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Climate Change and the Future of Coastal Fisheries: Ecological Shifts, Geopolitical Implications, and Pathways to Sustainable Development

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Abstract

Climate change is reshaping the world's coastal and marine ecosystems, posing complex challenges for ecological stability, food security, and maritime governance. This review synthesizes current knowledge on the ecological, social, and geopolitical dimensions of climate change impacts on coastal fisheries. Ecologically, ocean warming, sea-level rise, and habitat degradation—particularly in mangrove, seagrass bed and coral reef systems—are driving shifts in species distribution and altering ecosystem productivity. These biophysical changes cascade into socio-economic and geopolitical tensions as fish stocks migrate across national boundaries, challenging existing governance regimes and creating new arenas for negotiation and conflict. Drawing upon interdisciplinary literature from marine ecology, political geography, and sustainable development studies, this paper critically examines how ecological transformations intersect with economic dependency and regional power dynamics in coastal states. It further identifies gaps in current adaptation frameworks, highlighting the need for integrated, science-based, and inclusive policy responses that link local resilience with global cooperation. The review concludes by proposing pathways toward sustainable coastal fisheries grounded in ecosystem-based management, maritime diplomacy, and equitable blue economy strategies. By bridging ecological evidence and governance innovation, this study contributes a holistic perspective on how coastal fisheries can adapt to a rapidly changing climate while maintaining ecological integrity and social justice.

Keywords: Climate change; Ecological shifts; Blue economy; Maritime governance; Sustainable development

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INTRODUCTION

Climate change has become one of the most significant drivers of environmental transformation in marine and coastal regions worldwide. Rising sea surface temperatures (SST), ocean acidification, altered storm regimes, and accelerating sea-level rise are reshaping the physical and ecological foundations that support marine life. These changes are occurring simultaneously with growing anthropogenic pressures, creating complex and multilayered challenges for marine ecosystems and the coastal communities that depend on them. Marine ecosystems — including coral reefs, mangroves, seagrass beds, and other vegetated coastal habitats — are naturally slow-growing systems whose structural and functional integrity has developed over centuries to millennia. For instance, reef-building corals grow only around 3–20 mm per year, meaning that expansive reef structures represent "a thousands years work" of biological accretion [1,2]. Such slow growth rates illustrate how vulnerable these ecosystems are when faced with rapid climatic disturbances.

These habitats are also biodiversity hotspots and foundational ecological infrastructures. Coral reefs alone support more than 4,000 species of reef fish, or about 25% of all recorded marine fish species, alongside tens of thousands of associated marine organisms [3]. Mangroves and seagrass beds similarly provide food, nursery grounds, and protection for a wide array of marine fauna. Their interconnectedness forms complex trophic networks and productivity pathways that underpin coastal fisheries. Any disruption to these habitats therefore reverberates outward, affecting recruitment success, species composition, and the stability of entire marine communities.

However, the accelerating pace of climate-driven stressors threatens the resilience of these systems. Numerous coral species have shown declining population trends due to their low growth rates and restricted geographic distributions, with species such as Acropora suharsonoi and Tubastraea floreana already listed as endangered [4,5]. Warming seas and escalating acidification further undermine calcification processes essential for reef formation. As a result, an estimated 32.8% of global coral species are considered threatened and face potential extinction [6]. Mangroves and seagrasses face comparable vulnerabilities: projections suggest that mangrove forests could disappear entirely by 2050 if greenhouse gas emissions and associated climate impacts continue unabated [7]. Thus, climate change decline ecological stability, productivity and services.

The fisheries sector, as one of the key components of marine productivity, is heavily threatened by the climate crisis. Demand for fish resources has increased rapidly at the same time that natural fish stocks are declining. Marine capture fisheries currently contribute more than 80% of the world's fish supply [8], yet around 50–70% of global fish stocks have already been overfished [9,10]. Climate change intensifies this depletion by degrading habitats, altering water quality, and increasing the frequency of bleaching events. These stressors have collectively reduced global fish production, affecting billion people relying on fish as their primary source of animal protein. Thus, the combined pressures of overfishing and climate change pose a severe threat to global food security.

Despite a growing body of research on climate impacts, many studies remain siloed within ecological, biological, or physical domains. Yet the complexities of climate–ecosystem interactions demand an integrative perspective. The responses of coastal habitats, the reproductive cycles of fish and invertebrates, and the broader shifts in marine ecosystems are deeply intertwined. Likewise, the socio-economic and geopolitical ramifications of

ecosystem change—including transboundary fisheries conflicts, resource scarcity, and food insecurity—require analysis that bridges natural and social sciences.

This review seeks to address these gaps by synthesizing knowledge across multiple levels of ecological organization while linking them to broader policy and sustainability agendas. Specifically, this paper aims to: (1) summarize the major ecological impacts of climate change on coastal habitats, species' reproductive dynamics, and marine ecosystem functioning; (2) examine the social, economic, and geopolitical implications arising from these ecological shifts; and (3) outline pathways toward sustainable development that integrate ecological resilience with food security, resource governance, and long-term human well-being. Through a cross-disciplinary approach, this analysis positions climate change not only as an ecological issue but as a challenge that intersects with political, social, and developmental dimensions. By integrating insights across these fields, the review underscores how climate impacts reverberate beyond natural systems and demand holistic, multi-sectoral responses.

METHODS

This research employed a qualitative approach with a literature review method. This method was chosen to gain an in-depth understanding of the phenomenon under study. Data were collected from academic sources such as journal articles, books, research reports, and official documents. Literature was selected based on relevance, credibility, and suitability to the research objectives. Each source was analyzed to identify key concepts and significant findings. The analysis was conducted through a thematic review to identify patterns and relationships between ideas. The results were then synthesized to build a comprehensive understanding of the research topic. Through this approach, the research produced structured interpretations based on scientific evidence [11].

COASTAL HABITAT VULNERABILITY UNDER SEA-LEVEL RISE AND CLIMATE CHANGE

Physical Stressors and Regional Patterns of Sea-Level Rise

Coastal ecosystems are increasingly exposed to accelerating climatic stressors, with sea-level rise (SLR) emerging as one of the most disruptive long-term drivers of ecological change. Although sea levels fluctuated naturally due to geological processes—such as post-glacial rebound during warm periods 15 million years ago [12]—modern trends show a marked acceleration. Whereas past fluctuations remained around 0.1–0.2 mm/year [13-15], the global mean sea level has increased by 1.56 mm/year since the early 1900s and has nearly doubled in the last two decades [16,17]. This shift is widely recognized as a direct consequence of anthropogenic warming and melting land-based ice at unprecedented rates. This acceleration corroborates earlier findings that the persistence of global sea level is tightly linked to the stability of the Earth's ice sheets [18] (Figure 1).

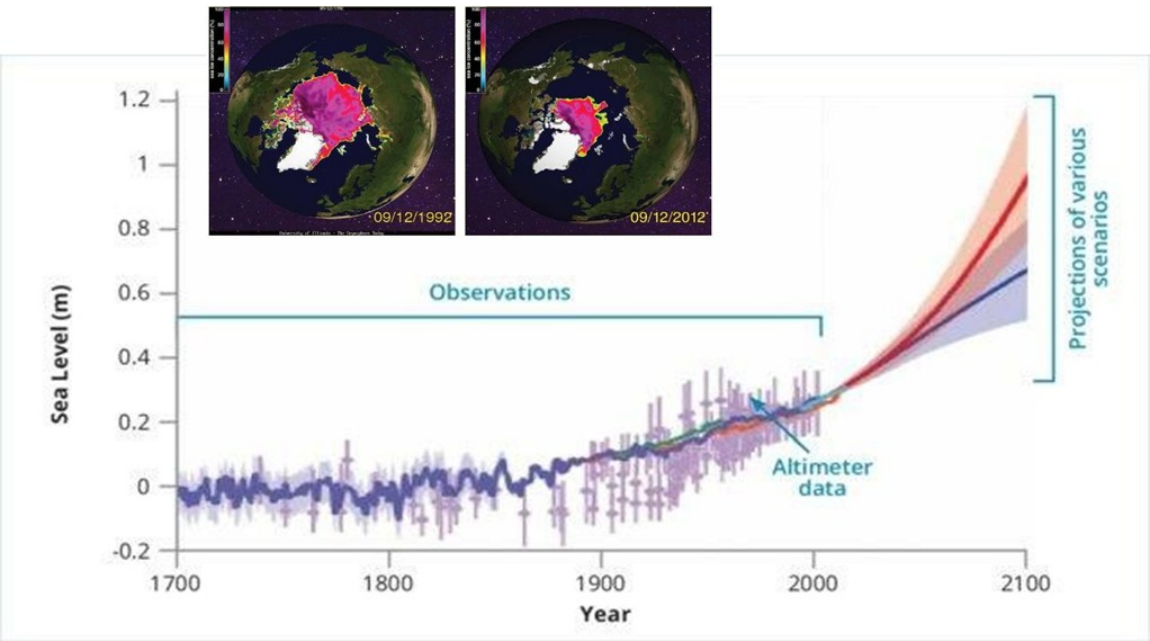

Figure 1. Projected sea-level rise derived from paleo–sea level records (purple), tide-gauge measurements (blue, red, green), and satellite altimetry (light blue). Inset satellite images from mid-September 1992 and 2012 illustrate the marked decline in sea ice (red-purple), consistent with rising SST and SLR (adapted from Davis-Reddy & Vincent [19] and Walsh [20]).

Importantly, SLR occurs unevenly across regions. Model simulations project that equatorial Pacific regions will experience higher-than-average sea-level rise by 2100 due to gravitational and oceanographic redistribution, while polar regions may encounter comparatively smaller increases [21]. These spatial disparities are critical because tropical shallow-water coasts host high diversity and coverage of mangroves, seagrass meadows, reefs, and estuarine systems—which among the most productive coastal nursery habitats on the planet (Figure 2).

