomarkers for assess the impact of chronic anthropogenic pollution in various areas of the Rybinsk Reservoir. *Siberian Journal of Ecology*, 2, 210-217. (in Russian)

Kori-Siakpere O., Ikomi R.B. and Ogbe M.G. (2010) Variations in alanine aminotransferase and aspartate aminotransferase activities in African catfish: *Clarias gariepinus* (Burchell, 1822) at different sublethal concentrations of potassium permanganate. *Scientific Research & Essays*, 5(12), 1501-1505.

Kotegov B.G. (2007) Organization of biological monitoring in the zone of influence of a production facility: method. Instructions. UdGU, Izhevsk. (in Russian)

Kovyrshina T.B. and Rudneva I.I. (2014) Fish cholinesterases as biomarkers of marine pollution with pesticides. *International Agricultural Journal*, 3, 38-42. (in Russian)

Kroon F., Streten C. and Harries S. (2017) A protocol for identifying suitable biomarkers to assess fish health: A systematic review. *PLoS ONE*, 12(4), e0174762.

Kuzminova N.S. (2008) Species, seasonal, sexual differences of the spleen index of some species of the Black Sea fish and its susceptibility to the anthropogenic factor. *Bulletin of zoology*, 42(2), 135-142. (in Russian)

Lagade V.M., Taware S.S. and Muley D.V. (2015) Seasonal Variation in the Biochemical Constituents, Percentage Edibility and Condition Index of the Estuarine Clam, *Soletellina diphos* (Linnaeus, 1771) (Mollusca: Bivalvia: Veneroida: Psammobiidae). *International Journal of Zoological Research*, 11, 127-139.

Lang T., Wosniok W., Barsiene J., Broeg K., Kopecka J. and Parkkonen J. (2006) Liver histopathology in Baltic flounder (*Platichthys fleus*) as indicator of biological effects of contaminants. *Marine Pollution Bulletin*, 53, 488-496.

Lapin A.A., Nigmetzyanova M.V., Govorkova L.K. and Zelenkov V.N. (2016) Bioindication of the state of aquatic ecosystems based on the chemical composition of fish organs. *Collection of scientific papers,* 146-157. (in Russian)

Lapirova T.B. (2011) Reaction of siberian sturge fingerling (*Acipenser baerii* Brandt) immunophisiological indicators to the permethrin action. *Tomsk State University Journal of Biology*, 4 (16), 124-135. (in Russian)

Lukyanova O.N. (2001) Molecular biomarkers. Publishing house FEGAEU Vladivostok. (in Russian)

Luk'yanova O.N. and Korchagin V.P. (2017) Integral biochemical index of the state of aquatic organisms under polluted conditions. *Biology Bulletin*, 4(2), 203-209.

Lushchak V.I. (2016) Contaminant-induced oxidative stress in fish: a mechanistic approach. *Fish Physiol. Biochem*., 42(2), 711-747.

Malakhova L.V., Skuratovskaya E.N., Malakhova T.V., Boltachev A.R. and Lobko V.V. (2018) Organochlorine compounds in scorpion fish *Scorpaena porcus* Linnaeus, 1758 in the Sevastopol marine area (Black Sea): Spatial distribution and biological response. *Marine Biological Journal*, 3(4), 51-63. (in Russian)

Malakhova L.V., Skuratovskaya E.N., Malakhova T.V. and Lobko V.V. (2020) The relationship between integrated biochemical index and content of organochlorine xenobiotics in the liver of the black scorpion fish *Scorpaena porcus* Linnaeus, 1758, from Sevastopol bays and coastal areas. *J. Sib. Fed. Univ. Biol.*, 13(4), 387-409. (in Russian)

Mashukova O.V., Skuratovskaya E.N. and Shilova J.B. (2019) Biophysical and biochemical techniques in

monitoring the coastal waters of Sevastopol (Black Sea). *Monitoring systems of environment*, 1 (35), 55-62. (in Russian)

Melekhova O.P., Egorova E.I., Yevseyeva T.I. *et al.* (2007) Biological Monitoring of Enviroment. Bioindication and Biotesting; textbook for university students. Moscow. (in Russian)

Menshchikova E.B. and Zenkov N.K. (1993) Antioxidants and inhibitors of radical oxidative processes. *Advances in modern biology*, 113(3), 442-445. (in Russian)

Moiseenko T.I. (2000) Morphophysiological rearrangements of the fish organism under the influence of pollution (in the light of Schwartz's Theory). *Ecology*, 463-472. (in Russian)

Moiseenko T.I., Kudryavtseva L.P. and Gashkina N.A. (2005) Assessment of the geochemical background and anthropogenic load by bioaccumulation of microelements in fish. *Water Resources*, 32(6), 640-652. (in Russian)

Nemova N.N. and Vysotskaya R.U. (2004) Biochemical indication of fish state. Nauka, Moscow. (in Russian)

Oluah N.S. (1999) Plasma aspartate aminotransferase activity in the Catfish *Clarias albopunctatus* exposed to sublethal zinc and mercury. *Bulletin of Environmental Contaminational & Toxicology*, 63(3), 343-349.

Otis L. (2007) Müller's Lab. Oxford University Press, Oxford.

Ozkan D., Dagdeviren M., Katalay S., Guner A. and Yavaşoglu N.U. (2017) Multibiomarker responses after exposure to pollution in the mediterranean mussels (*Mytilus galloprovincialis* L.) in the Aegean Coast of Turkey. *Bulletin of Environmental Contamination and Toxicology*, 98(1), 46-52.

