Evolving Paradigms and Innovations in Modern Fisheries Practices

CHAPTER 21

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SUMMARY

The sustainable development of aquaculture and effective fisheries management are crucial for ensuring nutritional security. This chapter examines the enlightened landscape of fisheries, total yield dynamics, environmental challenges, and accessibility of innovations to enhance the efficiency of the fishing industry. Despite the substantial increase in aquaculture production, environmental issues including climate change overfishing and pollution are causing significant threats to fisheries which highlight the necessity for innovations in fisheries management practices by exploring the ecosystem-based approach and the role of technological advancements. This chapter entails the data-driven pathways and emerging digital technologies, including robotics, drones, sensors, artificial intelligence and the internet of things as pivotal in revolutionizing fisheries practices. Ecosystem monitoring and management are evolving as a result of innovative modeling approaches that draw data from these and other techniques. Molecular technologies such as genomic selection and editing as well as waste management innovative strategies through the use of nanoparticles play a significant role in the improvement of sustainable fisheries management.

INTRODUCTION

Food security is essential for sustainable global development (Shen et al., 2021). Fisheries output has been increasing day by day because of the rising world population and the increasing demand for fish products (Ahmad et al., 2021). The term "fisheries" describes the sector of capturing, preparing, and marketing fish and other aquatic organisms. The fisheries sector is more diversified than other agricultural sectors in terms of species, products, production systems, marketing and business (FAO, 2022). The fisheries sector has been meeting the rising human demand for nutrient-rich seafood products by efficiently utilizing abundant water resources and the biodiversity of aquatic life (Gladju et al., 2022).

However, more challenging environmental problems such as climate change, pollution and nutritional deficiency in juvenile and broodfish populations in extensive culture systems, have caused several harms to fisheries (FAO, 2022). These environmental challenges have been acting as a major hindrance to the sustainability of the fisheries sector. In the context of fisheries management, fisheries innovation involves implementing new ideas, technologies, techniques and approaches to enhance the sustainability, efficiency, and overall performance of the fishing sector (Sarkar et al., 2022). Recent innovations in fisheries have focused on promoting sustainable practices, limiting environmental impacts, and reducing bycatch, driven by management requirements and shifting customer preferences for sustainable seafood (Kaur & Datta, 2021).

Innovative paradigms in the fisheries sector

Social-ecological systems related to fisheries often encounter numerous conflicts. Environmental factors play a significant role in certain issues, but internal changes to subsystem components and external stress at various temporal and spatial scales also contribute to several fisheries-related challenges (Preiser et al., 2018). Contributing factors to fishery conflicts include insufficient stakeholder education, spatial distribution, alteration in fish abundance, climate change, illegal, unreported and unregulated fishing as well as involvement in drug trafficking (Mileski et al., 2020; Mendenhall et al., 2020). To resolve these conflicts in fisheries, two fundamental emerging paradigms exist, the ecosystem approach and technological advancements. The ecosystem approach emphasizes on holistic understanding of the interaction between ecological and social components within a system for sustainable solutions that considered both human and environmental factors, while technological advancements include innovations to enhance fisheries management, monitoring and enforcement (Patrick & Link, 2015).

Adopting an ecosystem approach involves a shift from a single sector focus to considering multiple sectors and recognizing the sources of change that extend beyond the scope of ecology (FAO, 2022). This approach can contribute

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to achieving the goals of aquaculture conservation and fisheries (Townsend et al., 2019). Innovation in fisheries practices is driven mainly by enhanced profitability by means of increased yields per unit area and through the incorporation of new technologies. However, the potential to produce sustainable fisheries products is being severely limited due to the change in climate and environmental conditions and poor management practices (Shen et al., 2021). To overcome these problems, there is a need to adopt innovative fisheries management practices (Kaur & Datta, 2021).