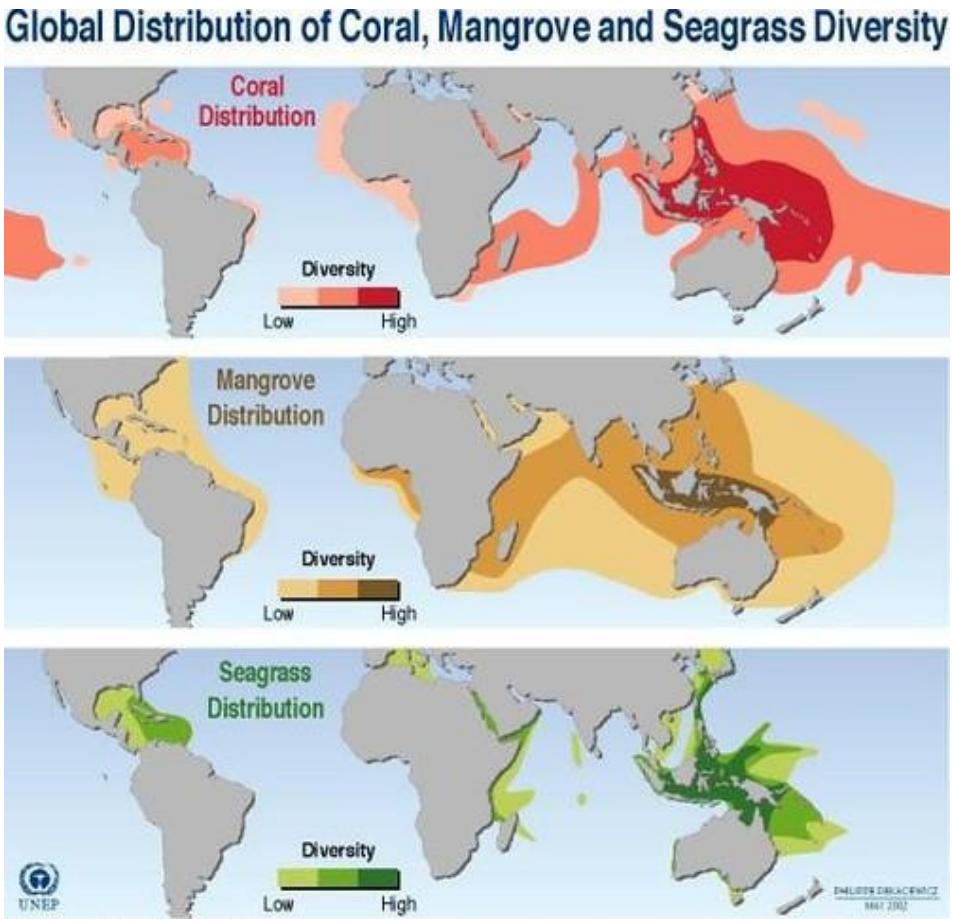

Figure 2. Coral reefs, mangroves, and seagrass habitats exhibit distinct levels of diversity and spatial distribution across the globe. Notably, the tropical Indo-Pacific region harbors the greatest diversity and the highest abundance of all three habitats compared to other marine regions [3].

Ecological and Socioeconomic Consequences for Coastal Nurseries

Mangroves are particularly vulnerable to rapid SLR. Although they possess adaptive mechanisms such as sediment trapping, vertical accretion, and landward migration, these processes cannot keep pace when sea-level rise exceeds sediment accumulation rates or when inland migration is obstructed by infrastructure. This phenomenon called 'mangrove forest shrinking and squeezed' (Figure 3). Under high-emission scenarios, global mangrove cover may collapse entirely by 2050 [7], with profound consequences for biodiversity, carbon storage, and fisheries.

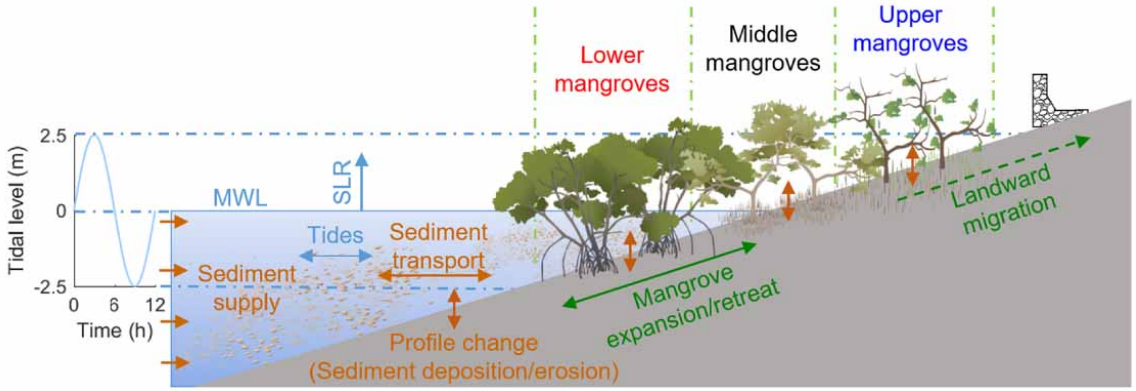

Figure 3. A schematic representation of the bio-morphodynamic model showing interactions between multi-species mangroves across lower–upper intertidal zones, hydro-sedimentary processes, and coastal profile change. MWL (Modulated Wave Level) and SLR (Sea Level Rise) indicate mean

water level and rising sea level. Increasing SLR forces mangroves to retreat inland, reducing forest extent, while inland physical barriers restrict this movement and create a coastal squeeze. [22].

Climate change driven the degradation of mangrove forests, which has cascading effects on adjacent seagrass beds, reefs and estuarine systems. Seagrass meadows are sensitive to turbidity, thermal anomalies, and sediment disturbance—factors exacerbated by SLR—while estuarine ecosystems depend on stable salinity gradients that are increasingly disrupted by saltwater intrusion. As these habitats degrade, their capacity to serve as nurseries for juvenile fish and invertebrates declines sharply. SLR also alters the bathymetric distribution of coral reefs, as deeper hermatypic corals may disappear with rising sea levels, while simultaneously, elevated sea temperatures threaten coral survival living in shallow water (Figure 4).

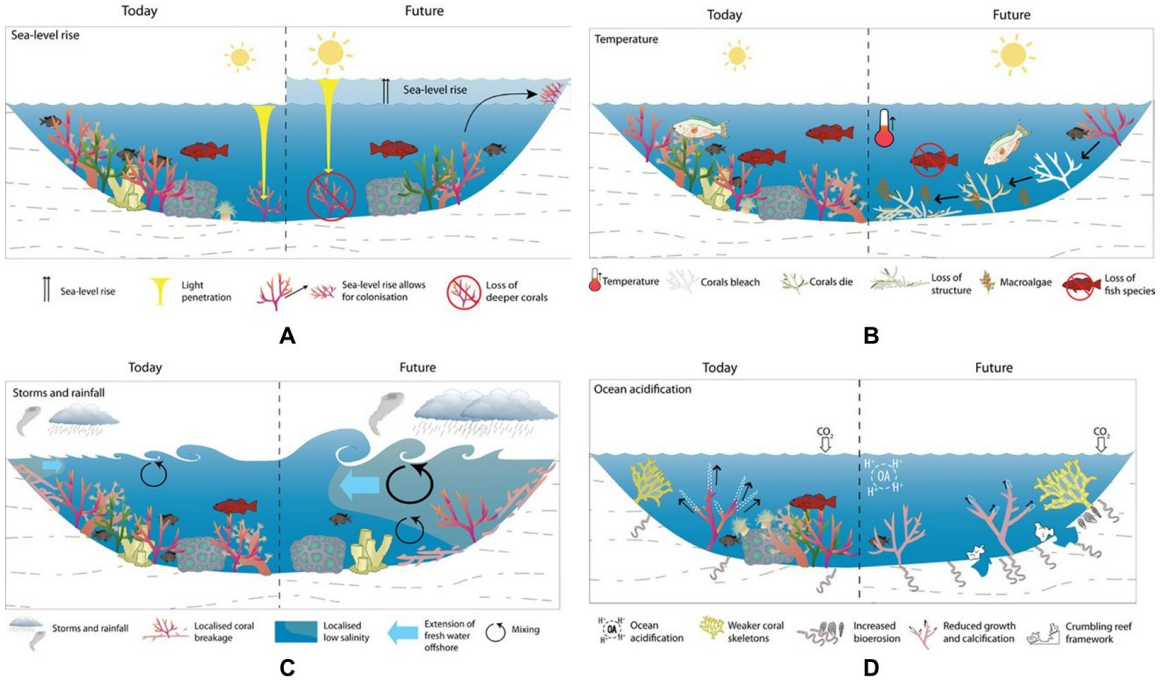

Figure 4. The effects of projected A) SLR, B) SST increase, C) storms and heavy rainfall, and D) ocean acidification on coral reef ecosystems (adapted from Hoegh-Guldberg et al. [23]).

Such habitat loss directly undermines global fisheries. Around 80% of the world's fish supply originates from marine capture [8], yet 50–70% of wild stocks are already overfished [9,10]. Climate-induced habitat degradation compounds this vulnerability, contributing to the estimated 60% decline in global fish production since 1950 [24]. For the 3.3 billion people who depend on fish as their primary source of animal protein [25], declining nursery habitat quality poses an escalating food security challenge.

Regional Ecological Resilience and Adaptation Limitations

Regional variations in ecological resilience further intensify climate-driven pressures across coral reef, mangrove, seagrass, and estuarine systems. In mangrove habitats, some coastlines still retain sufficient sediment supply and undeveloped inland zones that permit natural landward migration, while others are restricted by seawalls, dense settlements, and coastal industry. Where such adaptive space is absent, long-term mangrove decline becomes unavoidable—an outcome aligned with projections that global mangrove forests may collapse under rapidly rising sea levels [7].

