International Journal of Aquaculture, 2025, Vol.15, No.6, 287-297
http://www.aquapublisher.com/index.php/ija

Feature Review Open Access

Sustainable Fisheries Management: Balancing Resource Use and Conservation

Liqing Chen [1], Wenzhong Huang [2]

1 Tropical Marine Fisheries Research Center, Hainan Institute of Tropical Agricultural Resources, Sanya, 572025, Hainan, China

2 Biomass Research Center, Hainan Institute of Tropical Agricultural Resouces, Sanya, 572025, Hainan, China

Corresponding author: wenzhong.huang@hitar.org

International Journal of Aquaculture, 2025, Vol.15, No.6 doi: 10.5376/ija.2025.15.0028

Received: 17 Sep., 2025

Accepted: 01 Nov., 2025

Published: 22 Nov., 2025

Preferred citation for this article:

Chen L.Q., and Huang W.Z., 2025, Sustainable fisheries management: balancing resource use and conservation, International Journal of Aquaculture, 15(6): 287-297 (doi: 10.5376/ija.2025.15.0028)

Abstract The ultimate goal of sustainable fisheries is to strike a constantly changing balance between human utilization and natural restoration, ensuring the long-term sustainability of fish stocks and ecosystems while also providing a stable life for those who rely on them. This study reviews several key aspects of sustainable fishery management: ecological basis, policy and governance framework, technological innovation, socio-economic factors, and adaptation paths to address climate change. The article first reviews the formation and connotation of the concept of "sustainable fisheries", and then sorts out the overall trend and main predicaments of global fishery resources. Research has found that maintaining ecological balance cannot be achieved without the basic management of ecosystems, the protection of biodiversity and the scientific regulation of fishing intensity. Meanwhile, new technologies such as selective fishing, reduced concurrent fishing, and AI-driven digital regulation are transforming the way the fishery industry is transparent and compliant. Social-level issues cannot be ignored either. The equity of coastal communities, the roles of women and indigenous people, and how the fishery economy can be diversified are all key links affecting sustainability. In addition, the paper also discusses the position of aquaculture in the blue economy and the role of Marine ecological restoration in the protection system. Facing the more complex challenge of climate change, research has proposed response strategies centered on adaptive management and system resilience building.

Keywords Sustainable fishery management; Marine ecosystem; Aquaculture; Climate adaptation; Ecological protection

1 Introduction

When it comes to "sustainable fisheries", people often think of the sustainable utilization of resources and the maintenance of a healthy ecosystem. However, its meaning goes far beyond this. It is more like seeking a balance: meeting human demands for aquatic products while not allowing the Marine ecosystem to lose its regenerative capacity. Sustainable fisheries not only require the rational development of resources, but also involve issues of fairness at the social and economic levels - how to ensure the livelihoods of fishermen while preventing fish from disappearing completely in the future ocean. It is precisely because of such thinking that new models such as Ecosystem-based Fisheries Management (EBFM) have emerged. This type of model no longer focuses only on the catch quantity, but incorporates the complexity and uncertainty of the ecosystem into decision-making considerations (Holsman et al., 2020).

If we look back at the development process of fishery management, we will find that the turning points along the way are quite thought-provoking. In the early days, people were more concerned about "how many fish are appropriate to catch", neglecting the overall connection of Marine ecology. By the middle and late 20th century, fishery production had grown rapidly and technology had advanced by leaps and bounds. However, this was followed by a gradual decline in fish resources and the imminent collapse of the ecosystem. It was at this point that institutions such as the Food and Agriculture Organization of the United Nations (FAO) became alert, proposed management goals such as "Maximum Sustainable Production" (MSY), and introduced the Code of Conduct for Responsible Fisheries. Since then, "sustainability" has become a key word in global fisheries - it is not only related to food security, but also closely affects the livelihoods of hundreds of millions of people, and even concerns global ecological stability (Racioppo et al., 2021; Swasey et al., 2021).

There is often a gap between ideals and reality. The challenges faced by the global fishery today can be said to be piling up layer upon layer. Overfishing, illegal operations, insufficient management capabilities, climate change and Marine pollution are all intertwined, causing the resources of many fishing grounds to continue to decline. Data shows that the proportion of global fisheries regarded as sustainable has dropped from about 90% in 1990 to 66% in 2017, and in some regions, ecosystem-level crises have even emerged. Climate change has made the distribution and yield of fish even more unpredictable, intensifying the uncertainty of fishery management (Yang et al., 2025).

However, signs of change have already emerged. Countries around the world have begun to explore new management concepts, including basic management of ecosystems, climate-resilient management, fishery improvement projects (FIPs), community co-management, and performance evaluation systems, etc. The common point of these methods lies in emphasizing scientific basis, social participation and policy innovation. Meanwhile, the international community is also promoting the standardization and transparency of governance, expecting each country to formulate more suitable management strategies based on its own circumstances. The key to the future may not lie in "how to regulate more strictly", but rather in finding a dynamic balance between utilization and protection, making the fishery system more resilient and capable of moving forward steadily in the constantly changing Marine environment.

2 The Ecological Basis of Fishery Sustainability

2.1 Dynamics of marine ecosystems and biology of fish populations

The Marine ecosystem is like a vast network that never stops, with various organisms interlinked and energy and matter constantly flowing and circulating. Fish play a significant role in this. Their population size and changes are not only influenced by the structure of the food web but also affected by environmental fluctuations and human fishing. The responses of different fish species to environmental changes vary significantly: fish species with fast reproduction and short life cycles can recover relatively quickly even if they are caught in large numbers. Fish that have a long lifespan and mature late are often more prone to being "overdrawn" and have difficulty recovering. Extreme events such as climate change, Marine heatwaves, and storms often lead to fish migration and fluctuations in production, thereby impacting the stability of fishery resources (Marshak and Link, 2024; Cyr et al., 2025). Therefore, rather than merely focusing on catch volume, it is better to have a deeper understanding of the interrelationship between ecosystem dynamics and fish population biology - this is the fundamental logic for achieving scientific management and long-term utilization.

