International Journal of Aquaculture, 2023, Vol.13, No.5, 1-9
http://www.aquapublisher.com/index.php/ija

Review and Progress Open Access

# Design and Construction of Modern Marine Ranching: Technologies, Methods, and Challenges

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International Journal of Aquaculture, 2023, Vol.13, No.5 doi: 10.5376/ija.2023.13.0005
Received: 06 Jul., 2023
Accepted: 25 Jul., 2023
Published: 03 Aug., 2023

**Preferred citation for this article**:
Mai R.D., 2023, Design and construction of modern marine ranching: technologies, methods, and challenges, International Journal of Aquaculture, 13(5): 1-9 (doi: 10.5376/ija.2023.13.0005)

**Abstract** With the growing global population and increasing demand for marine products, the design and development of marine ranching have become increasingly important. This paper provides an in-depth exploration of the design concepts, construction technologies, and methods of modern marine ranching, and comprehensively analyzes the major challenges faced and corresponding strategies. Addressing different marine environments, various design principles are discussed, such as diversified aquaculture, optimal utilization of spatial resources, and environmental protection considerations. Furthermore, cutting-edge construction technologies and methods are introduced, including China's "Guoxin-1," which utilizes high-tech and innovative equipment to enhance farming efficiency and reduce environmental impacts. However, the construction and development of marine ranching face numerous challenges, such as climate change, marine pollution, and technological bottlenecks. In this context, potential solutions are proposed, including adopting new technologies, improving management systems, and implementing policy adjustments. Lastly, this paper provides detailed descriptions and in-depth analyses of five representative modern marine ranching cases worldwide, aiming to provide valuable references for the design and construction of future marine ranching.
**Keywords** Marine ranching; Design principles; Construction technologies; Challenges; Mitigation strategies

The concept of marine ranching has gradually gained public attention in recent decades. It is defined based on the concept of land-based farming and encompasses the entire process of cultivating and managing marine organisms in specific marine areas through artificial intervention and management, using efficient and environmentally friendly aquaculture methods (Britannica, 1998). These specific marine areas are typically located in environmentally conscious regions, where aquatic organisms such as salmon, cod, scallops, certain species of shrimp, European lobsters, abalone, and sea cucumbers are artificially released and nurtured. The species cultivated in marine ranching do not require any additional artificial feed, as they rely on the natural nutrients present in the water column of the marine ranching zone for survival until they are harvested. This approach not only enhances the productivity of marine biological resources while preserving biodiversity but also contributes to the maintenance and improvement of marine ecological environments.

The concept of marine ranching is not a recent phenomenon, and its development history can be traced back several centuries to the practice of releasing and harvesting marine organisms in marine environments (Mustafa, 2003). However, with technological advancements and a deeper understanding of sustainable marine resource management, the design and construction of modern marine ranching have surpassed early practices and evolved into a complex and sophisticated engineering system.

In the 21st century, the demand and value of marine ranching are increasingly recognized by researchers and the general public. With the growth of the world's population and the increasing pressure on marine resources, how to scientifically, efficiently, and sustainably utilize marine resources has become a crucial global issue. Marine ranching provides a viable solution aimed at improving the utilization of marine biological resources, protecting marine biodiversity, and achieving sustainable development of the oceans.

Therefore, in-depth research on the design and construction of modern marine ranching is not only beneficial for better understanding and addressing current challenges in marine resource management but also instrumental in exploring new approaches to marine resource management, advancing marine ranching technologies, and supporting the achievement of marine sustainability goals.

## 1 Design Principles of Modern Marine Ranching

### 1.1 Design concepts and principles

The design of modern marine ranching needs to consider its fundamental design concepts and principles. Design concepts primarily focus on achieving sustainable utilization of marine resources, ecological conservation, and economic benefits. Design principles guide the design of marine ranching from aspects such as feasibility, maintainability, cost-effectiveness, and safety.

Sustainability Principle: The design of marine ranching should prioritize the protection of the ecological environment, avoiding excessive damage to marine ecosystems, and achieving sustainable utilization of marine resources.

Integrity Principle: The design of marine ranching should consider the overall coordination and efficient operation of various components.

Safety Principle: The design of marine ranching should ensure the safety of personnel and equipment, preventing safety accidents caused by design flaws.

