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WORLD AQUACULTURE IN THE CONDITIONS OF THE ADAPTATION TO CLIMATE CHANGE

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The article examines the challenges and consequences of climate change on the planet, provoked by active human activity over the past 200 years, which led to the rapid accumulation of carbon dioxide in the atmosphere. An increase in the average annual temperature on Earth, melting glaciers and rising sea levels, extreme natural phenomena (floods, catastrophic storms, intense droughts and severe fires), a decrease in biodiversity and the disappearance of some species.

The world's oceans are becoming increasingly salty and acidic due to warming of the atmosphere and oceans, changes in the nature of precipitation and an increase in the frequency of extreme weather events. This creates serious dangers for fisheries and aquaculture, affects the physiology and behaviour of many species of aquatic organisms, changes their productivity, migration processes and habitat parameters.

Since the main pollutant of the atmosphere is carbon dioxide, methane and other greenhouse gas components, the concentrations of which are steadily increasing, this directly depends on the high rates of fossil fuel consumption. Therefore, the main task of combating the climate crisis is to achieve carbon neutrality by 2050 and adapt to climate change.

Aquaculture plays an important role in ensuring food security, economic development of territories and preserving biodiversity. This is of particular importance in the context of global challenges such as climate change and the reduction of natural fish stocks. Aquaculture allows reducing pressure on natural ecosystems, since the production of fish and seafood in specially created conditions is more sustainable and efficient compared to traditional fishing.

Most decisions made for the further development of the industry should be related to the transition to sustainable development of aquaculture.

The article reviews solutions that have already been proposed by the Food and Agriculture Organization of the United Nations (FAO). The Blue Transformation concept, developed in line with the FAO Strategic Programme 2022-2031 and the FAO Committee on Fisheries Declaration on the Sustainable Development of Fisheries and Aquaculture, a Blue Transformation Roadmap, Guidelines for Sustainable Aquaculture (GSA), prepared by the Subcommittee on Aquaculture of the FAO Committee on Fisheries, demonstrate the importance of an integrated approach to the management and sustainable development of global aquaculture. Indeed, the development of sustainable aquaculture has great potential to address the environmental crisis and deepen food security, provide populations with sufficient quantities of healthy, nutrient-rich foods, and adapt to climate change.

Keywords: climate change, ecological crisis, food security, sustainable aquaculture, adaptation to the effects of climate change.

Introduction. Climate change is a reality of today and is a problem that has been worrying the world community for the past few decades. Repeated changes in temperature and weather conditions have occurred throughout the Earth's existence, and were caused by changes in solar activity, volcanic eruptions, or other natural disasters. There are 7 known ice ages, after which warming always occurred. But warming is occurring 10 times faster than ever before, and is not just a natural process.

Since the end of the 19th century, such changes have intensified, which is explained by active human activity, the so-called «industrial revolution». The use of fossil fuels (coal, oil, gas) has become one of the main factors in climate change.

There is a misconception that climate change is mainly an increase in temperature. But rising temperatures are just the tip of the iceberg, as the Earth can be viewed as a system in which all processes are interconnected and changes in one area can cause changes in all others. The consequences of climate change are intense droughts and severe fires, water shortages, melting polar ice and rising sea levels, floods and catastrophic storms, a decrease in biodiversity and the disappearance of some species.

Climate change (warming of the atmosphere and oceans, changes in precipitation patterns and an increase in the frequency of extreme weather events) poses serious threats to fisheries and aquaculture. The world's oceans are becoming increasingly salty and acidic, which affects the physiology and behavior of many species of aquatic organisms and changes productivity, habitat parameters and migration routes. Rising sea levels and severe storms threaten coastal communities and ecosystems, affecting the conditions for the functioning of the production capacities of the fishing industry both on land and at sea. Further climate change will lead to the drying up of some inland reservoirs and lakes.

Materials and methods. The research was based on a review of global reports from the Food and Agriculture Organization of the United Nations, including the concept of the “blue” transformation of the fisheries sector, of The State of World Fisheries and Aquaculture 2024 studies by the Intergovernmental Panel on Climate Change (IPCC), international climate change agreements, as well as national and regional reports.

Results and discussion. According to the report of the Intergovernmental Panel on Climate Change, only one-third of the climate change that is occurring is caused by natural phenomena, and two-thirds is caused by human activity and, as a result, an increase in the level of greenhouse gases in the atmosphere.

In fact, over the past two centuries, it is humans who are responsible for global warming. Their activities in various sectors cause greenhouse gas emissions that are heating our planet faster than at any time in the past two millennia. Today, the average surface temperature of the Earth is about 1.2 °C higher than

at the end of the nineteenth century. The last decade (2011-2020) was the warmest in the entire history of observations, and each of the last four decades has been warmer than any previous one since 1850.

