Integrated Ecosystem-Based Fisheries Management: A Multidimensional Approach

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Abstract
Integrated Ecosystem-Based Fisheries Management (EBFM) is a relatively new concept that aims at the sustainable utilization of fish resources while considering ecological, economic, and social values. This paper seeks to present an overview of the history of fisheries management and more specifically the shift from a single species management approach to an ecosystem approach. Among the principles of EBFM are species interaction, habitat, and the impact of fishing on the socio-economic life in the community. The review is mainly based on the complex strategy of EBFM that includes traditional and innovative management of fisheries. The case of the California Current Large Marine Ecosystem (CCLME) and the Great Barrier Reef (GBR) presented the examples, management practices, and problems encountered. This paper also points out some of the limitations of the current research such as data collection, climate change models, and lack of incorporation of socio-economic factors. Some of the future trends include the improvement of monitoring gadgets and the growth of international collaboration on management. It therefore can be concluded that flexibility, data, and stakeholders should be used in the management of fisheries and ecosystems.

Keywords: Ecosystem-Based Fisheries Management, Fisheries Sustainability, Adaptive Management, Climate Change, Socio-Economic Integration, Marine Policy.

1. Introduction

The management of fisheries has been an evolving process over the years due to the growing concern of human beings for aquatic resources. In the past, fisheries management was carried out with single stock management where the main goal was to attain maximum sustainable yield of the target stock. This was to be used in fish stock management and include quotas, size limits, and the seasonal closure among others. However, it did not focus on the relation of these species with the environment hence resulting in negative impacts like overfishing, destruction of ecosystems, and decline of the biggest fish stock as observed by Larkin in 1977. Such challenges were a clear tell-tale sign that there was a need to adopt a more enhanced management strategy that would entail the management of the entire system and not just the fish species (Botsford et al., 1997). The previous approach to fisheries management was the Maximum Sustainable Yield (MSY), which focused on fishing the fish stocks in a way that would not over-exploit them. Even though some of the objectives of MSY included the management of fish stocks, it was heavily criticized for not considering factors such as the ratio between predators and prey, environmental factors, and other factors in this process. Therefore, the management that MSY was driving led to the degradation of the habitats, non-target species' mortalities, and a decline in species diversity that affected the marine systems (Hilborn, 2011; Rice & Garcia, 2011). Such limitations led to the development of more logical approaches to managing the marine systems at large. In this regard, Ecosystem-Based Management (EBM) was developed as a sustainable method to manage marine resources. EBM is interested in the form, function, and health of ecosystems due to this relationship between the species and other features such as climate change (O'Hagan, 2020). This approach aims at maintaining the ecosystems intact but at the same time allows for the sustainable utilization of the sea products for society's needs while at the same time protecting the species, their habitats, and the processes that support them (Levin & Lubchenco, 2008). Ecosystems are complex systems and an ecosystem is affected by factors that are inherent or influenced and therefore has to be managed in a way that will fit the changes. The transition from 'single species management' to 'ecosystem-based management' was prompted by the discovery that managing species in isolation was a disaster for the ecosystem. For instance, fishing of large carnivores like sharks may result in a population shift in abundance of other species that share the same trophic level (Garcia & Charles, 2007). The above effects are not observed in ecosystem-based approaches that seemingly focus on species interactions and other ecological and social factors (Browman et al., 2004). This has been done under the influence of international frameworks like the Convention on Biological Diversity (CBD) that promotes the EBM principles in the management of the world's fisheries. From a simplistic view, it is possible to define EBM as a complex process of maintaining ecosystems and their components because the various species have an interdependency with their surroundings (Christensen et al., 1996). EBM principles are Species and community conservation, ecosystem management, reduction of numerous anthropogenic effects, and an educationally-based management approach. Another form of sustainable utilization is long-term ecological conservation which is practiced by following the precautionary principle in the utilization of resources and by participatory involvement of the stakeholders such as scientists, policymakers, fishers, and other consumers of the resources (Pikitch et al., 2004). This aspect of participation encourages synergy and makes certain that all voices are heard in the management of fisheries. The EBFM stands for Ecosystem-Based Fisheries Management and this includes the social and economic elements (Trochta et al., 2018). Integrated EBFM acknowledges that the marine environment, people, and the economy are interrelated as pointed out by Levin & Lubchenco (2008). It is not only an approach to the ecological aspects of the problem but also to the coastal communities that are so significantly dependent on the sea. There is nothing unusual about the utilization of EBFM since the sustainability of fisheries cannot be realized based solely on biological factors. Some of the activities that are associated with the status of the marine environment include fisheries, recreation, and the construction of seashore structures. Thus, fisheries management has to come to terms with the fact that there are social and economic consequences. Fishes are a protein source for many people in the coastal areas and a source of resource and pride both economically and culturally for many people (Charles, 2014). Failure to consider such social and economic issues may result in resource competition and thus threaten the process of conservation. EBFM encourages the participation of the various stakeholders in the management of an organization and ensures that their needs are met. The EBFM is a multidimensional and integrated approach to fisheries management because it focuses on ecological, social, and economic aspects (Schreiber et al., 2018). It also makes sure that the fisheries policies protect the marine resources within the policies while at the same time making sure that the policies are adaptable to the challenges of the environment and people. EBFM is also an input to good governance in as much as it sustains the structure of ecosystems and optimizes the economic returns of the fishery and the welfare of the coastal people (Bundy et al., 2021). Therefore, it has been possible to conclude that the transition from single species management to EBFM is a shift in fisheries management. It is a combination of the ecological, social, and economic factors of the fishery resources and therefore more suitable for the management of fisheries.

