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Sustainability of Fished Populations Challenges, Strategies and Future Directions: A Review

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ABSTRACT

This review paper summarizes recent research on global fisheries, highlighting ecological, economic and social obstacles. Ecologically, overfishing, habitat degradation and climate change threaten the health of marine ecosystems, necessitating ecosystem-based management approaches and conservation measures. Economically, declining fish stocks and market dynamics pose challenges to the livelihoods of fishing communities, highlighting the importance of sustainable fishing practices and alternative earning options. Strategies such as ecosystem-based management, science-based decision-making and innovative technologies are identified as crucial for achieving sustainability. Effective fisheries management also requires legislative actions targeted at stopping illegal fishing and fostering global collaboration. The assessment recommends cooperative efforts in the future between communities, governments and stakeholders to maintain the long-term viability of fishing populations through the application of adaptive management techniques. By adopting these strategies and establishing resilience, it is aimed to preserve marine biodiversity, secure food sources and support the well-being of present and future generations.

Key words: Challenges, Fisheries management, Overfishing, Sustainability.

The sustainability of fished populations is crucial for marine biodiversity, ecosystem health and human well-being. Overfishing, habitat degradation, bycatch and illegal fishing threaten marine ecosystems and risk the livelihoods of millions dependent on fisheries for food security and economic stability. Fishing, the last major hunting and gathering activity, supports human health and food security (Kittinger *et al*., 2017). However, commercial fisheries often prioritize profits over ecological and social goals, leading to resource depletion and inequality (Pauly *et al.,* 1998).

Overfishing, driven by excessive harvesting and weak management, endangers fish species and disrupts marine ecosystems. Destructive practices like bottom trawling worsen habitat degradation. Despite centuries of sustainable fishing, modernization has introduced industrial trawlers, advanced shoal detection and large-scale netting. The FAO (2022) reports that over 60% of monitored fish stocks are fished at their maximum sustainable yield, with nearly one-third overfished.

Climate change further exacerbates sustainability challenges by altering ocean temperatures, currents and nutrient cycles. These changes affect spawning grounds, migration patterns and habitat stability. Addressing sustainability requires integrated scientific research, policy reforms and community engagement. Effective fisheries management-establishing marine protected areas, enforcing science-based harvest limits and promoting ecosystem-based approaches-is crucial. International collaboration and stakeholder engagement are also vital for ensuring equitable resource distribution and sustainable governance (Myers and Worm, 2003).

This review explores the complexities surrounding the sustainability of fished populations, highlighting the key challenges facing fisheries management and conservation efforts. In conclusion, coordinated effort at the local, national and international levels is necessary to address the complex and difficult issue of the long-term viability of fished populations. The recovery and resilience of fish stocks guarantee the long-term health of freshwater and marine ecosystems by addressing the underlying causes of excessive fishing, habitat loss and climate change.

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Ecological challenges

Overfishing: Causes and consequences

Fish populations that are diminishing as a result of defaunation and inadequate fishing are said to be

overfished (McCauley *et al*., 2015). Excessive overfishing alters habitat due to shifts in the biomass, composition of species and size structure, as well as community structures and fish sizes as a result of species-specific harvesting and bycatch of other species (Jennings and Blanchard, 2004). According to FAO (2012), over 85% of fish populations worldwide are either completely or overfished and the 40% decline in fish stocks in Europe can be attributed to overfishing or reduced biomass limitations (Sumaila and Tai, 2020). There are currently two to three times more fish in certain EU fisheries than there are sustainable levels (Sissenwine and Symes, 2007).

Fish populations and other aquatic resources become less climate change-adaptive as a result of overfishing (Pauly *et al*., 2005). Furthermore, adverse fishing practices such as bycatch, damaging subsidies and illicit, unreported and unregulated (IUU) fishing are all closely linked to overfishing (Sumaila *et al*., 2021). Fig 1 illustrates the concept of ecosystem overfishing, showing how multiple fish species are impacted simultaneously by excessive fishing pressure.

Habitat degradation and loss

Emergent structures like seagrass beds, salt marshes, mangroves, kelp, boulder shoals, rocky outcrops and epibenthic reefs enhance marine benthic environments' complexity (Peters and Cross, 1992). These structural components are vital to ecosystem health and provide critical habitats for various marine species, including fisheries important for recreation and the economy. They offer refuge from physical and chemical stress, competition and predators, while also serving as breeding or nursery habitats and food sources (Tupper and Boutilier, 1995).