FISHERIES PRACTICES

Both aquaculture and capture fisheries are important sources of protein for a significant portion of the world population (FAO, 2022). Fish and shellfish account for about 25% of animal protein consumed throughout the world and the consumer demand for fish is rising. Due to rising demand and technological advancements, it is predicted that the total world output of fish will surpass 200 million tons in 2030 (FAO, 2023). Capture fisheries play a significant role in ensuring food security and fulfilling protein requirements for approximately one-third of the global population (Thilsted et al., 2016). Marine fisheries are the most significant source of protein, and play a critical role in generating income, providing nutritional security and supporting the livelihoods of the increasing population (Asche et al., 2015).

Aquaculture and recreational fisheries

Due to overfishing and climate change, global supply of wild fish is diminishing rapidly (Table 1). Therefore, the aquaculture industry stands as the sole means to ensure an adequate supply of seafood (Yue & Shen, 2022). Aquaculture offers a platform for rural employment, survival, and assisting the national GDP through income production (Sarkar et al., 2022). Fish or other aquatic species are cultivated either in freshwater or in mariculture (Ahmad et al., 2021). Cultural systems vary depending on the basis of culture intensification, water exchange and fish farming techniques (Ho & Goethals, 2020; Goddard & Delghandi, 2020). Recreational fishing (RF) is a widely practiced activity in continental, estuarine, and coastal-marine environments (Arlinghaus et al., 2021). In numerous countries, one out of every ten individuals engage in fishing solely for recreational purposes. Recreational fishing independent of commercial fishing, offers a variety of psychological, social, educational, and economic advantages to fishermen and society instead of nutritional benefits (Arlinghaus et al., 2017).

Table 1: Total fisheries production and consumption from 2018-2023

Million tons (live weight)						
Fisheries production over the years	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Capture	96.5	92.2	90.3	91.2	91.1	89.6
Aquaculture	82.5	85.2	87.5	90.9	93.2	95.8
Total fisheries production	178.9	177.4	177.8	182.1	184.3	185.4
Utilization						
Human consumption	156.8	158.1	157.4	161.1	164.2	166.1
Trade (live Weight)	66.8	66.6	59.8	66.6	67.9	65.0

THREATS TO FISHERIES PRACTICES

Fisheries resources are the most productive and dynamic resources in the economy of a country, making a substantial contribution to food security, employment and foreign exchange earnings. A variety of interconnected factors like overfishing, illegal fishing, destructive practices, poor management, habitat destruction, climate change and pollution are primarily responsible for the depletion of fisheries resources (Sumaila et al., 2019; Gebremedhin et al., 2018). Reducing the loss of these resources requires the implementation of conservation initiatives, sustainable fisheries management strategies, and responsible consumption (Aswani et al., 2018). Fisheries resources encounter numerous socio-ecological challenges. Some common threats to the fisheries industry are presented in Fig 1.

Climate change and pollution

Climate change poses one of the primary challenges to the sustainable development of marine renewable resources. The worldwide increase in anthropogenic gas emissions has led to the oceans warming and consequently changes the marine food webs (Swart et al., 2018). Oceans absorb more than 90% of the heat increase caused by climate change (Cheng et al., 2021) resulting in a rapid increase in (Ruela et al., 2020) temperature and ocean acidity. Other challenges include increasing pollution and the over-exploitation of the water content for potable supplies, industries, irrigation, and thermal plants. As these sectors strive to meet the needs of the growing population, they significantly reduce their assimilative capacity (Lai et al., 2018).

Overexploitation, destructive fishing, and habitat degradation

The global ocean has been greatly influenced by the human population (Halpern et al., 2015). Over-exploitation, overfishing practices and habitat degradation are one of the major threats to ocean health and have a long-lasting impact on marine ecosystems (Gattuso et al., 2018). Overfishing involves all illegal activities that damage the primary aquatic ecosystems. The fisheries sector has frequently suffered substantial losses as a result of typhoons, tsunamis, floods, earthquakes, and other unpredictable natural events. Furthermore, stock depletion and the potential for sustainable fishery production are major risk factors associated with the decline of high seas fisheries resources (Trathan et al., 2015).