2. Principles of Ecosystem-Based Fisheries Management (EBFM)

Ecosystem-Based Fisheries Management (EBFM) is an organized attempt at managing fishery resources about the existing ecological, economic, and social structures. EBFM is distinct from a single species management approach that only focuses on the fish species and its stock without taking into account the other species, their environment, and the impact on human beings (Long et al., 2015). EBFM framework also considers the structure and function of the larger ecosystem as fisheries are sub-systems of the social-ecological systems (Gammage, 2019). This is a much more holistic view of the world and an understanding of conservation with economic and social objectives, the rational management of fish stocks, and the protection of the environment. EBFM's four principles are ecosystem health, flexibility, and participation. In EBFM, there is a focus on the conservation of biological diversity and the ecosystem since the dependency on species contributes to the stability of the ecosystem (Garcia & Cochrane, 2005). The other principle is adaptive management which focuses on policy assessment and research to change the policies (Levin et al., 2009). Another factor is the engagement of stakeholders such as government, scientists, fishers, and the local community to get their input in the decision-making process (Patrick & Link, 2015). EBFM employs fundamental components including ecosystem models, habitats, and fishery-independent data to assess the ecosystem status and fishing effects (Peters et al., 2018). Management also entails the participation of fishery managers, scientists, local people, and NGOs in formulating good strategies that will solve ecological, social, and economic issues (Crowder & Norse, 2008). Some aspects need to be considered in EBFM, such as species interactions and habitat conservation. The interactions between species such as predator-prey or competitors are crucial in ensuring that overfishing is prevented as well as maintaining the ecosystem (Mitchell & Harborne, 2020). Maintenance of species guarantees that the systems can adapt to change and pressures thereby increasing the level of resilience (Rice, 2011). Conservation and restoration of habitats are also necessary because some fish species depend on specific habitats like coral reefs and mangrove ecosystems at some stage in their life cycle (Halpern et al., 2008). Another factor that concerns the sustainability of the fishery is the maintenance of the ecosystem and avoiding the worsening of the current status of the habitats (Hughes et al., 2005). The socio-economic impacts of EBFM relate to consequences on local people and their economy. Fisheries are essential in offering a source of income and protein, particularly for the communities along the coastal areas (De Guzman et al., 2019). EBFM may lead to short-term reductions in catch quotas but the aim is to establish stocks that will support the livelihoods in the future (Hilborn, 2007). Involving the communities in the conservation activity aims to ensure that the objectives of the conservation do not conflict with the needs of the community hence minimizing conflict (Christie et al., 2007). In addition, socio-economic variables such as income per capita and market availability are mixed with ecological variables in resource management for the sustainable use of the resources for the well-being of the people (Cinner et al., 2012).

