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THE FISH FARMS IN THE OPEN BLACK SEA AS A STRATEGIC INITIATIVE FOR THE DEVELOPMENT OF THE NATIONAL ECONOMY: JUSTIFICATION AND IMPLEMENTATION PLAN

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Abstract. Developing fish farms in the open Black Sea is an important strategic step for Ukraine, with the potential to significantly improve the country's economic situation. Using aquaculture in the Black Sea not only increases seafood production, but also preserves the marine environment's ecological balance by minimising pollution and reducing environmental risks through the use of modern technologies. The aquaculture enterprises are to be operated in accordance with state-of-the-art, eco-friendly technologies, thus enabling a substantial reduction in the detrimental impact on the marine ecosystem when compared with conventional fishing methods. Investment in fish farming represents a strategic opportunity for Ukraine to gain integration into global seafood markets, given the country's advantageous geographical position in the Black Sea. This location facilitates the export of products to the European Union, the Middle East, and other regions, thereby exerting a positive economic impact and enhancing national food security. The paper provides a comprehensive analysis of the international experience of fish farms in the open sea, drawing particular attention to the practices of countries such as Norway, Chile, Scotland, Australia and China. The international experience demonstrates that fish farms in the open sea can be successful, provided that the correct technological facilities and effective management are in place. This is particularly relevant for Ukraine, which has great potential for the development of aquaculture in the Black Sea. The establishment of floating fish farms in the open sea represents a promising strategy for Ukraine, given the favourable climatic and ecological conditions of the Black Sea, which facilitate the implementation of effective and sustainable fish farming projects. The development of offshore aquaculture in Ukraine has the potential to contribute to the country's food independence and sustainable development. However, the successful implementation of these projects is predicated on the adoption of clear legislation that will regulate aquaculture outside territorial waters, thereby facilitating the attraction of investments and ensuring the sustainable development of this industry. The proposed adoption of the Law of Ukraine *"On Offshore Aquaculture"* should become the basis for the effective development of fish farms in the open sea, which in turn will facilitate the implementation of investment projects and the sustainable development of aquaculture in Ukraine. The project implementation stages are presented, including opportunities assessment, farm construction, launch and testing, as well as marketing and sales of products.

Keywords: fish farms, offshore aquaculture, Black Sea, strategic initiative, environmental impact, environmental assessment.

JEL Classification: Q22, Q01, Q56, L52, O13

1. Introduction

The Black Sea is a significant source of fish and other marine products for Ukraine. The fish farms in the open Black Sea represent a significant economic opportunity for Ukraine, as well as an essential component of its food security and environmental sustainability in the face of contemporary challenges. The relevance of fish farms in the open Black Sea is increasing in the context of changing economic and environmental conditions, as well as in view of the need for food security and economic recovery in the post-war period. In the context of prevailing geopolitical turbulence, aquaculture emerges as a pivotal potential solution for enhancing Ukraine's

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autonomy within the food sector. Following the annexation of Crimea and part of the Black Sea, Ukraine has found it increasingly important to maintain control over this area in order to access marine resources. For a country with access to large sea areas such as Ukraine, the application of such technologies could be a significant step towards developing a modern aquaculture sector. In light of the aforementioned factors, the attraction of investments in the construction of such farms, the introduction of the latest technologies, and the development of a legislative framework to regulate this process are pivotal steps in the establishment of a sustainable and effective aquaculture sector. These measures constitute a strategic initiative for the development of the national economy.

A significant component of contemporary aquaculture infrastructure initiatives is the utilisation of the open sea for the purpose of fish farming.

At the Economic Forum, Jones, Dewey & Seaver discussed the role of aquaculture in ensuring global food security and the sustainability of food systems. The growing demand for seafood, driven by population growth and changing food preferences, highlights the need for the development of aquaculture. Aquaculture can play an important role in reducing greenhouse gas emissions and preserving ecosystems due to its ability to provide high-quality protein with a lower environmental impact than traditional livestock farming (World Economic Forum, 2022).

In their study, Bekhit *et al.* (2020) analyse global trends in aquaculture growth and its role in addressing the issue of global food shortages. They also consider the resources of Ukraine that could be utilised in this area. The section devoted to the comparison of the growth rates of aquaculture in various regions of the world and Ukraine's capacity to attract state-of-the-art technologies, particularly intensive forms of fish farming, is of particular value. The authors emphasise the significance of state support, modernisation of technological facilities, and the implementation of European standards in the domain of fisheries, particularly the establishment of fish farms in the open sea. They also underscore the necessity to introduce innovations, including monitoring technologies, digital twins, biosecurity, and related concepts.

In the publication by Fenton (2024), the potential of offshore fish farming to address the escalating demand for seafood and alleviate the pressure on coastal ecosystems is examined. The author highlights various barriers to the adoption of this technology, including extreme weather conditions, high infrastructure costs, monitoring and maintenance difficulties, and environmental risks. The implementation of automated technologies, encompassing robotic systems, the Internet of Things (IoT), and digital twins, is identified as a pivotal solution. These technologies facilitate continuous monitoring, optimisation of cultivation conditions, and expeditious response to threats.

The scientists Irtishcheva *et al.* (2016) conducted an analysis of the economic potential of mariculture in the Black Sea as a basis for investors and entrepreneurs seeking promising business opportunities. They identified the presence of natural resources for growing marine organisms (in particular, mussels) and the untapped potential of marine aquaculture for the domestic market of Ukraine. Furthermore, they proposed organisational models of marine farms that can be adapted to the conditions of the Black Sea, thereby formulating a scientific and practical basis, risks and justification for the creation of pilot fish farms.

Selby has had a significant impact on the development of fish farms in the open sea, particularly with regard to the concept of sustainable ocean farming. In other words, the ocean can serve as an alternative 'agricultural field', particularly for cultivating algae. Modern integrated multitrophic aquaculture (IMTA) models involve cultivating fish, algae and shellfish in the same location. This means that seaweed farming complements, rather than competes with, offshore fish farming, making it more environmentally friendly (Food Ingredients First, 2023).

The study "Sustainable Aquaculture" on the website of The Ocean Foundation emphasises the importance of creating an integrated multitrophic aquaculture model. Ocean algae farms are a promising development in sustainable agriculture as they can simultaneously address several global challenges, such as ensuring food security, reducing biodiversity loss, and optimising animal feeding systems. A sustainable approach to aquaculture is predicated on the notion that farms should operate without causing harm to the natural environment. This involves the protection of the natural environment from pollution by modernising farms and reducing emissions, and the maintenance of natural biodiversity so that aquaculture does not result in the depletion of marine resources.

Recent research in the field of fish farming technologies has focused on the development of robotic systems and automated processes, with the potential to enhance production efficiency and sustainability. Amundsen *et al.* (2024) provide a comprehensive overview of the latest robotic technologies employed in aquaculture fieldwork in their seminal paper. These technologies encompass robotic systems designed for the monitoring of water conditions, automated fish feeding mechanisms, and infrastructure maintenance in fish farms. The authors emphasise the potential for robots to enhance production conditions, while underscoring the significance of technical limitations and the cost of implementing such technologies as substantial challenges. The studies emphasise the considerable potential of robotic systems to enhance efficiency and safety

in aquaculture. However, they also underscore the necessity to confront the technical and environmental challenges hindering their effective implementation. In the article, Evjemo *et al.* (2024) investigate how the introduction of robotic systems in commercial fish farms can affect fish behaviour. The authors concentrate on the manner in which diverse robotic technologies, including automatic feeders, net maintenance and environmental monitoring robots, have the capacity to modify fish habits and behaviour.