Innovation Principle: In addition to ensuring the basic principles, the design of marine ranching should also emphasize innovation by utilizing new technologies and methods to improve operational efficiency and economic benefits. For example, China's design of the "Changjing 1" modern marine ranching platform clearly reflects the aforementioned principles. "Changjing 1" employs intelligent and automated farming methods, greatly improving the efficiency and economic benefits of aquaculture. Through optimized design, it achieves sustainable utilization of marine resources and ecological protection.

### 1.2 Consideration of environmental factors

The When designing modern marine ranching, a range of environmental factors need to be considered, including but not limited to marine ecology, climate change, and marine environmental protection (De Voe, 1994; Ross, 1997; Read and Fernandes, 2003).

Marine Ecology: The design of marine ranching should strive to integrate harmoniously with the surrounding marine ecological environment, minimizing its impact, such as avoiding adverse effects on important ecosystems or endangered species (Forrest et al., 2007).

Climate Change: The design of marine ranching needs to account for the impacts of climate change, such as temperature fluctuations, sea-level rise, extreme weather events, which can affect the operation of marine ranching (Wu, 1995).

Marine Environmental Protection: When designing marine ranching, careful consideration should be given to how to protect the marine environment, such as reducing water pollution and preserving marine biodiversity (Ervik et al., 1997).

For instance, in designing multi-layered marine ranching, the Netherlands took these factors into account. The design incorporates three layers of seaweed, shellfish, and fish, aiming to mimic natural ecosystems for maximum resource utilization and ecological preservation. Additionally, new energy technologies such as solar panels, wind turbines, and tidal turbines are employed to achieve carbon-neutral operations.

## 2 Construction Technologies and Methods for Modern Marine Ranching

### 2.1 Main construction technologies

The construction technologies for modern marine ranching mainly include the selection of aquaculture facilities and construction materials. The types of aquaculture facilities need to be selected based on the characteristics and requirements of the aquaculture species and the characteristics of the aquaculture environment. For example, floating cages, fixed cages, and submersible cages are commonly used for fish farming. Hanging facilities or benthic facilities may be required for shellfish and seaweed farming. The selection of construction materials needs to consider durability, environmental friendliness, and cost-effectiveness. For instance, corrosion-resistant and environmentally friendly synthetic materials can be used as alternatives to traditional wood and metal materials.

For example, the parore (snapper) aquaculture ranches in New Zealand employ unique construction technologies. They utilize corrosion-resistant and durable plastic hanging facilities that have minimal impact on the marine environment.

### 2.2 Specific construction methods for different types of marine ranching

Different types of marine ranching may require specific construction methods. For example, fish farming ranches usually involve the installation of large floating cages or submersible cages, while shellfish farming ranches may require hanging facilities or benthic facilities. Seaweed farming ranches require specific attachment structures for the seaweed. The specific construction methods need to be determined based on the growth characteristics of the aquaculture species, the conditions of the aquaculture environment, and the aquaculture objectives.

For example, seaweed farming ranches in Guangdong, China, use specific attachment structures that enable effective growth of seaweed on the water surface while facilitating harvesting.

### 2.3 Modern technologies and methods for aquaculture management

Aquaculture management in modern marine ranching involves various technologies and methods, such as disease control and growth environment monitoring. Disease control includes prevention, detection, and treatment of diseases, often leveraging modern biotechnology and veterinary medicines. Growth environment monitoring requires real-time monitoring of parameters such as temperature, salinity, and dissolved oxygen levels in the aquaculture environment, which can be achieved through modern monitoring equipment and information technology.

For example, some fish farming ranches in Norway employ modern aquaculture management technologies. They use remote sensing and automation devices to monitor and regulate the aquaculture environment, ensuring optimal conditions for fish growth.

### 2.4 Integration of marine ranching with modern manufacturing

The construction and development of marine ranching rely on the technologies and methods of modern manufacturing, especially advanced shipbuilding technologies. One typical example is China's "Guoxin 1" marine ranching facility. As the world's first intelligent marine ranching facility with autonomous navigation, self-power supply, automated monitoring, and automated fishing, the construction of "Guoxin 1" heavily relies on modern shipbuilding design and construction technologies.

During the design and construction process, "Guoxin 1" utilized advanced ship design software for detailed system design and optimization. This includes not only the exterior design of the vessel but also the interior layout design, system equipment configuration, and more. Through efficient design and optimization, "Guoxin 1" can efficiently carry out a series of tasks such as aquaculture, fishing, and processing in the smallest possible space.