2.2 The role of biodiversity in fishery productivity

When discussing fishery output, people sometimes overlook a more fundamental factor: biodiversity. Biodiversity not only concerns the balance of ecosystems but also directly affects the "productive capacity" of the fishery industry. An ecosystem with species diversity is like a machine with a redundancy mechanism: even if one gear malfunctions, the others can still step in, thereby maintaining system stability (Lefcheck et al., 2021). Research has found that in areas with high biodiversity such as coral reefs and kelp forests, the biomass and sustained output of fish communities are both higher (Figure 1). On the contrary, once large fish species decline or some key species disappear, the function of the entire ecosystem will be compromised, and the catch will naturally decline accordingly. Rich ecological niches and complex food web structures enable more full utilization of resources and also make the system more resilient (Stanford-Clark et al., 2025). Therefore, protecting biodiversity is by no means an empty talk of ecological sentiment; rather, it is a practical issue concerning whether the fishing industry can be sustained in the long term and whether coastal communities can continue to rely on the sea for a living.

2.3 Analysis of the relationship between fishing intensity and ecological balance

How many fish should be caught to be just right? This is an inescapable core issue in fishery management. Excessive fishing intensity can lead to a decline in fish populations, disorder of food webs, and possible imbalance of the ecosystem as a result. However, if properly controlled, the fishery can maintain its population near the maximum sustainable yield (MSY), achieving rational utilization of resources. The problem is that in

most cases, human fishing always tends to "step on the line" or even cross it. Signs of a sharp decline in biomass and degradation of biodiversity have emerged in many sea areas around the world. Model studies indicate that excessive fishing pressure not only reduces the target fish species but also affects other biomes through chain reactions, reducing the stability of the entire ecosystem (Stanford-Clark et al., 2025). Once overfishing occurs, both high-trophic organisms and secondary productivity will decline, and the system's self-recovery ability will also deteriorate. To ensure the sustainable development of fishery resources, it is necessary to rely on scientifically setting fishing quotas, implementing Ecosystem-based management (EBFM), and adopting flexible dynamic strategies in order to maintain that delicate balance between utilization and protection.

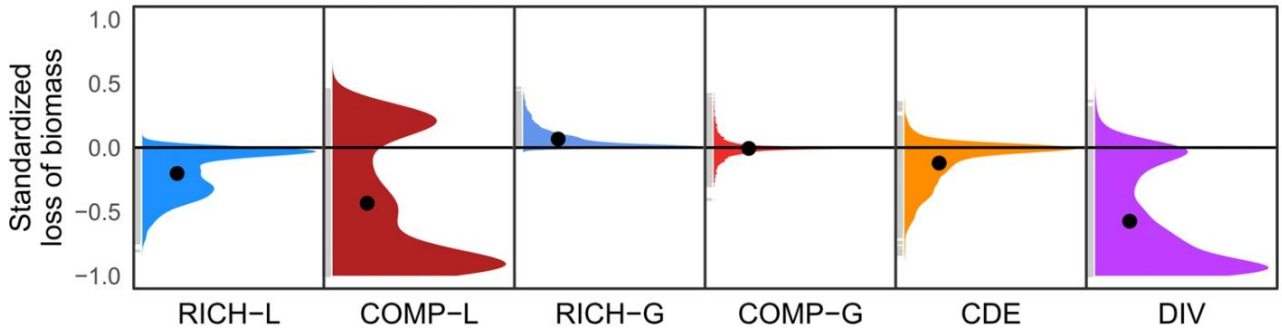

Figure 1 Declines in fish biomass between sites are driven primarily by loss of species (*RICH-L*) and compositional losses (*COMP-L*) (Adopted from Lefcheck et al., 2021)

3 Policy and Governance Framework for Fishery Management

3.1 International legal and policy system: the united nations convention on the law of the sea and the FAO code of conduct for responsible fisheries

When it comes to global fishery governance, most people first think of the United Nations Convention on the Law of the Sea (UNCLOS) and the Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries (CCRF). The UNCLOS was established in 1982, defining the rights and responsibilities of each country in the management of fishery resources within their exclusive economic zones, and calling for international cooperation in the management of transboundary and highly migratory fish resources. The CCRF was introduced by the FAO in 1995 and is equivalent to establishing a set of "codes of conduct" for global fisheries, emphasizing the balance of ecological, economic and social goals in management. The four International Action Plans (IPOAs) formed under the framework of CCRF are more like specific operational guidelines, promoting continuous improvement in aspects such as fishery resource protection, law enforcement compliance, legal construction and international cooperation among countries (Swasey et al., 2021). Interestingly, these seemingly high-level international rules actually provide a basis for countries to formulate local policies and also offer a common reference framework for regional fishery governance. It can be said that the reason why countries can now "match up" in fishery management is largely due to the significant role played by these international mechanisms.

