KAPITEL 3 / *CHAPTER 3* [3]
SUSTAINABLE DEVELOPMENT OF UKRAINE'S FISHERIES COMPLEX UNDER CONTEMPORARY ENVIRONMENTAL AND SOCIO-ECONOMIC CHALLENGES

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Introduction

Ukraine's fisheries complex is an important component of the national economy, the food security system, and the conservation of aquatic ecosystems. Its functioning is directly linked to the condition of inland waters and coastal marine areas, biodiversity, and the quality of water resources, which makes the sector highly environmentally sensitive. Fisheries are increasingly viewed not only as a source of food resources, but also as an object of ecosystem-based management aimed at balancing economic efficiency, social needs, and environmental protection.

The current stage of development of Ukraine's fisheries complex is characterized by a combination of complex environmental and socio-economic challenges. These include the degradation of aquatic ecosystems, a decline in natural fish stocks, the impacts of climate change on the hydrological regimes of water bodies, increasing anthropogenic pressure, and the consequences of military actions that have disrupted infrastructure, governance, and monitoring systems. At the same time, the sector is undergoing transformation driven by European integration processes and stricter environmental requirements.

Globally, the development of the fisheries sector is increasingly linked to achieving the UN Sustainable Development Goals, particularly those aimed at ending hunger, ensuring the sustainable use of water resources, responsible consumption and production, climate action, and the conservation of marine and freshwater ecosystems. For Ukraine, integrating these approaches into fisheries practice is an important factor not only for environmental security, but also for the socio-economic stability of regions and the modernization of the sector as a whole.

The aim of this study is to analyze the current state of Ukraine's fisheries complex

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under environmental and socio-economic challenges and to substantiate directions for its sustainable development, taking into account environmental requirements and innovative management approaches. To achieve this aim, the study seeks to: summarize the key problems and constraints limiting the sector's development; analyze the environmental aspects of the operation of fisheries enterprises; and outline promising directions for the sustainable development of Ukraine's fisheries in the context of current global and national challenges.

3.1 Current State of Ukraine's Fisheries Complex

Ukraine's fisheries complex is a multi-component system that combines commercial fishing, aquaculture, fish processing, as well as the infrastructure for the storage, transportation, and marketing of aquatic biological resources. Its development has historically been driven by the country's substantial natural resource potential, which includes the marine areas of the Black Sea and the Sea of Azov, as well as an extensive network of rivers, reservoirs, lakes, and ponds. In addition, Ukraine has access to fisheries conducted in waters beyond its national jurisdiction [1]. Taken together, these factors provide significant opportunities for producing goods derived from aquatic bioresources. At the same time, the efficiency of using this potential has remained uneven over recent decades and has been accompanied by a range of systemic problems.

The period 2014–2024 became one of the most challenging for Ukraine's fisheries complex in the entire history of its independence. The sector experienced several overlapping crises – from the loss of part of its resource base to the destruction of production infrastructure, shifts in market conditions, and a sharp increase in environmental risks. This combination of factors significantly affected catch volumes, the economic stability of enterprises, the condition of aquatic ecosystems, and the competitiveness of Ukrainian fish products.

After the annexation of Crimea, Ukraine effectively lost control over part of the Black Sea and Sea of Azov basin, which had provided up to half of the marine catch before

2014. This was compounded by the loss of industrial access to coastal zones and port infrastructure. As a result, the sector faced:

- a reduction in total commercial catch;
- changes in the production structure (a shift toward inland waters and aquaculture);
- excessive pressure on inland water bodies and the deterioration of their environmental condition.

Following a multi-year reform of fish protection and enforcement agencies, a number of problems emerged, including insufficient funding and staffing, limited technical capacity to control spawning areas, increased poaching,especially on the Dnipro and Dniester rivers and in coastal waters, and weak monitoring of fish stock status. In some years, the scale of unreported (shadow) catches was estimated to be comparable to or even higher than officially recorded figures [2].

In addition, long-accumulating environmental problems have intensified, including:

- eutrophication of rivers and reservoirs due to nutrient (biogenic) inputs;
- contamination by pesticides and heavy metals, especially in the lower reaches of the Dnipro and the Southern Bug;
- hydrological changes caused by river regulation;
- rising water temperatures, which reduce dissolved oxygen levels and affect populations of sensitive species;
- the spread of invasive species that displace native ones.

In many basins, declines have been observed in populations of pikeperch, bream, carp, and catfish, while the share of low-value species has increased.

After the full-scale invasion in 2022, the situation became critical. A large part of the Black Sea coastal waters became unsafe or effectively blocked. Fish processing facilities and cold-storage capacities in the south were destroyed. Fishing fleet vessels and port infrastructure were damaged [3]. Domestic logistics chains were significantly disrupted. Odesa, Mykolaiv, and Kherson regions were particularly affected – precisely the areas where key centers of the fishing industry had been concentrated.

All of these factors led to a decline in the overall number of business entities operating in the fisheries sector (Figure 1). Over the period 2014–2023, the decrease was almost twofold. At the same time, the number of entities engaged in aquaculture fell by 1.7 times [4]. In addition, it is important to consider substantial job losses in coastal communities due to the closure or reduction of fishing activities, as well as a significant decrease in tax revenues to the state budget, which amounted to 80% of the pre-war level [5].