A significant technological advancement in the domain of open marine aquaculture has been the implementation of digital twins for the purpose of monitoring the structural components of fish cages. The study by Katsidoniotaki *et al.* (2024) developed a digital twin model that integrates sensor data and multi-level simulations (low and high accuracy models) for real-time monitoring of the condition of net structures. Particular attention was paid to accurately predicting net displacement and anchor line loads, both of which are critical factors for farm safety. The most valuable aspect is that the model has been successfully validated in real-world conditions at the SINTEF ACE marine fish farm in Norway, which is one of the world's leading aquaculture research centres.

The research in the domain of smart fish farming has demonstrated considerable potential for the utilisation of the Internet of Things (IoT) and machine-aided cognition in the monitoring of environmental conditions within fish farms. In the scientific paper, Dhinakaran *et al.* (2023) presented an IoT system for environmental monitoring that integrates various sensors for data collection and uses machine-aided cognition for automated decision-making. The implementation of such technologies has the potential to mitigate the risks associated with environmental pollution, whilst concomitantly enhancing feeding efficiency and reducing resource costs. This is of particular significance for the sustainable development of fish farms in the open sea.

In the context of the digitalisation of aquaculture, the study by Naomi A Ubina *et al.* (2023) is significant as it describes the implementation of a digital twin in fish farming based on artificial intelligence of things (AIoT) technologies. Published in the Smart Agricultural Technology journal, the article presents an innovative infrastructure for real-time monitoring of fish farms, combining sensors, cloud computing, and analytical AI modules.

The present study explores the potential of smart aquaculture, utilising deep learning algorithms, to automate various aspects of fish farm management. In their paper, Yang *et al.* (2020) describe the application of deep learning in the context of fish ealth monitoring, prediction of needs, and analysis of environmental conditions in fish farms. The researchers focus on the application of sensor networks for real-time data collection, which has the potential to reduce costs and enhance the efficiency of agricultural processes. They also underscore the considerable potential of deep learning in promoting environmental sustainability in fish farms, particularly through accurate water status monitoring and optimised resource utilisation.

As demonstrated by the analysis of research by scientists specialising in offshore aquaculture, the problem of creating fish farms in the open Black Sea is a strategic initiative for the development of the national economy and is extremely relevant. The establishment of fish farms has the potential to enhance seafood production and contribute to the sustainable development of the Black Sea, thereby assisting in the maintenance of ecological balance and the enhancement of the nation's food security. The introduction of innovative aquaculture technologies has the potential to serve as a catalyst for the development of infrastructure and the attraction of investments in the industry. This, in turn, can contribute to the economic growth of the country.

2. Materials and Methods

The following methods were employed in the composition of the paper.

The research method of analysing international experience was applied to study the practices, technologies and results of the development of offshore (open sea) fish farms in leading countries in the industry, such as Norway, Chile, Scotland, Australia and China. The method was employed to evaluate the international experience of technical and technological solutions, to study successful cases and typical problems (technical, environmental, regulatory) that these countries faced, in order to adapt relevant experience to the conditions of the Black Sea.

The present paper employs a comparative analysis of innovative technologies and engineering solutions in the field of offshore aquaculture. It evaluates and compares innovative technologies applied in the fish farms of leading countries in the field of offshore aquaculture, with a view to identifying promising solutions for possible implementation in the Black Sea. A comparative analysis is conducted of the use of digital twins for the real-time monitoring of the structural dynamics of offshore fish farms. The present study considers a model that has been tested at the SINTEF ACE farm in Norway. This model employs digital twins to visualise and predict loads on fish farm structures in open-sea conditions. The paper analyses the experience of Ocean Farm 1, the world's first offshore salmon farm, developed by SalMar in collaboration with SINTEF. The present study examines the Arctic Offshore Farming (AOF)

project, which was implemented by Norway Royal Salmon in collaboration with Aker Solutions. This project involves the operation of a fish farm in harsh Arctic conditions. The Chinese innovative farm Yuanfang Smart Fishery Future Farm (Ningbo, Zhejiang Province) is considered a prime example of this integration, employing AIoT (artificial intelligence and the Internet of Things) technologies to manage aquaculture processes.

The paper also employs the Environmental Impact Assessment (EIA) method, predicated on an environmental analysis of the predictive parameters of the Ocean Farm 1 technology. The implementation of Ocean Farm 1 technology on fish farms in the Black Sea has been demonstrated to engender a substantial reduction in the negative environmental impact. This is attributable to a considerable decrease in ammonium and organic waste emissions due to treatment systems, the utilisation of renewable energy sources that provide up to 80% of the daily electricity demand, and a reduction in CO_2 emissions by more than 350 tons per year. Furthermore, the implementation of a recirculation system has been shown to reduce the risk of marine pollution.

The strategic planning method was applied in the development of a phased implementation model for the project, the aim of which was to create offshore fish farms in the Black Sea. The strategic planning method identified key stages in the development of the project to create offshore fish farms in the Black Sea, covering the entire life cycle of technology implementation (from initiation to scaling up).

3. Results and Discussion

3.1 The International Experience of Fish Farms in the Open Sea

Fish farms in open seas are an important part of the aquaculture industry and their development is key to understanding the potential and challenges of aquaculture businesses. Ocean fish farms allow for the production of large quantities of fish, helping to meet the world's growing demand for seafood. Due to their location in the open sea, these farms reduce pressure on coastal ecosystems, which is crucial for preserving biodiversity and maintaining the health of marine environments. In the context of increasing demand for food, aquaculture has the potential to become a significant source of healthy and affordable food, which is of great importance for global food security.

The international experience of fish farms in the open sea is of significant importance for the comprehension of the potential and challenges of aquabusiness. It is recommended that the examples of countries that demonstrate how to effectively use open waters for fisheries be considered (see Table 1).