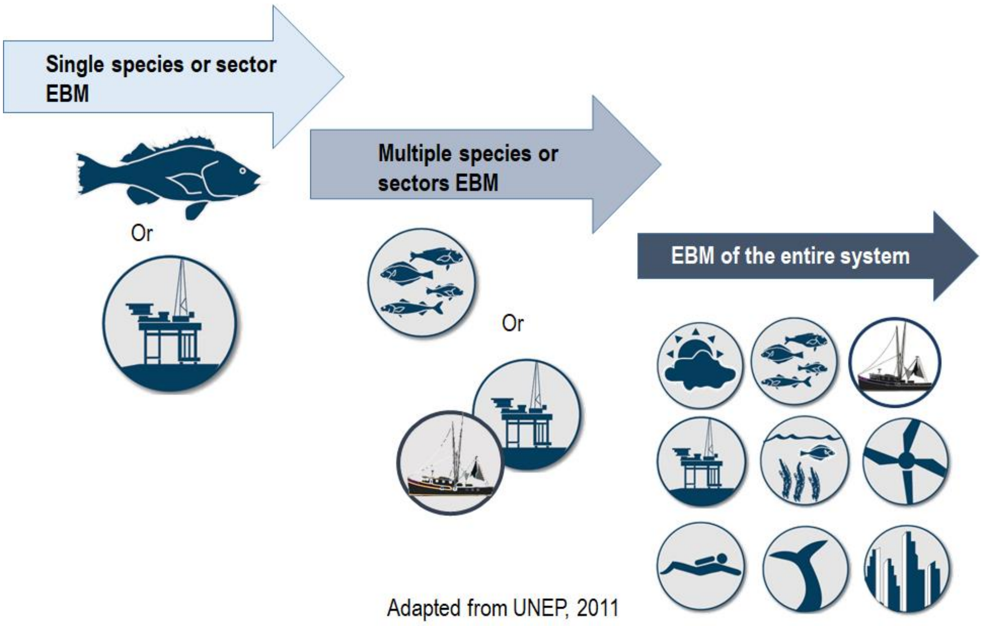

Figure 1: Transition from Single-Species to Ecosystem-Based Management (EBM) Across Multiple Sectors (Ecosystem-Based Management | Integrated Ecosystem Assessment, 2024)

3. Integrated Management Approaches

The ecosystem-based fisheries management (EBFM) is an integrated approach, which considers the biological, economic, and social factors of the fishery resources (Nguyen, 2012). It considers the species interactions, species requirements for the habitat, and the overall condition of the ecosystem (Marshall et al., 2019). Ecological dimensions are those that relate to the life cycle of the species, food chain, and other matters that may include breeding grounds. For example, the protection of seagrass beds and mangroves has significance in fish recruitment and species that are significant to the ecosystem (Brandl et al., 2016; Halpern et al., 2008). Economic dimensions aim at solving the problem of rationality of the benefits from the fisheries and the right degree of sustainability. This includes the evaluation of the profitability of the fishery resources, the cost incurred in fishing, and the impacts on the region's economy. In setting the quotas and regulating the fishing mortality rate and effort for the sustenance of yield, economic valuation is helpful (Costanza et al., 1997; Smith et al., 2017).