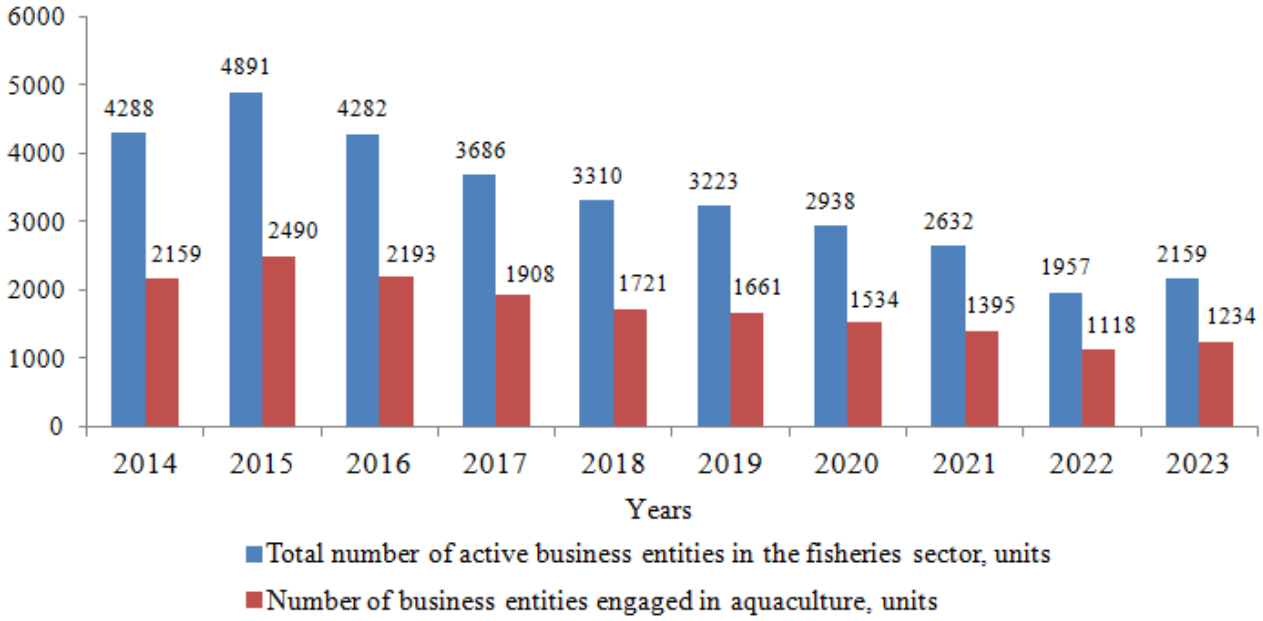

Figure 1 – Dynamics of the number of active business entities in Ukraine's fisheries sector, 2014–2023

A source: [4]

Studies of the state of Ukraine's fisheries sector over 2014–2024 indicate a significant decline in fish catch and the harvesting of other aquatic living resources – by more than 46 thousand tonnes, or 50.4% (Figure 2). At the same time, according to the State Statistics Service of Ukraine, in 2024 the total harvest of aquatic bioresources increased by 27.5% compared to 2023, including an 11.3% increase in fish catch and a 59.2% increase in other aquatic living resources [6]. This suggests that, despite accumulated environmental, economic, and political challenges, the fisheries complex is gradually showing signs of recovery; however, sustaining this trend requires systematic support and stable conditions for resource governance.

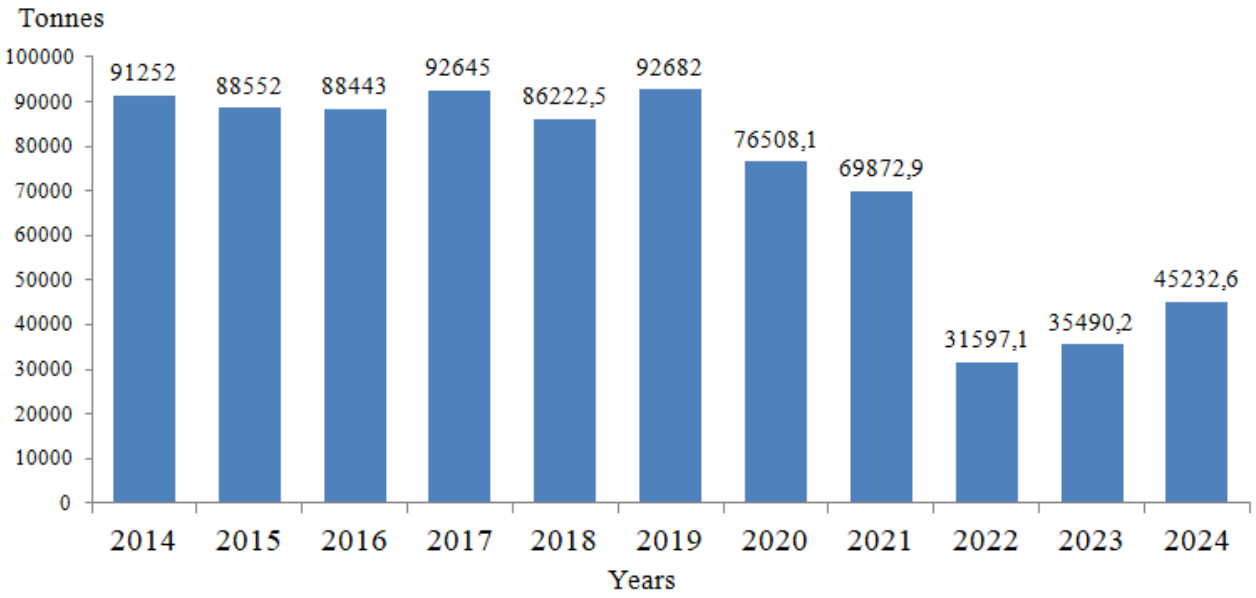

Figure 2 – Dynamics of aquatic bioresource harvesting in Ukraine, 2014–2024

A source: [6]

Most enterprises operate with equipment that is both technically and morally outdated. Experts note that the average age of vessels in Ukraine's fishing fleet exceeds 20–30 years, while the level of technical wear is over 80%. This negatively affects energy efficiency, the quality of wastewater treatment, the depth of fish processing, and the competitiveness of products in European markets [7].

Although Ukraine is actively moving toward alignment with the EU, the sector faces difficulties in implementing international environmental standards for product quality and hydrobiological monitoring. The main reasons include insufficient funding, inadequate staff competence, and underdeveloped infrastructure for potential environmental certification of products.

A significant number of fisheries enterprises operate under difficult conditions, including high interest rates, low investment attractiveness of the sector, limited access to state support programs, and the absence of specialized grant instruments for aquaculture modernization. As a result, most enterprises are unable to upgrade equipment or implement environmental projects.

In addition, climate change has intensified problems related to the instability of hydrological regimes. Temperature fluctuations, river shallowing, and reduced water

availability in the Dnipro, Southern Bug, and Dniester have affected fish feeding conditions and growth rates. Frequent fish-kill events (oxygen depletion) in water bodies have become a serious challenge for aquaculture enterprises.