Norway has established itself as a global leader in the field of aquaculture, and its expertise in offshore fish farming is of significant importance. Norway is home to some of the largest offshore fish farms globally, and the country is proactively implementing innovative technologies to minimise its environmental impact. The Norwegian aquaculture industry is predominantly focused on salmon farming, with the country accounting for more than 50% of the global farmed salmon export market. The country is committed to reducing its environmental footprint and ensuring the sustainability of aquaculture through innovations in recirculation systems, zero-emission technologies, the use of renewable energy sources, and improved monitoring methods. A model using digital twins to monitor the structural dynamics of open-sea fish farms in real time was tested at the SINTEF ACE fish farm in Norway (Katsidoniotaki *et al.*, 2024). It successfully predicted net displacement and anchor line loads, confirming its effectiveness in real-world conditions. SalMar, a Norwegian company, is a global leader in the field of salmon production, with a commitment to innovation in the domain of aquaculture. One such innovative project is "Ocean Farm 1", which is the world's first offshore fish farm designed for the purpose of salmon farming in open sea conditions. SalMar has initiated the establishment of Ocean Farm 1 for the purpose of scientific research in collaboration with the Norwegian University of Science and Technology (NTNU). This initiative has facilitated the examination of the biological and technological facets of offshore fish farming, thereby contributing to the advancement of more sustainable and efficient aquaculture methodologies. Open Ocean Farming is a Norwegian company that specialises in growing salmon and trout in the deep open seas using SubFarm technology. This involves submerging fish farms to an optimal depth where temperature, currents and oxygen levels are most favourable for growth. This improves fish health and reduces the risk of disease. This approach has the potential to prevent the exceeding of environmental loads on coastal ecosystems, to reduce the risk of the spread of diseases and parasites, and to improve water quality, which in turn has a positive effect on fish health.

The Arctic Offshore Farming (AOF) project, which was implemented in Norway by the Norway Royal Salmon in collaboration with Aker Solutions, is an excellent example of an innovative approach to salmon farming in the open sea. The primary objective of the initiative is to establish conditions that replicate the natural habitat of salmon to the greatest extent possible. This approach is expected to enhance fish health, reduce stress levels, and improve product quality.

The aquaculture industry in Chile, particularly the salmon farming sector, is a significant component of the nation's economy. Chile stands as a major global

Table 1

Characteristics of key aspects of the fish farms of leading countries and participants in the offshore aquaculture market

Countries	Key aspects	Characteristics of offshore aquaculture key aspects
Norway	Innovative technologies	Norway is actively investing in new technologies for the offshore farms, such as Closed Containment Systems, Zero Discharge Systems, fish and water health monitoring systems, aquaculture platforms and underwater farming technologies.
	Offshore farms	In open waters, large plastic containers and platforms are used to hold fish. Such farms can operate in strong waves and winds, which ensures stable production.
	Environmental responsibility	Norway is actively working to reduce the environmental impact of aquaculture, in particular through the use of technologies to reduce water pollution and monitor fish health.
Chile	Geography	Due to its location in the southwest of Chile, where there are numerous fjords and deep waters, the country has ideal conditions for aquaculture, with minimal environmental impact.
	Technologies and infrastructure	Chilean fish farms employ innovative technologies, including offshore closed containment systems, which reduce water pollution, control environmental conditions and minimise the risk of disease transmission among fish. These systems incorporate monitoring and automation technologies, utilising sensors, cameras and data collection systems to facilitate continuous monitoring of water quality parameters, temperature and oxygen levels. Additionally, biotechnology is employed for disease control, reducing the reliance on antibiotics and fostering a more robust and healthy environment for fish, thereby minimising the negative impact on the ecosystem.
Scotland	Innovative platforms	Scotland is actively working to develop innovative solutions for fish farms, ensuring sustainable development and increasing competitiveness in the international market. The Sustainable Aquaculture Innovation Centre (SAIC) is a key Scottish platform that supports aquaculture innovation through grants, partnerships and research projects. It co-operates with universities, technology companies and fish producers to support the development of offshore aquaculture, such as sea farms in open waters. The SAIC emphasises reducing environmental impact and increasing biosecurity.
	Environmental initiatives	Scotland is actively working to reduce the environmental impact of fish farms, implementing strategies and innovations to ensure the sustainable development of aquaculture. In September 2024, the Scottish Government proposed extending the marine planning zones for aquaculture to twelve nautical miles from the coast. This initiative is intended to reduce the impact on coastal ecosystems and improve the governance of aquaculture practices.
	Research and development, support for innovation and research	The country is investing in the development of new technologies to improve farm management in open sea conditions, particularly automated fish health monitoring systems. Scotland is investing in research and development to enhance aquaculture practices, including developing new technologies to monitor fish health, improve water quality, and minimise environmental impact.
Australia	Strategies for sustainable development of the offshore aquaculture sector	Offshore fish farms are becoming an increasingly important part of aquaculture in Australia, particularly in regions such as Tasmania. This sector involves farming species such as salmon and tuna. The country is actively developing technologies to support the ecological sustainability of these farms, such as creating natural barriers and producing environmentally friendly fish feed.
	Automation technologies	Australia is actively developing innovative technologies for offshore fish farms to help reduce their environmental impact, improve production efficiency, and ensure the sustainable development of the industry. One such technology is deep-sea fish farming, where fish farms are located far from the coast in deeper parts of the ocean, reducing the impact on coastal ecosystems.
China	Development of fish farms	China is engaged in aquaculture in both coastal and open sea areas, with a variety of fish species being cultivated, including shrimp, tuna, salmon and other seafood. In October 2023, the People's Republic of China published a White Paper on the Development of Offshore Fisheries, in which the country's commitment to sustainable development, resource conservation and improving the scientific and technological level of the industry was emphasised.
	Technical facilities, innovative technologies	China is investing heavily in automated monitoring systems, feed management and fish health. It is also implementing innovative technologies and strategies for developing offshore fish farms that focus on sustainable development and integration with renewable energy sources.
	Environmental solutions	In order to improve the efficiency and sustainability of aquaculture, China is implementing integrated multi-trophic aquaculture (IMTA) systems, which combine the cultivation of different species, such as fish, shellfish and algae. This helps to maintain water quality and reduce disease.

Note: based on Highlands and Islands Enterprise; Censor. Net. (2021); Xiamen Caharbor Import and Export Co., Ltd. (2022); Dhinakaran et al. (2023); Evjemo et al. (2024); Global Construction Review (2018); Griffith University (2025); Naomi A Ubina et al. (2023); Fish Farmer Magazine (2021) and Sustainable Aquaculture Innovation Centre.

exporter of salmon, ranking second worldwide after Norway in terms of production volume. The location of fish farms in Chile is often in quiet bays or offshore areas where conditions permit the construction of large net structures. In an effort to mitigate its ecological footprint, Chile is implementing innovative technologies, including closed fish farming systems. These systems eliminate direct contact between the fish and their environment, thereby reducing the risk of contamination and the propagation of diseases.

In the context of Chilean aquaculture, the Servicio Nacional de Pesca y Acuicultura (SERNAPESCA) plays a pivotal role in the supervision of the sector. This state institution is entrusted with the responsibility of environmental monitoring, sanitary control, and ensuring compliance with sustainable development standards in the fishing industry. Its activities are particularly important for ensuring environmental safety when transitioning to offshore fish farms, where controlling fish-keeping conditions is more difficult. SalmonChile, on the other hand, is an industry association that brings together leading salmon producers and actively promotes innovation, including the transition to offshore farming technologies.