During the construction phase, "Guoxin 1" leveraged modern shipyard facilities and manufacturing technologies to achieve high-quality construction of the vessel's structure. Additionally, it incorporated automation equipment and intelligent systems, such as an autonomous navigation system, automated monitoring system, and automated fishing system, to realize the automation of marine ranching operations. The success of "Guoxin 1" demonstrates the significant role of modern manufacturing technologies in the construction of marine ranching facilities, providing new insights and references for future marine ranching endeavors.

## 3 Major Challenges and Strategies for Modern Marine Ranching

### 3.1 Environmental challenges

Modern marine ranching faces various environmental challenges, such as climate change and marine pollution. Climate change can disrupt the stability of the marine ecosystem, thus negatively impacting marine ranching. Additionally, marine pollution can threaten the survival and growth of marine organisms (Ferreira, 2007). For example, plastic pollution may lead to marine organisms ingesting plastics, causing harm to their health.

### 3.2 Technological challenges

Modern marine ranching also encounters technological challenges. Firstly, there is an important challenge to improve aquaculture efficiency. Enhancing the growth rate and survival rate of marine organisms, such as fish and shellfish, is a critical issue for marine ranching. Secondly, the durability and stability of aquaculture facilities pose a challenge. Factors like ocean waves and salt corrosion can impact the integrity of aquaculture facilities (Kaiser et al., 2005).

### 3.3 Management challenges

In terms of management, major challenges for marine ranching include disease management and sustainable utilization of marine resources. Effectively preventing and controlling marine diseases is an important issue for marine ranching. Furthermore, marine ranching needs to consider how to protect marine resources and achieve sustainable development while attaining economic benefits.

### 3.4 Strategies and possible solutions

To address the aforementioned challenges, marine ranching can adopt certain strategies and solutions. For environmental challenges, strengthening environmental awareness and minimizing the impact on the marine environment can be pursued. Regarding technological challenges, innovation and the development of more efficient and reliable aquaculture technologies and equipment can be explored. For management challenges, enhancing management practices, such as improving disease prevention and control capabilities, and implementing sustainable utilization strategies, can help tackle these challenges.

In summary, modern marine aquaculture faces various challenges in terms of environment, technology, and management, requiring the comprehensive application of environmental awareness, scientific technology, and effective management strategies to address them. Through continuous innovation and collaboration, sustainable development of marine aquaculture can be achieved, providing reliable marine product supply while protecting the health of marine ecosystems.

## 4 Case Study

### 4.1 Successful cases of modern marine aquaculture development on a global scale

Multi-Level Marine Farm in the Netherlands: The OOS Group in the Netherlands has developed a semi-submersible mussel farming facility using renewable energy technologies, successfully achieving sustainable development in the mussel aquaculture industry. This farming facility not only improves production efficiency in aquaculture but also employs environmentally friendly renewable energy technologies to reduce its environmental impact. The vessel named "OOS Cees Leenaars" measures 76 meters in length and 32 meters in width. It utilizes solar panels, wind turbines, and tidal turbines, among other renewable energy technologies. It harnesses wind, solar, and tidal energy sources to charge supply vessels for mussel harvesting and transportation, enabling zero carbon emissions operations (Figure 1). According to reports, this semi-submersible mussel farming facility will operate in the North Sea for mussel cultivation. By employing renewable energy technologies, this farming facility reduces reliance on conventional energy sources, lowers carbon emissions, and consequently minimizes its environmental impact. Additionally, the semi-submersible design helps minimize disturbances to the marine ecosystem, thus safeguarding the marine ecological environment.


Figure 1 Semi-Submersible Mussel Farm, "OOS Cees Leenaars" (Image Source: International Ship Network)

"Guoxin 1" in China: This is China's first semi-submersible marine aquaculture facility and a product of advanced shipbuilding technology. It is a mobile "marine ranch," and the 100,000-ton large-scale aquaculture vessel is an important equipment for deep-sea aquaculture in China. It can effectively utilize suitable areas in the deep sea for aquaculture, while avoiding natural disasters such as typhoons and red tides. From stocking fry, feeding and nurturing to harvesting, processing, and transportation, it establishes a fishery aquaculture and processing factory on a single ship (Figure 2).


Figure 2 The world's first 100,000-ton aquaculture vessel, "Guoxin 1," under construction in Qingdao (Image Source: Qingdao News Network)

The design, development, and construction of "Guoxin 1" have achieved innovative results centered around "the functionality and hull form of large-scale aquaculture vessels" and "the intensive 'shipboard tank culture' process and equipment for fish." More than 30 independent intellectual property rights have been obtained, breaking through six key technologies: shipboard tank culture, water exchange, roll and pitch reduction, vibration and noise reduction, cleaning and anti-corrosion, and intelligent centralized control. The successful construction and operation of "Guoxin 1" not only provide strong technical support for China's marine aquaculture development but also serve as a reference for global marine aquaculture projects.