A natural phenomenon, the greenhouse effect, is a process in which greenhouse gases trap solar energy on the Earth's surface and in the atmosphere, preventing it from returning back to space. This effect maintains a comfortable temperature for life on Earth. However, since the mid-19th century, as a result of the "industrial revolution", due to an increase in the burning of fossil fuels, the concentration of greenhouse gases in the atmosphere has begun to increase sharply.

The main compounds related to greenhouse gases (carbon dioxide CO_2, methane CH4, nitrogen oxide (I) N_2O, ozone O_3, water vapor) are different, but sometimes quite long periods in the atmosphere, without undergoing changes (physical or chemical). Water vapor can remain in the atmosphere for only a few days and quickly reacts to temperature changes. The higher the temperature, the more water evaporates and enters the atmosphere. Thus, enhancing the process of global warming.

Human activity significantly changes the concentration of greenhouse gases in the atmosphere - when fossil fuels are burned, carbon is released, which combines with oxygen in the air and forms carbon dioxide CO_2. According to many years of observations, for the first time in the atmosphere there is a rapid increase in the content of CO_2. Recently, the term «climate crisis» has been very often used instead of «climate change». Thus, the importance of the problem of climate change and the need for its urgent solution are emphasized.

The climate crisis is a rapid change in climate due to an increase in the global average temperature, the average of all annual temperatures on Earth. An increase in the global average temperature on Earth means that there are more hot days per year and fewer cold days. According to observations, the average global temperature on Earth has already increased by 0.95 °C since 1880. However, global warming is occurring unevenly across the planet (for example, the average temperature in the Arctic regions of the planet has already increased by 2 °C).

Warming in the Arctic is occurring twice as fast as in other regions of the planet. Glaciers are melting faster, and since 1979 (the first full year of satellite observation), the volume of ice in the warmest season in the Arctic has decreased by 32 %. If this trend continues, by 2050 the Arctic ice cover will completely disappear in the summer. This process has several rather important negative consequences. First, the area of white cover, which reflects from 20 % to 50 % of solar radiation, is reduced, the area of the ocean increases, absorbing up to 95 % of this radiation. This leads to even greater warming and acceleration of the melting of glaciers, resulting in even greater climate change. Second, according to estimates by scientists from the National Snow and Ice Data Center, permafrost holds almost twice as much carbon dioxide as is in the atmosphere

today (up to 1.4 thousand gigatons). During the melting of glaciers, this gas is gradually released. Along with CO_2, methane (CH_4) enters the atmosphere, which has a greenhouse effect 84 times stronger. Thirdly, the level of the World Ocean is rising, as a result of which islands in the most vulnerable regions disappear under water (Maldives, Fiji, Seychelles, Marshall Islands, Canary Islands, French Polynesia, Philippines, Solomon Islands and others).

Another phenomenon against the background of climate change has been recorded by scientists in recent decades – these are the so-called «heat waves». They occur more often, last longer and have more unpredictable consequences. As an example, hot summers with extreme temperatures, which have been observed in Europe for the past five years.

Drought weather is the cause not only of forest fires, but also of dust storms, which carry dry land in the form of dust from ploughed open areas for tens of kilometres with strong winds. As a result, land fertility decreases, negatively affecting the health and living conditions of the population of these territories [1].

The rising temperatures increase evaporation and cause a redistribution of moisture. As a result, in some regions, excessive moisture evaporates and drought intensifies. In other regions, this moisture condenses, more frequent downpours and storms are observed, which causes the risk of flooding.

Due to climate change and human activity, the number of vertebrate populations has decreased by more than 70 % over the past half century. This is a direct threat to humanity in terms of loss of plant and animal food, water, medicines, etc.

According to Brian Murray Fagan, professor of anthropology at the University of California (USA), an increase in average temperature by one or two degrees can lead to changes in the ecosystems of individual regions or even destroy civilization [2]. The author shows what role climate has played in history and how societies of millennia ago reacted to climate change. The medieval warming (800–1300 AD) revealed both opportunities and dangers. Climate did not doom societies to destruction or prosperity; it all depended on how societies responded to its challenges. Some societies collapsed under the influence of these dangers, others avoided them, and some took advantage of the opportunities.

Pollution of the Earth's atmosphere, the increase in carbon dioxide concentration that causes global warming, is directly related to the consistently high rate of fossil fuel consumption. For many years, leading scientists have emphasized that in order to keep global warming within 2 °C, eighty percent of fossil fuels must remain in the ground.