3.2 Comparison of national and regional fishery governance models

Fishery governance models around the world are not set in stone, and there is no one-size-fits-all template. Take the United States and the European Union as examples. They tend to adopt a centralized management approach, setting quotas and allocating fishing rights through legal and scientific evaluations, and encouraging community participation. Among them, the Magnusson-Stevens Act of the United States and the Common Fisheries Policy of the European Union are typical representatives. In contrast, in some regions of Pacific island countries or Latin America, the situation is completely different - community co-management, local traditional knowledge and resource sharing are more important, and systems such as territorial use rights for fisheries (TURFs) are often more effective. Meanwhile, regional fisheries management organizations (RFMOs) play a key role in the governance of multi-national shared fishery resources, but they often encounter obstacles in implementation and interest coordination. The emerging Fisheries Improvement Project (FIPs) has broken some traditional boundaries

and filled the gap in government management through the cooperation of the market, enterprises and non-governmental organizations (Crona et al., 2019). No matter which model is adopted, its effectiveness ultimately depends on whether the legal basis is solid, whether the management capabilities are in place, whether the stakeholders actively participate, and whether the socio-economic conditions can provide support (Swasey et al., 2021).

3.3 Conflict of interest and coordination mechanism in policy implementation

The difficulty in fishery management often does not lie in the design of the system itself, but in the various resistances during the implementation process. Frictions are inevitable among different countries, regions and interest groups: whether it is the fishing rights and quota allocation of cross-border fish, or market access and resource protection, once the interests of all parties are touched, disputes are likely to arise. In addition, due to the lack of cross-scale coordination mechanisms, situations such as external fishermen "free-riding" and the failure of community supervision often occur. To address these contradictions, some collaborative mechanisms have gradually emerged internationally, such as data sharing, joint law enforcement, benefit compensation, cross-border fishing licensing systems, and the establishment of regional Marine protected areas. Meanwhile, a key point lies in the transparency and participation of the decision-making process: If the decision-making process is more open and transparent, the scientific basis is clearer, and all parties participate more fully, the effect of policy implementation is usually better (Seara et al., 2024). However, climate change is making the distribution of fish stocks increasingly unpredictable, and the old systems may soon fail. The future governance framework may need to be more flexible and inclusive, and be able to adjust in a timely manner in response to environmental changes. Otherwise, even the most perfect system will find it difficult to keep up with the pace of ocean changes.

4 Sustainable Fishing Practices and Technological Innovation

4.1 Selective fishing techniques and concurrent fishing reduction strategies

When it comes to sustainable fisheries, what many people may first think of is not technology but management. But in fact, technological innovation often precedes policy. Take selective fishing as an example. In recent years, improvements to different fishing gear have been emerging one after another. For instance, in the longline fishing industry in the North Atlantic, fishermen have attempted to replace the traditional J-shaped hooks with circle hooks. Although this change is minor, it has significantly reduced the concurrent catch rate of non-target species such as sea turtles and also decreased the damage caused by deep-water creatures being caught by mistake. Of course, this has also led to a slight decrease in the fishing efficiency of certain target fish species (Lima et al., 2023). In operations such as shrimp trawling and sardine trawling, the introduction of mechanical separation equipment (such as Nordmøre grilles and "sorter" sorting devices) has achieved remarkable results - while maintaining the stability of the main catch, the concurrent catch has been reduced by more than 80% (Larsen et al., 2022; Eigaard et al., 2024). There are also some simpler improvement measures, such as shortening the soaking time of gill nets or avoiding operations during specific time periods, which can also effectively reduce the accidental catch of seabirds (Collins et al., 2025). Behind these seemingly fragmented technical adjustments, it actually reflects that the fishery is attempting a new balance: to avoid wasting resources as much as possible while minimizing ecological disturbance.

4.2 Application of new technologies in transparency and compliance supervision of the fishery industry

Improving the transparency of the fishery industry sounds simple but is actually very difficult to do. Especially when the links of fishing, processing and transportation are disconnected from each other, illegal activities will have an opportunity to take advantage. Nowadays, new technologies are attempting to reconnect this chain. Technologies such as Radio Frequency Identification (RFID), Internet of Things (IoT), and blockchain have been able to achieve full traceability of fish catches from fishing to the market, making products "traceable" and enhancing consumer trust. Intelligent tags and wireless sensor networks can monitor the catch environment in real time and ensure the quality and safety of aquatic products. Some more complex applications also include fixed or mobile monitoring platforms, video acoustic imaging, and even environmental DNA (eDNA) detection. These means can continuously record the ecological changes in the deep sea or near the coast, providing first-hand data

for managers (Aguzzi et al., 2019; Kaidarova et al., 2023). Meanwhile, digital compliance tools (such as automatic analysis systems and visual dashboards) have also made data reporting and regulation more efficient (Tilley and Wilkinson, 2020). When these technological means work in concert, the "black box" areas in the fishery industry will become fewer and fewer, and governance will gradually shift from "post-event control" to "full visibility throughout the process".

5 The Socio-Economic Dimension of The Fishery Industry

5.1 Issues of livelihoods and equity in coastal communities

In many coastal areas, especially in tropical developing countries, the significance of fishery to the local people is far more than just making a living. It is related not only to three meals a day but also to social status and dignity (Gibson et al., 2020). Millions of small-scale and artisan fishermen earn their income and food from the ocean, but their earnings do not solely depend on the number of fish they catch; they are also influenced by multiple factors such as market prices, gender division of labor, information channels, and supply chain efficiency. Take Fiji, Kiribati, Tonga and New Caledonia as examples. Women engaged in sea cucumber fishing there are often forced to sell at low prices due to the small size of the individuals they catch or the lack of market information, and their income has long been lower than that of male fishermen. It should be noted that fishing families often do not merely rely on fishing for a living. They also grow crops, dry coconuts or catch other Marine resources to diversify economic risks. However, due to backward infrastructure, weak market connections, and high dependence on resources, these communities are particularly vulnerable when facing resource decline or climate change (Cinner et al., 2022). If the efficiency of the supply chain is not improved or social equity issues persist, the sustainability of the fishery industry will also be affected. In other words, enhancing community resilience, broadening livelihood options, and strengthening social equity are the keys to achieving truly sustainable fisheries.