Poor management strategies

Globally, fish supplies have significantly reduced, even though fisheries play a major role in providing livelihoods, jobs, and income (Gebremedhin et al., 2021). There is an urgent need for management techniques that successfully provide sustainable yields and conserve fish stocks (Aswani et al., 2018). Millions of people who primarily rely on these resources for their livelihoods and socioeconomic conditions could suffer greatly from poor management of world fish

stocks (Gattuso et al., 2018). Many young researchers lack the necessary knowledge and required skills which hinder the managers and young researchers from proper management of fish resources (Gebremedhin et al., 2018).

EVOLVING PARADIGMS IN FISHERIES

In fisheries management, the use of technology shows its potential to enhance outcomes in various fisheries sectors; however, the lack of innovation and adoption of novel technologies indicates substantial challenges that hinder the support for these technological advancements in global fisheries. In order to support the "Blue Economy," new industries, shoreline encroachment, coastal development, and increased use of ocean space present additional threats (Lee et al., 2020). These factors put additional pressure on migratory routes and critical habitats, which in turn increases stress on commercial and recreational fisheries as well as other fish communities (Copping et al., 2021). An ecosystem approach and interdisciplinary scientific knowledge are needed for the sustainable use and management of the fishing industry in order to resolve problems pertaining to the sector.

Ecosystem-based approach

Fish rely entirely on marine environments for both their habitat and prey. Thus, changes in ecosystem structure and function will automatically affect commercially significant fish and fisheries. The ecosystem approach has expanded the scope of fisheries management beyond the traditional single species focus to the ecosystem-based approach which takes into account the system resilience and habitat concerns (Patrick & Link, 2015). Management of the fishery resources by governments, direct users, and other stakeholders is encouraged under adaptive management. Ecosystem-based fisheries management has been expounded upon for many years as a holistic approach to fisheries management. It is thought to be a model of participatory management able to support the biological, social, and economic sustainability of fisheries (Townsend et al., 2019). Community-based approaches are a developing perspective, that has emerged as a mainstream strategy for governing dynamic small-scale fisheries. However, locally driven, community-led sustainability outcomes remain a persistent challenge (Trathan et al., 2015).

Innovative trends in fisheries

The development of innovative technology is a crucial factor in meeting the demand for fish and fisheries products in the future by enhancing the catchability of the harvesting sector and preventing resource depletion (Eigaard et al., 2014).

Fig 1. Threats to fisheries

Furthermore, new fisheries technologies have the potential to increase productivity, provide high quality fish products and aid in the protection of aquatic habitats (Fujii et al., 2017). Some important strategies related to fisheries sustainability are presented in Fig 2.

Innovations in fisheries management practices

Fisheries management is an intricate socio-political process and the cornerstone of efficient and sustainable fisheries management is data-driven knowledge. Access to precise data regarding the performance of a fishery, as well as what species are being caught, from where and in what quantities is a fundamental element for the effective fishery management establishment (Bradley et al., 2019). The recent shift in fisheries management systems to employ digital technologies for EM offers a solid platform for developing a more responsive system. The information about harvested catch collected from these processes can be used to build models and ongoing monitoring activities allowing for observation of changes in real time for the development of more effective management practices (Cerrano et al., 2017).

Gear advancements

Increasing the efficiency of fishing gear has become a priority, both from an environmental perspective and from a socioeconomic point of view (Sala et al., 2023). Modifications in active and passive gears are done in several ways. Passive gears are generally regarded as typically selective, and involve less advancement in gear design; however, in some fisheries, unwanted catches are not only operational challenges, but also an environmental issue (Hilborn et al., 2021). Active gear modifications involve simple coded adjustments such as altering mesh size or orientation and they have been among the most common and effective gear modifications to improve size-selectivity of target species.