Researchers at the Norwegian University of Science and Technology identify two main causes of atmospheric pollution [3].

The first cause is direct pollution through the consumption of necessary resources. These include greenhouse gases from cars, home heating, and water

use. Another cause of pollution is indirect costs, which account for up to 80 %, the so-called indirect pollution, or pollution whose origin we do not see directly (the activities of corporations, transportation, etc.). In order to prevent this pollution, experts suggest using different approaches (for example, the three "R"), established practices, sustainable development strategies and modernization of various industries, rethinking the general style of consumption, which depends on lifestyle.

The main task today in combating the climate crisis is to achieve carbon neutrality by 2050 and adapt to climate change. Carbon neutrality means that the amount of excess heat absorbed by the planet is proportional to the total CO_2 emissions. Therefore, as long as global emissions on the planet remain at least slightly above zero, the Earth will continue to warm.

The principle of carbon neutrality is the basis of the climate policy of most countries in the world, each of which has committed to completely stop greenhouse gas emissions in the next few decades.

For this to happen, all countries in the world need to completely abandon the burning of any fossil fuel, the combustion product of which is CO_2.

In 2015, 197 countries of the world signed the Paris Climate Agreement, agreeing to take all necessary measures to ensure that by 2100 average temperatures on the planet do not exceed pre-industrial values by 1.5-2 °C.

Warming of the atmosphere and oceans, changes in precipitation patterns and an increase in the frequency of extreme weather events) poses serious threats to fisheries and aquaculture. The world's oceans are becoming increasingly salty and acidic, which affects the physiology and behavior of many aquatic species and changes their productivity, habitat parameters and migration routes. Rising sea levels and severe storms threaten coastal communities and ecosystems, affecting the conditions for the functioning of the fisheries industry's production facilities both on land and at sea. Further climate change will lead to the drying up of inland reservoirs and lakes.

Fish are cold-blooded organisms that are subject to asymmetric climatic phenomena that affect a range of factors, from metabolism to behavior and the process of evolution. Temperature change can lead to biodiversity loss, affect global fish stocks, have negative socio-economic consequences, and contribute to food security.

Changes in the environment, disruption of spawning grounds, threaten reproduction and survival, and therefore the ability to maintain the viability of individual populations [4].

Long-term assessment of climate impacts has shown that precipitation, critical temperatures, and fish mortality rates were the main factors in changing species numbers.

According to some studies, scientists suggest that ocean acidification affects the circadian system (natural oscillations that repeat approximately every

24 hours), which may lead to further changes in fish reproduction. Changes in salinity also negatively affect the behavior of male marine fish. The salinization of freshwater and the increase in temperature lead to significant effects on the physiological responses of freshwater fish.

Global warming is causing marine fish to migrate to cooler waters towards the poles, according to observations. Researchers from the University of Glasgow have found that many fish populations in the world's oceans are responding to rising water temperatures by moving closer to the North and South Poles or to deeper waters where temperatures are cooler [5].

For marine life, water temperature is a critical factor that affects their metabolism, growth and reproduction. While some species can adapt to warmer conditions, those that live in areas where warming is occurring more rapidly are also showing changes in their geographic distribution. The rate of warming in some regions may be too fast for fish to adapt, so migration is their best survival strategy.

While migration to cooler waters may help species survive in the short term, it is not known how these changes will affect food chains and ecosystems as a whole. The impact of global warming on marine ecosystems is expected to increase, and the ability to predict fish movements is vital for the preservation of ecosystems and ensuring food security. For the first time, domestic experts conducted a large-scale study of the response of marine fish to increasing water temperature, during which data on 115 fish species from all major regions of the ocean were analyzed [6].

Agriculture is one of the main branches of the economy of many countries, and aquaculture, as one of its sectors, plays an important role in ensuring food security, economic development of territories, and preserving biodiversity.

The main advantage of aquaculture is its ability to provide the population with a significant amount of protein. This is of particular importance in the context of global challenges such as climate change and the reduction of natural fish stocks. Aquaculture plays an important role in the development of rural areas, creating jobs, and supporting local economies. In addition, aquaculture contributes to the development of related industries, such as the production of fish feed, equipment for growing aquatic bioresources, and the introduction of modern water purification technologies.

Aquaculture allows you to reduce pressure on natural ecosystems, since the production of fish and seafood in specially created conditions is more sustainable and efficient compared to traditional fishing.

But aquaculture also has some challenges. This is the need to minimize the negative impact on the environment, in particular, reducing water pollution and ecosystem degradation, ensuring the resistance of aquatic bioresources to diseases and parasites. The transition to sustainable management of the industry through the introduction of innovative technologies and practices will contrib-

ute to reducing the ecological footprint, reducing greenhouse gas emissions into the atmosphere and its adaptation to climate change.