Similar spatial disparities occur on coral reefs, where warming-induced bleaching, deoxygenation, and acidification fundamentally alter ecosystem resilience. Reef-building corals bleach after only a 1–2°C temperature anomaly [3], while acute deoxygenation events have caused mass mortality and persistent shifts in benthic community composition [26]. Ocean acidification further suppresses coral calcification by reducing carbonate ion availability, diminishing growth rates in multiple coral species [27].

Seagrass beds and estuarine systems exhibit parallel vulnerabilities: elevated seawater temperature, altered salinity, and greater turbidity disrupt photosynthesis, reproduction, and species distribution [28]. These coupled pressures reveal that climate impacts do not operate in isolation; rather, they propagate across adjacent coastal ecosystems, amplifying ecological instability and reducing the capacity of each habitat type to buffer environmental change..

Natural adaptation mechanisms may mitigate impacts in areas with ample sediment load or low development pressure. However, these mechanisms are often insufficient under rapid, accelerating climate pressure [16,17]. Human alterations to watersheds and atmospheric gasses composition further weaken ecological resilience. These antropogenic factors become more severe when combined with additional climate-driven stressors—most prominently global ocean warming and acidification. The simultaneous pressures of SLR, warming, and acidification therefore produce compounded ecological constraints, overwhelming natural adjustment processes and accelerating habitat degradation across global coastlines.

Addressing this growing vulnerability demands not only ecological restoration but also integrated coastal zone planning, protection of migration corridors, and governance systems capable of supporting long-term ecosystem resilience. The degradation of nursery habitats also disrupts the reproductive timing and migratory behavior of numerous fish and invertebrate species, reducing recruitment and intensifying fishery decline.

BIOLOGICAL RESPONSES: ALTERED BREEDING CYCLES AND MIGRATORY PATTERNS

Climate Cues and the Disruption of Reproductive Rhythms

Reproductive cycles in marine biota are regulated by finely tuned environmental cues, including seasonal changes in seawater temperature, photoperiod, salinity gradients, and coastal current patterns. These factors orchestrate gonadal maturation, spawning migrations, life cycle and the timing of larval release to ensure that offspring encounter optimal feeding and nursery conditions (see example in Figure 5). Under ongoing climate change, these cues have become increasingly unreliable. Rising sea temperatures, unpredictable thermal anomalies, and shifts in hydrodynamics distort the physiological triggers that once synchronized reproduction across populations. The problem is further compounded by intense global dependence on wild-caught fisheries; marine capture fisheries still provide more than 80% of the global fish supply [8], and many regions already experience severe stock depletion, with an estimated 50–70% of global fisheries classified as overfished [9,10]. When environmental cues destabilize reproduction while stocks remain heavily exploited, populations face simultaneous ecological and demographic stress.

Figure 5. Examples of life-cycle disruptions in marine organisms driven by anthropogenic stressors and climate change: A) dry-spawning in polychaetes, and B) mass coral bleaching [29,30].

Phenological Shifts and Reproductive Mismatch

One of the most widespread biological consequences of warming oceans is the emergence of phenological mismatches, in which the timing of spawning no longer aligns with seasonal peaks in food availability or with the developmental requirements of larvae. Even relatively small increases in temperature can accelerate metabolic processes, causing earlier spawning or extended reproductive windows. However, these shifts often become maladaptive when plankton blooms—critical for larval feeding—do not change accordingly. Altered current regimes disrupt larval drift routes, resulting in larvae being transported away from highly productive coastal areas into nutrient-poor offshore waters. Additional climate-driven disturbances, such as harmful algal blooms, declining water quality, and severe coral bleaching, further reduce larval survival [31,32]. The cumulative effect of these stressors contributes to the documented decline in global fish production, which has fallen by approximately 60% since the mid-20th century [24]. The biological mechanisms underpinning this decline increasingly point to reproductive misalignment rather than harvesting pressure alone.

Species-Specific Vulnerabilities on Major Commercial Fishery Products: Tuna, Mackerel, and Blue Swimming Crabs

Different species exhibit distinct vulnerabilities depending on their ecological niches and physiological thresholds. Migratory pelagic species such as tuna and mackerel depend on narrow thermal windows to initiate long-distance reproductive migrations. As sea-surface temperatures rise, these windows shift poleward, displacing spawning grounds into unfamiliar regions. Such displacement disrupts larval settlement patterns that historically connected spawning sites to coastal nurseries [33-35]. For crustaceans, the blue swimming crab exemplifies another climate-sensitive group. Its embryonic development and larval survival are highly responsive to temperature [36] and salinity conditions [37]. Climate-induced acidification, stimulated algal blooms, and warming-driven changes in water chemistry weaken reproductive output by reducing hatch success and juvenile fitness. Where populations are already heavily exploited for global seafood markets, these climate-driven reproductive stresses amplify the risk of rapid stock decline and long-term resource shortages (Figure 6).

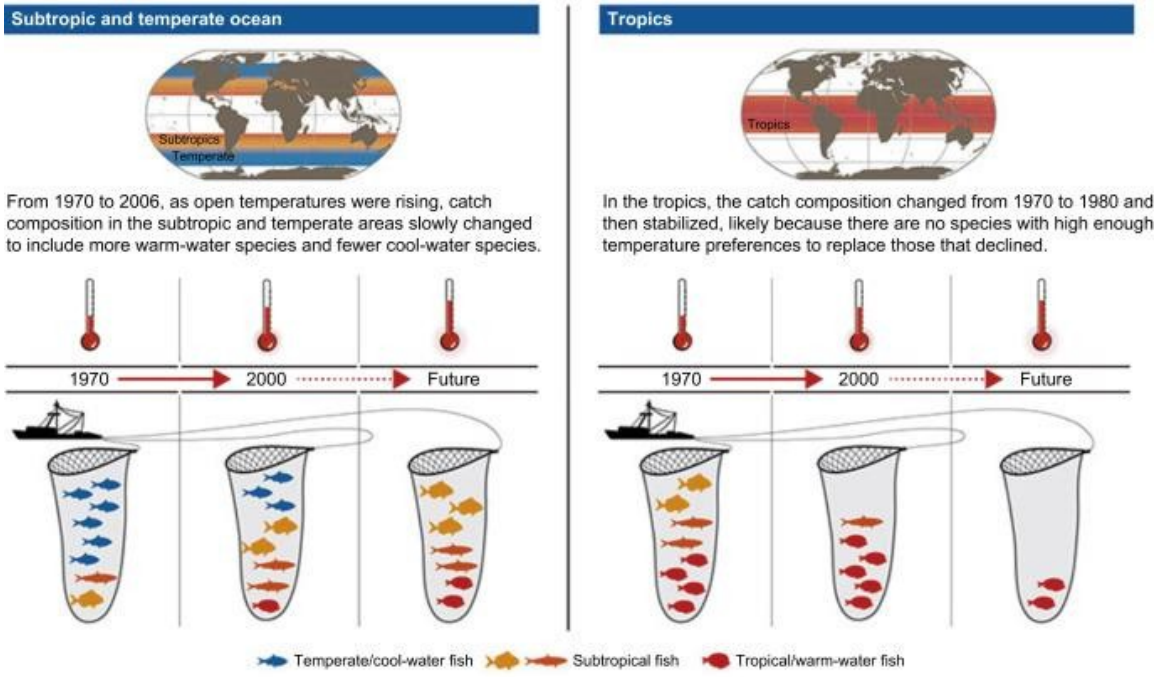

Figure 6. Rising ocean temperatures are transforming global fisheries. Many tropical species are shifting poleward, altering regional catch compositions and reducing yields in several equatorial areas. Projections indicate that these redistributions will continue throughout the century (PEW Oceans, 2020).

Habitat Collapse and the Erosion of Nursery Functions

Successful reproduction relies not only on spawning success but also on the availability of secure nursery habitats for juveniles. Many of these habitats—including mangrove forests, seagrass meadows, estuarine channels, and shallow coastal reefs—are degrading rapidly. Climate change accelerates sedimentation, turbidity, thermal stress, and hypoxia in these areas, reducing their capacity to support early life stages. Coral reef ecosystems, which serve as critical recruitment sites for thousands of species, have suffered widespread bleaching and mortality. Habitat destruction also stems from acidification and recurrent algal blooms, which destabilize local food webs and reduce juvenile refuge availability [31,32,38]. Without these protective environments, juveniles face increased predation, lower feeding efficiency, and reduced growth, weakening population replenishment. Ecological declines in nursery systems thus operate synergistically with disruptions in reproductive timing, creating a multi-level constraint on recruitment.

Shifts in Spawning Grounds and Larval Dispersal Pathways

Environmental changes also alter the geographic configuration of spawning grounds and larval dispersal patterns. Variability in ocean currents influences larval transport distances, depth distributions, and retention within coastal systems. When current velocity increases or changes direction, larvae may be swept offshore, beyond continental shelves, or into unsuitable thermal environments. Increased salinity intrusion—driven by sea-level rise and reduced freshwater input—can inhibit egg viability and interfere with chemical cues essential for larval orientation. In estuarine species, such interruption of salinity gradients can destabilize long-established spawning corridors. Global increases in sea temperature also force spawning grounds to shift poleward, introducing populations into unfamiliar regions (Figure 6). Numerous studies have already documented this phenomenon, and

projections indicate that it will continue (see Jansen & Gislason [33], Vaihola & Kininmonth [34], Afriana [35]). Over time, these altered dispersal dynamics weaken population connectivity across regions, disrupt metapopulation structure, and increase the likelihood of local population collapse even when adult biomass appears stable.

