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Review Article

From Overfishing to Resilience, A Global Review of Fisheries Management Strategies

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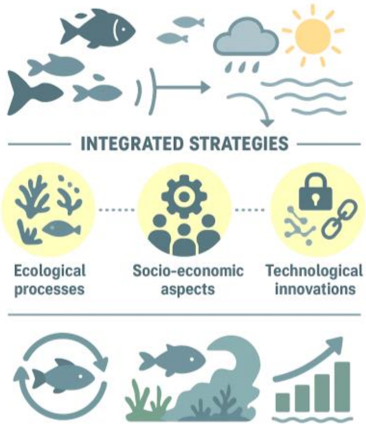
Abstract

Global fisheries stand at a critical juncture, grappling with a legacy of overexploitation while facing unprecedented pressures from climate change and increasing global demand. This comprehensive review examines the historical context, current paradigms, and future pathways for fisheries management, arguing that a transition from maximizing yield to building socio-ecological resilience is essential for sustainability. The analysis synthesizes insights across ecological, technological, and socio-economic domains, critiquing traditional single-species approaches and highlighting the emergence of integrated strategies. Key findings reveal that climate change acts as a force multiplier, exacerbating existing vulnerabilities such as stock depletion and habitat degradation, thereby necessitating adaptive and anticipatory management frameworks. Technological innovations, particularly in artificial intelligence, remote sensing, and blockchain, offer transformative potential for monitoring, enforcement, and transparency, yet their implementation is fraught with challenges related to equity, access, and ethical considerations. Socio-economically, the review underscores the failure of top-down governance models and the proven efficacy of collaborative, co-management systems that incorporate community stewardship and equitable benefit-sharing. The synthesis concludes that the future of sustainable fisheries lies in regenerative blue economy systems that actively restore marine capital rather than merely deplete it. This requires transdisciplinary approaches, robust policy integration, and a fundamental revaluation of ocean resources to ensure long-term ecological health and human well-being.



Graphical Abstract

Keywords: Fisheries Management; Socio-Ecological Resilience; Ecosystem-Based Management; Technological Innovation; Adaptive Governance; Blue Economy.

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INTRODUCTION

Global fisheries represent a critical component of food security, economic stability, and cultural heritage for coastal communities worldwide (McClanahan *et al.,* 2015). However, decades of intensive exploitation have pushed many marine ecosystems to the brink of collapse, underscoring the urgent need for transformative management strategies. The transition from abundance to scarcity in key fisheries epitomized by the catastrophic collapse of the Northwest Atlantic cod stocks in the late 20th century, serves as a sobering reminder of the consequences of unsustainable practices (Bolster *et al.,* 2012). Overfishing, driven by technological advancements, escalating market demands, and inadequate governance, has not only depleted target species but also triggered cascading ecological disruptions, including loss of biodiversity, habitat degradation, and altered trophic dynamics. These impacts extend beyond the environment, threatening livelihoods, exacerbating socio-economic inequalities, and undermining the resilience of marine-dependent communities (Forster *et al.,* 2014). As the global population continues to grow, the pressure on marine resources intensifies, necessitating a paradigm shift in how fisheries are managed and sustained.

The challenges confronting contemporary fisheries management are multifaceted and increasingly complex (Sumaila *et al.,* 2016). Climate change introduces unprecedented volatility, manifesting as ocean warming, acidification, and shifting species distributions, which compound the existing pressures of overexploitation. Traditional management approaches, often rooted in single-species models and static harvest rules, are ill-equipped to address these dynamic and interconnected stressors (Arlinghaus *et al.,* 2002). Moreover, governance structures frequently suffer from fragmented jurisdictions, insufficient enforcement, and a lack of inclusive decision-making processes, particularly in regions where small-scale fisheries play a pivotal role. These gaps are further amplified by data deficiencies, especially in developing nations, where monitoring capacity is limited and illegal, unreported, and unregulated fishing remains prevalent (Wilcox *et al.,* 2021). Despite international frameworks and policy instruments aimed at promoting sustainability, implementation gaps persist, highlighting the disconnect between global aspirations and local realities (Mbalisi *et al.,* 2025).