Overall, the distribution of aquatic bioresource harvesting by fishing areas in 2024 reflects a pattern typical of recent years. Inland water bodies accounted for 35.6% of the total catch, primarily due to the Dnipro reservoirs and major river systems. Aquaculture production represented 21.4% of the total volume of aquatic bioresources harvested in 2024 (Figure 3) [8]. This subsector is gradually recovering and may play a more significant role in shaping the national fish supply balance. In EU countries, aquaculture is the main driver of growth in the fisheries complex, whereas in Ukraine its share remains limited. Despite considerable potential, aquaculture in Ukraine is developing slowly due to difficulties in obtaining permits, a low level of innovation, a lack of specialized infrastructure, and significant investment risks.

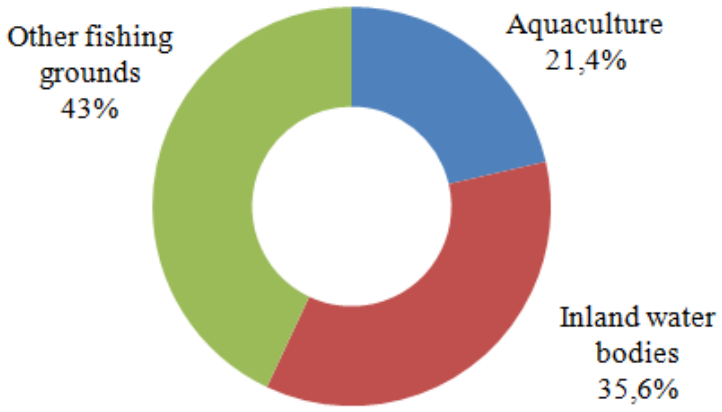

Figure 3 – Distribution of aquatic bioresource harvesting by fishing grounds

A source: [8]

In the species structure of fish catches in 2024, common carp, sazan, freshwater crucian carp, silver carp, freshwater bream, and freshwater pikeperch predominated. Among freshwater species, silver carp, crucian carp, and carp accounted for more than 63.2% of the total fish catch, as these species are traditionally the most widespread in domestic pond aquaculture and are in demand among consumers with average incomes. At the same time, commercial catches of marine species such as turbot, flounder, grey

mullets, anchovy, rapa whelk, goby, shrimp, and so-iuy mullet (pilengas), which represented a significant share of catches in pre-war years, are currently harvested only in small volumes due to the blockade of the Black Sea and the Sea of Azov as a result of Russia's military aggression.

Market linkages have been disrupted, and import competition has intensified. At present, dependence on imported fish remains substantial, while Ukrainian products lag behind in terms of supply stability. Exchange rate fluctuations also affect the production costs of the fisheries complex.

In 2024, more than 85% of domestic demand for fish products was covered by imports. At the same time, consumption and imports increased in both physical and value terms compared to 2022–2023 (Figure 4). Imports consisted predominantly of frozen fish and seafood (92%); the main suppliers were Norway, Iceland, the United States, Estonia, and Latvia, and the largest shares in the import structure were frozen fish, fish fillets, and fresh/chilled fish. Consumption and imports also show pronounced seasonality – declining during the warm season and rising during the cold season. Exports of fish products in 2024 amounted to 9.8 thousand tonnes valued at USD 47.8 million, with the main destinations being Moldova, Germany, Lithuania, Poland, and Denmark [9].

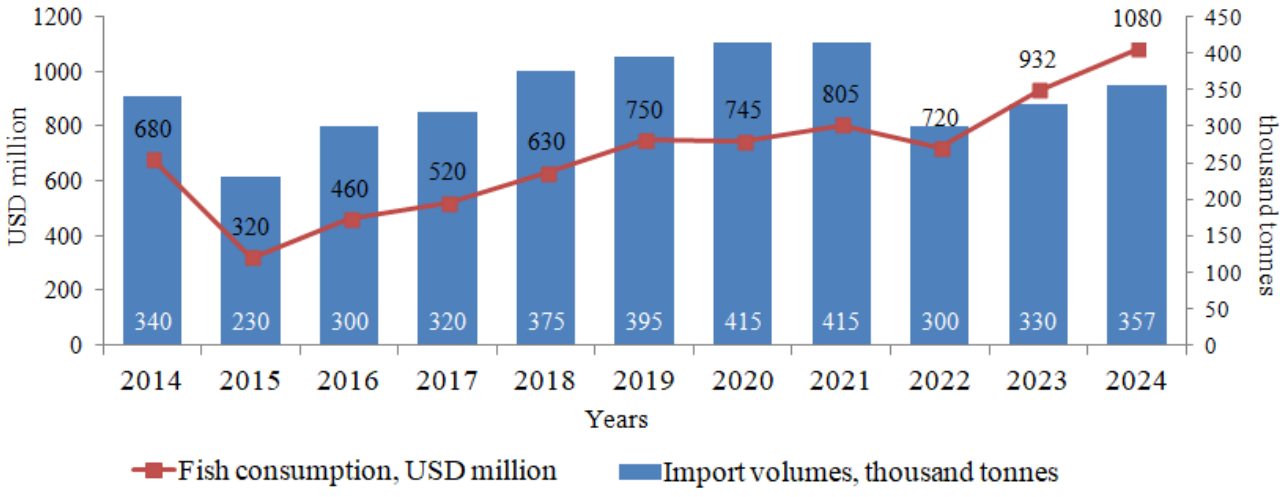

Figure 4 – Dynamics of fish consumption and import volumes in Ukraine

A source: [9]

As an indispensable component of a healthy diet and an element of the country's food security, fisheries products have a pronounced socio-strategic significance. Therefore, fish and fish product consumption is one of the important indicators of a country's economic and social development. The physiologically justified consumption norm for fish and fish products per person in Ukraine is 20–24 kg per year, including 5–6 kg of live fish. In 2024, this indicator was 13.3 kg per person per year, which is 33.5% below the recommended level and 58–78% lower than in developed countries [10].