Scotland is a major player in the salmon market and is actively developing offshore farms. The country has strict environmental and regulatory standards for aquaculture, including monitoring water quality, ensuring proper waste management, and implementing best practices to protect the environment. The Sustainable Aquaculture Innovation Centre (SAIC) is one of the leading innovation support centres for sustainable aquaculture and is based in Scotland. SAIC has been instrumental in the development of initiatives centred on the health of fish, biosecurity, environmental monitoring and sustainable feeding strategies. These initiatives are of paramount importance in facilitating the adaptation of fish farms to open sea conditions. The experience of SAIC may prove beneficial to other countries that are in the early stages of developing offshore farms, as the centre exemplifies an effective model of collaboration between science, business and government in the field of sustainable aquaculture production. The Scottish and UK governments are actively working to support the sustainable development of this industry, which includes investment in new technologies and environmental monitoring. Scotland has been identified as a nation that has adopted one of the most systematic approaches to the development of aquaculture, as evidenced by the implementation of national-level strategic programmes. Aquaculture Growth to 2030: A Strategic Plan for Farming Scotland's Seas is a strategic document designed to support the development and growth of aquaculture in Scotland. The document aims to double the economic contribution of aquaculture to the Scottish economy by 2030, whilst ensuring the sustainable development of fish farms and marine farming, which includes the cultivation of fish, crustaceans and shellfish. In the context of the development of offshore fish farms, Scotland's strategy demonstrates the importance of government support, regulatory regulation and infrastructure preparation, which allows for the effective integration of innovation without causing harm to the environment.

Australia is a significant participant in the global aquaculture market, particularly in the offshore fish farming sector. Aquaculture in Australia is expanding at a rapid rate, and the country has considerable expertise in establishing farms to raise fish species such as salmon, tuna, cod and other marine life. In the context of Australia, aquaculture plays a substantial role in the production of seafood for both the domestic market and for export. Innovative offshore fish farming technologies in Australia help to reduce environmental impact by ensuring more sustainable production methods and the efficient use of resources. These technologies preserve ecosystems and enable economically viable, environmentally friendly fish farming. The article "Tasmanian fish farming set to expand offshore" (2021), published in the specialised journal Fish Farmer Magazine, examines the strategic initiative of the Australian and Tasmanian governments to transfer fish farms from coastal areas to the open sea. This is associated with the need to reduce the environmental impact on coastal waters, improve growing conditions and ensure the long-term sustainability of the aquaculture sector. In September 2021, the governments signed a memorandum of understanding that provides for co-operation with the Blue Economy Cooperative Research Centre (CRC), a scientific platform that conducts research in the field of blue economy. The main areas of research of the CRC include assessing the economic feasibility of transferring production to the open sea, studying the environmental impacts on deep-sea marine ecosystems, and developing engineering solutions to ensure the sustainability of sea farms in harsh conditions. A study conducted in Australia demonstrates the significant potential of integrating fish farming with offshore wind energy, particularly in the Bass Strait region (Griffith University, 2025).

China is a major producer of fish, with extensive aquaculture operations, including offshore farms. The People's Republic of China is actively developing offshore fish farms in an effort to meet growing demand for seafood and reduce its reliance on imports. A notable achievement was the establishment of an offshore Atlantic salmon farm in proximity to the coast of Qingdao. The farm, designated "Shenlan 1", is currently cultivating approximately 100,000 Atlantic salmon, and has recently undergone

its inaugural commercial harvest of 15,000 fish. China is a major producer and consumer of seafood, and the development of offshore fish farms has enabled the country to meet domestic demand and to export high-quality products to international markets. The development of offshore fish farms in China represents a significant milestone in the pursuit of sustainable seafood production. This is primarily attributable to the adoption of novel technologies, which facilitate the mitigation of adverse environmental impacts, ensure the production of premium quality products and contribute meaningfully to global food security. The Yuanfang Smart Fishery Future Farm in Ningbo, Zhejiang Province, China, has invested 150 million CNY in the creation of a digital farming system that utilises the Internet of Things (IoT) and artificial intelligence (AIoT).

The article entitled "China to build huge structures for open-sea salmon farms in Norway" (Global Construction Review, 2018) details an agreement between the Norwegian company Nordlaks and the Chinese shipyard CIMC Raffles concerning the design and construction of substantial floating structures for the purpose of salmon farming in the open sea. The agreement stipulates the establishment of innovative floating platforms, which are designed to enhance the efficiency of salmon production while concurrently reducing the environmental impact on marine ecosystems. The project has become part of a global trend towards increasing aquaculture capacity, which is important for ensuring food security in the world, particularly for countries that actively export seafood, such as Norway.

In October 2023, the People's Republic of China published a White Paper on the Development of Offshore Fisheries, which emphasised the importance of sustainable development and international co-operation in the domains of aquaculture and fisheries. The White Paper establishes the overarching strategic framework, encompassing the management of resources, scientific research, and the conservation of marine ecosystems. The White Paper emphasises the importance of sustainable resource utilisation, marine ecosystem conservation and innovative technologies in ensuring the sustainable development of offshore fish farms (State Council Information Office of the People's Republic of China, 2023).

The extant body of international experience demonstrates that fish farms in the open sea can become very successful if the correct approach is applied to technology, ecology and management. This experience has the potential to be advantageous for Ukraine, as the Black Sea has the potential for the development of aquaculture. However, the correct implementation of technology and environmental standards is required in order to ensure the sustainable development of this industry.

3.2 The Fish Farms in the Open Black Sea as a Promising Strategic Initiative for Ukraine

The establishment of floating fish farms in the open sea represents a strategically promising initiative for Ukraine, given the numerous advantages inherent in this region for the development of aquaculture on an international scale.

Consider the advantages of floating fish farms. *Firstly*, they have a minimal impact on the ecosystem. Floating farms in the open sea avoid depleting coastal ecosystems such as reefs and sea meadows. They are located in areas where sea currents can disperse waste and feed residues, reducing the risk of pollution. *Secondly,* the implementation of floating fish farms ensures the provision of stable access to natural resources and mitigates competition with conventional fishing methodologies. This can engender considerable economic advantages, particularly in the domain of fish and seafood exports, which are poised to become a pivotal component of Ukraine's foreign trade. *Thirdly,* the establishment of floating fish farms in the Black Sea will enable Ukraine to reduce its reliance on imported seafood, a crucial element in ensuring food security, particularly during periods of crisis and military conflict. *Fourthly,* floating farms reduce pressure on coastal areas, where fishing can lead to the degradation of the natural environment. They offer an alternative method of fish production that does not harm coastal ecosystems.

The fish farms in the open Black Sea have significant potential for Ukraine, especially in the context of reducing dependence on imports and developing export potential. However, in order to ensure the successful development of this sector, it is necessary to take into account environmental, technological and political risks, as well as to invest in infrastructure, technology and personnel. The establishment of clear regulations is also imperative to support the sustainable development of this business. The fish farms in the Black Sea have the potential to become a significant component of Ukraine's economic recovery. However, in the context of challenging political conditions, there are substantial risks that necessitate a strategic approach to the planning and implementation of such projects.