In response to these challenges, the concept of resilience has emerged as a guiding framework for reimagining fisheries management (Holsman *et al.,* 2019). Resilience thinking emphasizes the capacity of socio-ecological systems to absorb shocks, adapt to change, and transform in the face of adversity. This approach recognizes that effective management must extend beyond biological conservation to encompass economic flexibility, social equity, and institutional adaptability (Berkes *et al.,* 2004). Recent trends in fisheries research reflect this holistic perspective, exploring innovative strategies such as adaptive co-management, rights-based approaches, and the integration of advanced technologies. For instance, digital tools like artificial intelligence, remote sensing, and blockchain are increasingly being harnessed to enhance monitoring, traceability, and transparency across supply chains (Omisola *et al.,* 2023). Simultaneously, nature-based solutions, such as habitat restoration and the establishment of marine protected areas, are gaining traction for their dual benefits in bolstering ecosystem health and supporting fisheries productivity.

The scope of this review is to synthesize the evolving trajectory of fisheries management from its historical focus on extraction to its contemporary emphasis on resilience and sustainability. We examine the global impacts of overfishing, the limitations of conventional management paradigms, and the promising strategies being explored to foster resilient fisheries systems. By integrating insights from ecology, technology, and socio-economic studies, this article aims to provide a comprehensive overview of the opportunities and barriers associated with transitioning toward sustainable fisheries. Furthermore, we highlight critical gaps in current research, such as the need for better understanding of climate interactions, the scalability of technological innovations, and the equitable distribution of benefits from management interventions. Ultimately, this review seeks to inform policymakers, researchers, and stakeholders about the integrated and adaptive approaches required to secure the long-term viability of global fisheries and the communities that depend on them.

The Legacy of Overexploitation: Drivers and Consequences

The history of global fisheries is, in large part, a history of escalation. For millennia, fishing was limited by the power of human muscles, the reach of sailing vessels, and the perishability of the catch. The industrial revolution initiated a paradigm shift, but it was the post-World War II period that unleashed the full force of technological modernization on the world's oceans (Moris *et al.,* 2014). The development of synthetic materials like nylon led to stronger, more durable nets. The refinement of echo-sounding and sonar technology allowed fishers to locate schools of fish with unprecedented accuracy, eliminating the element of search and transforming fishing from a pursuit into a systematic harvest. The onboard freezing of catches enabled factory trawlers to remain at sea for months, processing and storing immense volumes of fish, thus distancing the act of extraction from its port-based limitations (Warren *et al.,* 2025). This technological arms race created a feedback loop of increasing efficiency and effort, where the solution to declining catches per vessel was invariably to invest in larger boats, more powerful gear, and longer trips, further intensifying the pressure on marine populations.

Underpinning this technological drive was a suite of powerful socio-economic and political drivers. Governments, viewing fisheries as engines for rural employment and national food security, often provided substantial subsidies for vessel construction, fuel, and modernization (Garcia *et al.,* 2010). These financial incentives artificially enhanced profitability and encouraged overcapitalization, where far too many vessels chased too few fish. On a global scale, international demand for seafood, particularly from developed nations, created a powerful market pull for high-value species like tuna, shrimp, and groundfish. This demand often marginalized small-scale, artisanal fishers who could not compete with the volume and efficiency of industrial fleets, leading to social inequity and the loss of traditional livelihoods. Furthermore, the legal architecture of the ocean, particularly through the establishment of Exclusive Economic Zones (EEZs) under the United Nations Convention on the Law of the Sea, created a complex patchwork of national jurisdictions and high-seas areas, complicating international management and enforcement and creating sanctuaries for unsustainable practices (Oda *et al.,* 1983).