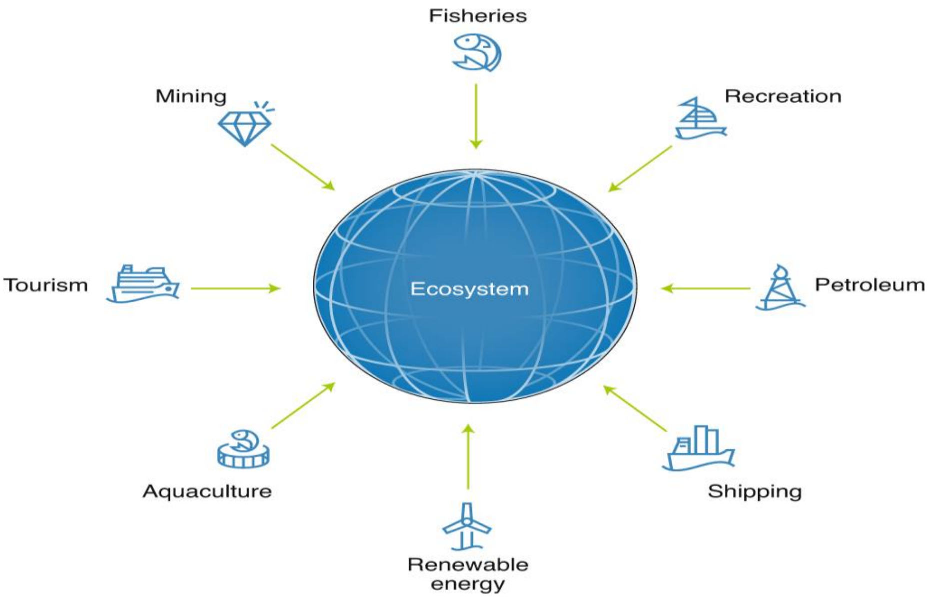

Figure 2: Interactions Between Marine Ecosystems and Key Economic Sectors (Winter et al., 2020).

Economic reasoning in management approaches helps in the opportunities to optimize the use of resources, the reduction of economic costs and therefore improving the incentives for preservation. Social aspects stress the requirement to include the community values and culture and the perspective of the stakeholders in the management. Engaging the local and the indigenous people ensures that they get to be part of the process and to share their knowledge and needs thus increasing their confidence and cooperation (Berkes et al., 2000). It also evaluates the impact of management measures on people's well-being, cultural assets, and social inclusion, for equity (Jentoft, 2005; Cinner et al., 2012). The inclusion of stakeholders in decision-making processes may lead to better and acceptable management measures and thus enhance compliance. It is therefore important to apply both traditional and advanced techniques to enhance the efficiency and flexibility of the processes. That is why, the idea can be proposed to apply traditional ecological knowledge (TEK) that is based on the local experience as the complement to the existing approaches. For example, TEK can be used to define historical baseline data and ecosystem changes which when combined with current data improve understanding of marine systems (Friedlander et al., 2014). On the same note, modern technologies used to control and collect data can improve management effectiveness and adaptability. This paper also posits a need to assess the value of ecosystem services in managing fisheries. Ecosystem services refer to the benefits that people derive from ecosystems that support their well-being and economic activities such as food production, provision of shelter, and water purification (McMichael et al., 2005). Economic valuation quantifies these benefits and demonstrates the cost and benefit of the various management strategies. For instance, awareness of the economic values of coral reefs like fish breeding and shoreline protection makes one appreciate the need to conserve the reefs (Sukhdev et al., 2014). The application of these valuations in management practices helps in the determination of the interventional options that can be used in enhancing the health of ecosystems and their resilience of the same (De Groot et al., 2002). Other knowledge involves ecosystem services that include nutrient cycling as well as the provision of habitat. These functions assist in the maintenance of the species and an improvement in the stability of the fisheries (Wilson et al., 2010). Mangroves and seagrass beds are the habitats that are crucial in fish stock production through the recruitment and growth of fish stocks for the fisheries. Maintenance of these functions is one of the goals of EBFM that is aimed at long-term resilience (Culhane et al., 2020; Gunderson, 2002). This is the case because EBFM's central idea of adaptive management entails that the management actions taken are always changeable and the outcomes of these actions are incorporated. This is a cycle of designing and implementing measures and reflecting on the results obtained based on the new knowledge that has been attained (Holling, 1978; Williams et al., 2009). It makes it possible to apply trial and error as more data and information are produced in the process of implementing the adaptive management approach. Some examples include the North Atlantic cod fisheries recovery where iterative adjustments based on monitoring data were used to improve the results (Hutchings & Reynolds, 2004; Rose, 2007). Other countries like Australia also apply adaptive management in which there is always an assessment and appraisal of the measures and information from the stakeholders to ensure that there is achievement of sustainable goals (Brooks et al., 2015; Ogier et al., 2016). The above examples illustrate how the application of adaptive management makes fisheries more resistant and sustainable.