Digital technologies

Smart aquaculture also called digital aquaculture (Yang et al., 2021) is a perception that includes the use of modern technologies and data-driven pathways for increasing the efficacy, sustainability, and production of fisheries related activities (Zhao et al., 2021). The fish industry is developing rapidly, and more advancements need to be made to increase its sustainability and profitability (FAO, 2022). The digital technologies listed below have the potential to revolutionize the fishing sector:

Robotics: Production of aquaculture is a challenging process because feeding, maintaining ponds and nets, observing behavior, and removing sick fish are costly and labor-intensive activities and poses several challenges to the industry. There are technological approaches available to handle these challenges in the aquaculture industry (Sun et al., 2020). In addition, there are some customized systems that can work universally for all the production systems of fish (Kruusmaa et al., 2020). For instance, automated underwater robots have potential to perform laborious tasks and they are already being used in feeding, removing diseased fish (Sun et al., 2020), cleaning nets and ponds (Paspalakis et al., 2020).

Drones: Drones are remote control systems used to screen the fisheries farm in coastal areas and help to monitor the cages damages and holes. This system works under radio frequencies and pre-programmed GPS-guided flight scripts and helps to gather novel information, which is a very problematic task for humans (Clarke, 2014). Drones are appropriate tools for perceiving illegal fishing activities and unrestricted fishing gear (Bloom et al., 2019). Drones with the combination of Artificial intelligence (AI) can enhance fisheries operations and reduce production costs (Kelaher et al., 2019).

Sensors: A sensor is a device that senses and responds to some kind of input from the physical surroundings like light, heat, motion, moisture, pressure etc. Sensors are used to monitor water quality parameters such as turbidity, salinity, DO, pH and pollutants. In aquaculture, the salt concentration and temperature can be measured by using biosensor. Sensors are evolved from simple sensing apparatuses to modern, stretchable and temperature resistant sensors with high capacities to perform different tasks such as traceability of the system (Zhang et al., 2021). Sensors help to trace the hunger level in cultured fish through internet thus improving the suitable feeding practices and decreasing the general production expenses (Saeed et al., 2022).

Artificial intelligence: AI has developed as a transformative technology with the potential for revolutionizing the fisheries sector. Many research organizations used AI to make more informed decisions. Even though drones, sensors and robots have made it easy to gather information rapidly but the amount of data gathered can make it extremely difficult to use this information to make correct decisions. Operators can get real time data and make informed decisions by applying AI tools which can lead to sustainability and improved productivity of the fisheries sector (Panudju et al., 2023). Furthermore, AI provides a real-time system that can improve the administration of fish health and development (Mustapha et al., 2021). The AI can limit the input waste and cut costs by up to 30% in aquaculture (Burke et al., 2021).

Novel molecular technologies for genetic manipulation

The global aquaculture industry's success has been largely attributed to genetic modification through breeding. The combination of molecular technologies in current breeding programs has efficiently enhanced the genetic development of some culturable species (Yue, 2014). Marker-assisted selection (MAS) has been successfully employed to enhance disease resistance in a variety of species, including salmon resistant to infectious pancreatic necrosis, lymphocytes in Japanese flounder, and achieving an all-male population in Tilapia (Fujii et al., 2017). Other biotechnologies, such as gynogenesis, androgenesis and polyploidization have significantly contributed to enhancing fisheries production.