The solutions to the problems associated with climate change are to adapt to the current and future consequences of climate change and mitigate them by minimizing the carbon footprint of the fisheries and aquaculture sectors by reducing greenhouse gas emissions. Today, various ways are used to achieve progress in the fisheries and aquaculture sectors in reducing their carbon footprint, but it is also worth paying attention to the need to adapt to changing conditions.

Up to sixty percent of fisheries costs are spent on fuel used to propel vessels, when processing, cooling and freezing fish products on board. Further processing, transport and marketing of fish products add to the carbon footprint. At the same time, fishing and aquaculture have smaller carbon footprints than other animal protein production. Moreover, almost the entire carbon footprint of aquaculture comes from the production and transport of feed and fishmeal.

Aquaculture producers on the European continent depend on imported feed and raw materials for their production. According to scientists from the Faculty of Food and Resource Economics at the University of Copenhagen, aquaculture is a promising sector for the production of animal-based food products worldwide. But feed production accounts for the largest share of CO_2 emissions from aquaculture. Although feed ratios can be reduced, reducing CO_2 emissions depends on reducing dependence on imported feed ingredients. To make this sector more sustainable, the issue must be addressed by reducing the content or replacing ingredients. By-products such as fish heads, skeletons, trimmings, skin, and other organs of local origin are being considered as feed ingredients, which will eliminate greenhouse gas emissions associated with transportation.

The Nordic (Scandinavian) industry is already moving towards the production of completely ecologically clean fish feed. Currently, marine ingredients make up approximately 20 % of the feed, but only 10 % of them are of local origin (from the Nordic countries). Therefore, in order to switch to local marine ingredients, industry producers in these countries will have to increase the production of seafood, stimulate the production of local raw materials for feed. Thus, it will be possible to reduce the carbon footprint by reducing dependence on raw materials from countries of other regions. The use of more by-products in feeds, more ingredients from single-cell technologies and more ingredients from lower trophic levels is not excluded. Recently, there has been a shift to ingredients of plant origin or using insects as alternatives to fish feed with a lower carbon footprint.

Other factors contributing to the increase in greenhouse gas emissions from aquaculture and environmental degradation include land use and deforestation for the production of plant materials (e.g., soybeans) for feed; feed and faecal matter, which can contain nitrogen and phosphorus and can contaminate surrounding

water resources; and fish escapes and high concentrations of parasites, which are detrimental to both the local environment and natural fish stocks.

According to FAO, global fish consumption has increased by 122 % since 1990, and aquaculture now accounts for more than 50 % of this [7, 8]. The world population is projected to reach 9.7 billion by 2050, an increase of 1.7 billion from 2022 (Fig. 1). This will have significant implications for the supply of feed for aquatic animals. To maintain apparent per capita aquatic animal feed consumption at the estimated level of 20.7 kg projected for 2022 by 2050, the total supply of aquatic animal feed would need to increase by 36 million tonnes (in live weight equivalent), representing an increase of 22 percent.

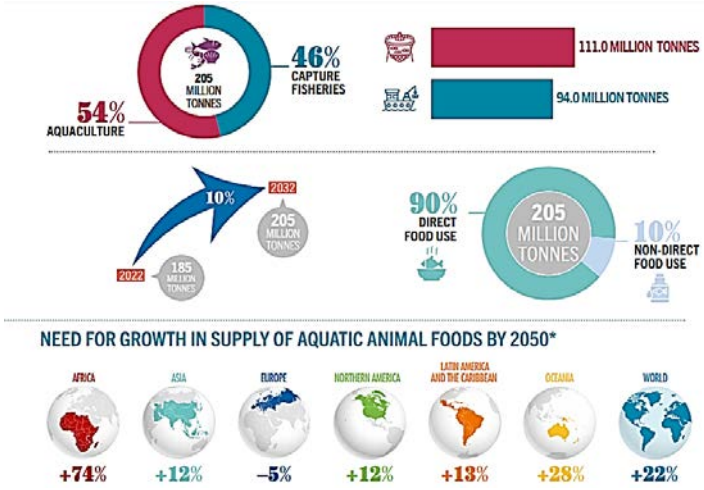

Fig. 1. **Aquatic animal production and use for human consumption by 2032**

The growth of the world's population is putting a strain on fisheries and aquaculture due to the need to increase production volumes, which will require 70 % more protein. Aquatic products can meet this need in the future. Protein from fish and other seafood, obtained from fisheries or aquaculture, is a vital nutrient for providing the population with animal protein, fat and Omega-3 fatty acids. By 2050, aquaculture will double its production and become the main source of aquatic products [9].