Climate change's effects on marine and freshwater ecosystems

Climate change poses a significant global threat to biodiversity (Pandit *et al*., 2017). According to the IPCC-AR5, marine species are expected to shift their ecological niches due to climate change, endangering marine biodiversity and fisheries (Pachauri *et al*., 2014). This shift, combined with existing pressures such as overfishing, habitat loss and pollution, further intensifies the challenges faced by fisheries systems (Brander, 2010; FAO, 2020a; Pecl *et al*., 2017). Climate change will directly and indirectly impact fisheries, affecting coastal communities and economies (Koenigstein *et al*., 2016). It will also influence fishermen's livelihoods, vulnerability and adaptive capacity (Islam *et al*., 2014). Tropical fisheries are especially at risk, highlighting the need for a better understanding of climate change risks in these areas (Lam *et al*., 2020).

Economic challenges

Unsustainable fishing practices and economic incentives

Unsustainable fishing harms marine ecosystems and global food security, driven by short-term profits over conservation. To promote sustainability, fishers need secure fishing rights, such as territorial fishing licenses. These rights encourage responsible fishing without granting full ownership. They include individual harvesting rights, community-based rights (Baland and Platteau, 1996) and territorial user rights (The World Bank, 2004).

Despite being practiced for millennia, economic fishing rights are sometimes seen as a new concept, especially individual harvesting rights. In Oceania, cooperative management and territorial user rights ensured sustainable fisheries for generations (Johannes, 1978). However, exclusive property rights do not guarantee sustainability. When many people have rights with differing interests, overexploitation may still occur (Clark, 1973), leading to incentives for cheating and abuse. Incentive-based systems, where those most affected by overexploitation pay the cost, strengthen management by aligning interests with long-term sustainability.

Market dynamics shape the fish market through supply, demand, pricing, policies, technology and consumer preferences. Factors like population growth, higher living standards and better product access (Matuli *et al*., 2016) drive demand. Sustainable fisheries management aligns market forces with conservation. Consumer awareness influences demand for sustainably sourced seafood, encouraging responsible fishing.

Economic implications of fisheries depletion

Fisheries depletion, caused by overexploitation, leads to reduced fish populations and potential collapse, affecting local and global economies.

Loss of livelihoods: Coastal communities reliant on fishing face economic insecurity, with decreased catch yields leading to unemployment and poverty.

Decline in economic value: Reduced fish stocks lower fishing business profitability, affecting related industries like processing, distribution and tourism.

Increased food prices: Fisheries depletion leads to higher seafood prices, disproportionately affecting vulnerable populations dependent on fish for protein.

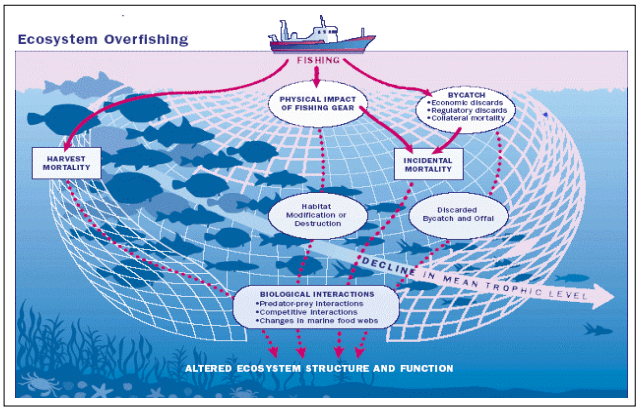


Fig 1: Ecosystem overfishing (Source: Pauly *et al*., 1998).

Impact on trade: Depletion disrupts international trade, causing shortages and worsening trade imbalances.

Environmental costs: Fisheries depletion causes habitat degradation and biodiversity loss, leading to long-term economic impacts and harming ecosystem functions essential for human welfare.

Social challenges

Fisheries governance and management

Legal, social, economic and political frameworks used to regulate fisheries are combined to form fisheries governance. Lawfully binding regulations and customary social arrangements are all part of it and it has global, national and local dimensions (FAO, 2001). National fisheries management authorities, which stand for the legal state body having the power to carry out particular fishery management tasks, are often an integral element of governance frameworks. Institutional frameworks for fisheries governance also include co-management committees, fishermen's associations and other entities, as well as the connections between them.