MARINE ECOSYSTEM SHIFTS AND FUNCTIONAL CONSEQUENCES

Consequences for Recruitment and Fisheries Yields

The combined effects of altered reproductive cues, phenological mismatch, habitat degradation, and disrupted dispersal contribute to widespread declines in juvenile recruitment, the key demographic process that replenishes fisheries. Recruitment collapse reduces fishery yields and destabilizes multi-species food webs. The magnitude of these declines is particularly concerning given current exploitation pressures. With 50–70% of global fish stocks classified as overfished [9,10], populations have little buffer against climate-induced reproductive failure. Projected shortages threaten global food security, especially for billions of people who depend heavily on fisheries product [25]. In many coastal regions, compromised recruitment has already resulted in lower catch-per-unit-effort, altered species composition, and increased dependence on lower-value or opportunistic species.

Human Responses and Local Adaptations

Faced with rapidly shifting biological rhythms, some fishing communities and management agencies have begun experimenting with adaptive strategies. These include adjusting fishing seasons to reflect changing spawning periods, applying dynamic closures based on real-time environmental data, and modifying gear to reduce pressure on vulnerable life stages. Observations in many fisheries show delayed or failed spawning events, altered migration timing for both fish and crustaceans, and unpredictable juvenile pulses [30,39]. While these localized adaptations offer short-term resilience, they remain insufficient without broader ecological stabilization. Effective management requires aligning fisheries policies with the new biological realities imposed by climate change while simultaneously restoring degraded nursery habitats. These emerging responses represent only a fraction of the broader adjustments occurring across climate-impacted marine ecosystems, as summarized in Table 1.

Table 1. Summary of climate-driven marine ecosystem shifts, functional consequences, and human responses to the issue

Ecosystem / Biological Component	Primary Climate Stressor(s)	Major Shift / Ecological Impact	Functional Consequences	Key Human Responses / Adaptations
Mangrove Forests	SLR; sediment loss; warming; coastal squeezing	Inland retreat; forest contraction; impaired regeneration	Nursery habitat decline; reduced juvenile recruitment; loss of coastal protection	Landward corridor protection; sediment restoration; managed retreat; mangrove rehabilitation
Coral Reefs	SST warming; acidification; SLR depth change; storms	Mass bleaching; reduced calcification; structural degradation	Collapse of reef-dependent fisheries; poor larval settlement; reduced carbonate production	Thermal-tolerant coral restoration; MPAs; water-quality control; dynamic reef monitoring
Seagrass Meadows	Warming; turbidity; sedimentation; SLR light limitation	Meadow loss; reduced productivity	Nursery function decline; carbon-sink reduction	Watershed management; seagrass restoration; limits on coastal development
Estuarine / Nursery Systems	Salinity fluctuation; hypoxia; habitat loss	Degraded nursery areas; higher larval mortality	Disrupted trophic links; reduced early-life survival	Estuary rehabilitation; pollution/runoff reduction; seasonal closures
Fish Reproductive Cycles	SST anomalies; current shifts; photoperiod mismatch	Altered spawning timing; failed spawning events	Recruitment failure; phenological mismatch with prey	Adaptive fishing seasons; reproductive monitoring
Migratory Pelagic Fish	SST rise; prey-field shifts; thermocline change	Poleward range shifts; altered migration routes	Regional productivity declines; displaced fisheries	Dynamic ocean management; mobile fleet operations
Planktonic Systems	Stratification; warming; acidification	Shifts in bloom timing; dominance of smaller taxa	Larval food mismatch; weakened energy transfer	Plankton phenology monitoring; adaptive quotas
Benthic Invertebrates	Warming; hypoxia; sediment	Failed spawning; distribution	Lower benthic biomass;	Hatchery enhancement; adjusted

change	changes	reduced demersal yields	harvest schedules

GEOPOLITICAL AND SOCIOECONOMIC IMPLICATIONS

The impact of climate change is not just an ecological issue, but also a cross-border geopolitical and socio-economic problem. One of the impacts of climate change is the shifting distribution of fish populations across national borders, which has the potential to cause fisheries conflicts. Climate change and temperature affect fish population distribution patterns. Changing temperature, currents, and habitat conditions are driving many fish species to move to cooler or deeper waters. The goal is to survive amidst fluctuating environmental conditions. This shift in the distribution pattern of fish populations has not only ecological impacts but also social, economic, and political consequences. The phenomenon of shifting distribution patterns causes changes in the availability of fish resources. A country that once had an abundant supply of fish can now lose its catch. Meanwhile, a country that previously had a limited supply of fish can suddenly experience an abundance. This phenomenon causes socio-economic instability and potential fishing conflicts in certain regions [40,41].

The stability of the marine ecosystem affects geopolitical stability. Shifts in the distribution of marine resource populations can lead to interstate conflict in a region. This is because the movement of marine resources is not limited to the EEZ (Exclusive Economic Zone). Human activities in the waters, on the other hand, must adhere to these political boundaries. However, the movement of marine resource populations has the potential to eliminate a country's access, rights, and fishing quotas, as these populations are already located within the EEZ of another country. Significant impacts will be felt by countries that are highly dependent on the availability of marine resources as a major commodity, such as small island nations (Figure 7). When this happens, territorial claims and overlapping fishing rights are also unavoidable [42,43].

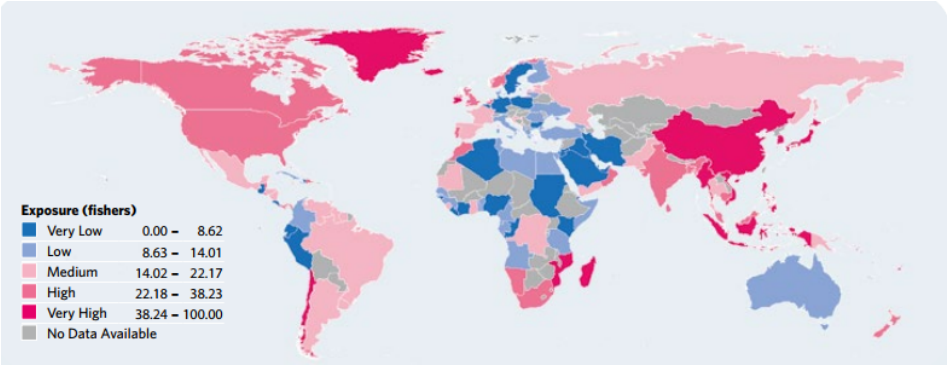

Figure 7. Global distribution of fisher's exposure level. Countries are categorized by five different exposure classes, from very low (dark blue) to very high (dark red). These five different classes are indicating the extent to which fishers in each country are vulnerable to the environmental and socio-economic risk. Meanwhile, the grey areas indicate missing data [40].

One example is the migration of crabs and tuna to cooler regions in the north due to changes in habitat conditions. According to NOAA (National Oceanic and Atmospheric Administration), the snow crab population in the eastern Bering Sea region is highly vulnerable to climate change. They are highly dependent on the cold habitat under the sea ice cover. The phenomenon of decreasing ice cover over the past two decades is affecting the distribution patterns of snow crab populations. NOAA stated that crab and fish species will shift northward by 50-200 km by the end of this century due to global warming. The snow

crab population that previously inhabited the United States territory of Alaska is now migrating to colder northern regions of Russia. The crab stock that was once a resource for the United States is now in fishing grounds closer to Russia [44-46].

Neither the EEZ nor UNCLOS (United Nations Convention on the Law of the Sea) 1982 contains regulations regarding the cross-border transfer of resources. While marine resources can move geographically, they are not limited by political boundaries. However, their displacement can cause a country to feel disadvantaged due to the loss of livelihood. This makes quota agreements and fishing permits irrelevant. Russian fishermen can claim fishing rights over crab populations that have migrated to their waters, while US fishermen will protest because it seems unfair for them to lose these marine resources. This has the potential to cause socio-economic instability, geopolitical tensions, and make the Arctic a new zone of interstate conflict [47-49].

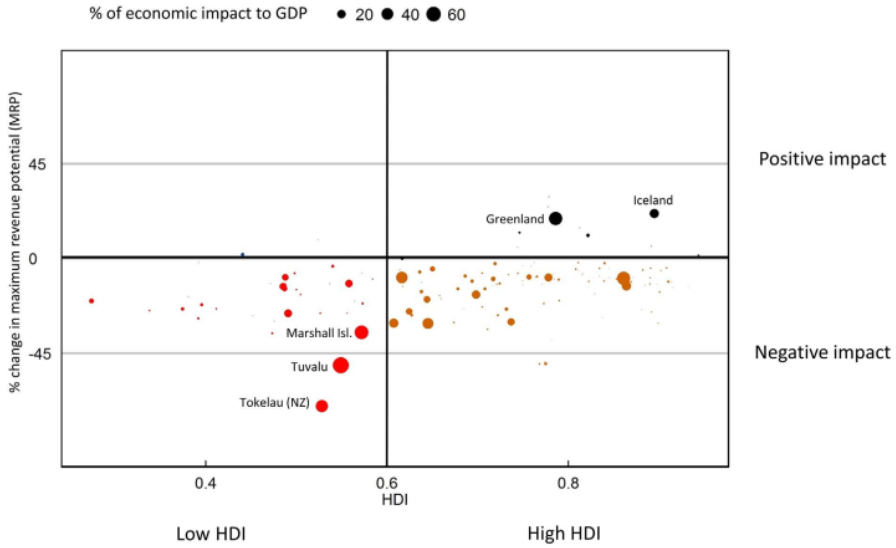

Figure 8. Percentage change in MRP (Maximum Revenue Potential) due to climate change which mapped against countries' HDI (Human Development Index). The larger circle shows greater fisheries sector's contribution to the countries' GDP (Gross Domestic Product) [50].