5.2 The role of women and indigenous groups in fishery management

When it comes to fishing, people often think of fishermen at sea, but they frequently overlook the women and indigenous groups that also support the entire system. Data shows that approximately 2.1 million women worldwide are directly involved in small-scale Marine fishing operations, accounting for 11% of the total number of practitioners. They contribute about 10% of the global small-scale fishery catch and are an important pillar of the economies of many families and communities (Harper et al., 2020). Women are mostly active in nearshore, low-tech fishing activities, catching fish for their own use at home and selling the products to the market. However, the value of their labor has long been underestimated, and due to the lack of gender-disaggregated data, policies often fail to accurately respond to their needs. Similarly, indigenous communities rely on Marine resources for their livelihoods and cultural heritage. Their per capita consumption of seafood is much higher than that of the general population, and they also possess unique traditional ecological knowledge. In resource conservation and community management, these traditional knowledge often play irreplaceable roles that modern institutions cannot (Reeder-Myers et al., 2022). Regrettably, both women and indigenous people still have a weak say in policy-making and benefit distribution. Truly involving them in the governance process is not only necessary for achieving social justice, but also concerns whether the ecology and society can achieve a win-win situation.

5.3 Diversification of the fishery economy and social sustainability

As the saying goes, "Don't put all your eggs in one basket." This statement is most appropriate in the fishery economy. Many studies have found that diversified fishing communities are better able to withstand the shocks brought about by climate or market fluctuations. For instance, in places like Alaska and Monterey Bay in California, fishermen do not engage in a single type of fishery. Instead, they combine different types of fisheries or seasonal activities to form a "fishery investment portfolio". In this way, when there are policy changes or resource shortages, their income can still remain relatively stable. Such diversified operations not only disperse economic risks but also alleviate social tensions caused by uneven resource distribution. Meanwhile, measures such as community participatory management, collective property rights, and collaborative governance are constantly enhancing social capital, making communities more cohesive and resilient in the face of external

pressure (Berman, 2024). Looking ahead, the community that is more flexible and diverse economically and more inclusive and cohesive socially is more likely to remain invincible in the development process of sustainable fisheries.

6 The Integration of Aquaculture and The Blue Economy

6.1 Development trends and significance of sustainable aquaculture

Nowadays, aquaculture is no longer a niche industry but has become one of the world's fastest-growing food production sectors. Aquaculture has played the role of a "pressure relief valve" in easing the pressure on wild fisheries, and at the same time, it has played a key role in meeting the protein demand brought about by the rapid population growth. Over the past few decades, the livestock industry has undergone earth-shaking changes, ranging from output to technology and management concepts. Overall, freshwater aquaculture is considered to have greater potential in terms of food security and price affordability, while mariculture is often incorporated into the grand narrative of "blue growth" and linked to goals such as Marine economy, ecological conservation and nutritional health (Garlock et al., 2024). However, some studies have pointed out that the "halo" of Marine fish farming might have been exaggerated. Especially the farming of high-value carnivorous fish, its profits are often concentrated among high-income groups, and its contribution to the food security of low-income groups is limited (Belton et al., 2020). Therefore, the future development of aquaculture cannot merely focus on economic growth; it must also take into account ecological and social balance. The investment direction should be more inclined towards those affordable, sustainable and truly people-benefiting breeding models (Wang and Wu, 2025).

6.2 Environmental impacts of aquaculture and mitigation measures

The rapid expansion of aquaculture has brought considerable yields, but it has also been accompanied by environmental pressure. Problems such as habitat destruction, eutrophication pollution, microplastics and antibiotic residues have been frequently mentioned in recent years. Aquaculture wastewater often contains organic matter, heavy metals and even pathogenic microorganisms. If not properly treated, it will cause the surrounding water bodies to be overburdened. Among them, the problem of microplastics is particularly intractable - it may enter the aquaculture system from the external environment or originate from the aquaculture process itself, posing a potential threat to the health and growth of fish, and even human food safety. To alleviate these problems, the industry is trying every possible way to introduce new measures: technologies such as recirculating aquaculture systems, biological filtration treatment, and ecological purification zones have been successively launched to improve wastewater treatment efficiency and reduce emissions (Liu et al., 2024). Meanwhile, feed formulas are also being innovated. For instance, single-cell protein is being used to replace part of fish meal and fish oil, and the multi-nutrient-level integrated aquaculture (IMTA) model is widely adopted to achieve ecological circulation through "waste reuse". Overall, for the livestock industry to achieve truly sustainable development, technological progress alone is not enough. Stricter regulations, more meticulous management, and continuous policy support are also required (Garlock et al., 2024).

6.3 Case analysis: norwegian salmon farming and sustainable certification mechanism

If one is looking for a model of aquaculture that combines efficiency and environmental protection, the salmon farming industry in Norway is almost an unavoidable example. This industry is renowned for its strict environmental standards, advanced feed technology and highly automated production systems. Its performance in terms of energy consumption, utilization rate of biological resources and greenhouse gas emissions is far superior to that of similar industries in many countries. Norwegian aquaculture enterprises generally adopt third-party sustainable certification mechanisms, such as Marine Stewardship Council (MSC) certification and Aquaculture Stewardship Council (ASC) certification. These certifications prompt enterprises to continuously improve in environmental and social governance (ESG), and also enhance the transparency of the management process (Van Putten et al., 2020). Although certification does not always bring about a significant economic premium, it enhances the reputation of the product in the international market and also strengthens public trust. Norway's experience shows that only when a sound legal system, scientific regulatory methods and appropriate market incentives are combined can the aquaculture industry truly be both sustainable and competitive.