The ecological consequences of this prolonged overexploitation are profound and multifaceted. The most direct impact is the reduction in biomass and spawning potential of target species, pushing many commercially valuable populations far below levels capable of producing their maximum sustainable yield (Zabel *et al.,* 2003). However, the damage extends far beyond the target catch. Bycatch, the incidental capture of non-target species, remains a devastatingly persistent issue. Millions of tons of marine life, including endangered sea turtles, marine mammals, seabirds, and countless juvenile fish, are discarded dead or dying each year, representing a massive waste of resources and a significant threat to marine biodiversity. Furthermore, certain fishing gears, particularly bottom trawls and dredges, have widespread physical impacts on marine habitats. Dragged across the seafloor, these gears can destroy fragile deep-sea coral ecosystems, sponge beds, and other structurally complex habitats that provide essential nurseries, feeding grounds, and refuge for a vast array of marine organisms. This habitat degradation diminishes the overall productivity and resilience of the marine ecosystem, creating a negative feedback loop that further imperils the very resources the industry depends upon (Wang *et al.,* 2024).

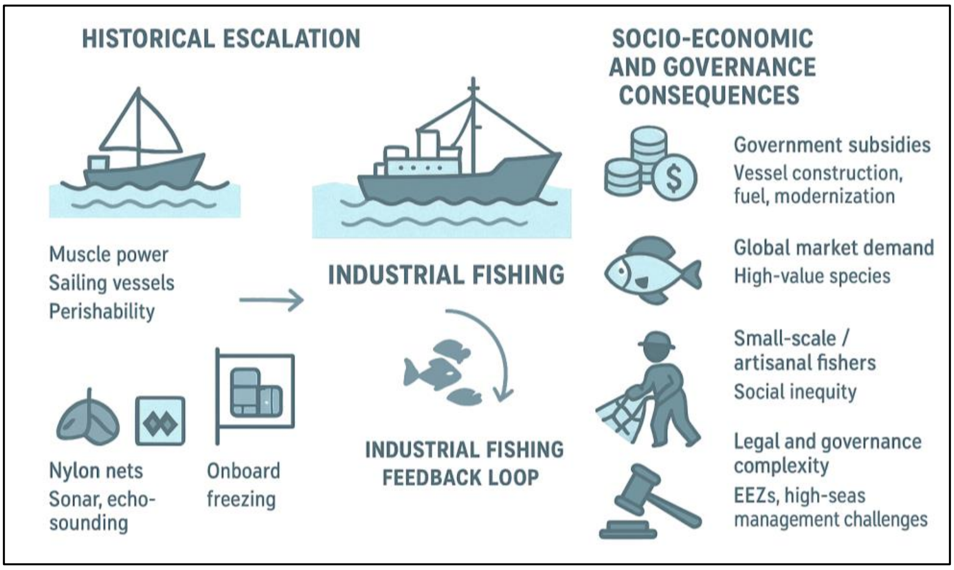

Fig. 1: The Legacy of Overexploitation: Drivers and Consequences

Ecological Foundations for Resilient Fisheries

The management of fisheries can no longer be confined to the simplistic model of single-species population dynamics (Burgess *et al.,* 2017). A resilient fishery is embedded within a complex ecological network, and its health is contingent upon the integrity of the entire ecosystem. This necessitates a foundation built on a sophisticated understanding of ecosystem structure and function. Key ecological concepts such as trophic interactions, nutrient cycling, and habitat connectivity must form the bedrock of management decisions. For instance, the selective removal of top predators through fishing can trigger trophic cascades, where the release of mesopredator populations leads to the overconsumption of herbivores and, subsequently, the decline of primary producers like seagrasses or algae, fundamentally altering the energy flow and stability of the ecosystem. Recognizing these interdependencies is paramount. The presence of biodiversity hotspots and areas of high biological productivity often serves as a critical indicator of management efficacy, signaling environments where ecological processes remain largely intact and capable of supporting sustainable harvests (Lindenmayer *et al.,* 2000).