Ukraine faces a significant deficit of basic fish processing capacity, and modern, economically efficient technologies for producing canned and preserved products, as well as equipment for high-quality processing of delicacy fish, are not used to their full potential. This creates an unfavorable situation in the domestic fish market, leading to higher production costs and rising consumer prices.

Socio-economic factors also have a substantial impact on the current state of the fisheries complex. Declining employment in rural and coastal areas, population migration, lower income levels, and the limited attractiveness of fisheries-related activities for young people create additional risks for the sector's sustainable functioning. Under these conditions, fisheries often lose their role as an important driver of local development, giving way to other types of economic activity.

Thus, the current state of Ukraine's fisheries complex can be characterized as transformational, combining significant natural potential with accumulated structural, environmental, and socio-economic problems. These circumstances necessitate a comprehensive rethinking of sector governance approaches, strengthening the environmental dimension of its development, and integrating sustainable development principles across all stages of fisheries activities, which creates a basis for further analysis of challenges and prospects for the sector's transformation.

3.2 Environmental and Socio-Economic Challenges to the Development of Ukraine's Fisheries Complex

The current challenges facing the development of Ukraine's fisheries complex are multifaceted and arise at the intersection of two interrelated dimensions: environmental and socio-economic. Importantly, these groups of factors do not operate in isolation: environmental degradation directly reduces productivity and the predictability of production, while socio-economic constraints, in turn, hinder modernization and the implementation of environmental protection practices. As a result, a vicious circle of risks emerges, in which limited resources and weak governance exacerbate environmental problems, and environmental problems, in turn, intensify the sector's economic instability. A systematization of the key issues characterizing the current state of Ukraine's fisheries complex is presented in Table 1.

The key environmental challenge for the fisheries sector is the deterioration of surface waters and aquatic habitats that determine the conditions for the existence and reproduction of aquatic bioresources. In practice, this is reflected in reduced fish productivity of natural water bodies and increased risks for pond fish farming and aquaculture.

The most common environmental problems manifest in the following ways:

- eutrophication, accompanied by dissolved oxygen depletion, especially during the warm season and under conditions of limited water exchange;
- siltation, overgrowth, and degradation of spawning grounds, which undermines the natural reproduction of fish;
- local or chronic pollution (organic matter, petroleum products, agrochemicals, heavy metals), which affects fish physiology, product quality, and sanitary indicators [11].

From an analytical perspective, these processes should be understood as a reduction in the ecosystem carrying capacity of water bodies: a water body becomes less able to provide a sufficient food base, stable oxygen conditions, suitable spatial niches, and spawning habitats. For enterprises, this means not only lower production

Table 1 – Current challenges to the development of Ukraine's fisheries complex

Challenges	Problem description	Main implications for the sector
Resource and environmental	Degradation of aquatic ecosystems, declining water quality, eutrophication, siltation of water bodies, and a reduction in natural fish stocks	Reduced fish productivity, disrupted reproduction of aquatic bioresources, and increased environmental risks
Climatic	Changes in hydrological regimes, rising water temperatures, and an increasing frequency of droughts and extreme events	Deterioration of fish habitat conditions, increase in fish mortality, instability of production
Technological	Outdated material and technical base, low levels of mechanization and automation, and limited adoption of modern aquaculture technologies	Low productivity, higher resource costs, and environmental inefficiency
Institutional and governance-related	Weaknesses in the governance system for aquatic bioresources, fragmented regulation, and weak enforcement of environmental requirements	Inefficient resource use, increased illegal fishing, and reduced trust in regulatory mechanisms
Socio-economic	Declining employment, workforce outflow, low investment attractiveness of the sector, and limited access to financial resources	Slower enterprise development and reduced product competitiveness
Infrastructure-related	Deterioration of hydraulic engineering structures and insufficient development of processing and logistics infrastructure	Product losses, constraints on production scale, and reduced economic efficiency
Security and crisis-related	Consequences of military actions, damage to water bodies and infrastructure, and restricted access to certain water areas	Disruption of production chains, reduced catches, and additional environmental pressure

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volumes, but also higher costs to maintain key technological parameters (aeration, water exchange, disease prevention), i.e., increased production costs.

A separate aspect is the disturbance of ecological balance due to invasive species and changes in trophic chains. Even without a sharp deterioration in the chemical parameters of water, biological invasions can alter the structure of biocenoses, displace native species, or reshape feeding competition, which in the long term reduces the resilience of aquatic ecosystems and the predictability of catches.

In the context of fisheries, climate change should be interpreted not as a background threat but as a driver of variability that makes outcomes less predictable. For the sector, the most critical trends are:

- rising water temperatures and more frequent temperature extremes;
- increasing aridity in a number of regions, with reduced runoff and lower water availability in water bodies;
- anomalous floods and heavy rainfall events that lead to erosional wash-off and abrupt fluctuations in water quality [12].

As temperatures rise, oxygen solubility decreases, biochemical processes accelerate, water bodies "age" more rapidly, and the likelihood of fish-kill events increases. For pond fish farming, this means greater technological dependence on engineering measures (aeration, regulation of water exchange, optimization of stocking density). For natural waters, it leads to reduced population stability, shifts in species ranges, and changes in spawning timing and seasonal migration patterns.

Overall, the climate factor becomes a risk multiplier: even moderate problems with water quality or anthropogenic pressure can have much more severe effects under thermal stress conditions.

A major constraint for Ukraine's fisheries complex is competition for water resources from other users (the municipal sector, industry, agriculture, and the energy sector). This competition manifests itself in two dimensions:

- quantitative – water scarcity, redistribution of runoff, restrictions on water abstraction, and changes in water-level regimes;
- qualitative – deteriorating water conditions due to discharges, surface runoff,

and diffuse pollution.

For fisheries, this means that even well-organized, technologically managed production often depends on external environmental conditions that enterprises cannot control. Under such circumstances, environmental incidents (accidental discharges, sudden deterioration of water quality parameters) become not an exception but a systemic risk affecting fish health and disease spread, the preservation of the food base, and the safety and marketability of products.