Unlike fisheries, where fish can move/change their position in open water bodies in response to changing conditions, fish in aquaculture are kept in a certain place and the farm is affected by specific conditions caused by climate change, which must be taken into account in each specific case.

Other negative impacts of climate change on aquaculture include impacts on growth rates (fish grow faster and mature earlier in warmer water), productivity, the growing season and increased mortality, increased escapes, and the

occurrence of harmful algal blooms, etc. In terms of fisheries, climate change is pushing fish north, but the effects on ecosystems cannot yet be fully modelled.

The carbon footprint of fisheries is dominated by the use of fossil fuels to propel boats, and fuel use varies significantly by fishery. Exploiting depleted stocks requires more fuel per kilogram of fish caught, as low abundance and density forces fishermen to search longer and use heavier gear to catch fish. Higher catches and greater abundance of aggregations result in lower emissions per unit of production. It is noted that greenhouse gas emissions can be significantly reduced by switching from fuel-intensive methods, such as dredging and bottom trawling, to alternative methods, such as traps, seines and gillnets.

Common environmental impacts of both fisheries and aquaculture include energy consumption, greenhouse gas emissions, other toxic substances, plastic pollution, seabed degradation and the introduction of invasive species.

Unfortunately, most of the changes to CO_2-reducing fisheries that have been implemented in recent years have been market-based management reforms aimed at increasing efficiency. The reforms have not been specifically aimed at reducing greenhouse gas emissions. Additional changes are needed, such as finding a balance between fishing gears, increasing fuel efficiency by using, for example, low-carbon engines, etc.

Iceland has a good track record in transitioning to sustainable fisheries. The fishing industry has been and remains an important contributor to the national economy and an important part of the culture. In the 1980s, Icelandic fisheries faced two problems: overfishing and economic inefficiency, which have gradually been addressed. Energy consumption by fish processing plants has decreased by 85 %. Soon, production facilities will run almost exclusively on renewable electricity. And when ships are in port, they will also use renewable electricity. By 2030, Iceland's fisheries sector is forecast to reduce carbon emissions by 50 percent (compared to 2005 levels), and by 2040, the country will become fossil fuel independent. Total consumption of petroleum products in fisheries has decreased by almost 50 percent (compared to 1990 levels). While in 1980, 90 to 100 workers were involved in catching 2,400 tons of fish, in 2016, only eight workers were needed to catch 3,200 tons of fish. This success was achieved thanks to effective and consolidated fisheries management and investments in new modern vessels, equipment and fishing gear. Quota systems were introduced, which contributed to the reduction of overfishing and the restoration of fish stocks.

According to experts, incentives should be created for companies to implement innovative solutions and use resources more efficiently: not to try to increase the volume of catches, but to look for solutions to create added value and get the most out of each fish without waste; to open up new markets for their products, in particular outside the food chain (medical products, cosmetics, etc.).

Ukrainian and foreign scientists are working to improve fisheries and aquaculture management, using an integrated approach to limit the impact of

climate change on the reproductive biocomplex of fish. Such studies combine various factors, such as knowledge of the fishing area used by fishermen, knowledge of the biology and ecology of specific species, as well as data from biological studies of fish. All this will contribute to improved management and sustainable development. Understanding how different environmental factors interact to manage fish reproduction is important for predicting environmental phenomena related to fish populations and for potential applications in aquaculture. According to recent studies, climate vulnerability assessment should be part of the fisheries management system and planning for the industry's adaptation to climate change. Monitoring long-term demographic responses to climate change is essential to protect vulnerable fish populations. The rate of climate change often outpaces the average rate of evolutionary change. Therefore, monitoring multiple responses and understanding their limitations is essential for effective resource management and conservation of endangered species.

It is difficult to distinguish the effects of climate change from the effects of poor management, as, for example, failures in natural fish stocking can be caused by a variety of factors. The development of adaptation methods, such as breeding climate- or salt-tolerant species, may have real prospects [10].

Most decisions taken for the further development of the industry should be aimed at its sustainability.

Sustainable aquaculture can be a solution to the problem of feeding a growing population. Aquaculture can make a significant contribution to the food chain (food supply), and therefore should be developed in a way that is sustainable. Various closed system technologies are considered, including recirculating tanks, flow-through systems, internal ponds, which can be used for many types of aquatic bioresources (fish, molluscs, algae). The advantages of closed aquaculture systems are obvious, but their use is also aimed at avoiding the environmental and food safety disadvantages of open aquaculture. Today, aquaculture is the fastest growing food sector in the world with huge growth potential and plays a key role in global food production.