Climate change now represents the most significant external stressor acting upon these marine systems, introducing a layer of profound uncertainty and volatility (Payne *et al.,* 2016). The relentless warming of the ocean is causing a large-scale redistribution of marine species, with many shifting poleward or into deeper, cooler waters. These range shifts are dismantling established ecological communities and creating novel species assemblages, which complicates traditional management based on static spatial boundaries and historical stock assessments. Perhaps even more insidiously, ocean acidification interferes with the fundamental biochemical processes of marine life. The lowering pH of seawater reduces the availability of carbonate ions, making it more energetically costly for organisms like corals, mollusks, and some planktonic species to build their calcium carbonate shells and skeletons. This physiological stress can lead to reduced growth, lower reproductive success, and increased mortality, weakening the overall resilience of both individual species and the ecosystems they support, making them more vulnerable to other stressors, including fishing pressure (Lowerre-Barbieri *et al.,* 2017).

In this context of rapid change, the technological capacity to monitor and predict ecosystem responses has become indispensable (Ims *et al.,* 2017). The emerging field of ecosystem-based management is increasingly reliant on sophisticated technological tools to move from a reactive to a proactive stance. Artificial intelligence and machine learning algorithms are being deployed to integrate massive, disparate datasets, from satellite imagery tracking sea surface temperature and chlorophyll levels, to acoustic data from scientific surveys, to real-time information from vessel monitoring systems. These integrated models can provide a near-real-time picture of ecosystem health, predict the likely movement of fish stocks in response to environmental cues, and identify areas of high bycatch risk. This allows for the implementation of dynamic ocean management, where fishing regulations, such as temporary area closures or gear restrictions, can be adaptively applied in response to current conditions, rather than being fixed by static, outdated rules. This technological empowerment is crucial for aligning human extraction with the natural variability of marine ecosystems, thereby reducing ecological risks and enhancing long-term sustainability (Free *et al.,* 2023).

Technological Innovations for Sustainable Management

The digital revolution is poised to transform fisheries management, offering an unprecedented toolkit for improving transparency, efficiency, and sustainability. At the forefront of this transformation is the application of artificial intelligence and advanced data analytics (Eboigbe *et al.,* 2023). AI algorithms can process complex environmental and fisheries data to create highly accurate predictive models for stock assessment, forecasting population trends under various climate and harvest scenarios. Computer vision systems are being deployed on fishing vessels and in processing plants to automatically identify species, estimate sizes, and quantify bycatch, providing verifiable data that is free from human error or misreporting. Furthermore, the rise of the Internet of Things (IoT) enables the deployment of networked sensors on gear, vessels, and even marine animals, creating a continuous stream of data on ocean conditions, fishing effort, and animal behavior, feeding into a centralized system for comprehensive ecosystem monitoring (Glaviano *et al.,* 2022).

A critical challenge in fisheries has always been the lack of transparency and traceability within complex, global supply chains. Here, blockchain technology offers a groundbreaking solution (Nisar *et al.,* 2024). By creating an immutable, decentralized digital ledger, blockchain can record every transaction in a fish's journey from vessel to consumer. Each catch can be registered with verifiable information on location, time, species, and fishing method. This record is then updated at each subsequent step, processing, export, import, retail, creating an auditable chain of custody. This not only empowers consumers to make informed choices, ensuring they are purchasing legally and sustainably caught seafood, but it also provides regulators with a powerful tool to combat illegal, unreported, and unregulated (IUU) fishing by closing markets to illicit products. When integrated with unique vessel identifiers and automatic identification systems (AIS), blockchain creates a system of accountability that was previously impossible to achieve (Ismail *et al.,* 2023).

Beyond information technologies, novel biological and engineering innovations are also emerging. Advances in molecular techniques, including environmental DNA (eDNA) sampling, allow scientists to assess biodiversity and detect the presence of rare or endangered species simply by analyzing water samples, providing a non-invasive and highly efficient method for monitoring ecosystem health (Banerjee *et al.,* 2022). In aquaculture, which plays an increasingly important role in meeting global seafood demand, technological strides in closed-containment recirculating systems, alternative feed development, and selective breeding are reducing environmental impacts and pressure on wild forage fish stocks. However, the application of more controversial technologies like gene editing for stock enhancement or disease resistance requires careful ethical consideration and robust regulatory frameworks to assess potential ecological risks and societal acceptance. The critical challenge remains ensuring that these technological advancements are accessible and adaptable to the diverse contexts of global fisheries, particularly for developing nations and small-scale fishers, to avoid a "digital divide" that exacerbates existing inequities (Lopez-Ercilla *et al.,* 2021).