Environmental risks in the fisheries complex are often amplified by socio-economic constraints that reduce the sector's adaptive capacity. Investment barriers are among the most significant and include:

- the high capital intensity of modernization (upgrading hydraulic infrastructure, water supply and drainage systems, and temperature-controlled logistics);
- limited access to long-term credit resources;
- elevated risks (natural-climatic, regulatory, and security-related), which reduce investors' willingness to operate in the sector.

The economic effect of this barrier is twofold: first, technological renewal is slowed; second, environmental vulnerability increases because outdated systems are less controllable and less efficient in terms of resource use.

Market constraints are reflected in demand volatility, competition from imports, price fluctuations, and stricter quality requirements. For many producers, the challenge is not only to raise or catch fish, but also to ensure value-added processing, loss-free storage and logistics, and compliance with sanitary and environmental market requirements [13]. This, in turn, reinforces a structural problem—namely, the predominance of low-margin business models (selling raw materials without deep processing), which reduces the resources available for modernization and greening.

Institutional and governance challenges include fragmented regulation, uneven enforcement, difficulties in reconciling interests among water users, and insufficient transparency in certain market segments. In practice, this is manifested in:

- weak governance of bioresources and risks of illegal fishing;
- slow implementation of the ecosystem approach;

- a lack of incentives to shift toward environmentally safe technologies.

Equally important is the human capital challenge: a shortage of qualified personnel, an aging workforce, migration processes, and the generally reduced attractiveness of employment in the sector. As production becomes more technology-intensive and environmental requirements become stricter, workforce shortages turn into a factor that directly affects:

- the quality of production process management;
- compliance with environmental regulations;
- an enterprise's capacity to implement innovations and improve efficiency.

Additionally, territorial unevenness is observed: some water bodies and enterprises have better starting conditions (infrastructure, access to markets, adequate water quality), while others operate in much more challenging environmental and economic contexts. From a strategic planning perspective, this means that universal solutions may be insufficient. Measures need to be differentiated by types of water bodies, regions, and production models [14].

Current Ukrainian realities add a security dimension to the classical environmental and economic challenges: damage to infrastructure, restricted access to certain water areas, disruptions of logistics chains, and additional risks for monitoring and enforcement. This factor increases uncertainty, raises transaction costs, and makes long-term planning more difficult. For the fisheries complex, it underscores the growing importance of resilient risk management models in which environmental, economic, and security threats are addressed jointly.

3.3 Ukraine's Fisheries Complex in the Sustainable Development Framework

The analysis of challenges shows that the current development of Ukraine's fisheries complex cannot be viewed solely as a sectoral issue of food production or natural resource use. It is increasingly becoming a comprehensive sustainable development task, where economic outcomes must be achieved while preserving the ecological functions of aquatic ecosystems and maintaining the social viability of

coastal and rural areas. In this sense, fisheries simultaneously act as a user of natural resources, a component of the food system, an instrument of regional development, and an object of environmental regulation and risk management.

In general terms, the sustainable development of the fisheries complex implies balancing three interrelated dimensions:

- Environmental – conservation of aquatic ecosystems and biodiversity, maintaining the renewability of populations, and ensuring adequate water quality as the basic conditions for the sector's functioning;
- Economic – increasing productivity, competitiveness, and value added of fish products through resource-efficient use of water, energy, and feed;
- Social – supporting employment and incomes, ensuring safe working conditions, and maintaining food accessibility for the population.

In practical terms, this means moving away from the approach of "maximizing catch and production at any cost" toward the concept of "ecosystem-acceptable limits," where the scale and methods of activity are determined not only by demand and enterprise capacity, but also by the ability of the aquatic environment to sustain resource reproduction without degradation.

The fisheries complex is directly linked to a number of UN Sustainable Development Goals (SDGs), not merely in a declarative sense but through specific mechanisms of impact:

SDG 2 "Zero Hunger" – achievement of this goal is associated with the stability of the domestic food market, while aquatic bioresources are regarded as a source of protein and micronutrients;

- SDG 6 "Clean Water and Sanitation" – this relates to requirements for water quality in water bodies and effluents, pollution control, and the restoration of aquatic ecosystems;
- SDG 12 "Responsible Consumption and Production" – reducing losses along the supply chain, greening feeds and technologies, and ensuring product traceability;
- SDG 13 "Climate Action" – adaptation to climate risks, energy efficiency, and reducing the vulnerability of production;

- SDG 14 "Life Below Water" and the related objective of biodiversity protection in inland waters – fisheries regulation, protection of spawning grounds, and limiting impacts on habitats.

Therefore, fisheries should be viewed as an intersection point of food, water, environmental, and regional policies. This is particularly important for Ukraine, where resource constraints and risks often have a basin-wide or territorially integrated character.

One of the key methodological principles for the sustainable development of the fisheries complex is the ecosystem approach. Its essence is that the management of bioresources and production processes is carried out with due consideration of:

- interactions among species within trophic chains and the role of habitats;
- water quality, oxygen regimes, and hydrological dynamics;
- impacts of other water users within the basin;
- the limits of acceptable pressure on the ecosystem [15].

In practice, the ecosystem approach implies a shift from reactive management (addressing the consequences of fish-kill events, diseases, and declining catches) to preventive management (planning operating regimes, pressures, and habitat restoration measures). It also involves moving toward managing the interconnections between an enterprise and the water body and basin in which it operates. All of this provides a basis for integrating fisheries into basin water resources management as a mechanism for reconciling interests and minimizing conflicts over water use.

Under current conditions, sustainable development becomes an economic necessity. For the fisheries complex, this is reflected in resource- and eco-efficiency approaches that include:

- water efficiency, involving controllable water exchange, minimization of losses, and reduction of water-related risks;
- energy efficiency in processes such as aeration, water pumping, and product cooling/storage;
- feed-use efficiency, which affects production costs and the aquatic environment through organic loading;

- reducing product losses along the chain "farming/catch – storage – processing – logistics."

In this context, the fisheries complex can be viewed as part of the circular economy, where the following become important: the use of processing by-products (subject to sanitary compliance), minimization of waste and discharges, and the reuse of resources within acceptable technological limits (e.g., recirculating water solutions) [16].