4. Tools and Techniques for Integrated Management

4.1 Data Collection and Monitoring

The two major elements of Ecosystem-Based Fisheries Management (EBFM) are information gathering and assessment (Marshall et al., 2019). Various methods are employed to obtain a lot of data about the marine setting. Traditional field censuses involve capturing samples of biological populations to assess their species abundance, distribution, and health status. This method occasionally requires the accumulation of such physical samples like fish, water, and sediment which are useful in determining the state of the environment and the biological standards (Holling et al., 1998). Some of the remote sensing tools that are applied for the evaluation of the large-scale environmental alterations and statuses of the habitats include satellite images and aerial drones. SST, chlorophyll concentration, and habitat data obtained from these technologies are significant in understanding ecosystem processes (Groom et al., 2006). Also, the advancement in monitoring tools such as automatic tracking devices and acoustic tags makes it possible to track species and the use of space in real-time. These tools provide valuable information on migration and behavioral changes occasioned by the changes in the environment (Roussel et al., 2015). To acquire useful information data collected must be analyzed. Some of the analytical techniques that are used in the identification of trends and patterns include multivariate analysis and time series analysis. Advanced techniques like Geographic Information Systems and Artificial Neural Networks are employed to work through large data to come up with forecasts on the state of the ecosystem and species population (Joy & Death, 2004). There is no denying the fact that data is one of the most valuable assets in the decision-making process. Proper information available assists the managers in making the right decisions so that ecological aspects are taken into consideration alongside other socio-economic factors. Quantitative methods are useful in the identification of ecological factors, assessment of the impact of human activities, and assessment of the effectiveness of management strategies (Long et al., 2015). Ecological inventories, remote sensing, and socio-economic assessment together provide the decision-makers with an integrated view of the ecosystem dynamics and socioeconomic factors (Pikitch et al., 2004). However, data is the key component of adaptive management, which refers to the adjustment of management strategies based on new information and circumstances.

4.2 Modeling and Simulation

In EBFM, modeling and simulation are the tools that are utilized to analyze the impacts of the management measures on ecosystems and their interactions (Ainsworth et al., 2008). Such models are the trophic models and the habitat models that depict the relations between the species and the habitat. These models help in estimating the effects of changes in species density, habitat attributes, and environmental factors on ecosystem attributes and processes (Pikitch et al., 2004). The stock assessment models are used in the assessment of fish stock growth, recruitment, and mortality (Cotter et al., 2004). These models are useful in setting the appropriate quotas for fishing and the right methods of managing the fisheries resources (Walters, 1998). Whereas, spatial models are more or less about the geographical distribution of the marine species and habitats and provide important data regarding the spatial distribution and utilization of the habitat which is, in fact, very much essential for the creation of marine protected areas and other spatial management techniques (Melo-Merino et al., 2020). Simulation tools are useful in the testing and forecasting of scenarios and therefore assist the managers in evaluating the effects of the various management strategies under different environmental and socio-economic situations. For instance, simulation models can be used to assess the impacts of fishing gear, the impacts of coastal environment restoration, and the impacts of climate change on the marine environment (Chapman et al., 2020). In this way, managers can find various threats, compromises, and opportunities for improving the state of ecosystems and their sustainability. Other uses of simulation tools are in the development of management strategies where the strategies are dynamic in form. The actions of management can be modeled with the help of simulation models and the strategies changed according to the results and conditions. This way, it is possible to ensure that the management practices remain abreast with the new information as well as challenges.