Table 1: Technological Innovations for Sustainable Management

Technology Name	Application / Use Case	Benefits for Sustainability	Key Challenges or Limitations	Socio-Economic or Policy Considerations
Artificial Intelligence (AI) & Data Analytics	Predictive stock assessments, population modeling, climate impact forecasting	Enhances accuracy of stock predictions, reduces overfishing, supports adaptive management	Requires large datasets, expertise in algorithm development, potential biases	Investment in training and infrastructure; integration into national fisheries policy
Computer Vision Systems	Species identification on vessels, bycatch monitoring, automated catch recording	Reduces bycatch, ensures regulatory compliance, increases transparency in fisheries	High cost of equipment, limited performance in low-visibility conditions	Adoption may require regulatory incentives; training for fishers on technology use
Internet of Things (IoT) Sensors	Real-time monitoring of water quality, temperature, oxygen, and ecosystem parameters	Enables proactive ecosystem management, early warning for environmental stress	Sensor maintenance, data reliability, high initial investment	Policy support for environmental monitoring; potential for community-based management
Blockchain	Traceability of seafood supply chains, verification against illegal, unreported, and unregulated (IUU) fishing	Ensures supply chain transparency, builds consumer trust, reduces illegal fishing	Scalability, interoperability between platforms, technological literacy	Regulatory frameworks may be needed; encourages ethical sourcing practices
Environmental DNA (eDNA)	Biodiversity assessment, detection of rare or invasive species, habitat monitoring	Non-invasive monitoring, rapid detection of ecosystem changes	Sensitivity to environmental factors, requires specialized lab infrastructure	Policy may support eDNA as part of ecosystem monitoring programs
Advanced Aquaculture Technologies	Closed-containment systems, alternative feed formulations, selective breeding for disease resistance	Reduces environmental impacts, improves feed efficiency, supports sustainable production	High capital costs, technical expertise required, genetic diversity concerns	Incentives for sustainable aquaculture; regulatory oversight on feed and genetic selection
Gene Editing (CRISPR, etc.)	Disease resistance, growth optimization, selective breeding in aquaculture	Potential to reduce chemical treatments, improve productivity, enhance resilience	Ethical concerns, regulatory hurdles, off-target effects	Requires clear regulatory guidelines and stakeholder engagement; public acceptance is critical

Socio-Economic Frameworks and Equitable Governance

Technological and ecological solutions will inevitably fail if they are not underpinned by equitable and adaptive socio-economic frameworks. The history of fisheries management is replete with examples of well-intentioned top-down policies that foundered because they ignored local context, incentivized cheating, or marginalized the very communities most dependent on the resource (Kamoto *et al.,* 2013). The limitations of centralized, command-and-control governance have become increasingly apparent, leading to a global shift towards more collaborative and participatory models. Co-management, which shares power and responsibility between government authorities and local resource users, has emerged as a particularly effective strategy. By engaging fishers directly in the process of setting rules, monitoring compliance, and enforcing regulations, co-management fosters a sense of ownership and stewardship. This approach often leads to more practical and legitimate rules, higher rates of compliance, and the incorporation of valuable local and indigenous knowledge into the decision-making process, thereby enhancing both social and ecological outcomes (Wheeler *et al.,* 2020).