The United Nations (UN) has approved the Sustainable Development Goals (SDGs) (Luo and Chi, 2022), which are related to habitat, ecosystems and other aspects of fisheries sustainability. The legal, economic, social and political arrangements employed to accomplish these goals are collectively referred to as sustainable fisheries governance (Butt *et al*., 2022). Sustainable fishing ensures the preservation of fish habitats and the safeguarding of fisheries resources for future generations. One feature of marine fish, in contrast to other disciplines of sustainable governance, is that they are not constrained in their mobility by artificially partitioned ocean zones, unlike migratory and transboundary species (Nandan and Lodge, 2005).

Ocean governance is based on maritime law, dividing the ocean into five main zones: interior waters, territorial seas, contiguous zones, exclusive economic zones (EEZs) and high seas. The United Nations Convention on Law of the Sea (UNCLOS, 1994) assigns states varying rights and obligations in these areas (Luo and Chi, 2022). Since states cannot achieve ocean governance alone, cooperation is essential, especially in marine fisheries governance. This distinction between artificially divided and natural oceans suggests that domestic laws rarely apply to the high seas (Ventura, 2015; Cho, 2024; Hai and Duong, 2024; Maltare *et al*., 2023; Bagga *et al*., 2024; AlZubi, 2023).

Strategies for sustainability

Marine protected areas and ecosystem-based management

Fisheries are crucial for food, nutrition, revenue and jobs in both developed and emerging countries. Marine fisheries produce 148 billion US dollars worth of fish annually, supplying most of the world's fish (FAO, 2020b), with yields exceeding 80 million tonnes. However, uncontrolled fishing harms marine ecosystems (Weaver *et al*., 2011). Innovative management systems, such as those by Galarza and Collado (2013), are possible in "single-state single-species" fisheries. Managing shared resources presents challenges due to national sovereignty, maritime ecosystems and international relations. Link and Browman (2014) suggest combining Ecosystem-based management (EBM) and Single Species Fisheries Management (SSFM). SSFM focuses on individual species, incorporating ecosystem factors, while EBM takes a broader approach, addressing multiple sectors and conflicting interests (Fogarty, 2014).

Innovative technologies for fisheries monitoring and surveillance

Traceability alone cannot ensure ecosystem health, increased fish populations, or long-term human benefits. However, it helps detect fraud, monitor environmentally friendly practices and enforce regulations for supply chain transparency. Reducing start-up costs and overcoming adoption barriers can support sustainable fisheries. Increasing cost efficiency and capacity development will aid in using these technologies.

Genetic tools at the molecular level

Modernising marine fisheries monitoring has been possible with the development of more accessible and inexpensive molecular genetics methods and technology (Willette *et al*., 2014). One such technique for identifying seafood replacement is traditional DNA barcoding, which has been extensively utilised and well-tested late in the seafood supply chain. Environmental DNA (eDNA) techniques have emerged to detect numerous current species simultaneously, avoiding the requirement for direct fish tissue collection by focusing on the residual DNA and waste products of metabolism left behind in their surroundings (Deiner *et al*., 2017). Every day, there are new uses for eDNA that address a variety of scientific and managerial issues. There is growing exploration of its potential utility in providing abundance indices to assist fisheries management (Rourke *et al*., 2022). Nonetheless, several methodological obstacles still need to be addressed and promising new strategies still need to be investigated (Yao *et al*., 2022).

Automatic identification systems

Under SOLAS rule V/19, boats over certain tonnage are gradually equipped with Automatic Identification Systems (AIS) for collision avoidance and maritime safety. Similar to VMS, AIS broadcasts vessel positions and movements in an open format, allowing anyone with the appropriate receiver to access the data. The introduction of commercial satellite-AIS constellations and web-based data providers shifted AIS usage from ship-to-ship communication to a commodity for organizations such as shipping companies and fishing businesses. Some fishermen disable AIS to protect fishing locations or engage in illegal activities like AIS spoofing (Welch *et al*., 2022; Androjna *et al*., 2021).

Remote electronic monitoring

Kindt-Larsen *et al*. (2012) state that remote electronic monitoring (REM) is a promising tool for assessing accidental captures, such as marine animals and for discouraging illegal, commercial and underwater fishing at sea. CCTVs, winch sensors, conveyor belts, freezers and REM's whole VMS are all part of it. Real numbers may not match those reported in electronic reports and even the greatest AIS or VMS cannot reveal which species and in what quantities are collected. The ability of REM to discourage IUU fishing is best illustrated by the monitoring of bycatch. The non-targeted creatures that are caught when fishing for a particular species are referred to as bycatch. A vessel that has reached its quota for a particular species (the choke species) and is unable to bear the risk of continuing to fish for other species may find it alluring to discard it at sea to preserve the restricted hold space for target species or to prevent a full fishery closure (Alshahrani, 2024; Koike *et al*., 2023; Sharun *et al*., 2024).