According to researcher Yang Hongsheng, digitization and systematization are driving the development of marine aquaculture, gradually becoming mainstream. "The current phase of marine aquaculture is characterized by the ecological, precise, and intelligent development of core technological systems," said Yang Hongsheng. "For example, the development of mechanized seedling sowing, automated monitoring, precise measurement, and intelligent harvesting equipment for ecological ranches; the establishment of information monitoring platforms for ecological ranch resources and environments; the development of disaster warning and expert decision-making systems to improve the intelligent management of ecological ranch operations, and more."

"Deep Blue 1," the world's largest fully submersible intelligent fishery aquaculture equipment, independently developed by China (Figure 3). It can be described as a maritime "giant." The circumference of the net cage is 180 meters, the height is 38 meters, and it weighs approximately 1,400 tons. It operates at an effective aquaculture depth of 30 meters with a diameter of 60.44 meters. The total volume of the aquaculture water is about 50,000 cubic meters, equivalent to 40 standard swimming pools, and the net area is close to the size of two football fields. It is designed to achieve an annual fish production of 1,500 tons and can simultaneously cultivate 300,000 salmon. During the summer, it submerges to the seabed, while during the winter, it floats to the water surface. According to researcher Dong Shuanglin, the biggest feature of "Deep Blue 1" is its "fully submersible" capability, allowing it to completely dive underwater or resurface to the sea level according to water temperature requirements. Wave power can generate electricity for the semi-submersible platform, providing green energy. It is an intelligent net cage that can monitor water quality in real-time, observe fish behavior, and intelligently dispense feed based on the behavior of the fish. Currently, it is deployed in the waters of the Yellow Sea, specifically in the cold water mass located 130 nautical miles east of Rizhao City.

Figure 3 "Deep Blue 1," the world's largest fully submersible intelligent fishery aquaculture equipment independently developed by China (Image Source: xindemarinenews.com)

Norway's SalMar company's Ocean Farm 1, constructed by China Shipbuilding Industry Corporation's Wuchang Shipbuilding Industry Group for the SalMar Group（Figure 4）, is the world's first deep-sea floating fish farming facility. Ocean Farm 1 fully utilizes modern aquaculture technology and improves farming efficiency and production quality through the use of automation and remote monitoring. It is the first deep-sea aquaculture facility for the large salmon producer SalMar, and it was put into operation in the autumn of 2017 as a full-scale pilot project with an offshore design. The project has entered the second phase of farming with excellent biological conditions, ideal salmon growth rates, and low incidence of fish diseases and mortality.

Atlantic salmon farming in Tasmania, Australia: This project utilizes a method called "marine nitrogen fixation" that converts most of the nitrogen emissions into harmless nitrogen gas, greatly reducing the environmental impact of aquaculture.

Marine aquaculture farms in Japan: Marine aquaculture farms in Japan primarily focus on seaweed cultivation, which helps maintain marine ecological balance and contributes to economic development. Japan also emphasizes the development of aquaculture technology, including disease prevention and control, and growth environment monitoring (Masuda and Tsukamoto, 1998; Arnason, 2001).