A fundamental pillar of equitable governance is the fair and transparent allocation of access rights. The tragedy of the commons persists where access is open and unregulated, leading to a competitive race to fish. Rights-based management systems, such as Individual Transferable Quotas (ITQs) or territorial use rights for fishing (TURFs), aim to address this by assigning a secure privilege to harvest a specific share of a fishery's total allowable catch or to fish in a designated area (Soliman *et al.,* 2014). When designed carefully, these systems can eliminate the race to fish, improve economic efficiency, and increase the value of the catch. However, they also carry significant social risks, including the consolidation of quota into the hands of a few large players, the dispossession of small-scale fishers, and the transformation of a public resource into a private commodity. Therefore, the design of these systems must include safeguards to protect community interests, such as limiting quota concentration, recognizing historical participation, and supporting owner-operator models to ensure that benefits flow to coastal communities (Pinkerton *et al.,* 2018).

Ultimately, the goal of these frameworks is to facilitate a transition towards a truly regenerative blue economy (Elston *et al.,* 2024). This requires a fundamental rethinking of economic value, moving beyond the gross tonnage of landed catch to account for the full spectrum of ecosystem services provided by healthy marine environments. Blue carbon financing, which values the carbon sequestration capacity of coastal wetlands like mangroves, salt marshes, and seagrasses, can generate revenue for conservation and create economic incentives for habitat restoration. Similarly, payments for ecosystem services schemes can reward fishers for sustainable practices that maintain biodiversity, water quality, and cultural heritage. Diversifying livelihoods within coastal communities is also critical for building resilience; reducing dependence on a single fishery through opportunities in sustainable aquaculture, marine ecotourism, and ocean-based renewable energy creates social safety nets that allow for more conservative and adaptive fishing practices. This holistic approach to valuation and economic development is essential for aligning human well-being with the long-term health of marine ecosystems (Hernández-Blanco *et al.,* 2022).

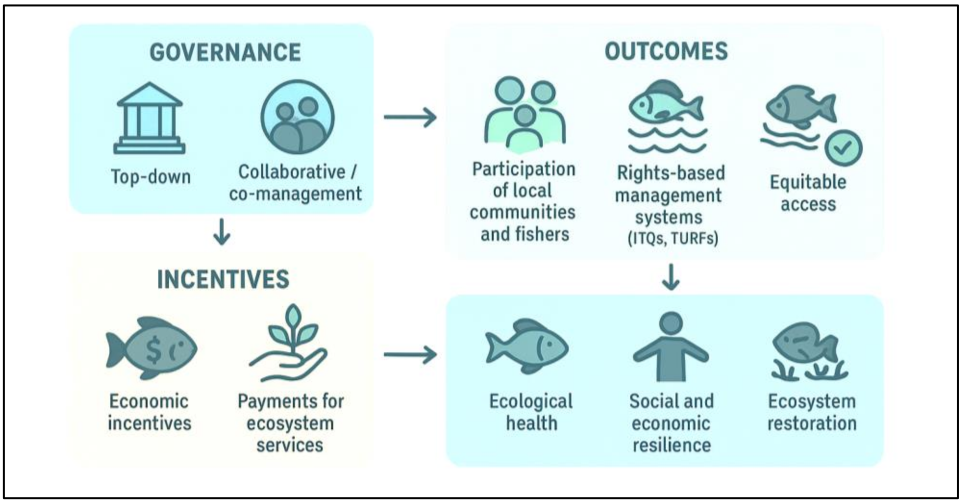

Fig. 2: Socio-Economic Frameworks and Equitable Governance

Synthesis and Pathways to Regenerative Blue Economies

The analysis presented in this review underscores a central, inescapable conclusion: the siloed approaches of the past are inadequate to address the interconnected crises facing global fisheries. Ecological health, technological capability, and socio-economic equity are not separate domains but deeply interwoven strands of a single complex system (Hariram *et al.,* 2023). A technological solution like AI-driven monitoring is only effective if the resulting data informs adaptive management decisions that are socially accepted and ecologically sound. An ecologically informed policy like a network of marine protected areas, will fail without the buy-in and stewardship of local communities whose livelihoods are affected. Therefore, the pathway to resilience demands transdisciplinary integration, where marine biologists, economists, social scientists, technologists, fishers, and policymakers collaborate to develop holistic strategies. This requires the development of new, synthesized metrics that can quantify resilience across these dimensions, measuring not just stock biomass but also distributional equity, technological accessibility, and ecosystem functionality (Lewandowski *et al.,* 2024).