Socio-economic instability can be felt by coastal communities in a country experiencing a loss of marine resources. This affects food security and the coastal economy. Changes in the distribution patterns of fish and marine crustaceans can cause a country's coastal communities to lose their main fish stocks. Stock loss means a potential decrease in the catch of coastal communities, which could lead to a decline in fishermen's incomes. Meanwhile, a decrease in catch could cause a reduction in the domestic supply of fish and marine crustaceans. When supply decreases and demand remain the same, the price of marine resources will increase. The price increase could make it difficult for low- and middle-income people to access marine resources. Reduced fish supply could also indirectly affect the stability of the fish processing industry and employment conditions. The potential for importing marine resources can also increase due to domestic demand that cannot be met. For countries heavily reliant on marine resources, the impact will be felt across the national economy as a whole. As shown in Figure 8, the most vulnerable countries are those with lower HDI and heavily reliant to the fisheries sector, such as Tokelau, Marshall Island, and Tuvalu. These small countries' GDP are negatively impacted by the climate change. Meanwhile, those countries with higher HDI tend to experience positive to smaller impact, such as Greenland and Iceland [40,50].

Changes in marine resource distribution patterns bring both advantages and disadvantages to certain parties. Northern countries are expected to gain additional marine resource stocks due to changes in stock distribution patterns caused by climate change. According to Lam et al. [50], high-latitude (northern) countries will experience an increase in fish stocks of up to 30%. Meanwhile, southern countries are expected to experience a loss of catch stocks of up to 38%. Northern countries are mostly developed nations with comprehensive fishing technology and fleets. With these advantages, they can easily predict fish migration, adjust target fishing areas, and create adaptive fishing policy mechanisms [40,50]. Meanwhile, southern countries, mostly developing nations, will struggle with these changing conditions. Pacific nations, whose national income largely depends on marine products, will experience significant socio-economic impacts. Furthermore, southern countries often lack the technology and fleets of their northern counterparts, making them vulnerable to the impacts of climate change. Although most southern countries are not major contributors to climate change, they are still the ones most significantly affected. Limited human resources, technology, and facilities will make it difficult for countries in the South to compete and defend their fishing rights (Table 2). This creates an imbalance in the capacity to adapt to climate change between countries in the North and South [51,52].

Table 2. Top 10 countries ranked across four vulnerability categories (food dependency, economic dependency, employment dependency, and non-climate stressor). Higher values indicate higher level of vulnerabilities [40].

Rank	Vulnerability categories	Vulnerability categories	Vulnerability categories	Vulnerability categories	Vulnerability categories	Vulnerability categories	Vulnerability categories	Vulnerability categories
Rank	Food dependency	Food dependency	Economic dependency value	Economic dependency value	Employment dependency	Employment dependency	Non-climate stressors	Non-climate stressors
Rank	Country	Value	Country	Value	Country	Value	Country	Value
1	Sierra Leone	100	Kiribati	100	Samoa	100	Nigeria	100
2	Togo	97.68	Greenland	65.13	Vanuatu	89.95	Bulgaria	95.31
3	Mozambique	97.38	Micronesia	50.73	Myanmar	89.3	Bahamas	77.46
4	Solomon Islands	85.76	Belize	24.5	Panama	87.16	Qatar	72.63
5	Nigeria	85.65	Iceland	20.45	St. Vincent and the Grenadies	86.94	Iraq	72.17
6	Sri Lanka	79.02	Maldives	19.22	Turks and Caicos	83.46	Dominican Rep.	69.22
7	Sao Tome and Principe	78.06	St. Vincent and the Grenadines	18.81	Cambodia	83.3	Finland	68.97
8	Ivory Coast	70.7	Solomon Islands	13.74	Sao Tome and Principe	82.61	Djibouti	59.83
9	Gambia	70.35	Vanuatu	13.41	Maldives	82.5	Belgium	59.83
10	Ghana	64.13	Senegal	12.22	Cape Verde	81.73	Vietnam	58.43

The impacts of climate change demand adaptation and renewal of the international system to address previously unseen challenges. The blue economy concept can offer an alternative opportunity to address these issues. The blue economy concept proposes the utilization and management of marine resources based on sustainable principles to ensure their availability in the future. This concept offers opportunities for economic growth and improved social welfare, guided by the principles of marine sustainability and preservation (Figure 9). One such opportunity is coastal economic diversification. The goal is to eliminate dependence on a single economic opportunity. Coastal communities can be empowered with marine resources beyond fishing. Opportunities for coastal economic development include the development of marine tourism, the utilization of renewable energy from waves or coastal winds, the use of microalgae as cosmetic ingredients, and the expansion of maritime logistics for trade [53,54].

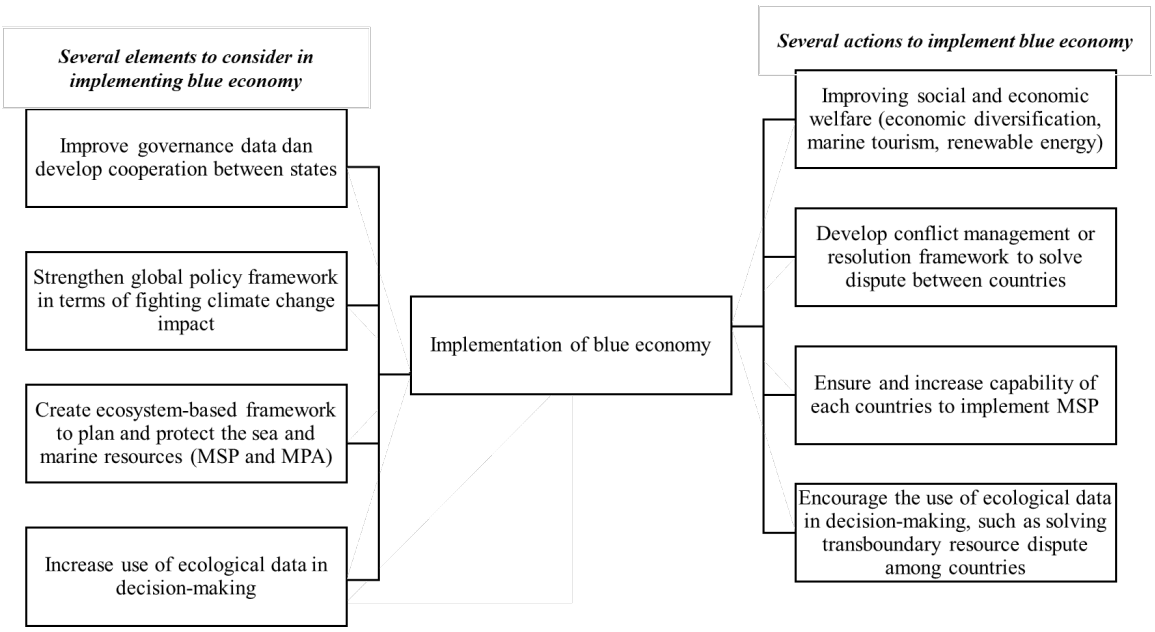

Figure 9. Key elements and recommended actions for implementing the blue economy [53-55].

The implementation of the blue economy can run smoothly through cooperation between countries. One way to achieve this is through maritime diplomacy. This negotiation tool is not only useful for facilitating the implementation of the blue economy but can also help resolve cross-border maritime disputes and conflicts (Figure 9). Maritime diplomacy can provide opportunities for countries worldwide to collaborate on managing marine resources with sustainable principles. Countries disputing catch quotas can create mechanisms for sharing catch quotas and monitoring systems to avoid conflict. A marine resource dispute once occurred between Norway, Iceland, and several European Union countries. The trigger was changes in mackerel migration patterns in the North Atlantic. The dispute lasted for years. Finally, an agreement was reached in 2014. This multilateral agreement established a Total Allowance Catch (TAC) and fair quotas for all parties involved [55-61].

The implementation of the blue economy and maritime diplomacy is strengthened by global policy frameworks such as the 1982 UNCLOS, the 2015 Paris Agreement on Climate Change, the MSP (Marine Spatial Planning) and MPAs (Marine Protected Areas) (Figure 9). The 1982 UNCLOS provides guidelines for the implementation of states' rights and obligations regarding waters, from the EEZ to the boundaries of the high seas or shared waters. This international law can serve as the basis for the implementation of maritime diplomacy. Furthermore, the 2015 Paris Agreement broadened the scope of maritime diplomacy. The Paris Agreement encourages diplomacy to address not only fishing quota disputes but also to address the imbalance in countries' adaptive capacity to climate change. Diplomacy supported by the Paris Agreement opens up alternative climate financing, blue carbon negotiations, and climate change adaptation cooperation. The MSP serves as a technical tool for the implementation of the blue economy through maritime diplomacy. This guideline serves as a technical tool for avoiding fisheries conflicts. Moreover, The MSP can be designed as a marine spatial planning map to prevent overlapping EEZs in waters. Furthermore, MPA would be reference to employ the MSP to conserve biodiversity in all coastal countries. Thus, countries no longer dispute based on political or historical boundary claims, but rather on ecological data and sustainable principles. The existence of UNCLOS

1982, the Paris Agreement 2015, and the MSP strengthens the implementation of maritime diplomacy for the implementation of the blue economy [53,55,57].

Although various international laws and regimes support the implementation of the blue economy, countries need ecological data to facilitate negotiations in practice. Ecological data has become a new tool for maritime diplomacy (Figure 9). It validates a country's position in making demands or asserting the legitimacy of its fishing rights. Several countries in the western Pacific are experiencing declining tuna stocks as populations increasingly shift eastward. Regions such as Kiribati, Nauru, the Marshall Islands, and Tuvalu are experiencing an increase in tuna populations in their waters. However, the problem is that the catch quota system has not changed. The Western and Central Pacific Fisheries Commission (WCPFC) still uses the old principle (historical catch basis) in determining catch quotas. This disadvantages smaller countries with modest fishing fleets [41,43,58,62].