7 Strategies for Marine Ecological Protection and Restoration

7.1 Marine protected areas (MPA) and ecosystem-based management

When it comes to Marine conservation, people can hardly avoid the concept of "Marine Protected Areas" (MPAs). Whether it is a large-scale MPA established by the state or a small sea area jointly managed by local communities, their roles have been verified in numerous cases. Studies have shown that in key ecosystems such as coral reefs and seagrass beds, MPA can often significantly increase the number, individual size and biomass of fish, and these changes can eventually translate into economic returns (Viana et al., 2024). Even if the community-level protected areas are not large in area and have been established for a short time, they can still play a role in protecting high-value fish species and restoring ecological services. In addition to "fish farming and protection", MPA has also brought about an overall improvement in ecosystem functions, such as an increase in the number of herbivorous fish, a rise in coral coverage, and a rise in the replenishment of juvenile fish. Meanwhile, the concept of Ecosystem Infrastructure Management (EBFM) is increasingly integrated into the fishery governance system. EBFM places greater emphasis on the impact of multi-species relationships, food web structures, and environmental changes on management decisions (Klein and Watters, 2020). Against the backdrop of numerous uncertainties brought about by climate change, this approach makes ecosystems more resilient and better able to withstand resource decline. Perhaps, only by organically integrating MPA with EBFM can a win-win situation of ecological protection and sustainable fishery be truly achieved.

7.2 Restoration of damaged marine habitats: coral reefs, mangroves and seagrass beds

Nowadays, merely establishing protected areas is no longer sufficient to restore damaged Marine ecosystems to their original state. Proactive restoration is becoming an inevitable measure for an increasing number of countries. Coral reef restoration is one of the earliest and most complex fields to start. From establishing coral nurseries and fragment transplantation to stabilizing substrates and acoustic gain, various technologies have emerged one after another, with only one goal: to increase the survival rate and biodiversity of corals (Bostrom - Einarsson et al., 2020). The Great Barrier Reef Restoration and Adaptation Program (RRAP) in Australia is at the forefront, enhancing the coral's ability to cope with climate change through various means such as coral horticulture, lart release, and substrate reinforcement, and encouraging collaborative participation of communities and researchers (McLeod et al., 2022). The restoration of mangroves may seem more "simple and unadorned", but the results are remarkable: not only does the ecological function recover quickly, but also the carbon sink capacity is enhanced, and even direct economic benefits are brought (Su et al., 2021). Seagrass bed restoration is often combined with the restoration of mangroves and coral reefs to improve water quality, stabilize the coast and defend against storm attacks. Global analysis shows that the average success rate of Marine ecological restoration is approximately 64%, with mangrove and coral reef projects standing out particularly. However, restoration is not always effective. Extreme weather, pollution or poor management can all cause all previous efforts to be in vain. Perhaps, the combination of active restoration and passive protection (such as setting up buffer zones) can truly bring the degraded ecosystem back to life (Danovaro et al., 2025).

7.3 Case analysis: adaptive management model of the great barrier reef marine park

The Great Barrier Reef Marine Park in Australia is hailed as a "living sample" of global Marine conservation. Facing multiple pressures brought about by global warming, pollution and human activities, Australia has chosen a flexible and adaptive management strategy. In recent years, they have tried various restoration techniques in the Great Barrier Reef: coral horticulture, fragment transplantation, substrate reinforcement, algal removal, larval release. Almost every method imaginable has been employed (Figure 2) (McLeod et al., 2022). Interdisciplinary projects like RRAP also involve research institutions, governments and communities, making restoration no longer just a scientific experiment but a result of social collaboration. In terms of management, the Great Barrier Reef Authority focuses on risk assessment, goal setting and continuous feedback to ensure that policies can be adjusted in a timely manner in response to ecological and social changes. Meanwhile, the management department has enhanced the effectiveness of protection by designating buffer zones, optimizing spatial planning, and strengthening the enforcement of regulations. Despite the ongoing climate crisis and the frequent occurrence of

extreme events, the experience of the Great Barrier Reef tells us that scientific guidance, flexible adjustment and multi-party collaboration are the keys to ensuring that large Marine ecosystems still have breathing space in the future.