The establishment of a fish farm in the open Black Sea is a venture with considerable potential. In circumstances where traditional fish suppliers are diminished due to military operations or restrictions on trade routes, demand for fish can escalate, and fish farms can assume considerable importance as a source of stable supply for domestic and foreign markets. International organisations and countries may be interested in supporting projects that contribute to the recovery of the Ukrainian economy, in particular by financing sustainable agricultural initiatives such as aquaculture. In the context of growing demand for

environmentally friendly products, fish farms have the potential to become a benchmark for sustainable production, which would have a positive impact on the country's image and would enable it to attract environmentally conscious consumers. The entry of Ukraine into new markets, particularly those within Europe, where there is a consistently high demand for fish and seafood, will allow the country to gain new economic opportunities. The Black Sea has the potential to become a significant supplier of fish to Europe and other regions with a high demand for seafood. Ukraine has the potential to become a major player in the international market for fish products. The aquaculture industry has the potential to meet the growing demand for eco-friendly products, a development that is set to become a pivotal factor in global markets. This is driven by a discernible trend towards increased consumption of organic seafood.

The implementation of a fish farm project in the open Black Sea in Ukraine is comprised of several stages, from initial research and planning to direct operation and monitoring. The following section outlines the primary phases of the project implementation process (see Table 2).

Table 2
Main stages of the fish farm project implementation in the open Black Sea

Project stages	Stages characteristics
1	2
1. Preparatory stage	
A. Opportunity assessment and selection of the place for the farm	A.1. Geographical location A study should be conducted to select the optimal location for the fish farm, which should take into account factors such as water depth, salinity, water temperature, distance to coastal areas, and the presence of sea currents. A.2. Environmental assessment Assessment of the potential impact on the marine environment, including the impact on marine biodiversity, the level of water pollution, in particular by waste, feed, and fish excrement. A.3. Permits and licenses Obtaining all necessary permits from government agencies (environmental, water, construction licenses, etc.) for the implementation of the project.
B. Project development and technology selection	B.1. Farm design Based on the selected location, a detailed farm design is developed, including the placement of all structures (floating platforms, feeding stations, monitoring systems). B.2. Technologies Selection of technologies for fish farming in open sea conditions, including types of nets, oxygen supply systems, automated feeding systems and water condition monitoring. B.3. Infrastructure. Development of infrastructure to service the farm (ports for transporting feed, harvesting fish, storing equipment).
2. Stage of construction of a fish farm in the open Black Sea	
A. Procurement of equipment and materials	A.1. Purchase of floating platforms, nets, feeding systems, monitoring systems, equipment for keeping fish. A.2. Supply of building materials for infrastructure and operational activities.
B. Construction and assembly of the farm	B.1. Creation of floating platforms or structures for keeping fish, with the installation of the necessary equipment. B.2. Installation of feeding stations, nets, water exchange and water circulation systems. B.3. Installation of monitoring systems for control of the water quality, fish health, feeding.
C. Infrastructure development	C.1. Construction of ports or piers for delivering feed and unloading finished products. C.2. Creation of logistics routes for transporting fish to processing plants or markets.
3. Fish farm launch and testing stage	
A. Initial system start-up and testing	A.1. Testing of the systems performance, including automated feed delivery, water monitoring systems and fish health. A.2. Check of the reliability of nets and structures that hold fish in the sea. A.3. Preparing for the launch of the first batch of fish (purchase of fry, check of the conditions for their maintenance).
B. First batch of fish	B.1. Bringing and landing the first batch of fish (for example, salmon fry or other species). B.2. Monitoring of their adaptation to new conditions, adjusting feeding technologies and conditions of maintenance.
4. Operation and production stage	
A. Farm monitoring	A.1. Continuous monitoring of water quality (temperature, oxygen level, pollution level). A.2. Fish health control: disease prevention, feeding control, identification and elimination of problems that may affect fish growth. A.3. Assessment of ecological impact on the environment (checks for water pollution from feed residues and excrements).

End of Table 2

1	2
B. Cultivation and harvesting	B.1. Regular feeding and monitoring of fish growth and weight gain. B.2. Periodic assessments of fish health and taking necessary measures to combat diseases. B.3. Harvesting fish after reaching optimal size, transportation to processing facilities or markets.
5. Marketing and sales stage	
A. Development of a marketing strategy	A.1. Identifying target markets for fish sales (domestic market, export). A.2. Developing a brand and packaging that meets consumer requirements (quality, environmental friendliness, certification). A.3. Establishing relationship with buyers, supermarkets, restaurants, export partners.
B. Product sales	B.1. Organising transportation of fish to markets or processing plants. B.2. Maintaining permanent sales channels through online platforms, wholesale sales, and export supplies.
6. Stage of monitoring and evaluating the effectiveness of the fish farm	
A. Assessment of the results	A.1. Evaluation of production efficiency (profitability, production costs, sales volumes). A.2. Assessment of the environmental impact of the project (whether water pollution has been reduced, whether biodiversity has been preserved).
B. Making adjustments	B.1. Adjustment of technological processes in case of identified shortcomings or problems. B.2. Improvement of conditions for fish farming (for example, improved feeding or changes in water management).
7. Expansion and modernisation of the fish farm	
A. Farm expansion	A.1. After a successful launch and stable production, it is possible to plan for capacity expansion, increase the number of fish and infrastructure. A.2. Expansion of the export markets, increase in productivity to meet growing demand.
B. Equipment modernization	B.1. Introduction of the state-of-art technologies to reduce environmental impact, automate processes, improve fish health and feeding efficiency. B.2. The implementation of a fish farm project in the open Black Sea necessitates an integrated approach, encompassing meticulous planning, environmental studies and constant monitoring. Such an approach will facilitate the maintenance of production stability, the minimisation of environmental risks and the assurance of sustainable development of the project.

Source: developed by the authors

A critical component of the implementation of a fish farm project in the open Black Sea is the environmental assessment, which is of paramount importance. This stage enables the identification of potential environmental risks and their subsequent impacts on the environment. Furthermore, it facilitates the development of measures that are designed to minimise the negative impact on the ecosystem. The fish farms can cause a number of environmental impacts, such as:

1. The release of feed residues, fish waste and other chemicals has been demonstrated to result in water pollution. Excess levels of ammonia, nitrates and phosphates have been shown to cause eutrophication, a process whereby excessive enrichment of water with nutrients results in algal blooms and a decrease in oxygen content.

2. The accumulation of feed waste, inedible parts of feed and undigested residues on the seabed can change the chemical composition of the sediment and have a negative impact on local organisms.

3. In conditions of high fish concentration on farms, infectious diseases can develop and spread to wild fish populations, particularly in areas close to natural habitats.

4. Genetic mixing can occur if farmed fish escape and interbreed with wild populations. This can alter the genetic composition of local species, reducing their ability to adapt.

3.3 Calculation of the Reduction of Ecological Impact as a Result of Implementation of the Innovative Ocean Farm 1 Technology for Fish Farms in the Black Sea on the Environment

The latest achievement in the aquaculture industry is the launch of the world's first ocean farm for growing fish, initiated by the Norwegian company SalMar. This innovative farm, named "Ocean Farm 1", aims to move traditional fish farming from coastal areas to the open ocean, where fish can be raised in a more natural environment. As stated in the paper (Censor. Net, 2021), the establishment of such ocean farms presents novel prospects for the sustainable advancement of aquaculture, chiefly by diminishing the effect on coastal water ecosystems, in addition to the potential for cultivating fish in conditions analogous to their natural environment. This approach has the potential to enhance biodiversity and mitigate the adverse effects on local ecosystems, which is a significant milestone in the advancement of sustainable fish farming. The project, designated "Ocean Farm 1", is indicative of the prevailing trend within the aquaculture sector towards automation and innovation. It serves to illustrate the potential for the development of novel technologies in sea farms, with the capacity to diminish reliance on conventional methods and enhance the efficiency of fish farming.