Important steps towards the sustainable development of sectors that are part of the food chain, including aquaculture, are being taken by the Food and Agriculture Organization of the United Nations (FAO). Achieving the Sustainable Development Goals is important for aquaculture. As it turned out, against the backdrop of economic crisis, shocks and conflicts in recent years, combined with extreme climate events and environmental degradation, modern agri-food systems are very vulnerable, which has exacerbated the growing threat to food security. The number of people worldwide facing hunger is 735 million, 122 million more than before the COVID-19 pandemic. In addition, more than 3.1 billion people today cannot afford a healthy diet, and projections show that 600 million people will be chronically undernourished by 2030. At the United Nations Food Systems Summit (UNFSS) (2021) and the UNFSS Final Conference (2023),

UN Member States recognized the multifaceted nature of food insecurity and the need to address both supply chains and communities involved in all food production sectors through the transformation of agri-food systems. In 2021, FAO adopted the Blue Transformation Framework, developed in line with the Strategic Framework of the Food and Agriculture Organization of the United Nations (FAO) 2022–2031 and the FAO Committee on Fisheries Declaration on the Sustainability of Fisheries and Aquaculture [9]. Its main objectives are to maximize the opportunities offered by aquatic food systems to increase food security, improve nutrition, eradicate poverty and support the achievement of the 2030 Agenda for Sustainable Development. At the same time, they are fully consistent with FAO's key strategies on climate change, innovation and biodiversity. The concept of the «blue» transformation aims for sustainable development and resilience.

The «blue» transformation envisages minimizing environmental impacts, improving biological protection and disease control through technology and innovation, and developing capacity to ensure equitable outcomes that contribute to the further development of the human, social, cultural and economic aspects of aquaculture.

Sustainable production alone does not necessarily lead to a reduction in hunger, so the Blue Transformation takes a systemic approach to creating sustainable, resilient, gender-sensitive and inclusive fisheries and aquaculture at local, regional and global levels. At the same time, it ensures the resilience of aquatic food systems to climate change and other natural and man-made disasters.

FAO has developed a Blue Transformation Roadmap for three global goals (Fig. 2), which reflect FAO's vision of what the transformation of aquatic food systems should achieve by 2030:

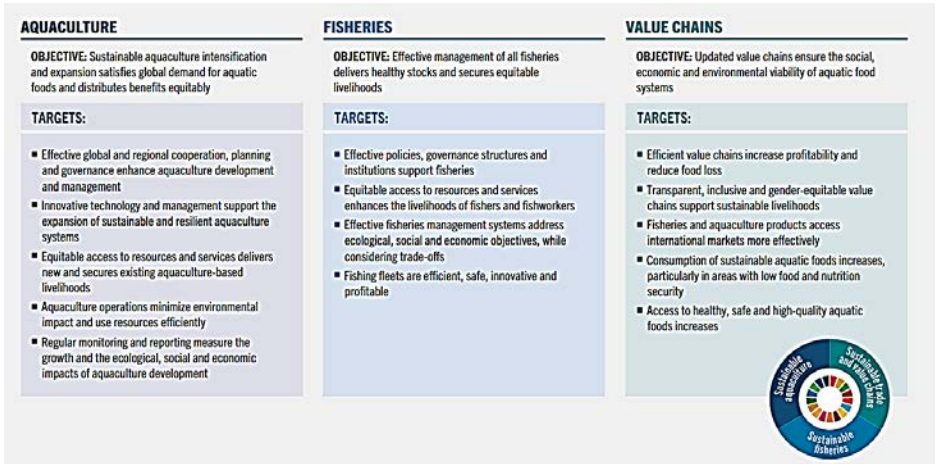

Fig. 2. **Blue transformation roadmap. Objectives and targets of blue transformation**

1) sustainable expansion and intensification of aquaculture that meets global demand for aquatic food, while ensuring equitable distribution of benefits;

2) effective management of all fisheries that ensure healthy stocks and equitable livelihoods;

3) modernized water value chains that ensure the social, economic and environmental sustainability of water-based food systems.

For each global goal, the roadmap outlines a set of targets that reflect the social, economic and environmental aspects that need to be addressed to transform aquatic food systems.

Sustainable aquaculture has the potential to provide sufficient quantities of healthy, nutrient-rich food for the world's population.