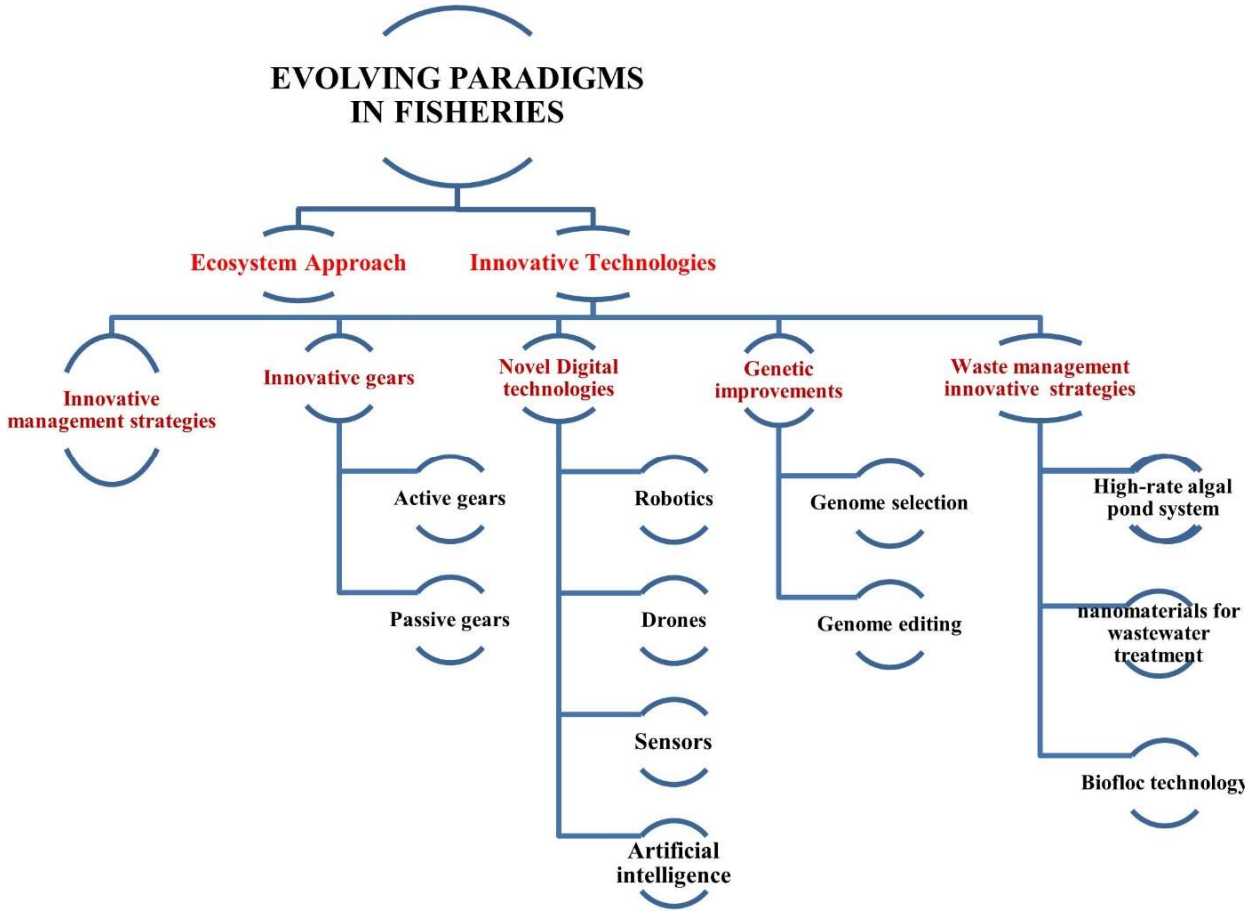

Fig 2. Evolving fisheries paradigms

Genomic selection and editing: Genome selection (GS) is a new molecular breeding technique. As sequencing and bioinformatics technologies continue to progress and the cost of SNP (single-nucleotide polymorphism) genotyping continues to decline, GS which uses SNPs associated with specific traits or SNPs covering the entire genome is being used in a wide range of aquaculture species to accelerate genetic improvement and optimize selective breeding programs (Shen & Yue, 2019). When the genes to be edited are known, genome editing by using CRISPR/Cas can speed up the process of genetic improvement of species (Gratacap et al., 2019). GE permits rapid introduction of favorable alleles, increases the frequency of preferred alleles at loci determining specific traits, and introduces favorable alleles from other species (Yue & Shen, 2022).