Salmar has developed a new technology termed "Ocean Farm 1", which is the world's first sea farm that uses a closed system on the ocean surface to grow salmon. This technology has been designed to reduce pollution by ensuring that the water entering the system is cleaned before being released back into the sea. The "Ocean Farm 1" technology, developed by SalMar, is an example of an innovative sea farm that aims to reduce its environmental impact through the use of water purification technologies and pollution reduction. This farm represents a pioneering development as the first to utilise a recirculation system in the open sea, thereby enabling a substantial reduction in water pollution. In "Ocean Farm 1", the water circulates in a closed system, which allows:

– To purify the water before it is released back into the sea;

– to filter out waste (fish excrement, feed residues) using special filters such as mechanical filters, biological filters and filters for dissolved particles;

– to use biological filters to process organic waste (ammonium, nitrites) and maintain proper water quality, which reduces pollution levels.

The Ocean Farm 1 technology has been demonstrated to have a substantial impact on the reduction of polluted water entering the environment when compared with conventional sea farms. The system facilitates the collection of organic waste (e.g., fish excrement, feed residues), which is then treated or removed from the ecosystem. Consequently, the water is purified and returned to the sea without significant pollution. Furthermore, filtration systems are employed to ensure the quality of the water is maintained at a level conducive to the health of the fish, thereby reducing the likelihood of disease development and the necessity for chemical interventions.

The Ocean Farm 1 technology has been demonstrated to significantly reduce the environmental impact of fish farms through the implementation of efficient water treatment systems, the reduction of organic waste pollution, and the use of renewable energy sources.

The environmental impact and pollution reduction of the Ocean Farm 1 technology must be given full consideration. In order to facilitate the implementation of the Ocean Farm 1 technology for the purpose of establishing fish farms in the Black Sea, it is necessary to consider several factors, including the area and depth of the sea, the volume of water required, the cost of the technology, and the potential environmental benefits.

1. Estimating the required water volume for a fish farm:

Assume that the farm in the Black Sea should have a size of 30,000 m^3 of water (30,000 cubic meters), as it was in the Ocean Farm 1 technology case.

2. Installation cost of Ocean Farm 1 technology.

This technology is both new and innovative, and therefore has its own installation price, which includes the cost of infrastructure, water treatment systems, recirculation systems, energy sources and other components.

The installation cost of the Ocean Farm 1 technology is approximately 20,000,000 EUR per farm. This includes all infrastructure components, particularly the recirculation system, filtration systems, waste collection equipment, and renewable energy sources.

3. Energy costs.

Energy demand:

Assume that the farm requires 100 kW of power per hour, which ensures the circulation of water and the operation of filtration systems.

Energy demand per day:

100 kW × 24 hours = 2,400 kWh/day.

Energy savings per day from renewable sources: 2,400 kWh × 0.8 = 1,920 kWh/day.

4. Water pollution reduction.

One of the main advantages of the Ocean Farm 1 technology is the purification of water from pollutants (ammonium, nitrates, organic waste).

Ammonium emissions:

In traditional fish farms, ammonium pollution can be 10 mg/l. In Ocean Farm 1, this level can be reduced to 0.5 mg/l (with a 95% reduction).

Ammonium reduction in water:

– 10 mg/l × 30,000,000 l = 300 kg of ammonium.

– After purification (95% reduction): 300 kg × 0.05 = 15 kg of ammonium.

Reduction of organic waste:

In conventional fish farms, the amount of organic waste can be up to 2 kg/1,000 kg of fish per day. In Ocean Farm 1, due to improved feeding and cleaning, the amount of waste can be reduced by 50-70%.

Assume that the farm grows 1,000 tons of fish per year:

– In conventional farms: 1,000 tons of fish × 2 kg of waste/1,000 kg of fish = 2,000 kg of waste/day.

– In Ocean Farm 1, a 50-70% reduction:

2,000 kg × 0.5 = 1,000 kg/day.

2,000 kg × 0.3 = 600 kg/day.

5. Assessment of environmental benefits for the Black Sea.

The application of Ocean Farm 1 technology can significantly reduce water pollution in the Black Sea, in particular due to:

– Reduction of ammonium and other pollutants;

– reduction of organic waste emissions;

– improvement of water quality due to a recirculation system;

– use of renewable energy sources, which allows to reduce CO_2 emissions and other greenhouse gases.

6. Reduction of CO_2 emissions due to renewable energy sources.

Thanks to the use of renewable energy sources, CO_2 emissions can be reduced.

– CO_2 emissions from electricity consumed from traditional sources: 0.5 kg CO_2/kWh.

– Reduction of CO_2 emissions due to renewable sources: 1,920 kWh × 0.5 kg CO_2/kWh = 960 kg CO_2/day.

Annual CO_2 reduction:

– 960 kg × 365 days = 350,400 kg CO_2/year, which corresponds to 350.4 tons CO_2/year.

7. The overall implementation calculation for farm 1 in the Black Sea is presented in Table 3.

Table 3

Overall forecast implementation calculation for Ocean Farm 1 technology for a farm in the Black Sea

Parameter	Value
Water volume on farm	30,000 m^3
Cost of technology installation	20,000,000 EUR
Energy demand per day	2,400 kWh
Energy savings from renewable sources (80%)	1,920 kWh/day
Ammonium emissions before treatment	300 kg
Ammonium emissions after treatment (95% reduction)	15 kg
Organic waste (50-70% reduction)	1,000-600 kg/day
CO_2 emissions reduction (annual)	350.4 tons CO_2/year

Source: authors' own calculations

Therefore, the implementation of Ocean Farm 1 technology for fish farms in the Black Sea will significantly reduce the environmental impact on the environment due to:

– Reduction of water pollution by ammonium and organic waste;

– use of renewable energy sources to reduce CO_2 emissions;

– water purification through a recirculation system;

– high initial investments (20 million EUR per farm), however, taking into account environmental benefits, this can be a sustainable solution for the sustainable development of fish farming in the Black Sea.

The implementation of the Ocean Farm 1 experience in Ukraine has the potential to represent a significant step towards the sustainable development of fish aquaculture in the Black Sea. The implementation of these technologies will assist Ukraine in mitigating its environmental impact on marine ecosystems, ensuring the sustainable development of fish farming, and enhancing food security. However, for successful implementation, it is necessary to take into account the specific climatic and technical conditions of the Black Sea, as well as to develop appropriate legislative support and infrastructure.