The unfair catch quota system is being addressed through demands based on ecological data. This effort is necessary to enforce fair catch quotas. Small nations like Kiribati, Tuvalu, the Marshall Islands, and Nauru lack fishing fleets as sophisticated as those of larger nations like Japan, Korea, or the United States. Consequently, their abundant tuna catches do not translate into increased catches, as their catch quotas remain the same. Meanwhile, larger nations can fish in their territories through access agreements and capable fishing fleets. Ultimately, small Pacific nations can only sell access permits to foreign vessels to catch tuna in their territories. Given this situation, Pacific nations demand that catch quotas be adjusted to reflect contemporary fish stock locations, that EEZ sovereignty be respected, and that marine climate justice be upheld. In their demands, Pacific nations include ecological data such as tuna distribution and biomass, changes in ocean temperature and currents, and domestic catch and production data. Ecological data serves as a legitimacy for Pacific nations' positions and a maritime diplomacy tool to secure fair catch quotas [41,43,48,50,56,63].

Climate change, the blue economy, maritime diplomacy, and the role of ecological data in maritime conflicts are closely related to the goals of the Sustainable Development Goals (SDGs). The SDGs were agreed upon with the aim of balancing economic, social, political, and environmental dimensions (Figure 10). Efforts to address the impacts of climate change are one of the goals of SDG 13, namely climate action. One of these concerns the negative impacts on waters and the potential for maritime conflicts between countries. The concept of the blue economy provides an opportunity to implement marine resource management based on principles of sustainability and minimizing conflict through maritime diplomacy. Its implementation is strengthened by the existence of an international legal basis, international regimes, and ecological data. Thus, the SDGs summarize the direction and objectives of global sustainable development in addressing economic, social, political, and environmental issues [53,54,64].

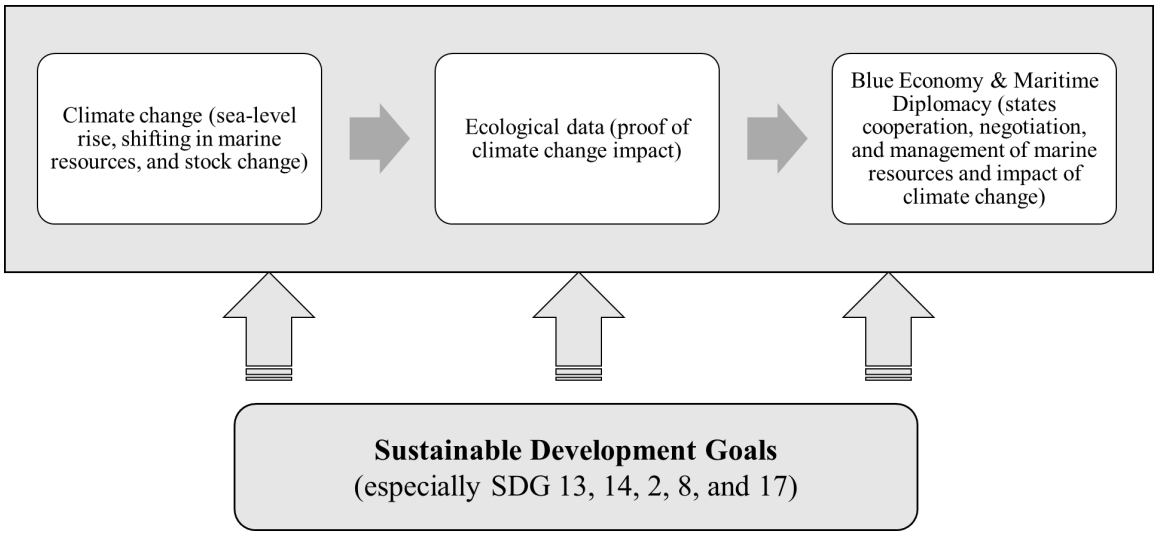

Figure 10. The relation between impact of climate change, ecological data, blue economy, maritime diplomacy, and SDGs. SDGs are supporting the process of implementing maritime diplomacy and blue economy [40,41,53-55]

LINKAGES TO SUSTAINABLE DEVELOPMENT GOALS

The condition of the fisheries sector and the progress of efforts to realize SDG 13 (Climate Action) and SDG 14 (Life Below Water) are intertwined. The fisheries sector contributes to the two SDGs through mitigation, adaptation, and management of marine resources to maintain the ecological and socio-economic balance of coastal communities. The fisheries sector plays a role in encouraging the achievement of SDG 13 through its role in mitigation and adaptation. The fisheries sector is crucial in maintaining and managing coastal ecosystems, such as mangroves, seagrasses, and coral reefs, in a sustainable manner. This can help preserve fish habitats and maintain marine ecosystem services. In addition, the fisheries sector can also help promote fisheries management with low-emission fuels and renewable energy and develop green aquaculture to support climate resilience. The fisheries sector contributes to the realization of SDG 14 through its role in enforcing laws against overfishing and in protecting and restoring marine ecosystems. The fisheries sector can help maintain the sustainability of marine resources by implementing regulations related to responsible fishing practices, encouraging the use of environmentally friendly and low-pollution fishing gear, and promoting marine resource conservation through national laws based on ecological data [64-66].

However, the implementation of SDGs 13 and 14 cannot be separated from other sustainable development goals. The phenomenon of climate change has cross-sectoral impacts, so many aspects need to be addressed. The impacts of climate change are not only related to climate action and marine life, but also related to food security (SDG 2), economic growth (SDG 8), and cooperation (SDG 17) (Figure 10). Rising sea temperatures are driving changes in fish distribution patterns, shifting the distribution of stocks globally. Countries experiencing declining fish stocks will experience economic turmoil and food security vulnerabilities. Coastal communities will lose jobs and experience reduced incomes due to declining catches. This phenomenon needs to be addressed through interactions across sustainable development goals. These goals need to be pursued in tandem. Each SDG goal also needs to be implemented jointly through cooperation between countries. Collaborative research, funding, and technological innovation can encourage countries to create better systems to address the impacts of climate change. By strengthening the synergy of the five

SDG goals, economic systems can be restored and the sustainability of marine resources can be ensured (Table 3) [41,54,67].

Table 3. Linkages between blue economy, fisheries sector, and SDGs [53,55,64,67]

Blue Economy Sector	Relevant SDGs	Action
Fisheries	SDG 13 (Climate Action) aims to combat the impact of climate change	Maintaining and managing coastal ecosystem Encourage sustainable principle in mitigation and adaptation measures Incorporating low-fuels and renewable energy in fisheries
Fisheries	SDG 14 (Life Below Water) aims to conserve and manage the use of marine resources for sustainable development	Effectively regulate fishing to end overfishing Develop a science-based or ecological data based marine resources management plan Ensure access for small-scale fishers to marine resources and markets
Fisheries	SDG 2 (Zero Hunger) aims to eradicate hunger, attain food security, and encourage sustainable agriculture	Encourage the use of fish as source of affordable and nutritious protein based on sustainable principles Improve facilities and develop scientific-based solution to ensure higher and stable fish productivity to guarantee sustainable fish stock globally
Fisheries	SDG 8 (Decent Work and Economic Growth) aims to encourage the inclusive, sustained, and productive employment and decent work for anyone	Create better work environment for fishers by improving facilities and guarantee long-term decent work Promote sustainable fisheries and fishing to the fisher in order to make sure they also have same goals to secure long-term and sustainable future of marine resources
Fisheries	SDG 17 (Partnership to Achieve Goals) aims to strengthen the implementation and reinforce global cooperation in realizing sustainable development	Encourage brands and retailers' commitment worldwide to the MSC (Marine Stewardship Council) certification in order to increase market demand for sustainable marine resources product and guarantee sustainable consumption Build collaborative partnership between states and non-state actor (Non-Governmental Organization, scientist, conservationist, business owner, and fishers) in order to create sustainable sourcing policies

However, barriers to cross-level policy integration often pose challenges to the realization of the SDGs. At the local level, limited technical and financial capacity and low community involvement often lead to policies being oriented only toward short-term interests. Meanwhile, at the national level, weak inter-agency coordination often results in poorly integrated policies. At the regional and global levels, differences in capacity, commitment, and interests across countries result in disparities in funding, technology use, and the implementation of sustainable development commitments. Barriers at each policy level are interconnected and influence each other. If policies at the global level are not well organized, implementation strategies at the national level will also be ineffective. Ineffective strategies lead to a decline in national policy responses, which will exacerbate the impacts of climate change on food security, the economy, and the environment. Proper management and handling of barriers through cross-level policy integration is crucial. The goal is to ensure that policies for realizing the five SDGs in combating the impacts of climate change on marine ecosystems and coastal communities are not fragmented. One way to overcome these barriers is to align priorities, capacities, and knowledge bases at all levels of policymaking [51,57,64,66].

Integrated science plays a role in strengthening cross-policy integration and promoting the use of ecological data in policymaking. Ecological data plays a crucial role in providing an objective picture of the real environmental conditions, which are useful for policymaking. Unfortunately, the integration of ecological data as a basis for policymaking is often neglected. Ecological data is treated as if it were separate from the cross-sectoral coordination process and social and economic policymaking. Integrated science is useful in addressing these challenges by acting as a bridge between data from various disciplines that can be used as a basis for policymaking. An integrated science approach helps map the relationship between climate change, marine ecosystem productivity, and the socio-economic conditions of coastal communities. This allows countries to develop more adaptive policies based on the real conditions depicted in the ecological data. Integrated science also serves as a means of promoting cooperation in line with SDG 17. This approach encourages

collaboration among researchers worldwide, government agencies, and international organizations. Integrated science also enables them to share information and transfer technology for capacity building. Therefore, integrated science is not only crucial for understanding environmental change but also contributes to creating equitable, inclusive, and data-driven policies at every level of decision-making [51,64].