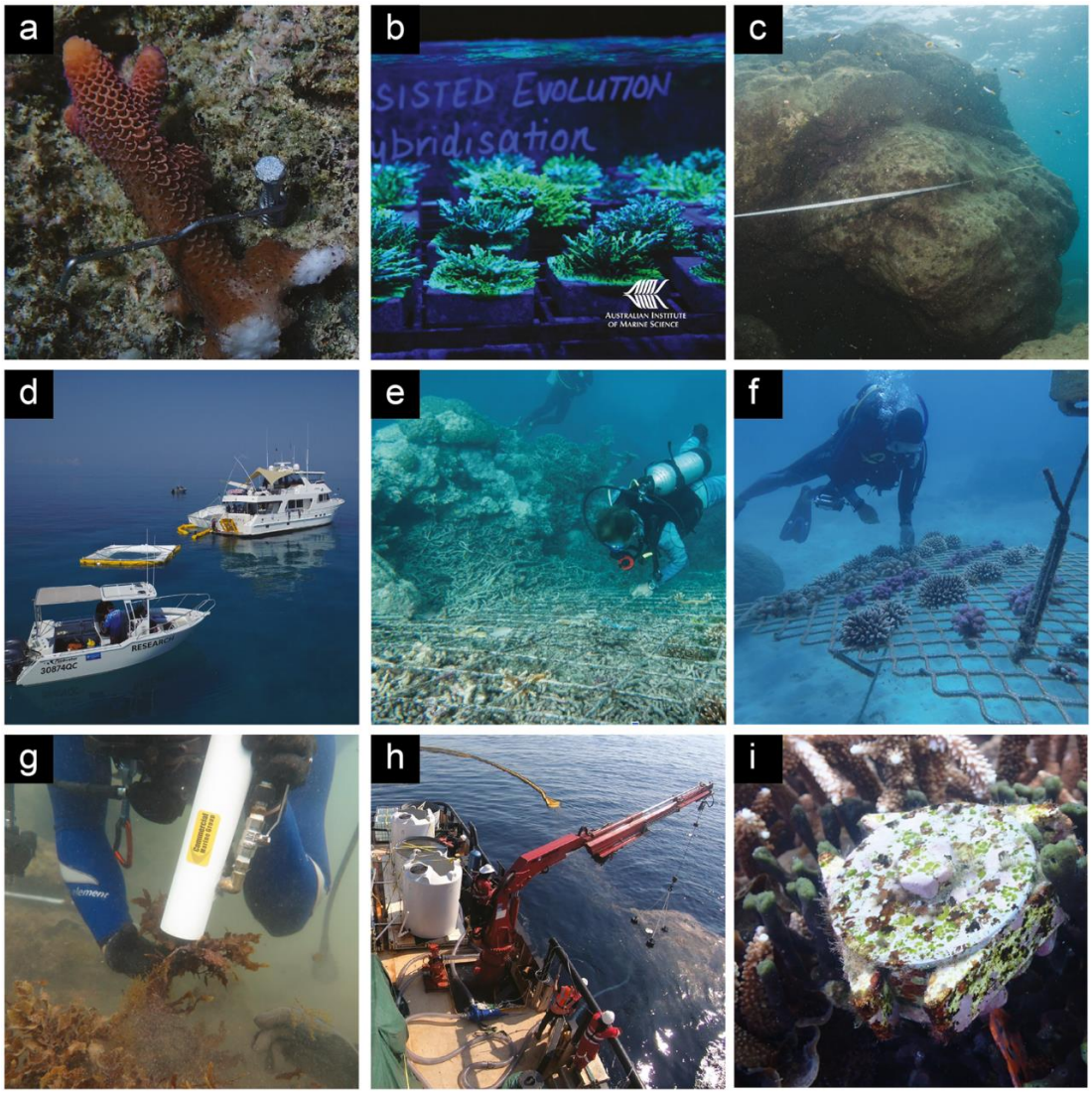

Figure 2 Coral restoration projects and methods currently underway in Australia: (a) the CoralClip®, (b) assisted evolution research, (c) coral repositioning, (d) larval-based restoration, (e) substrate stabilisation, (f) coral gardening, (g) 'supersucker' for macroalgae removal, (h) industrial larval capture, (i) coral seeding units (Adopted from McLeod et al., 2022)

8 Adaptation Strategies for Climate Change and Fishery Management

8.1 The Impact of ocean warming and acidification on fishery resources

Over the past few decades, the Marine environment has been quietly changing: the temperature has been gradually rising, and the chemical properties of seawater have also been slowly altering. This seemingly unhurried process is actually reshaping the global fishery landscape. The distribution of many fish species is shifting towards high-latitude regions, their reproductive rhythms are disrupted, and their population structures are beginning to loosen. Take high-latitude regions as an example. Arctic cod seems to still be able to "reap some benefits" from the warming at present, but this is only a temporary respite. Once ocean warming and acidification intensify further, even the strictest fishery management will be difficult to avoid the risk of population collapse (Hansel et al., 2020). In contrast, the problems brought about by acidification are more concealed - they do not manifest immediately but start to have an impact from the early stages of fish development. In a high CO_2 environment, the mortality rate of Atlantic cod larvae will rise sharply, and the population's replenishment capacity will also decline accordingly. What's more troublesome is that this chemical change does not only affect fish. When the ecological

foundation such as low-trophic organisms, coral reefs and seagrass beds is damaged, the chain reaction will be transmitted upwards all the way, making the entire food web unstable. In the end, those who are most affected are often those who make a living by the sea. Coastal and island communities bear the brunt: ecological damage is one aspect, and economic decline and increased social vulnerability are the other (Cinner et al., 2022).

8.2 Adaptive management and resilience building of fishery systems

In the face of these constantly changing challenges, the traditional "static" fishery management approach is clearly no longer sufficient. More and more countries are beginning to try more flexible and timely adaptive management models. Ecosystem-based Fisheries Management (EBFM) is one of the core ideas. It takes into account multi-species relationships, environmental fluctuations and food web structure comprehensively, thereby delaying resource decline and enhancing system resilience under the pressure of climate change. There are various specific approaches: some use scenario planning and risk assessment to predict trends in advance, some use real-time biological and environmental data to dynamically adjust fishing areas and times, and others continuously test the effectiveness of new rules through management strategy assessment (MSE). In some regions with limited management capabilities, decision-makers are more inclined to adopt "prudent" measures, such as setting minimum fishing sizes, seasonal fishing bans or establishing protected areas, giving priority to maintaining species structure and genetic diversity. In addition, encouraging fishery diversification and establishing a flexible mechanism for transferring fishing efforts can also help communities have more fallback options when resources or markets fluctuate. This kind of "resilient thinking" is obviously more realistic than simply controlling fishing.