Looking forward, several cutting-edge trends offer promising avenues for building this integrated resilience. The concept of digital twins, virtual, dynamic replicas of marine ecosystems, is moving from theory to practice (Chen *et al.,* 2023). These sophisticated models, powered by AI and fed by real-time data from satellites, sensors, and fishers, can simulate the responses of socio-ecological systems to different management interventions under various climate scenarios. This allows managers to conduct virtual experiments, stress-test policies, and anticipate unintended consequences before implementing them in the real world, thereby enabling truly adaptive and anticipatory governance. Furthermore, the integration of bioeconomic modeling with climate projections is becoming increasingly refined, allowing for the identification of climate-resilient stocks and the development of robust harvest strategies that can withstand environmental fluctuations and safeguard future productivity (Collie *et al.,* 2021).

The actionable pathway forward must be ambitious and multifaceted. At a policy level, long-delayed reforms, such as the ratification and rigorous implementation of the World Trade Organization agreement to curb harmful fisheries subsidies, are imperative to remove perverse incentives for overfishing (Cisneros-Montemayor *et al.,* 2022). International cooperation must be strengthened through regional fisheries management organizations empowered with better science and stronger enforcement mechanisms to manage transboundary and high-seas stocks. Investment must be strategically directed towards hybrid nature-tech solutions, such as restoring blue carbon ecosystems enhanced by drone-based monitoring, or supporting community-based co-management with digital traceability tools. Ultimately, the goal is to catalyze a transformative shift from extractive to regenerative economies. This means redefining success not by the volume of extraction but by the health of the marine capital base. It requires policies that reward stewardship, innovation that enhances sustainability, and a global ethic that values the ocean not merely as a resource pantry but as a shared, vital life-support system. The resilience of future fisheries, and the human communities that depend on them, hinges on our collective commitment to this regenerative vision (Buckton *et al.,* 2023).

Table 2: Synthesis and Pathways to Regenerative Blue Economies

Dimension	Key Strategies / Approaches	Mechanism of Action	Benefits / Outcomes	Innovative Trends / Tools
Ecological	Marine Protected Areas (MPAs)	Protect critical habitats, replenish fish stocks, preserve biodiversity	Increased stock resilience, restored ecosystems, enhanced ecosystem services	Spatial modeling, remote sensing, biodiversity monitoring platforms
Ecological	Ecosystem-Based Fisheries Management (EBFM)	Integrates multispecies interactions and habitat considerations into management	Sustainable harvesting, balanced trophic structures, ecosystem stability	Ecological network modeling, simulation platforms for trophic interactions
Ecological	Habitat Restoration & Reef Rehabilitation	Restores degraded habitats to support spawning and juvenile survival	Enhanced recruitment, resilience to climate change, carbon sequestration	Underwater drones, GIS mapping, habitat suitability models
Technological	AI-Driven Monitoring & Surveillance	Real-time data collection on fish stocks, illegal fishing, and environmental parameters	Adaptive management, reduced overfishing, timely interventions	Machine learning algorithms, IoT sensors, satellite-based monitoring
Technological	Digital Twins for Fisheries	Virtual simulation of fisheries dynamics integrating ecological and socio-economic data	Predictive management, scenario testing, risk assessment	High-resolution modeling platforms, integrated databases
Technological	Bioeconomic Modeling	Combines biological data with economic incentives to optimize harvest strategies	Balances conservation with profitability, informs policy	Dynamic simulation tools, decision-support systems, agent-based modeling
Socio-Economic	Co-Management Systems	Collaborative governance involving fishers, communities, and authorities	Increased compliance, equitable access, localized knowledge integration	Participatory GIS, community dashboards, mobile reporting apps
Socio-Economic	Market-Based Incentives (Eco-labeling, MSC Certification)	Rewards sustainable practices through premium markets	Promotes responsible fishing, consumer awareness, economic resilience	Blockchain for traceability, supply chain analytics
Socio-Economic	Community-Based Adaptation & Capacity Building	Engages local stakeholders in	Social equity, enhanced local	Online training platforms, knowledge exchange networks