3.4 Launching the Fish Farm Project in the Open Black Sea as a Strategic Initiative for Ukraine's Post-War Reconstruction

The initiation of the fish farm project in the open Black Sea can be regarded as a strategic initiative for Ukraine's post-war reconstruction. The project has the potential to ensure food security and to attract investment, create employment opportunities, and develop environmentally sustainable business. The Black Sea is a strategically important water resource for aquaculture, given its substantial surface area. The development of fish farms has the potential to serve as a pivotal source of fish supply, catering not only to domestic consumption but also to export markets in Europe and beyond. This transition is expected to reduce reliance on imports, thereby creating new economic opportunities. This fact is of particular significance in the context of the country's food security following the war, when reliance on imports can carry significant risks. The fish farms in the Black Sea have the potential to serve as a model for sustainable production through the implementation of cutting-edge environmental technologies, including water monitoring systems, resource management, and the preservation of marine biodiversity.

Consider the key advantages of Ukraine's post-war reconstruction. Firstly, creating fish farms will contribute to developing infrastructure in coastal areas. This is an important factor in economic recovery and includes constructing port facilities, roads and transport networks. This will significantly improve the regions' overall level of development. Secondly, the development of fish farms in the open sea will provide local communities with job opportunities, which could be crucial for social stability in the post-war period. Thirdly, the development of fish farms engenders opportunities for investment in new technologies and innovations, in particular automated monitoring systems, environmental protection systems and other tools that increase production efficiency. Fourthly, the post-war recovery of Ukraine has the potential to be accompanied by support from international organisations, such as the EU, the UN and other financial institutions, which could provide the necessary funding for the sustainable development of aquaculture and other agricultural initiatives.

For the successful launch of fish farms, it is important that the region is stable and that investors and operators are secure. Strategies must be developed to attract investors, including tax breaks, grants and credit programmes. In the post-war period, establishing special economic zones for aquaculture development could be beneficial.

It is evident that fish farms in the open Black Sea have considerable potential to become a pivotal

component of Ukraine's post-war recovery strategy. Beyond ensuring economic development and food security, these aquaculture enterprises have the capacity to generate employment opportunities and serve as the foundation for the sustainable development of coastal regions.

Ukraine's heavy reliance on imports of fish products from other countries is also a significant problem. Despite its large natural resources and potential for aquaculture development, Ukraine still imports a significant proportion of its fish and seafood. Most of the fish products sold in Ukraine originate from other countries, including Norway (salmon), Chile (trout and salmon) and Egypt (seafood), resulting in high dependence on external suppliers and exposure to fluctuations in global fish prices. In order to reduce its reliance on imports, Ukraine must increase its domestic production of fish and seafood significantly. The viability of this approach is bolstered by the provision of state support in the form of subsidies, investments in modern technologies, and the enhancement of the quality of national products.

The development of fish farms in the open sea necessitates the enhancement of national legislation pertaining to the utilisation of marine resources, the establishment of regulatory frameworks for environmental protection, and the assurance of sustainable utilisation of natural resources. The development of offshore aquaculture in Ukraine, particularly fish farms in the open sea (e.g., in the Black Sea), necessitates the establishment of a suitable regulatory and legal framework. In the contemporary context, Ukraine is conspicuously devoid of a distinctly regulated legal apparatus for aquaculture beyond the confines of territorial waters. This crucial deficit significantly hinders the attraction of investments and the implementation of innovative projects. The adoption of the Law of Ukraine "On Offshore Aquaculture" is proposed, with the aim of establishing a legal framework for the development of sustainable fish farms in the open sea (outside inland waters). This will ensure environmental safety and the rational use of marine resources, whilst also attracting foreign and national investments in the aquaculture sector. Furthermore, the integration of the sector into European environmental policy and the green transformation will be facilitated. The proposal is for the initiation of the development of a draft law to be undertaken in conjunction with the Ministry of Agrarian Policy, the Ministry of Environment, the State Fisheries Agency, marine scientific institutes and specialised associations. In the draft law on offshore aquaculture, a preferential tax regime is proposed for offshore farms during the start-up period. The implementation of the Ukrainian legislation pertaining to offshore aquaculture has the potential to attract funding and support from both domestic and international sources. It is evident that a significant proportion of state funding programmes are contingent upon legal regulation. The aforementioned legislation will facilitate the official inauguration of a state support programme (comprising subsidies, preferential lending, and grants) for offshore aquaculture entities, thereby providing an opportunity to secure financing through the Sustainable Fisheries Support Fund. The existence of a legal basis constitutes a fundamental EU prerequisite. The majority of European funds mandate that the activity for which a grant is sought be governed by national legislation. The proposed Law of Ukraine *"On Offshore Aquaculture"* will provide official recognition of this sector, allow companies/projects to be registered as legal entities, and provide environmental and administrative control mechanisms that meet EU requirements.

4. Conclusions

Consequently, the development of fish farms in the open Black Sea represents a significant strategic initiative for Ukraine, with the potential to substantially enhance the country's economic prospects. The Black Sea is of significant strategic importance for the development of fisheries, and the introduction of fish farms in the open sea has the potential to substantially increase the volume of seafood production, which, in turn, has a positive impact on the economy. The implementation of fish farms in the open sea has the potential to contribute to the maintenance of the ecological balance of the Black Sea. The utilisation of modern aquaculture technologies enables these farms to operate in a manner that is less detrimental to the marine ecosystem, thereby minimising pollution and reducing environmental risks in comparison with conventional fishing methods. Investment in fish farming has the potential to facilitate Ukraine's integration into global seafood markets, given the strategic location of the Black Sea, which creates opportunities for the export of products to the European Union, the Middle East, and other regions.

The paper examines the international experience of fish farms in the open sea, presenting a characterisation of key aspects of fish farms of leading countries and participants in the offshore aquaculture market (Norway, Chile, Scotland, Australia, China). The international experience demonstrates that fish farms in the open sea can become extremely successful with the right approach to technology, ecology and management.

The establishment of floating fish farms in the open sea represents a strategically promising initiative for Ukraine, given the numerous advantages of the Black Sea that render it well-suited to the development of

aquaculture on an international scale. In consideration of contemporary technologies, environmental standards and the experience of other nations, Ukraine possesses the potential to become a significant participant in the global aquaculture market. This development would contribute to the advancement of the national economy and ensure food security.

The paper under scrutiny herein substantiates the importance of an environmental assessment when implementing a fish farm project in the open Black Sea. Such an assessment allows for the identification of possible environmental risks and impacts on the environment, as well as the development of measures to minimise the negative impact on the ecosystem. The paper presents a calculation of the reduction of the environmental impact of implementing the innovative Ocean Farm 1 technology for fish farms in the Black Sea on the environment. The implementation of Ocean Farm 1 technology for fish farms in the Black Sea has the potential to represent a significant step towards sustainable development of fisheries. The technology is expected to have a substantial impact on the environment, with a reduction in water pollution from ammonium and organic waste, use of renewable energy sources to reduce CO_2 emissions, and a recirculation system for water purification. While the establishment of such enterprises necessitates substantial initial capital investments, the experience of Ocean Farm 1 can serve as a significant milestone in Ukraine's pursuit of sustainable development in the field of fish aquaculture.

Fish farms in the open Black Sea have significant potential to become an important part of Ukraine's post-war recovery strategy. Their development would contribute to economic growth, ensure food security and create new jobs. It would also attract investment and revitalise the socio-economic life of coastal communities. Therefore, introducing offshore aquaculture to the Black Sea is considered a strategically important step towards strengthening Ukraine's food independence and the sustainable development of its regions in the post-war period, as well as restoring its economy.