8.3 Case analysis: climate-adaptive fisheries management practices in Pacific Island countries

For Pacific island countries, climate change is not a distant scientific concept but a real problem in daily life. The decline in fish catches and the migration of fish to more distant seas mean that there are fewer fish on the dining table for communities that almost rely on the sea for a living, and family incomes have also shrunk accordingly. In the face of this situation, some communities did not wait for external assistance but took the initiative to find ways to deal with it: some expanded the scope of their operations, some adjusted their fishing methods, and others simply changed their fishing targets, all to ensure that the total catch and income would not fluctuate significantly. Meanwhile, cooperation at the regional level is regarded as another way out. Island countries have begun to share monitoring data, establish dynamic quota systems and carry out joint law enforcement to address the complex issues of cross-border fishery resource allocation. More subtle changes are taking place within the community: fishermen are encouraged to get involved in managing affairs, develop side businesses, and even shift to more sustainable fishing models. Such measures may seem scattered, but they all point to the same core, to survive in a changing climate, scientific management, regional collaboration and community participation are all indispensable. The various practices of Pacific island countries are different, but they collectively demonstrate a pragmatic wisdom and provide a referenceable path for fishery adaptation in other regions (Cinner et al., 2022).

Acknowledgements

Thank you to all reviewers for their meticulous review, and also thank the members of the research team and technicians for their support in experimental design and data analysis.

Conflict of Interest Disclosure

The authors confirm that the study was conducted without any commercial or financial relationships and could be interpreted as a potential conflict of interest.

References

Belton B., Little D., Zhang W., Edwards P., Skladany M., and Thilsted S., 2020, Farming fish in the sea will not nourish the world, Nature Communications, 11(1): 5804.
https://doi.org/10.1038/s41467-020-19679-9

Boström-Einarsson L., Babcock R., Bayraktarov E., Ceccarelli D., Cook N., Ferse S., Hancock B., Harrison P., Hein M., Shaver E., Smith A., Suggett D., Stewart-Sinclair P., Vardi T., and McLeod I., 2020, Coral restoration – a systematic review of current methods successes failures and future directions, PLoS ONE, 15(1): e0226631.
https://doi.org/10.1371/journal.pone.0226631

Cinner J., Caldwell I., Thiault L., Ben J., Blanchard J., Coll M., Diedrich A., Eddy T., Everett J., Folberth C., Gascuel D., Guiet J., Gurney G., Heneghan R., Jägermeyr J., Jiddawi N., Lahari R., Kuange J., Liu W., Maury O., Müller C., Novaglio C., Palacios-Abrantes J., Petrik C., Rabearisoa A., Tittensor D., Wamukota A., and Pollnac R., 2022, Potential impacts of climate change on agriculture and fisheries production in 72 tropical coastal communities, Nature Communications, 13(1): 3530.
https://doi.org/10.1038/s41467-022-30991-4

Crona B., Käll S., and Van Holt T., 2019, Fishery improvement projects as a governance tool for fisheries sustainability: a global comparative analysis, PLoS ONE, 14(10): e0223054.
https://doi.org/10.1371/journal.pone.0223054

Cyr F., Adamack A., Bélanger D., Koen-Alonso M., Mullowney D., Murphy H., Regular P., and Pepin P., 2025, Environmental control on the productivity of a heavily fished ecosystem, Nature Communications, 16(1): 5277.
https://doi.org/10.1038/s41467-025-60453-6

Danovaro R., Aronson J., Bianchelli S., Boström C., Chen W., Cimino R., Corinaldesi C., Cortina-Segarra J., D'Ambrosio P., Gambi C., Garrabou J., Giorgetti A., Grehan A., Hannachi A., Mangialajo L., Morato T., Orfanidis S., Papadopoulou N., Ramirez-Llodra E., Smith C., Snelgrove P., Van De Koppel J., Van Tatenhove J., and Fraschetti S., 2025, Assessing the success of marine ecosystem restoration using meta-analysis, Nature Communications, 16(1): 3062.
https://doi.org/10.1038/s41467-025-57254-2

Garlock T., Asche F., Anderson J., Eggert H., Anderson T., Che B., Chávez C., Chu J., Chukwuone N., Dey M., Fitzsimmons K., Flores J., Guillen J., Kumar G., Liu L., Llorente I., Nguyen L., Nielsen R., Pincinato R., Sudhakaran P., Tibesigwa B., and Tveterås R., 2024, Environmental economic and social sustainability in aquaculture: the aquaculture performance indicators, Nature Communications, 15(1): 5274.
https://doi.org/10.1038/s41467-024-49556-8

Gibson E., Stacey N., Sunderland T., and Adhuri D., 2020, Dietary diversity and fish consumption of mothers and their children in fisher households in Komodo District eastern Indonesia, PLoS ONE, 15(4): e0230777.
https://doi.org/10.1371/journal.pone.0230777

Hänsel M., Schmidt J., Stiasny M., Stöven M., Voss R., and Quaas M., 2020, Ocean warming and acidification may drag down the commercial Arctic cod fishery by 2100, PLoS ONE, 15(4): e0231589.
https://doi.org/10.1371/journal.pone.0231589

Harper S., Adshade M., Lam V., Pauly D., and Sumaila U., 2020, Valuing invisible catches: Estimating the global contribution by women to small-scale marine capture fisheries production, PLoS ONE, 15(3): e0228912.
https://doi.org/10.1371/journal.pone.0228912

