CHAPTER 24

Sustainability of Fisheries Under Climate Change Pressures

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SUMMARY

Climate change is a growing factor across the world's marine fisheries, affecting them in varying, but widespread, ways that affect individuals, stocks, populations, communities, food webs, and large ecosystems. As such, observed and projected changes in the yield, distribution, quality, and composition of fish stocks are evident across many measures. In fisheries, the vulnerability is affected by impacts on fishing techniques and changes in fish distribution. Other than ecological impacts, climate change has economic consequences on fisheries, such as increased costs and damage. Research emphasizes the spatial issues regarding the redistribution of benefits and losses in fisheries due to species migration and ecosystem shift. Climate change also causes shifts in marine habitats and oceanographic conditions, which affect marine species' biogeochemical cycles, trophic flows, life histories, productivity and distributions. Considering the complexity and multidimensionality of the effects of climate change on fisheries, policymakers must have a holistic understanding of ecological and socioeconomic implications to engage in effective policy dialogue and adaptation. Multidisciplinary research into the effects of climate change on fisheries is essential, as is creative policymaking to counter the negative aspects, and stakeholder involvement to ensure that policies are correctly implemented. By combining scientific knowledge with the practice of adaptive management, it is possible to prevent climate change from destroying marine ecosystems and harming livelihoods dependent on fisheries.

INTRODUCTION

Urbanization and global warming are among the most important global trends of the twentieth and twenty-first centuries (Helbling & Meierrieks, 2023). While the discourse on climate change typically focuses on its environmental consequences and the immediate impact on human life, the concern about its future implications, particularly on the mental health of the younger generation, has not been adequately addressed (Warsini et al., 2014). Since the inception of the Kyoto Protocol was adopted in 1997, and its first commitment period lasted from 2008 to 2012 and up to the 26th UN Climate Change Conference of the Parties, better known as COP 26, was organized in November 2021 in Glasgow, United Kingdom, and was an essential platform for world leaders and negotiators to discuss and negotiate national and global climate action plans. There have been observable efforts across various industries, notably the energy sector, to curb greenhouse gas emissions in response to the growing demand for sustainable energy production(Acar et al., 2018). Among various clean energy alternatives, renewable hydrogen is increasingly being recognized as a low-carbon energy medium (Dawood et al., 2020). It does not produce greenhouse gas emissions for power generation (Siddiqui & Dincer, 2019). Hydrogen holds promise as an energy resource that could supplant the present use of natural gas, such as providing heat to industries and substituting transport fuels. It offers several benefits, including the versatility in the choice of raw materials, spanning from waste products to fossil fuel sources (Akhlaghi & Najafpour-Darzi, 2020).

The current scenario of hydrogen production emphasizes the reliance on fossil fuels and the need for a conversion to renewable sources to minimize emissions. However, the overall contribution of low-emission hydrogen remains relatively small (Dincer, 2012; Acar & Dincer, 2014; Hosseini & Wahid, 2016; Kumar & Himabindu, 2019).

DIRECT AND INDIRECT IMPACTS OF CLIMATE CHANGE ON FISHERY RESOURCES

Climate change can have direct and indirect impacts on fishery resources, with implications for individuals, populations, communities, food webs and ecosystems (Flannery-Sutherland, 2021). Indirect effects are seen as occurring or potentially occurring as a result of changes in primary and secondary productivity, changes in ecosystem structure, fluctuations in input supplies, and alterations in the trailing output demanded by a product. The fishing industry and aquaculture producers require a variety of goods and services to function. These inputs include fishmeal and fish oil for aquaculture feed and other essential goods and services for fisheries. These indirect impacts reflect the complex interconnectedness of climate change with broader ecological

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and economic factors in the context of fisheries. Additionally, direct effects are mentioned, encompassing the effect of change in climate on the physiology, physical characteristics of finfish and shellfish stocks within production systems. This implies that this alteration can lead to observable fluctuations in the biological and physical attributes of the targeted fish and shellfish species, possibly affecting their growth, reproduction, and overall health (Adhikari et al., 2018).

According to a study in 2017 by the FAO, aquaculture's global contribution to human greenhouse gas emissions was a mere 0.49% with a total annual GHG emissions from aquaculture estimated at 245 million metric tons of CO_2 in 2017. This is far less than the predicted much larger GHG emissions imprint of terrestrial farming (MacLeod et al., 2020).