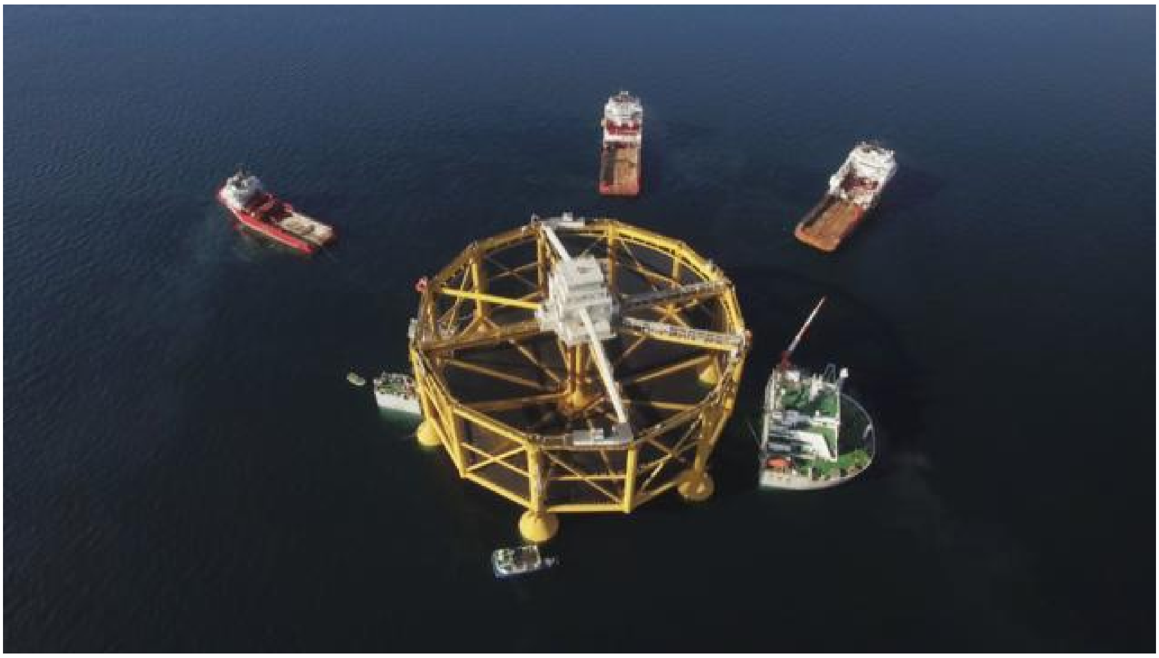

Figure 4 SalMar's Ocean Farm 1 in Norway (Image Source: Fish Farmer Magazine, By Vince McDonagh - 2nd March 2021)

### 4.2 In-depth analysis of the technologies and methods used in each case

Each case utilizes advanced principles, construction techniques, and methods in marine aquaculture farm design, addressing challenges in environmental, technological, and management aspects, and they have developed their own strategies and solutions. For example, the OOS group in the Netherlands achieved energy self-sufficiency and environmental sustainability in their farming facilities through the use of new energy technologies. China's "Guoxin 1" improved the stability and durability of their farming facility through advanced shipbuilding technology. Norway's Ocean Farm 1 increased farming efficiency and production quality through automation and remote monitoring. Tasmania's Atlantic salmon farming project reduced environmental impact by utilizing the "marine nitrogen fixation" method. Japan focused on research and development in aquaculture technology, particularly in disease prevention and control and growth environment monitoring, yielding significant results.

## 5 Discussion and Outlook

Significant progress has been made in the development of marine aquaculture farms worldwide, with their advantages lying in their ability to provide sustainable marine products in vast ocean spaces, making them an important approach for future ocean resource development. However, the construction and operation of marine aquaculture farms also face numerous challenges. Factors such as environmental conservation pressures, technological bottlenecks, financial investments, and policy regulations can all impact the sustainability and economic viability of these farms.

The construction and operation of marine aquaculture farms rely on various technologies and management strategies. Advanced farming equipment and methods can improve farming efficiency, environmental measures can reduce the impact of these farms on the environment, and scientific management strategies can optimize operational effectiveness. However, these technologies and strategies often encounter various issues and challenges in practical applications. Addressing these problems through technological innovation and management optimization is a crucial task for the development of marine aquaculture farms.

From a global perspective, the development of marine aquaculture farms is expected to accelerate in the coming years. With increasing global emphasis on sustainable development, marine aquaculture farms as environmentally friendly and efficient means of utilizing ocean resources will receive more attention. Furthermore, technological advancements will continuously improve the construction and operational techniques of marine aquaculture farms. For example, the application of AI and big data technology can enable precision management of these farms, enhancing farming efficiency and environmental standards.

With technological advancements and changing societal demands, significant transformations may occur in the construction and operation of marine aquaculture farms. New farming technologies, environmental conservation measures, and management strategies may emerge, exerting a profound impact on the construction and operation of these farms. These transformations will not only enhance production efficiency but also elevate the farms to new heights in terms of environmental conservation and sustainability. To address these changes, builders and operators of marine aquaculture farms need to maintain sensitivity to new technologies and trends, actively learn and apply new knowledge and skills to enhance their competitiveness.

## Acknowledgements

During the process of completing this article, we have used some photos sourced from the internet to enhance readers' understanding and experience of the content. Due to communication limitations, we were unable to directly reach out to all the owners of these photos. We sincerely apologize to the owners of the photos and express our heartfelt gratitude for their understanding and tolerance.

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Finally, we would like to once again express our sincere thanks to all the owners of the photos for adding color to our research and article.

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