Concurrently, the advancement of offshore aquaculture in Ukraine necessitates the enhancement of national legislation governing the utilisation of marine resources, environmental protection, and the assurance of sustainable natural resource management. At present, Ukraine is without a definitive legal framework for aquaculture outside territorial waters, a situation which considerably restricts the potential for investment and the implementation of innovative projects in this domain. In order to overcome these barriers, the Law of Ukraine *"On Offshore Aquaculture"* is proposed for adoption, with the aim of establishing clear rules and mechanisms for the effective and environmentally safe development of fish farms in the open sea. It is anticipated that this will in turnbecome the basis for the implementation of investment projects and ensure the sustainable development of this industry in Ukraine.

References:

Amundsen, H. B., Xanthidis, M., Føre, M., Ohrem, S. J., & Kelasidi, E. (2024). Aquaculture field robotics: Applications, lessons learned and future prospects. *Cornell University, ArXiv.* DOI: https://doi.org/10.48550/arXiv.2404.12995

Bekh, V. V., Andriushchenko, A. I., & Kovalenko, V. O. (2020). Trends in the development of world aquaculture and the fisheries potential of Ukraine. *The National University of Life and Environmental Sciences of Ukraine*. Available at: https://nubip.edu.ua/node/78731

Censor. Net. (2021). Norwegian company SaLMar is launching the world's first ocean fish farm. Available at: https://censor.net/ua/n3287716

Dhinakaran, D., Gopalakrishnan, S., Manigandan, M. D., & Anish, T. P. (2023). IoT-Based Environmental Control System for Fish Farms with Sensor Integration and Machine Learning Decision Support. *Cornell University, ArXiv.* DOI: https://doi.org/10.48550/arXiv.2311.04258

Evjemo, L. D., Zhang, Q., Alvheim, H.-G., Amundsen, H. B., Føre, M., & Kelasidi, E. (2024). Biology and Technology Interaction: Study identifying the impact of robotic systems on fish behaviour change in industrial scale fish farms. *Cornell University, ArXiv*. Available at: https://arxiv.org/abs/2409.15069

Fenton, P. (2024). Offshore Aquaculture: Overcoming Challenges of Open-Ocean Fish Farming. *Fisheries and Aquaculture Journal*, 15(3). Available at: https://www.longdom.org/open-access/offshore-aquaculture-overcoming-challenges-of-openocean-fish-farming-1100291.html

Fish Farmer Magazine (2021). *Tasmanian fish farming set to expand offshore.* Available at: https://www.fishfarmermagazine.com/fish-farmer-all-content/tasmanian-fish-farming-set-to-expand-offshore/

Food Ingredients First (2023). *Growing in the ocean: Developing seaweed farming pegged as sustainable alternative to land-based agriculture.* Available at: https://www.foodingredientsfirst.com/news/growing-in-the-ocean-developing-seaweed-farming-pegged-as-sustainable-alternative-to-land-based-agriculture.html

Foreign Policy (2023). *The Other Global Food Crisis.* Available at: https://foreignpolicy.com/2023/09/19/global-food-crisis-fishing-blue-foods-conflict-water-ocean-climate-resources/

Global Construction Review (2018). *China to build huge structures for open-sea salmon farms in Norway.* Available at: https://www.globalconstructionreview.com/china-build-huge-structures-open-sea-salmon-farms/

Griffith University (2025). Australia can benefit from offshore industries: study. Available at: https://news.griffith.edu.au/2025/03/18/australia-can-benefit-from-offshore-industries-study/

Highlands and Islands Enterprise. *Aquaculture Growth to 2030: A strategic Plan for farming Scotland's seas*. Available at: https://www.hie.co.uk/media/6164/aquaculture-growth-to-2030.pdf

Irtishcheva, I. O., Archibisova, D. S., & Ryzhkova, H. S. (2016). Economic diagnosis of mariculture: untapped potential of the Black Sea. *Global and National Problems of Economics,* (14): 166–170. Available at: http://global-national.in.ua/archive/14-2016/212.pdf

Katsidoniotaki, E., Su, B., Kelasidi, E., & Sapsis, T. P. (2024). Multifidelity digital twin for real-time monitoring of structural dynamics in aquaculture net cages. *Cornell University, ArXiv.* DOI: https://doi.org/10.48550/arXiv.2406.04519

Mind RFID. (2023). *Ningbo Has Cultivated and Expanded the Intelligent Agriculture Industry of RFID Iot Comprehensively.* Available at: https://www.mindrfid.com/uk/news/ningbo-has-cultivated-and-expanded-the-rfid-iot-smart-agriculture-industry-in-an-all-round-way/

Naomi A Ubina, Hsun-Yu Lan, Shyi-Chyi Cheng, Chin-Chun Chang, Shih-Syun Lin, Kai-Xiang Zhang, Hoang-Yang Lu, Chih-Yung Cheng, Yi-Zeng Hsieh (2023). Digital twin-based intelligent fish farming with Artificial Intelligence Internet of Things (AIoT). *Smart Agricultural Technology*, 5. DOI: https://doi.org/10.1016/j.atech.2023.100285

Open Ocean Farming. *Bringing the salmon back to its natural habitat.* Available at: https://openoceanfarming.no/

SalMar. *Official website*. Available at: https://www.salmar.no/

SalmonChile. *Official website*. Available at: https://www.salmonchile.cl

Sernapesca. National Fisheries and Aquaculture Service. Available at: https://www.sernapesca.cl

Shpalta. (2021). *A new era in fish farming – artificial conditions in the open sea.* Available at: https://shpalta.media/2021/09/16/nova-era-u-viroshhuvanni-ribi-shtuchni-umovi-u-vidkritomu-mori/

Sustainable Aquaculture Innovation Centre. *Official website.* Available at: https://www.sustainableaquaculture.com

The Ocean Foundation. Sustainable aquaculture. Available at: https://oceanfdn.org/uk/стійка-аквакультура/

The State Council Information Office the People's Republic of China. (2023). *China releases white paper on development of distant-water fisheries.* Available at: http://english.scio.gov.cn/m/whitepapers/2023-10/24/content_116769897.htm

The United Nations Academic Impact. *The World's Food Supply is Made Insecure by Climate Change*. Available at: https://www.un.org/en/academic-impact/worlds-food-supply-made-insecure-climate-change/

World Economic Forum. (2022). *Aquaculture: why the world needs a new wave of food production.* Available at: https://www.weforum.org/stories/2022/01/aquaculture-agriculture-food-systems/

Xiamen Caharbor Import and Export Co., Ltd. (2022). *Chinese Offshore Salmon Farm Makes First Commercial Harvest.* Available at: https://www.caharborfood.com/news/chinese-offshore-salmon-farm-makes-first-comme-58354945.html

Yang X., Zhang, S., Liu, J., Gao, Q., Dong, S., Zhou, C. (2020). *Deep learning for smart fish farming: applications, opportunities and challenges. Cornell University, ArXiv.* DOI: https://doi.org/10.48550/arXiv.2004.11848

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