To overcome barriers to policy integration and ensure the implementation of integrated science, an inclusive adaptation strategy is needed. This strategy connects evidence-based policies and ecological data with the active involvement of coastal communities as key actors in climate change. It also bridges ecological data-driven policies with concrete actions at the local level, particularly regarding the management of coastal areas vulnerable to the impacts of climate change. An inclusive adaptation strategy encourages policymaking based not only on one-sided interests but also on the needs of the entire community. Conservation and the blue economy are at the heart of an inclusive adaptation strategy. The combination of the two enables the protection of marine ecosystems, mitigation of the impacts of climate change, and improvement of socio-economic well-being of communities to go hand in hand. Ultimately, an inclusive adaptation strategy not only implements integrated science but also serves as a means to achieve these sustainable development goals [41,51,57].

FUTURE DIRECTIONS AND CONCLUSION

Based on the findings, fisheries dynamics are strongly influenced by the interconnectedness and balance between habitat, biology, and ecosystems. Changes in any one aspect can cause ecosystem imbalance and have a ripple effect on human life. Changes in the distribution of fish stocks and fish productivity in a region impact the stability of the ecosystem as a whole. These ecosystem changes even give rise to geopolitical issues between countries that share borders. These new problems caused by the impacts of climate change require an inclusive approach. The international maritime law system also needs to adapt to the emergence of these new issues. This is because these issues involve cross-border dynamics that encompass national interests, maritime diplomacy, and the national economy. Therefore, a comprehensive approach is crucial in understanding the marine system, its ecological dimensions, and the socio-economic aspects of human life. This will ensure that the resulting policies are sensitive not only to ecological aspects but also to the political context and maritime justice [42,43,48].

However, research gaps remain that need to be filled, particularly regarding transboundary resource management and policy integration between the local and global levels. This research gap highlights the need for future multidisciplinary research. Ecological, social, and political disciplines are interconnected, particularly in the area of climate change impacts. Multidisciplinary research can help operationalize scientific data into adaptive policies. Furthermore, discussions on the interrelationships between climate change impacts, sustainable development, and transboundary conflict management still need to be developed. Cross-border coordination and collaboration mechanisms are also crucial aspects that need to be addressed in the future to prevent and resolve transboundary resource conflicts by applying the principles of sustainability and inclusivity [51,64,68,69].

Based on the findings, several policy recommendations are needed regarding the integration of science, governance, and socio-economic justice in marine ecosystem management and mitigating the impacts of climate change. Countries need to encourage research on marine ecosystem connectivity (connectivity modeling), which focuses on mapping the relationship

between ocean currents, sea temperatures, and transboundary fish movements. This is necessary to support the establishment of conservation areas. Furthermore, policies regulating coordination mechanisms between countries are essential to regulate fish stock management based on fair and sustainable principles. Furthermore, policy integration from the local to the global level needs to be strengthened to support the realization of SDGs 13 and 14. Policies taken must also be based on the latest scientific data, so that the determination of catch quotas and climate adaptation strategies can be effective. Inclusivity is another aspect that needs to be considered in policymaking. Increasing the capacity of coastal communities through active involvement and support for economic diversification is crucial for the realization of SDGs 2 and 8 [41,46,51,54,57,64]. All of these policies require monitoring and evaluation mechanisms that can be implemented jointly by all countries worldwide. The goal is to ensure that these policies can continue to adapt to the dynamics of marine ecosystems and global climate change in a sustainable manner.

The future of sustainable fisheries amidst global climate change depends crucially on the ability to align science, relevant policies, and justice. Fisheries are no longer just about economics, but also encompass more complex social and ecological aspects that transcend national borders. These shifts are driven by climate change. The impacts of climate change cause habitat degradation, shifts in fish population distribution, and even socio-economic instability in coastal communities. Adaptive approaches are needed to address these impacts. Scientific data and increased public participation are also needed to support adaptation efforts to the impacts of climate change on the fisheries sector. International coordination and collaboration in realizing a blue economy are needed to balance conservation efforts and marine resource management based on principles of justice and sustainability [41,51,53,63,66]. Thus, sustainable fisheries not only serve as a pillar of the economic sector and maintain the balance of aquatic ecosystems, but also play a crucial role in maintaining social and political harmony in the region.

REFERENCES

1. Hohn S, Reymond CE. Coral calcification, mucus, and the origin of skeletal organic molecules. Coral Reefs. 2019;38:973–984. doi:10.1007/s00338-019-01826-4.
2. Veron JE. Corals of the World (Vol. 3). Townsville, Australia: Australian Institute of Marine Science and CRR. 2000.
3. Spalding MD, Ravilious C, Green EP. World Atlas of Coral Reefs. Cambridge: UNEP-WCMC. 2001.
4. Goreau TJ, Trench RK. Innovative Methods of Marine Ecosystem Restoration. Boca Raton: CRC Press. 2013.
5. Aeby G, Lovell E, Richards Z, Delbeek JC, Reboton C, Bass D. IUCN Red List. 2008. doi:10.2305/IUCN.UK.2008.RLTS.T133254A3656302.en.
6. Carpenter KE, Abrar M, Aeby G, Aronson RB, Banks S, Bruckner A. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science. 2008;321(5888):560-563. doi:10.1126/science.1159196.
7. Saintilan N, Khan NS, Ashe E, Kelleway JJ, Rogers K, Woodroffe CD, Horton BP. Thresholds of mangrove survival under rapid sea level rise. Science. 2020;368(6495):1118-1121. doi:10.1126/science.aba2656.
8. Tidwell JH, Allan GL. Fish as food: aquaculture's contribution - Ecological and economic impacts and contributions of fish farming and capture fisheries. EMBO Reports. 2001;2(11):958–963. reports/kve236. doi:10.1093/embo-.
9. Bardey DJ. Overfishing: pressure on our oceans. Research in Agriculture Livestock and Fisheries. 2020;6(3):397-404. doi:10.3329/ralf.v6i3.44805.
10. Palomares ML, Froese R, Derrick B, Meeuwig JJ, Tsui G, Woroniak J, Zeller D, Pauly D. Fishery biomass trends of exploited fish populations in marine ecoregions, climatic zones and ocean basins. Estuarine Coastal and Shelf Science. 2020;243(11):106896. doi:10.1016/j.ecss.2020.106896.
11. Miles MB, Huberman AM. Qualitative data analysis: An expanded sourcebook (2nd ed.). SAGE Publications Sage UK: London, England. 1994.
12. Kominz MA. Sea Level Variations over Geologic Time. San Diego: Academic Press. 2001. doi:10.1006/rwos.2001.0255.