4.3 Policy and Regulatory Frameworks

This paper identifies that policy and regulation are the two principal structures of EBFM. Such frameworks include a set of tools and measures that are directed to the reasonable use of marine resources and the protection of the environment. Fishing quotas are other policy instruments that regulate the amount of fish that can be caught while MPAs are areas protected for conservation and the protection of marine habitats (FROESE, 2010). Other regulations may include those that relate to bycatch, fishing gear, and habitat protection. National and international treaties and regional management organizations also play an important role in coordinating the activities that span across different jurisdictions. For example, the United Nations Convention on the Law of the Sea (UNCLOS) provides legal tools for the proper utilization and conservation of the marine stock outside the national waters of the coastal state (Gamble, 1985). RFMOs are the bodies that manage the transboundary fishery stocks and these are the bodies that have been established at the regional level (Pauly et al., 2002). The analysis of policy implementation examples shows that effective and adaptable policy measures can be applied to achieve the goals of EBFM. One of the success stories is the Great Barrier Reef Marine Park in Australia where zoning, habitat protection, and fisheries management measures have been used in marine diversity conservation and sustainable tourism (Day et al., 2012). Similarly, the Ecosystem Approach to Fisheries (EAF) implemented in South Africa also considers the ecological, social, and economic factors of fisheries management and this proves that the holistic approach works (Petersen et al., 2015). These examples therefore show a need for good policy and regulation integration in the formulation of good EBFM. Scientific information application, stakeholder engagement, and incorporation of adaptive management concepts allow policy frameworks to address the complexity of marine ecosystem management issues.

5. Case Studies of Integrated Ecosystem-Based Management

5.1 California Current Large Marine Ecosystem (CCLME)

California Current Large Marine Ecosystem (CCLME) is one of the best examples of Integrated Ecosystem-Based Fisheries Management (EBFM) that contains ecological, economic, and social components. Overseen by the Pacific Fishery Management Council the CCLME employs ecosystem status reports (ESRs) on density of species, habitats, and socio-economics. It has assisted in the identification of the measures of the harvest that have been instrumental in the fight against overfishing and the rebuilding of stock of some species including the sardines and the rockfish.

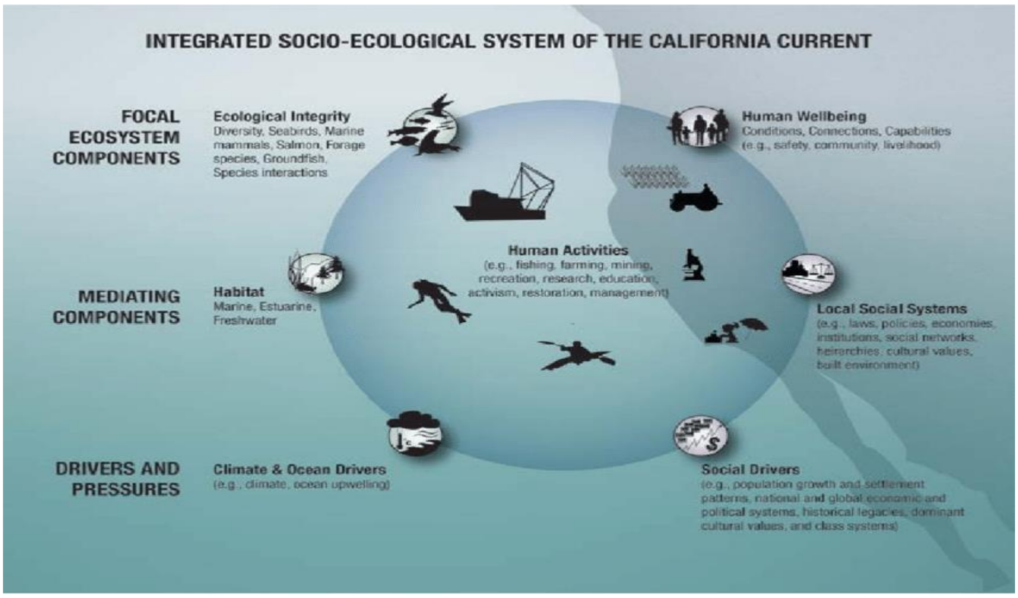

Figure 3: Integrated Socio-Ecological System of the California Current Connecting Ecosystem Components, Human Wellbeing, and Environmental Drivers (Breslow et al., 2014).

Climate variability is also incorporated into the system due to differences in productivity and distribution of species because of climate change. What has been done by the CCLME indicates that the stakeholders such as the fisheries, scientists, and conservation groups are instrumental in fine-tuning the ecosystem models. The other challenges that the CCLME managers face are those associated with the issues of inadequate data and uncertainty arising from the dynamic nature of the marine environment, which is primarily affected by climate change. However, this change has made the fisheries and the ecosystem more sustainable by the use of ecosystem indicators and cooperation (Tommasi et al., 2021).