Pronina G.I. and Koryagina N.Yu. (2017) Methodology of physiological and immunological assessment of aquatic organisms. Textbook. Lan, St. Petersburg. (in Russian)

Rudneva I.I. (2012) Antioxidant defence in marine fish and its relationship to their ecological status. In: Fish Ecology. (ed. Dempsy S.P.) Nova Science Publishers, Inc. New York, USA.

Rudneva I.I. (2016) Ecotoxicological studies of coastal Black Sea ichthyofauna in the Sevastopol region. GEOS, Moscow. (in Russian)

Rudneva I.I., Shevchenko N.F., Zalevskaya I.N. and Zherko N.V. (2005) Biomonitoring of the coastal waters of the Black Sea. *Water Resources*, 32, 215-222.

Rudneva I.I., Skuratovskaya E.N., Chesnokova I.I., Shaida, V.G. and Kovyrshina T.B. (2016a) Biomarker response of Black Sea scorpion fish *Scorpaena porcus* to anthropogenic impact. *Advances in Marine Biology*, 1, 119-147.

Rudneva I.I., Skuratovskaya E.N., Kovyrshina T.B., Chesnokova I.I., Omelchenko S.O. and Zalevskaya I.N. (2016b) Response of fish belonging to different ecological groups on marine pollution. Biodiagnostics and assessment of environmental quality: approaches, methods, criteria and reference standards in ecotoxicology. Book of Abstracts of the International Symposium. GEOS, Moscow. (in Russian)

Rudneva I.I., Skuratovskaya E.N. Dorokhova I.I., Grab Yu. A., Zalevskaya I.N. and Omel'chenko S.O. (2011) Bioindication of the Environmental State of Marine Areas with the Use of Fish Biomarkers. *Water resources*, 38(1), 107-112.

Rudneva I.I., Skuratovskaya E.N., Omelchenko S.O. and Zalevskaya I.N. (2008) Application of fish blood biomarkers for ecotoxicological assessment of coastal marine areas. *Ecological chemistry*, 17(3), 77-84.

Reynoldson T.B. (1942) Vorticella as an Indicator Organism for Activated Sludge. *Nature*, 149, 608-609.

Rouane-Hacene O., Boutiba Z., Belhaouari B., GuibboliniSabatier M.E., Francour P. and Risso-de Faverney C. (2015) Seasonal assessment of biological indices, bioaccumulation and bioavailability of heavy metals in mussels *Mytilus galloprovincialis* from Algerian west coast, applied to environmental monitoring. *Oceanologia*, 57, 362-374.

Serafim A., Companya R., Lopes B., Fonseca V.F., Franc S.¸Vasconcelos R.P., Bebianno M.J. and Cabral H.N.

(2012) Application of an integrated biomarker response index (IBR) to assess temporal variation of environmental quality in two Portuguese aquatic systems. *Ecol. Indicators,* 19, 215-225.

Shaida V.G., Skuratovskaya E.N. and Rudneva I.I. (2015) The influence of pollution on the parameters of oxidative stress in fish tissues. *Problems of pathology, immunology and health protection of fish and other aquatic organisms: extended materials of the IV International Conference*, 369-374. (in Russian)

Shvarts S.S., Smirnov V.S. and Dobrinsky L.N. (1968) Method of morphophysiological indicators in the ecology of terrestrial vertebrates. Sverdlovsk. (in Russian)

Skuratovskaya E.N., Doroshenko Y.V., Alyomova A.S. and Kovaleva M.A. (2020) Bioindication assessment of the ecological state of Sevastopol coastal waters. *Russian Journal of Biological Physics and Chemisrty*, 5(3), 517-523. (in Russian)

Sole M., Rodriguez S., Papiol V., Maynou F. and Cartes, J.E. (2009) Xenobiotic metabolism markers in marine fish with different trophic strategies and their relationship to ecological variables. *Comparative Biochemistry and Physiology*, 149, 83-89.

Sturve J., Hasselberg L. and Fälth H. (2006) Effects of North Sea oil and alkylphenols on biomarker responses in juvenile Atlantic cod (*Gadus morhua*). *Aquat. Toxicol*.,78, 73-78.

Tsema N.I. (2015) Bioindication of pollution in the Azov Sea based on physiological and biochemical indicators of fish. *Modern problems of hydrochemistry and monitoring of surface water quality: materials of a scientific conf.*, 154-158. (in Russian)

Van der Oost R., Beyer J. and Vermeulen N.P.E. (2003) Fish bioaccumulation and biomarkers in environmental risk assessment: a review. *Environmental Toxicology and Pharmacology*, 13, 57-149.

Vladimirov Yu.A. (2001) Activated chemiluminescence and bioluminescence as a tool in medical and biological research. *Soros Educational Journal*, 7, 16-20. (in Russian)

Volkova I.V., Ershova T.S. and Shipulin S.V. (2018) Assessment of the water quality of reservoirs for fishery purposes. Uright, Moscow. (in Russian)

Winston G.W. and Giulio R.N. (1991) Prooxidant and antioxidant mechanisms in aquatic organisms. *Aquatic Toxicol*., 19, 137-161

Zhidenko A.A. (2008) Traits of carps constructive metabolism of different ages under influence of herbicides. *Bulletin of Dnipropetrovsk University. Biology. Ecology,* 16 (1), 84-92. (in Russian)