The Subcommittee on Aquaculture of the FAO Committee on Fisheries has developed the Guidelines for the Sustainable Development of Aquaculture (GSA). The GSA proposes a comprehensive approach to the management and sustainable development of aquaculture, with the aim of implementing the 1995 Code of Conduct for Responsible Fisheries [11]. The GSA was developed in response to the rapid expansion of aquaculture as the world's fastest-growing food sector, driven by scientific progress, technological innovation and investment, in the face of ever-increasing global demand for aquatic products. However, as with all food sectors, this rapid growth has raised concerns about the sustainability of aquaculture and potential negative impacts. The GSA is the first international document developed for this important sector.

The GSA is a set of common and agreed principles and practices that all countries and stakeholders can use to make their aquaculture sectors synonymous with food security and nutrition, fair livelihoods, restored ecosystems and climate resilience.

At the global level, climate change is one of the most pressing challenges that prevent humanity from ensuring agro-ecological and food security, reducing poverty and achieving sustainable rural development. Anthropogenic influence on the climate system is a determining factor in the warming observed in many countries of the world, including Ukraine. Due to the increase in average air temperature and uneven distribution of precipitation, favorable conditions are created for the spread of atypical species of flora and fauna, which in the next 30-50 years may lead to a significant transformation of the majority of climatic and natural zones in the world and in Ukraine.

In 2022, a total of 3,891 aquaculture enterprises were registered in Ukraine. Of these, 1,286 are legal entities and 2,695 are individuals [12]. These entities have grown up to 15,000 tons of aquaculture products. Aquaculture is stagnating, which is primarily due to the military aggression of the Russian Federation and its consequences – the destruction of infrastructure, equipment, property, the destruction of established production and social ties and relation-

ships, the loss of entrepreneurial efforts and other factors. At the same time, climate change (decrease in the amount of surface water and increased fish morbidity) remains a global problem in the field of aquaculture.

In 2019, a draft Strategy for Adaptation to Climate Change in Agriculture, Forestry and Fisheries of Ukraine until 2030 was developed, which became the basis of the Strategy for Environmental Security and Adaptation to Climate Change for the period until 2030 [13].

The proposed measures for adaptation to climate change for fisheries and aquaculture are based on an ecosystem approach and biodiversity conservation. Among the most relevant measures for adaptation to climate change in fisheries and aquaculture are:

– stimulating the improvement of monitoring of ichthyofauna in all subsectors of fisheries in connection with climate change;

– strengthening the industry's resilience to natural weather phenomena, developing an early warning system for such phenomena;

– creating an effective insurance system in the fisheries sector to minimize financial losses to agricultural producers from adverse weather conditions;

– study, monitoring, development and implementation of plans for preventive and curative measures to reduce the risks of fish diseases in the context of climate change;

– reorientation of fishing and breeding to species that demonstrate a tendency to expand their range, improve the state of populations, or whose stocks are in a satisfactory state;

– consideration of such changes in the rules of industrial and recreational fishing;

– selection and breeding of new fish species; expanded implementation of polyculture and increase in cultivation types;

– implementation of water-saving technologies, in particular the creation of full or partial systems of UZV, technologies for water reuse;

– increasing the resistance of fish to the manifestations of climate change by improving the conditions of their cultivation (full feeding, shading with nets).

Therefore, climate change requires significant transformations in the fisheries and aquaculture sectors: creation and operation of information systems for the systematization and consolidation of data on fisheries, aquaculture, and climate change at the level of a separate country; development and implementation of early warning systems that reduce the risk of disasters, accidents, fatalities and contribute to the provision of humanitarian support in extreme situations due to climatic factors; introduction of innovative technologies, including decarbonization of the entire life cycle chain of fishery and aquaculture products (from production to marketing and sales); introduction of energy-saving technologies, availability of loans and programs to stimulate sustainable development of enterprises, etc.

Conclusion. Climate change, its consequences and challenges facing the world are perhaps the biggest problem of our time. However, the warming observed in recent decades is not just a natural process. Active human activity over the past 200 years has led to the rapid accumulation of carbon dioxide in the atmosphere. The consequences are an increase in the average annual temperature on Earth, melting polar ice and rising sea levels, floods and catastrophic storms, intense droughts and severe fires, water shortages, a decrease in biodiversity and the disappearance of some species.

Due to climate change and human activity, the number of vertebrate populations has decreased by more than 70 % over the past half century. This is a direct threat to humanity in terms of losses of plant and animal food, water, medicines, etc.

Warming of the atmosphere and oceans, changes in precipitation patterns and an increase in the frequency of extreme weather events pose serious dangers to fisheries and aquaculture. The world's oceans are becoming increasingly salty and acidic, which affects the physiology and behavior of many species of aquatic organisms and changes their productivity, habitat parameters and migration routes.