Environmental requirements in fisheries should be understood as a system of rules and practices that must be integrated into production. Key implementation areas include:

- reducing negative impacts on water bodies through control of organic loading, pollution prevention, compliance with water-use regimes, and environmentally responsible use of substances and materials;
- strengthening biosecurity and prioritizing preventive measures over responding to consequences (disease outbreaks, mass fish kills);
- supporting reproduction and protecting habitats, preserving spawning grounds and riparian buffer zones, and minimizing habitat destruction as the basis for long-term productivity;
- ensuring product quality control and increasing producers' environmental responsibility.

To practically implement the principles of sustainable development, a clear management system is needed that translates broad objectives into controllable parameters. It is advisable to follow the sequence: "Sustainable development goals for the sector – Measures – Indicators – Evaluation of results". In this sequence, indicators play a crucial role because they convert planned measures into measurable parameters and enable an objective assessment of goal achievement. This system of indicators has practical value for regulation and sustainable development instruments: it specifies what should be monitored and where management interventions are required. General examples of indicators (without reference to any specific methodology) include:

- environmental indicators – water quality parameters, frequency of incidents

(fish kills, pollution), condition of habitats/spawning grounds;

- economic indicators – productivity, production costs, share of processing and value added, losses in logistics;

- social indicators – employment, workforce stability, occupational safety, product accessibility.

Thus, integrating Ukraine's fisheries complex into the sustainable development framework implies combining the ecosystem approach, resource and eco-efficiency, incorporation of environmental requirements into production models, and the use of indicators for results-based management. However, implementing these principles requires clear regulatory mechanisms, standards, control procedures, and coordination of water use at the basin level, which makes it necessary to examine in detail the environmental requirements and regulatory instruments governing the fisheries complex.

3.4 Environmental Requirements and Regulatory Mechanisms for the Functioning of the Fisheries Complex

Sustainable development of the fisheries complex is impossible without clear and predictable rules for natural resource use that simultaneously: limit excessive pressure on aquatic ecosystems; create conditions for the reproduction of bioresources; ensure fair competition in the market; and reduce risks for the population and consumers. Under current conditions, environmental requirements for fisheries are shaped at the intersection of water, environmental, fisheries, and sanitary–epidemiological regulation. A key shift is moving from formal compliance control to managing environmental outcomes, where the focus is not only on permits and reporting, but on real dynamics in water quality, habitat condition, and the reproduction of aquatic bioresources.

In national practice, environmental requirements for fisheries activities can be conditionally grouped into four blocks.

1) Requirements for water use and impacts on water bodies. For fisheries, critical

rules regulate water abstraction, water exchange, maintenance of hydraulic structures, and the prevention of deterioration of water bodies. In practical terms, this means aligning technological regimes (filling/draining ponds, flow-through rates, aeration) with environmental constraints, especially during periods of low water availability or high temperatures. Where production involves discharges, a key requirement is preventing exceedance of permissible limits and avoiding an increase in organic loading on the water body.

2) Requirements for the protection and reproduction of aquatic bioresources. This block covers fisheries regulation (catch regimes, restrictions, bans, protection of spawning grounds) as well as reproduction measures (stocking, biotechnical works, and habitat protection). From a sustainability perspective, it is important that regulation focuses not only on catch volumes, but also on qualitative population parameters: age/size structure, the condition of the spawning base, and the accessibility of migration pathways.

3) Environmental safety requirements and incident prevention. This block includes rules aimed at minimizing risks of pollution and accidents (fuel leaks, chemical releases, violations of technological regimes that may cause mass fish kills). In aquaculture, biosecurity rules become particularly important: control of pathogen introduction, quarantine procedures, restrictions on uncontrolled movement of biological material, and disease prevention [17].

4) Sanitary and food safety requirements for products.This block directly links the environmental condition of water bodies to the marketability of products. Water pollution, improper feeding practices, uncontrolled use of substances, or poor hygiene during processing translate into risks to food safety – especially important as quality standards become stricter and access to demanding markets expands.

Regulatory mechanisms in the fisheries complex are implemented through a combination of administrative, enforcement, and economic instruments.

Permitting mechanisms (water use, special regimes for the use of bioresources, and other approvals) should create a framework of acceptable impact, i.e., define the limits within which economic activity does not ухудшує the ecological status of water

bodies. A practical weakness is that the permitting system can sometimes become a formality if it is not supported by effective monitoring and a clear "indicator – response" logic.

Enforcement mechanisms (supervision of compliance with fishing rules, prevention of illegal catches, and inspections of environmental safety) in resilient governance models should be risk-based. In other words, control efforts should be prioritized where risks are highest: water bodies with chronic pollution, periods of temperature extremes, areas with high levels of conflict over water use, and segments with a high prevalence of shadow practices.

Economic instruments (resource use fees, penalties for violations, and incentives for modernization) can significantly strengthen the environmental effect of regulation, but only if they are designed to change stakeholders' behavior in practice. For example, supporting modernization toward water- and energy-efficient solutions is more effective than compensating for the consequences of recurring incidents.

For the fisheries complex, monitoring is not an additional element but a core condition of effective management. Without systematic control of water conditions and bioresources, it is impossible to set fishing regimes on a sound basis, plan stocking measures, assess the impacts of other water users, or forecast risks of fish kills and disease outbreaks.

It is reasonable to organize monitoring through three interconnected loops:

- water environment monitoring – tracking basic physico-chemical parameters (oxygen regime, nutrients, organic loading), seasonal fluctuations, and eutrophication indicators;
- biological monitoring – population status, catch structure, reproductive capacity, indicator species, and biodiversity;
- risk and incident monitoring – recording cases of mass fish kills, accidental discharges, abrupt changes in water quality, and the spread of diseases.

The effectiveness of monitoring is determined not only by the frequency of measurements, but also by the existence of a management mechanism of "signal – decision." If parameters go beyond permissible limits, predefined actions should be in

place (e.g., catch restrictions, adjustment of technological regimes, increased aeration, temporary suspension of operations, etc.).

The European integration vector strengthens requirements for fisheries in three areas: environmental objectives for water bodies, responsible management of bioresources, and requirements for quality and traceability. In practical terms, this implies:

- a stronger focus on the ecological status of water bodies and preventing deterioration;
- broader implementation of ecosystem-based management practices (spawning grounds, migration routes, coastal zones, and basin-level integration of interests);
- stricter requirements for traceability of the origin of fish products and compliance with food safety standards.