13. Tanner WF. 3000 Years of sea level change. Bulletin of the American Meteorological Society. 1992;73(3):297-303.
14. de Lange WP, Carter RM. Sea-Level Change: Living with Uncertainty-GWPF Report 15. London: The Global Warming Policy Foundation. 2014.
15. Helfensdorfer AM, Power HE, Hubble TC. Atypical responses of a large catchment river to the Holocene sea-level highstand: The Murray River, Australia. Scientific Reports. 2020;10:7503. doi:10.1038/s41598-020-61800-x.
16. Church JA, White NJ. Sea-level rise from the late 19th to the early 21st century. Surveys in Geophysics. 2011;32:585–602. doi:10.1007/s10712-011-9119-1.
17. Frederikse T, Landerer F, Caron L, Adhikari S, Parkes D, Humphrey VW, Dagendorf S, Hogarth P, Zanna L, Cheng L. The causes of sea-level rise since 1900. Nature. 2020;584(7821):393-397. doi:10.1038/s41586-020-2591-3.
18. Bittermann K, Rahmstorf S, Perrette M, Vermeer M. Predictability of twentieth century sea-level rise from past data. Environmental Research Letters. 2013;8(1):014013. doi:10.1088/1748-9326/8/1/014013.
19. Davis-Reddy CL, Vincent K. Climate Risk and Vulnerability: A Handbook for Southern Africa (2nd Ed). Pretoria: CSIR. 2017.
20. Walsh JE. Melting ice: what is happening to Arctic Sea ice, and what does it mean for us? Oceanography, 26(2), 171-181. 2013. doi:10.5670/oceanog.2013.19.
21. Spada G, Bamber JL, Hurkmans RT. The gravitationally consistent sea-level fingerprint of future terrestrial ice loss. Geophysical Research Letters. 2013;40(3):482-486. doi:10.1029/2012GL053000.
22. Xie D, Schwarz C, Brückner MZ, Kleinhans MG, Urrego DH, Zhou Z, van Maanen B. Mangrove diversity loss under sea-level rise triggered by bio-morphodynamic feedbacks and anthropogenic pressures. Environmental Research Letters. 2020;15(11):114033. doi:10.1088/1748-9326/abc122.
23. Hoegh-Guldberg O, Andréfouët S, Fabricius KE, Diaz-Pullido G, Lough JM, Marshall PA, Pratchett MS. Vulnerability of coral reefs in the tropical Pacific to climate change. In: Bell, J. D., Johnson, J. E., & Hobday, A. J. (eds.), Vulnerability of Tropical Pacific Fisheriesand Aquaculture to Climate Change. pp. 253-296. Secretariat of the Pacific Community, Noumea, New Caledonia. 2011.
24. Eddy TD, Lam VW, Reygondeau G, Cisneros-Montemayor AM, Greer K, Palomares ML, Bruno JF, Ota Y, Cheung WW. Global decline in capacity of coral reefs to provide ecosystem services. One Earth. 2021;9(4):1278-1285. doi:10.1016/j.oneear.2021.08.016.
25. FAO. The State of World Fisheries and Aquaculture 2020: Sustainability in Action. Rome: FAO. 2020. doi:10.4060/ca9229en.
26. Johnson MD, Scott JJ, Leray M, Lucey N, Bravo LM, Wied WL, Altieri AH. Rapid ecosystem-scale consequences of acute deoxygenation on a Caribbean coral reef. Nature Communications. 2021;12:4522. et al., 2025. doi:10.1038/s41467-021-24777-3Koenigbauer.
27. Marubini F, Ferrier-Pagès C, Furla P, Allemand D. Coral calcification responds to seawater acidification: a working hypothesis towards a physiological mechanism. Coral Reefs. 2008;27:491–499. doi:10.1007/s00338-008-0375-6.
28. Short FT, Neckles HA. The effects of global climate change on seagrasses. Aquatic Botany. 1999;63(3-4):169–196. doi:10.1016/s0304-3770(98)00117-x.
29. Ghafari MIA. Recurrence of severe coral bleaching in Bidong and Karah island, Peninsular Malaysia: Mid-2024. Galaxea, Journal of Coral Reef Studies. 2024;26(1):48-49. doi:10.3755/galaxea.G26N-8.
30. Ghafari MIA, Bachtiar I. Unprecedented “dry-spawning” of nyale worms (Polychaeta, Eunicidae) in the south coast of Lombok, Indonesia: a mass-suicide toward future population decline? Bulletin of Marine Science, 101(4). 2025. doi:10.5343/bms.2024.0101.
31. Hoegh-Guldberg O. Coral reefs in the Anthropocene: persistence or the end of the line? Geological Society, 395(1), 167–183. 2014. doi:10.1144/sp395.17.
32. Hoegh-Guldberg O, Poloczanska ES, Skirving W, Dove S. Coral reef ecosystems under climate change and ocean acidification. Frontiers in Marine Science. 2017;4:158. doi:10.3389/fmars.2017.00158.
33. Jansen T, Gislason H. Temperature affects the timing of spawning and migration of North Sea mackerel. Continental Shelf Research. 2011;31(1):64-72. doi:10.1016/j.csr.2010.11.003.
34. Vaihola S, Kininmonth S. Climate change potential impacts onthe tuna fisheries in the Exclusive Economic Zones of Tonga. Diversity. 2023;15(7):844. doi:10.3390/d15070844.
35. Afriana W. Economic impact of climate change on pelagic fish migration: a systematic review of the literature. AACL Bioflux. 2025;18(5):2114-2122.
36. Azra MN, Ikhwanuddin M, Abol-Munafi AB. Growth, molting duration and carapace hardness of blue swimming crab, Portunus pelagicus, instars at different water temperatures. Aquaculture Reports. 2019;15:100226. doi:10.1016/j.aqrep.2019.100226.
37. Ikhwanuddin M, Azra MN, Noorulhudha NF, Siti-Aishah A, Abol-Munafi AB. Embryonic development and hatching rate of blue swimming crab, Portunus pelagicus (Linnaeus, 1758) under different water salinities. Turkish Journal of Fisheries and Aquatic Sciences. 2016;16:669-677. doi:10.1016/10.4194/1303-2712-v16_3_21.
38. Ghafari MIA, Fitrianti V. Pioneer assessment on megabenthic community suggest the recent ecological condition of coral reef in Senggigi Beach, Western Lombok Island, Indonesia. Indo Pacific Journal of Ocean Life. 2021;5(1):14-21. doi:10.13057/oceanlife/o050103.

39. Koenigbauer ST, Cubbage ML, Warren LD, Tellier JM, Selz OM, Sass GG, Höök TO. Fish reproductive phenology shifts with increasing temperature and year. Biology Letters, 21(1). 2025. doi:10.1098/rsbl.2024.0240.
40. Heck N, Agostini V, Reguero B, Pfliegner K, Mucke P, Kirch L, Beck MW. Fisheries at Risk: Vulnerability of Fisheries to Climate Change. 2020.
41. Palacios-Abrantes J, Santos BS, Frölicher TL, Reygondeau G, Sumaila UR, Wabnitz CCC, Cheung WWL. Climate change drives shifts in straddling fish stocks in the world's ocean. Science Advances. 2025;11(1):1–13. doi:10.1126/sciadv.adq5976.
42. Vivero JLS, Mateos JCR. Forecasting geopolitical risk: oceans as source of instability. Marine Policy. 2017;75:19–28. doi:10.1016/j.marpol.2016.10.009.
43. WWF. The Geopolitics of the Ocean: Why Healthy Seas Are Vital to America's National Security. 2025.
44. Fedewa EJ, Jackson TM, Richar JI, Gardner JL, Litzow MA. Recent shifts in northern Bering Sea Snow crab (Chionoecetes opilio) size structure and the potential role of climate-mediated range contraction. Deep-Sea Research Part II, 181–182(March), 1–11. 2020. doi:10.1016/j.dsr2.2020.104878.
45. NOAA Fisheries. Some Fish and Crab May Shift Further North in Alaskan Waters Than Previously Predicted. NOAA Fisheries. https://www.fisheries.noaa.gov/feature-story/some-fish-and-crab-may-shift-further-north-alaskan-waters-previously-predicted. 2024.
46. Zacher LS, Hennessey SM, Richar JI, Fedewa EJ, Ryznar ER, Litzow MA. The 2024 Eastern Bering Sea Continental Shelf Trawl Survey: Results for Commercial Crab Species. 2024.
47. Klimenko E. The Geopolitics of A Changing Arctic (Issue December, p. 16). 2019.
48. House of Lords. UNCLOS: The Law of the Sea in the 21st Century (Issue February). 2022.
49. öhret M. Geopolitical impacts of climate change: arctic case. Yönetim ve Ekonomi. 2025;32(1):67–83.
50. Lam VWY, Cheung WWL, Reygondeau G, Sumaila UR. Projected change in global fisheries revenues under climate change. Scientific Reports. 2016;6:1–8. doi:10.1038/srep32607.
51. Karp MA, Peterson JO, Lynch PD, Griffis RB, Adams CF, Arnold WS, Barnett LAK, DeReynier Y, DiCosimo J, Fenske KH, Gaichas SK, Hollowed A, Holsman K, Karnauskas M, Kobayashi D, Leising A, Manderson JP, McClure M, Morrison WE, Link JS. Accounting for shifting distributions and changing productivity in the development of scientific advice for fishery management. ICES Journal of Marine Sciences, March, 1–11. 2019. doi:10.1093/icesjms/fsz048.
52. Melnychuk MC, Baker N, Hively D, Mistry K, Pons M, Ashbrook CE, Minto C, Hilborn R, Ye Y. Global Trends in Status and Management of Assessed Stocks: Achieving Sustainable Fisheries Through Effective Management. 2020.
53. Irish Aid. Climate Change and the Blue Economy: A Sustainable and Equitable Blue Economy Can Support Climate Action (pp. 1–4). 2022.
54. Maris L. Blue Economy for Ocean Health and Sustainable Development. 2024.
55. The World Bank. The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries. 2017.
56. Ishikawa Y. The EU-Faroe Islands herring stock dispute at the WTO : the environmental justification. SSRN Electronic Journal. 2014;18(4):1–7. doi:10.2139/ssrn.2577648.
57. Mière, C. Le. Maritime Diplomacy in the 21st Century: Drivers and Challenges. Routledge. 2014.
58. Spijkers J, Boonstra WJ. Environmental change and social conflict: the Northeast Atlantic mackerel dispute. Regional Environmental Change. 2017;17:1835–1851. doi:10.1007/s10113-017-1150-4.
59. Starr A. Total allowable catches and fishing opportunity decisions of the Council of the EU – a voting power index approach. Marine Policy. 2023;156:1–8. doi:10.1016/j.marpol.2023.105798.
60. Zulfiqar K, Chang Y. Climate change and maritime law: a review of IMO governance mechanism. Journal of Atmosphere and Oceanography Environment. 2023;11(1):1–11. doi:10.18686/jaoe.v11i1.9511.
61. Apriani E, Supriyadi AA, Prakoso LY, Widodo P, Suwarno P. Strengthening maritime geopolitics strategy to counter marine resource plundering in the North Natuna Sea. East Asian Journal of Multidisciplinary Research (EAJMR). 2024;3(10):4761–4776.
62. Oliveira GC. Ocean governance, maritime security, and international relations. Contexto Internacional. 2025;47(2):1–28. doi:10.1590/s0102-8529.20244603e20230042.
63. Andriamahefazafy M, Haas B, Campling L, Goodman C, Adams TJH, Hanich Q. Advancing tuna catch allocation negotiations: an analysis of sovereign rights and fisheries access arrangements. Ocean Sustainability. 2024;3(16):1–8. doi:10.1038/s44183-024-00055-9.
64. Meharoof M, Albert A, Kumar R. Sustainable Development Goals and Fisheries Sector: Progressing Towards A Sustainable Future. Aquaculture Spectrum. 2023;6(3):12–25.
65. NOAA Fisheries. Code of Conduct for Responsible Fisheries. NOAA Fisheries. https://www.fisheries.noaa.gov/national/international-affairs/code-conduct-responsible-fisheries#:~:text=and sustainable manner.-,Overview,and freshwater living aquatic resources. 2017.
66. Petrova E. The Role of Fisheries in Achieving United Nations Sustainable Development Goals. Journal of Fisheries Research. 2024;8(6):1–2.
67. Marine Stewardship Council. Fishing and the Sustainable Development Goals: How the MSC Program Enables Meaningful Action and Measurement Towards Delivering the SDGs (Issue September). 2023.
68. Tayia A. Transboundary water conflict resolution mechanisms: substitutes or complements. Water. 2019;11(1137):1–40.

69. Farah L. Cross-border water management in transboundary river conflicts in Palestine. JCM: Journal of Conflict Management. 2024;4(2):23–36.