Oral vaccination: Fish immunization has been in practice for over 50 years as an efficient method to control viral and bacterial diseases (Ma et al., 2019). In fisheries, only a few vaccines have been approved and are being used (Erkinharju et al., 2021). Oral vaccines offer an alternative to the labor-intensive conventional method of vaccination, which involves manual injection by hand. Opting for oral vaccination minimizes the need for extensive handling and potential harm to fish, thereby lowering mortality rates associated with the vaccination process (Adams, 2019). Microencapsulation, involving the incorporation of antigens from pathogens, could serve as a technological approach for delivering oral vaccines to fish (Dezfooli et al., 2019).

Waste management innovative strategies

Waste may come from by-products such as feed leftover, chemicals, and pathogens (Hesni et al., 2020) and it can be categorized into solid wastes and dissolved waste. With the increasing demand in the fishery industry a large amount of waste will be produced, posing serious threats to fisheries in the form of wastewater, chemical residue, and microorganisms (Abdel-Shafy & Mansour, 2018). Some innovative waste treatment strategies are the following:

High-rate algal pond system: The efficacy of High-Rate Algal Ponds in treating wastewater from aquaculture and other sources is gaining attention (Robles et al., 2020). These are shallow ponds with a one-meter depth and the paddle wheels are used to move the water horizontally. The countercurrent gas sparging sump, located under paddle wheel is filled with carbon dioxide (Robles et al., 2020). In these ponds, increased algal growth is allowed and subsequently, the algae are collected for processing into other beneficial products such as biofuels and algae also absorb the excessive nutrients from the water which can be then used or discarded into surroundings. A notable benefit of this technique is that these algae can be transformed into other commercially significantly materials, thereby contributing to the farmer's profitability (Iber & Kasan, 2021).

Use of nanomaterial for wastewater treatment: Nanomaterials are being used in numerous ways for the treatment of wastewater such as Nanoadsorbents, polymeric Nanoadsorbents and nanomaterial-based membrane and the nanomaterials are characterized by their size which range from 1-100nm (Ighalo et al., 2021). Nano-adsorbents play crucial role in shrimp culture for treatment of wastewater through the process of adsorption. This involves extracting all types of contaminants from effluent water by attracting them to the active sites on the outer surface of the adsorbent material (Manyangadze et al., 2020). Polymeric nanoadsorbents are designed in a way that the inner part repels water and exclusively adsorbs organic molecules, while the outer part attracts hydroxyl or amine groups of contaminants (Thamer et al., 2020).

Biofloc technology

The BFT is a key solution to rapidly increasing environmental issues like waste water problems, limited feed issues, high expenses and land availability problems (Khanjani & Sharifinia, 2020). Biofloc technology has emerged as a sustainable and eco-friendly approach in the aquaculture industry in contrast to traditional cultural practices (Dauda et al., 2019). BFT is a technique of improving water quality through the addition of carbon sources to produce high levels of microbial floc in the culture system. Under such conditions, the production of microbial proteins increases, thereby improving water quality and also serve as sources of dietary protein for culture organisms (Ahmad et al., 2017).

CONCLUSION

Effective fisheries management practices are becoming more and more crucial as overfishing puts hundreds of millions of people's livelihoods and food security at risk, lowers biodiversity, affects ecosystem functioning, and threatens fish stocks globally. For establishing sustainable fisheries practices, access to accurate and precise data regarding species catch and fishery performance is essential. Technological advancements in robotics, AI, remote sensing, and electronic monitoring are providing fisheries stakeholders with promising solutions by providing the necessary information and resources they need to protect marine ecosystems and make informed decisions. These technologies enable expanded data collection and analysis offering spatially and temporally relevant insights for fisheries management. By adopting these advancements and utilizing data-driven approaches, we can contribute to the sustainable use of marine resources, assuring a healthier future for both the fishing industry and the ecosystem.

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