For fisheries enterprises, this translates into the need to move beyond meeting minimum standards toward management systems in which environmental and food safety risks are assessed, prevented, and documented at all stages of production and marketing.

Alongside state regulation, the internal environmental orientation of enterprises is crucial, as it largely determines whether requirements become real practices. The most effective directions include:

- environmentally informed planning of technological regimes (water exchange, stocking density, feeding, aeration) with consideration of seasonal risks;
- preventive biosecurity (quarantine, control of biological material supplies, regular diagnostics);
- management of waste and by-products (minimizing the release of organic matter into water bodies, controlling sludge accumulation, and ensuring proper disposal);
- traceability and quality as elements of market resilience (especially for processing and logistics).

As a result, environmental requirements cease to be an external administrative pressure and become part of operational efficiency, as they reduce losses, increase

production stability, and lower the frequency of incidents.

Therefore, environmental requirements and regulatory mechanisms in the fisheries complex create a framework within which sustainable sector development is possible—from water quality control and the protection of bioresources to risk-based oversight and enterprise-level management. At the same time, turning this framework into practical results requires clear, forward-looking directions for modernization and greening that combine environmental priorities with economic viability and adaptation to current challenges.

3.5 Promising Directions for the Sustainable Development of Ukraine's Fisheries Complex

The prospects for the sustainable development of Ukraine's fisheries complex are determined by the sector's ability to address three interrelated tasks simultaneously: increasing productivity and value added, reducing environmental pressure on aquatic ecosystems, and ensuring resilience to climatic, economic, and security risks. Under current conditions, the focus should be not on isolated local measures, but on systemic modernization directions that shape a strategic development trajectory within ecosystem-acceptable pressures while strengthening enterprises' competitiveness.

The first foundational direction is the greening of production, which implies reducing pressure on water bodies through more controllable technological regimes and resource-efficient solutions. For fisheries enterprises in practice, this means:

- optimizing stocking density and feeding regimes to minimize excessive organic loading and eutrophication risks;
- improving water efficiency (managing water exchange, reducing water losses, maintaining adequate oxygen regimes);
- implementing energy-efficient solutions (aeration, pumping, and product cooling and storage as the most energy-intensive processes);
- ensuring environmentally safe management of by-products (sludge, organic residues, processing waste) while minimizing their release into water bodies.

The economic rationale of this direction is that greening delivers not only

environmental benefits but also practical operational gains: it reduces technological losses, stabilizes production, and increases predictability, which is an important factor in the sector's investment attractiveness.

Given the limitations of wild capture fisheries and the environmental vulnerability of aquatic ecosystems, aquaculture is increasingly emerging as a strategic segment of Ukraine's fisheries complex. At the same time, its development should be based on sustainability principles, combining economic efficiency with environmental safety. The following approaches are particularly promising:

- a transition from extensive to more intensive, yet well-controlled technologies (depending on the type of enterprise and the carrying capacity of the water body);
- gradual introduction of elements of closed-loop/recirculating solutions where appropriate (biofiltration, mechanical treatment, water quality control);
- strengthening biosecurity (control of the origin of stocking material, quarantine, disease prevention);
- diversification of farmed species with consideration of climate change and local conditions.

It is important that technological modernization does not shift pressures to other environmental components (for example, through uncontrolled discharges or excessive resource use). Therefore, sustainable aquaculture development should be built on the principle of a managed cycle with clearly defined impact boundaries [18].

Because fisheries depend directly on the condition of aquatic ecosystems, promising development directions should include ecosystem restoration as an investment in long-term productivity. In practical terms, this involves:

- conserving and restoring spawning grounds, riparian buffer strips, and shallow-water habitats;
- measures to enhance the natural self-purification capacity of water bodies (reducing nutrient inputs, restoring water exchange, and targeted rehabilitation of critical areas);
- coordinating water use at the basin level to reduce conflicts and avoid environmentally hazardous regimes;

- scientifically justified fish stocking as a supporting tool that complements – rather than replaces – habitat protection.

This direction is important because the natural capital of aquatic ecosystems forms the basis for resource reproduction. Without restoring this foundation, any production and infrastructure investments will have a limited effect.

Sustainable development under current conditions is impossible without systematic risk adaptation, as climate instability and crisis factors increase the frequency of deviations from normal operating conditions [19, 20]. Priority measures include:

- risk-oriented planning at the enterprise level (response plans for fish kills, abnormal temperatures, water shortages);
- early warning based on monitoring (critical oxygen thresholds, temperature, nutrient indicators);
- improving infrastructure reliability (aeration systems, backup power supply, maintenance of hydraulic structures);
- diversification of production models and logistics to reduce dependence on a single supply channel or market.

The essence of this direction is not only to respond to problems after they arise, but to prepare in advance for potential risks and prevent them, which is an important feature of a modernized sector.

The economic resilience of the fisheries complex is determined not only by production volumes, but also by the share of value added that the sector can create within the country. This requires the development of:

- processing capacities focused on quality and standardization;
- cold storage and temperature-controlled transportation systems to reduce losses and ensure product safety;
- traceability of origin and quality standardization, which strengthens consumer trust and opens access to more demanding markets;
- cooperative models (pooling producers to jointly use logistics, processing, and marketing).

This direction is particularly important for regional development: processing and logistics create jobs and form a more resilient economic base than selling raw materials without deeper value-added processing.

Even the best technologies and environmental solutions will not be effective without institutional support. Therefore, the prospective development of the fisheries complex requires:

- transparent rules for access to resources and clear regimes for protection and reproduction;
- strengthened enforcement against illegal fishing and violations;
- integration of fisheries interests into basin water resources management (coordination of water use, water quality priorities, and planning of measures);
- incentives for greening (financial and organizational mechanisms to support modernization, resource-efficiency practices, and biosecurity).

This block is essential for the transition to sustainability because it creates conditions in which environmentally responsible behavior becomes not an exception, but an economically and institutionally justified norm.