Holsman K., Holsman K., Haynie A., Hollowed A., Hollowed A., Reum J., Reum J., Reum J., Aydin K., Aydin K., Hermann A., Hermann A., Cheng W., Cheng W., Faig A., Ianelli J., Ianelli J., Kearney K., Kearney K., and Punt A., 2020, Ecosystem-based fisheries management forestalls climate-driven collapse, Nature Communications, 11: 4579.
https://doi.org/10.1038/s41467-020-18300-3

Klein E., and Watters G., 2020, Comparing feedback and spatial approaches to advance ecosystem-based fisheries management in a changing Antarctic, PLoS ONE, 15: e0231954.
https://doi.org/10.1371/journal.pone.0231954

Lefcheck J., Edgar G., Stuart-Smith R., Bates A., Waldock C., Brandl S., Kininmonth S., Ling S., Duffy J., Rasher D., and Agrawal A., 2021, Species richness and identity both determine the biomass of global reef fish communities, Nature Communications, 12(1): 6875.
https://doi.org/10.1038/s41467-021-27212-9

Liu X., Wang Y., Liu H., Zhang Y., Zhou Q., Wen X., Guo W., and Zhang Z., 2024, A systematic review on aquaculture wastewater: pollutants impacts and treatment technology, Environmental Research, 262: 119793.
https://doi.org/10.1016/j.envres.2024.119793

Marshak A., and Link J., 2024, Responses of fisheries ecosystems to marine heatwaves and other extreme events, PLoS ONE, 19(12): e0315224.
https://doi.org/10.1371/journal.pone.0315224

McLeod I.M., Hein M.Y., Babcock R., Bay L., Bourne D.G., and Cook N., 2022, Coral restoration and adaptation in Australia: the first five years, PLoS ONE, 17(11): e0273325.
https://doi.org/10.1371/journal.pone.0273325

Mohamed K., Sathianandan T., Vivekanandan E., Kuriakose S., Ganga U., Pillai S., and Nair R., 2021, Application of biological and fisheries attributes to assess the vulnerability and resilience of tropical marine fish species, PLoS ONE, 16(8): e0255879.
https://doi.org/10.1371/journal.pone.0255879

Racioppo A., Speranza B., Campaniello D., Sinigaglia M., Corbo M., and Bevilacqua A., 2021, Fish loss/waste and low-value fish challenges: state of art advances and perspectives, Foods, 10(11): 2725.
https://doi.org/10.3390/foods10112725

Reeder-Myers L., Braje T., Hofman C., Smith E., Garland C., Grone M., Hadden C., Hatch M., Hunt T., Kelley A., LeFebvre M., Lockman M., McKechnie I., McNiven I., Newsom B., Pluckhahn T., Sanchez G., Schwadron M., Smith K., Smith T., Spiess A., Tayac G., Thompson V., Vollman T., Weitzel E., and Rick T., 2022, Indigenous oyster fisheries persisted for millennia and should inform future management, Nature Communications, 13: 2383.
https://doi.org/10.1038/s41467-022-29818-z

Seara T., Williams S., Acevedo K., Garcia-Molliner G., Tzadik O., Duval M., and Cruz-Motta J., 2024, Development and analyses of stakeholder driven conceptual models to support the implementation of ecosystem-based fisheries management in the U.S, Caribbean, PLoS ONE, 19(5): e0304101.
https://doi.org/10.1371/journal.pone.0304101

Stanford-Clark C., Bulle C., Loiseau E., and Helias A., 2025, Ecosystem-scale biodiversity in fisheries life cycle impact assessment, Environmental Science and Technology, 11: 4579.
https://doi.org/10.1021/acs.est.4c13066

Su J., Friess D., and Gasparatos A., 2021, A meta-analysis of the ecological and economic outcomes of mangrove restoration, Nature Communications, 12: 5050.
https://doi.org/10.1038/s41467-021-25349-1

Swasey J., Iudicello S., Parkes G., Trumble R., Stevens K., Silver M., and Recchia C., 2021, The fisheries governance tool: A practical and accessible approach to evaluating management systems, PLoS ONE, 16(7): e0253775.
https://doi.org/10.1371/journal.pone.0253775

Van Putten I., Longo C., Arton A., Watson M., Anderson C., Himes-Cornell A., Obregón C., Robinson L., and Van Steveninck T., 2020, Shifting focus: the impacts of sustainable seafood certification, PLoS ONE, 15(5): e0233237.
https://doi.org/10.1371/journal.pone.0233237

Viana D., Gill D., Zvoleff A., Krueck N., Zamborain-Mason J., Free C., Shepon A., Grieco D., Schmidhuber J., Mascia M., and Golden C., 2024, Sustainable-use marine protected areas to improve human nutrition, Nature Communications, 15(1): 7716.
https://doi.org/10.1038/s41467-024-49830-9

Wang Q., and Wu J.N., 2025, The origin and global spread of *Scomberomorus* spp.: the intersection of ecological adaptation and fisheries management, International Journal of Marine Science, 15(2): 75-91.
https://doi.org/10.5376/ijms.2025.15.0008

Yang Q., Shi X., Wang F., Cheng H., Luo Y., Li Z., Ren Z., Ding W., Wu J., Jiang H., Han Z., and Fan W., 2025, Trends in fishery ecosystem stability in the East China Sea under dual pressures of fishing and global warming, Environmental Science and Technology, 25: 13.
https://doi.org/10.1021/acs.est.4c14605