Dimension	Key Strategies / Approaches	Mechanism of Action	Benefits / Outcomes	Innovative Trends / Tools
		adaptive practices and resilience planning	governance, adaptive capacity	
Ecological & Technological	Real-Time Ecosystem Monitoring	Integrates sensor data, remote sensing, and AI to track ecosystem health	Early detection of stressors, adaptive intervention, ecosystem resilience	Integrated sensor networks, cloud analytics, AI prediction models
Ecological & Socio-Economic	Adaptive Marine Spatial Planning	Zoning strategies considering ecological importance and community needs	Conflict reduction, sustainable resource allocation, resilience	GIS tools, scenario modeling, participatory mapping platforms
Technological & Socio-Economic	Decision Support Systems for Policy	Combines ecological, economic, and social data to inform management	Evidence-based policy, optimized harvests, reduced conflict	Multi-criteria decision analysis, AI-driven simulations, dashboards
Ecological, Technological & Socio-Economic	Transdisciplinary Adaptive Management	Integrates science, technology, and stakeholder inputs iteratively	Continuous learning, system resilience, holistic sustainability	Digital platforms for data integration, AI for adaptive scenarios, participatory tools
Ecological	Climate-Resilient Stock Management	Adjusts quotas and species selection based on climate projections	Maintains sustainable yields under changing conditions	Climate modeling, oceanographic forecasting tools
Technological	Predictive Analytics for Stock Recovery	Uses historical and real-time data to forecast population trends	Optimized harvests, proactive conservation, reduced collapse risk	Big data analytics, machine learning, predictive dashboards
Socio-Economic	Livelihood Diversification Programs	Supports alternative income sources for fishers	Reduces dependency on vulnerable stocks, improves social resilience	Microfinance platforms, skill-building apps, market intelligence tools
Ecological & Technological	Integrated Ocean Observing Systems	Combines biological, chemical, and physical data for comprehensive monitoring	Holistic understanding, anticipatory management, ecosystem protection	Satellite sensors, AI integration, cloud-based analytics
Ecological & Socio-Economic	Participatory Conservation Planning	Engages communities in mapping priorities, enforcement, and monitoring	Social buy-in, improved compliance, co-benefits for livelihoods	Mobile apps, community GIS, citizen science platforms
Technological & Socio-Economic	AI-Based Simulations for Policy Testing	Simulates social and economic impacts of management interventions	Evidence-based decisions, scenario planning, and reduced conflicts	Multi-agent simulations, real-time dashboards, predictive modeling
Ecological, Technological & Socio-Economic	Regenerative Blue Economy Integration	Combines conservation, technology, and inclusive governance for holistic sustainability	Long-term resilience, equitable benefits, ecosystem regeneration	Digital twins, AI-informed adaptive management, participatory platforms

CONCLUSION

This review has charted the complex trajectory from the historical overexploitation of global fisheries to the emergent paradigm of socio-ecological resilience. The core finding is that overcoming the legacy of depletion and navigating contemporary challenges like climate change requires a fundamental integration of ecological understanding, technological innovation, and socio-economic equity. Success hinges on moving beyond single-species, top-down management towards adaptive, ecosystem-based strategies that are co-developed with resource users. While technologies like

AI and blockchain offer powerful tools for monitoring and transparency, they are not silver bullets; their efficacy is entirely dependent on the governance frameworks and equitable economic systems within which they are embedded. The ultimate limitation remains the political will and institutional capacity to implement these integrated approaches at a meaningful scale. Future perspectives must focus on transdisciplinary research to operationalize resilience metrics, alongside bold policy actions that eliminate harmful subsidies, protect rights, and incentivize restoration. The future pathway is clear: a transition towards regenerative blue economies that actively restore marine ecosystem health while securing equitable benefits for society, ensuring the ocean's bounty can endure for generations to come.

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