5.2 Great Barrier Reef Marine Park (GBR)

Another successful example of EBFM is the GBR where management is founded on the multiple attributes of the ecosystem and responds to the utilization of the resource for fishing and tourism.

The Great Barrier Reef Marine Park (GBR) is managed by the Great Barrier Reef Marine Park Authority (GBRMPA) and the GBR has a zoning system comprising no-take areas and habitat protection zones which is about 33% of the park. These zones play a significant role in the conservation of both the shallow and the deep reef communities that have significant contributions to the support of the diversity and productivity of the fishery resources. Another concept is also useful in the GBR plan since it allows the authorities to mitigate the stressors affecting the area including coral bleaching and climate change. Techniques such as Baited Remote Underwater Video Stations (BRUVS) enable the identification of species and the conditions of habitats in the deeper parts and the details are used to change the management styles. In addition, the GBR has been efficient in engaging stakeholders particularly the Indigenous people in the integration of socio-cultural considerations in the management of the region. However, some gaps such as the absence of knowledge in deep-reef habitats and the different interests of the various stakeholders from tourism, fishing, and so on persist (Sih et al., 2019).

5.3 Integration and Best Practices

The CCLME and GBR also highlight two of the major strategies in EBFM, which are adaptive management and stakeholder engagement. In both cases, there were uncontrollable conditions that could not be altered such as climate change which requires management strategies that can be modified depending on the amount of information acquired. Stakeholder participation especially the locals in the CCLME and Indigenous people in the GBR was vital to ensure that the management practices that were adopted were sustainable both in terms of the environment and socially acceptable. Furthermore, scientific data integration was the central element in both systems; ESRs in the CCLME and BRUVS in the GBR were important in gathering relevant information for decision-making.

5.4 Challenges and Strategies to Overcome Limitations

Some of the challenges that are likely to present in both regions include; inadequate data and multiple interests. The CCLME is hampered in terms of variability of ecosystem data, especially with the change in species distribution in the face of climate change (Nelson et al., 2022). Similarly, in the GBR, the deep-reef habitats are rather unknown due to the lack of information which is considered a problem in management (Bridge et al., 2019). Additionally, both regions face socio-economic tensions: the challenge of coordinating the resources for the welfare of the fisheries, tourism, and ecosystems (Kyvelou et al., 2020). To overcome these challenges there is a need to increase the monitoring systems which include satellite and the sonar systems. Besides, the efficiency of EBFM in both ecosystems can also be improved by increasing the collaborative governance by involving more stakeholders in the decision making which can minimize the conflict (Porobic et al., 2018).

6. Conclusion

EBFM is a new form of managing fisheries resources and it involves the consideration of the biological, economic, and social systems of the environment. EBFM is in a way a more liberal approach to the more traditional single-species management approach because it aims at the ecosystem in its attempt to sustain fish stocks, structure, and function of the ecosystem. It also allows for sustainable utilization of marine resources at the same time taking into account the social and economic rights of people who rely on the fisheries. This is because EBFM can monitor the environment as well as adapt to the changes in the environment and the anthropogenic activities hence making EBFM a very flexible and sustainable framework for the management of fisheries. However, there are still some barriers that should be addressed in the future for the further development of EBFM, especially regarding data collection, involvement of multiple stakeholders, and policy transfer. The relationship between ecological models and socioeconomic factors is complex and more data is needed as well as cooperation between the governments, local communities, and industries. Also, marine ecosystems are universal, and as a result, the management of the ecosystems has to be done across borders. In the future, the factors that could enhance the implementation of EBFM are technology improvements such as artificial intelligence monitoring and satellite observation if the implementation has better data. There is also a need for more research to be carried out on the impacts of climate change on fish stocks and how EBFM can contribute to building the marine ecosystem's capacity. The future of ecosystem-based fisheries management will therefore depend on the improvement of cooperation with other countries and the formulation of sustainable policies.

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