Policy interventions

Adaptive policy framework development

Researchers and practitioners have identified several essential elements of fisheries management to enhance the resilience and sustainability of fisheries systems. While these elements are broadly applicable, they must be tailored to specific contexts. The Food and Agriculture Organization's Fishery Managers' Guidebook, for example, outlines nine operational principles for fishery management (Cochrane and Garcia, 2009). These principles generally fall into three categories.

Inclusive, democratic management: Implement management structures where authority is distributed and responsibilities are clearly assigned. At larger scales, such as for highly migratory species, co-management at regional, local, or national levels can promote fair decision-making procedures (Wilson *et al*., 2018).

Efficient data collection and monitoring: This is crucial, particularly as climate change affects the productivity and distribution of fish stocks (Bradley *et al*., 2019).

Adaptive, science-based management: Management strategies should control human impacts using impartial assessments of stock and fisheries status, ensuring sustainability, especially with the added uncertainty of climate change (Pinsky and Mantua, 2014).

Recent research on the effects of and adaptation to climate change (Free *et al*., 2020) suggests several strategies for building climate-resilient fisheries, including.

Forward-looking research: Focus on future conditions rather than managing for past states that no longer exist due to climate change.

Enhanced cross-border collaboration: Strengthen multinational and subnational partnerships as stock distributions and productivities shift.

Whole-system resilience: Consider the broader socioeconomic and ecological factors to reduce vulnerability and enhance resilience, addressing structural inequalities worsened by climate change.

These six strategies represent adaptive policy approaches to achieve resilient, sustainable and equitable fisheries. While they are not separate or mutually exclusive, a combination of these approaches may be necessary, depending on the specific fishing system. Since these strategies are derived from existing literature, they are based on practices that have already been developed or implemented.

National fisheries policies and regulations

The National Fisheries Policy 2020 (NFP) combines the National Policy on Marine Fisheries 2017, the Draft National Inland Fisheries and Aquaculture Policy and the Draft National Mariculture Policy. It aims to guide states and UTs in developing region-specific legislation with regulatory and developmental components. The policy envisions sustainable fisheries development, increased exports, higher incomes for fishermen and improved customer choice. By adhering to national and international guidelines, the policy promotes responsible and inclusive growth. It aligns with India's Blue Growth Initiative, Agriculture Export Policy 2018 and Sustainable Development Goals, while fostering better fisheries governance and collaboration with stakeholders.

Future directions

Ensuring sustainable fish populations is vital for marine ecosystem health and the livelihoods of millions relying on fisheries. A key approach is Ecosystem-Based Fisheries Management (EBFM), which considers species, habitats and human activities in marine ecosystems to support sustainability. Science-based management techniques, using reliable data and models, are crucial for decision-making, including setting harvest levels and forecasting population changes. Better monitoring, data collection and stock assessments are necessary for sustainability. Investing in fisheries science and research is essential to fill knowledge gaps, understand ecosystem dynamics and create innovative solutions for sustainable management.

CONCLUSION

Ensuring the sustainability of fished populations requires addressing ecological, economic and social challenges. Climate change, habitat loss and overfishing threaten marine ecosystems. Conservation measures and ecosystem-based management are crucial for biodiversity. Declining fish stocks and market shifts endanger fishing communities, making sustainable practices and alternative livelihoods essential. Fisheries support food security, emphasizing the need for inclusive governance and community-based management. Strategies should focus on conserving fish stocks and tackling overexploitation. Science-based management, innovative fishing methods

and policy interventions are vital. Strengthening legal frameworks and international cooperation is necessary to combat illegal fishing and enforce sustainability standards.

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Authors' contributions

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Data availability

The data analysed/generated in the present study will be made available from corresponding authors upon reasonable request.

Availability of data and materials

Not applicable.

Use of artificial intelligence

Not applicable.

Declarations

Authors declare that all works are original and this manuscript has not been published in any other journal.

Conflict of interest

Authors declare that they have no conflict of interest.

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