Pollution of the Earth's atmosphere, increasing carbon dioxide concentrations, is directly related to the consistently high rates of fossil fuel consumption

The main task of today in combating the climate crisis is to achieve carbon neutrality by 2050 and adapt to climate change.

Aquaculture, as one of its agricultural sectors, plays an important role in ensuring food security, economic development of territories, and preserving biodiversity. The main advantage of aquaculture is its ability to provide the population with a significant amount of protein. This is of particular importance in the context of global challenges such as climate change and declining natural fish stocks. Aquaculture plays an important role in the development of rural areas, creating jobs, and supporting local economies. In addition, aquaculture contributes to the development of related industries, such as the production of fish feed, equipment for growing aquatic bioresources, and the introduction of modern water purification technologies.

Aquaculture allows you to reduce pressure on natural ecosystems, since the production of fish and seafood in specially created conditions is more sustainable and efficient compared to traditional fishing.

Most decisions made for the further development of the industry should be related to the transition to sustainable aquaculture development.

Important steps towards sustainable aquaculture are being taken by the Food and Agriculture Organization of the United Nations (FAO). The Blue Transformation Concept was adopted in accordance with the FAO Strategic Framework for 2022–2031 and the Declaration of the FAO Committee on Fish-

eries on the Sustainability of Fisheries and Aquaculture, and the Blue Transformation Roadmap was developed for three global goals. The Subcommittee on Aquaculture of the FAO Committee on Fisheries has prepared the Guidelines for Sustainable Aquaculture (GSA), which propose an integrated approach for the management and sustainable development of aquaculture with a view to implementing the Code of Conduct for Responsible Fisheries.

Therefore, the development of sustainable aquaculture has great potential to address the environmental crisis and enhance food security, providing sufficient quantities of healthy, nutrient-rich food for the world's population.

СВІТОВА АКВАКУЛЬТУРА В УМОВАХ АДАПТАЦІЇ ДО ЗМІНИ КЛІМАТУ

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У статті розглянуто виклики та наслідки для клімату на планеті, спровоковані активною діяльністю людини за останні 200 років, яка привела до швидкого накопичення вуглекислого газу в атмосфері. Підвищення середньорічної температури на Землі, танення льодовиків та підвищення рівня Світового океану, екстремальні природні явища (повені, катастрофічні шторми, інтенсивні посухи та сильні пожежі), зменшення біорізноманіття та зникнення деяких видів.

Світовий океан стає все більш солоним і кислим внаслідок потепління атмосфери та океанів, зміни режиму опадів і збільшення частоти екстремальних погодних явищ. Це несе загрозливі небезпеки для рибальства та аквакультури, впливає на фізіологію та поведінку багатьох видів гідробіонтів, змінює їх продуктивність, міграційні процеси та параметри оселища.

Так як основним забруднювачем атмосфери є вуглекислий газ, метан, інші компоненти парникових газів, концентрації яких стабільно збільшуються, це напряму залежить від високих темпів споживання викопного палива. Тому, головним завдання протидії кліматичній кризі є досягнення вуглецевої нейтральності до 2050 року та адаптація до зміни клімату.

Аквакультура відіграє важливу роль у забезпеченні продовольчої безпеки, економічному розвитку територій, збереженні біорізноманіття. Це має особливе значення в умовах глобальних викликів, таких як зміни клімату та зменшення природних рибних запасів. Аквакультура дозволяє зменшити тиск на природні екосистеми, оскільки виробництво риби та морепродуктів у спеціально створених умовах є більш сталим і ефективним порівняно з традиційним виловом.

Більшість рішень прийнятих для подальшого розвитку галузі мають бути пов'язані з переходом до стійкого розвитку аквакультури.

У статті розглянуто рішення, які вже запропоновані Продовольчою та сільськогосподарською організацією ООН (ФАО). Концепція «Блакитної трансформацію», що розроблена відповідно до Стратегічної рамкової програми ФАО на 2022–2031 роки та Декларації Комітету ФАО з рибного господарства про стійкість рибальства та

аквакультури, «Дорожня карта «Блакитної трансформації», Керівні принципи сталого розвитку аквакультури (GSA), підготовлені Підкомітетом з аквакультури Комітету ФАО з рибальства, демонструють важливість комплексного підходу для управління та сталого розвитку світової аквакультури. Адже, розвиток сталої аквакультури має великий потенціал для вирішення проблем екологічної кризи та поглиблення продовольчої безпеки, забезпечення населення достатньою кількістю здорової, багатої на поживні речовини харчової продукції, адаптації до зміни клімату.

Ключові слова: зміна клімату, екологічна криза, продовольча безпека, стала аквакультура, адаптація до наслідків зміни клімату.

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