To summarize the logic of the promising directions for the sustainable development of the fisheries complex, it is advisable to use a cause-and-effect scheme that links current sector challenges with modernization priorities and expected outcomes. This approach makes it possible to show that greening production, developing sustainable aquaculture models, restoring the ecosystem basis of bioresources, risk adaptation, increasing value added, and institutional improvement are complementary components of a unified strategy. In addition, the scheme highlights the role of monitoring and regulation as a feedback mechanism that supports the adjustment of management decisions and increases the sector's long-term resilience (Figure 5).

Implementing the directions presented in Figure 5 makes it possible to shift from short-term responses to problems toward long-term modernization of the sector, in line with sustainable development principles and contemporary environmental and socio-economic requirements.

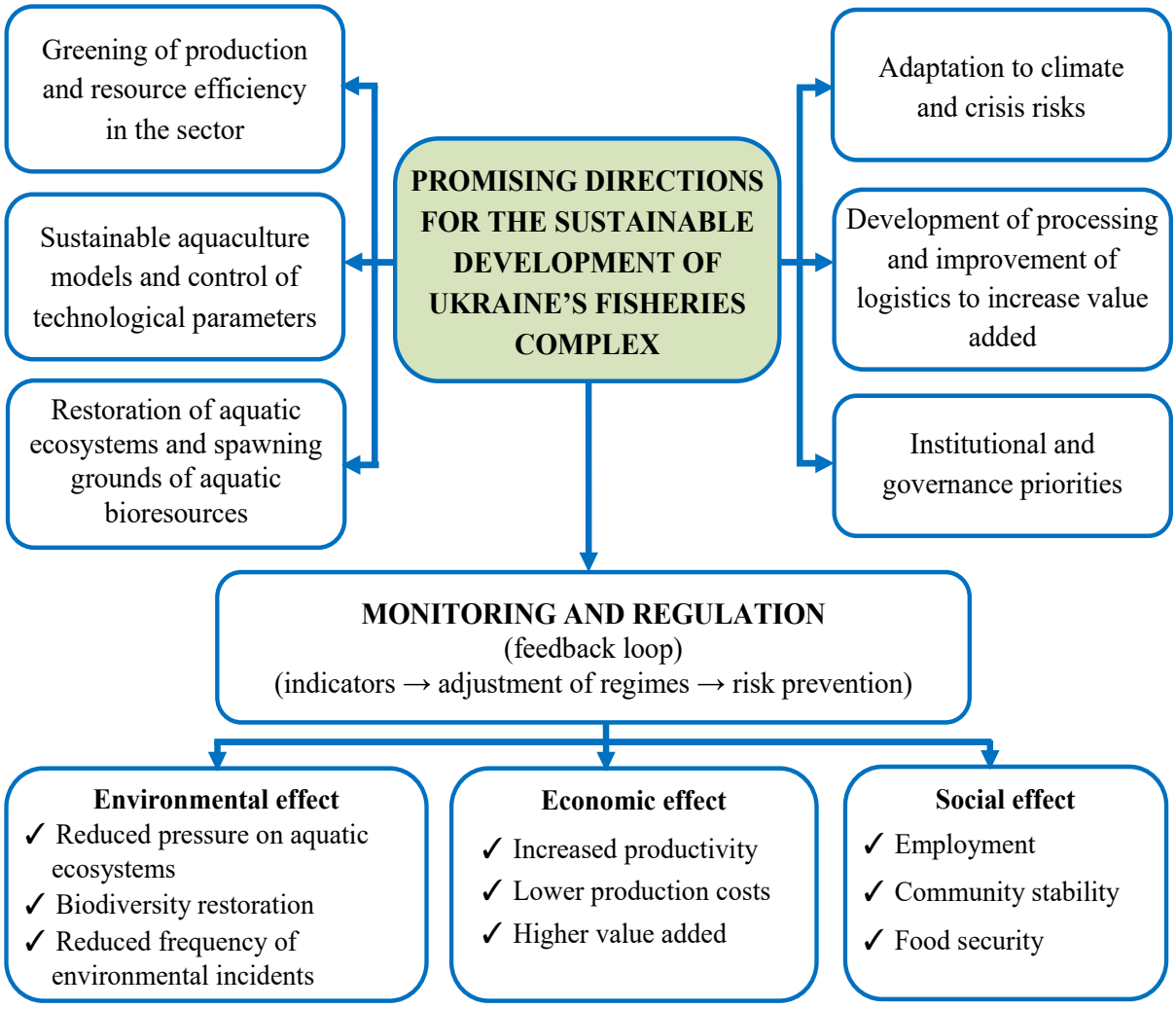

Figure 5 – Promising directions for the sustainable development of Ukraine's fisheries complex

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Summary and conclusions.

The current state of Ukraine's fisheries complex is examined under environmental and socio-economic challenges, including the degradation of aquatic ecosystems, climate variability, increasing anthropogenic pressure, investment and infrastructure constraints, as well as institutional risks related to resource governance and enforcement.

The key problems of the sector and their implications for productivity, production stability, product quality, and market development are systematized, with particular emphasis on the high dependence of domestic consumption on imports and the insufficient development of high value-added processing.

The conceptual foundations of sustainable fisheries development are substantiated, based on the ecosystem approach, resource efficiency, integration of environmental requirements into production models, and results-based management through the sequence: "Sustainable development goals for the sector – Measures – Indicators – Evaluation of results."

Basic regulatory mechanisms required for sustainable sector functioning are outlined, including risk-based oversight, monitoring of water quality and bioresource status, prevention of illegal fishing, and coordination of water use at the basin level.

Priority modernization directions are proposed: greening and improving resource efficiency of production, development of sustainable aquaculture models and biosecurity, restoration and protection of habitats and spawning grounds, adaptation to climate and crisis risks, expansion of processing and cold storage/temperature-controlled transportation systems, and strengthening institutional transparency and investment support.

It is concluded that the transition to sustainable development principles can simultaneously reduce environmental pressure on water bodies, increase the predictability and economic viability of enterprises, and strengthen food security and the socio-economic resilience of regions, provided that governance, monitoring, and the implementation of targeted modernization measures are consistently improved.