GENERAL IMPACTS

Warmer waters and thermal stress: For the development and growth of aquatic animals, temperature plays a critical role (Ngoan, 2018). Ocean, river, and lake water temperatures may rise in parallel with world temperatures. Fish distribution and migration patterns may be impacted, which may alter fish quantity and fishing accessibility. Certain species could find it difficult to adapt, which would lower their productivity. Fish are especially vulnerable to temperature fluctuations brought on by climate change because of their poikilothermic nature (Adhikari et al., 2018). Temperature variations can cause thermal stress in fish because they are sensitive to them. Fish behavior, growth, reproduction, and survival rates might be impacted by this stress. The potential consequences of global temperature rise on fish populations, especially the effects on intertidal shellfish and cold-water animals like Atlantic halibut, salmon, and cod. In typical world temperature, the projection of a 1.5°C increase throughout this period carries implications for the health and survival of these aquatic species due to thermal stress. Higher temperatures can result in increased mortality rates, and this thermal stress is particularly detrimental to cold-water species that are adapted to cooler environments. Additionally, the adverse effects extend to intertidal shellfish, which are also sensitive to changes in temperature. Chronic stress, induced by prolonged exposure to elevated temperatures, is noted for its potential to impact various physiological systems in economically significant species (Stewart et al., 2019; Zhang et al., 2019).

Loss of coastal habitats: The rise in sea levels will increase by around 0.1m less below 1.5°C global warming than under 2 °C through 2100, according to IPCC (2018) projections. However, it is predicted that this rise will continue until 2100, through the pace and amount of increase most expected to be decided by the future emission pathways. The potential negative impacts of salinization on aquaculture, making it environmentally inappropriate and leading to amplified production costs and reduced economic advantages. Salinization refers to the increased salt content in soil or water, and in the context of aquaculture, it can have detrimental effects on the suitability of environments for fish and other aquatic species (Haroon et al., 2017). Critical coastal ecosystems, such as salt marshes, estuaries, and mangroves, may disappear as a result of rising sea levels. Numerous fish species frequently use these places as nurseries. It can alter coastal habitats where aquaculture farms are located. Coastal aquaculture infrastructure may also face risks from inundation. Fish populations may decline, and fishing chances may be limited if certain habitats are lost. Fish health and reproduction are impacted when saltwater intrusion occurs in freshwater environments. The salinity of groundwater has been reported by way of destructive to agricultural output, fisheries in freshwater and aquaculture (Kibria et al., 2017). This might contribute to the sustainability of aquaculture output by creating new options, especially for coastal locations.

Ocean Acidification: The oceans play a crucial role in regulating the Earth's carbon cycle, and they act as a significant sink for CO_2 from the atmosphere. The route includes the absorption of atmospheric CO_2 by the surface waters of the ocean. However, as CO_2 levels in the atmosphere increase, the oceans absorb more CO_2, leading to changes in seawater chemistry and a phenomenon known as ocean acidification. It is estimated that 50 times as much CO_2 is stored in the seas than in the atmosphere (Seggel et al., 2016). Ocean acidification results from a prolonged decrease in the pH levels of seawater, primarily caused by the absorption of atmospheric CO_2. This process occurs over decades and poses a significant threat to marine ecosystems. The predictable rise in CO_2 uptake by oceans, especially under global warming scenarios of 1.5 °C or more, anticipated to adversely affect various aquatic species. This includes effects on survival, development, growth, calcification, and overall abundance. Changes in the lower trophic levels of the food web, such as plankton, can have implications for fish populations. Disruptions in the availability of prey or changes in the distribution of species can affect the entire ecosystem, influencing fish abundance and distribution. Ocean acidification could lead to lower production outputs and profits in aquaculture. The rising acidity levels in oceans have direct implications for the economic sustainability of aquaculture production. As acidity levels increase, it can negatively impact the health and productivity of marine species cultivated in aquaculture systems. This, in turn, can lead to reduced yields, increased production costs, and potential economic losses for the aquaculture industry.

A positive effect of ocean acidification is the economic gains for hatchery owners. The increased demand for spat production could result in more employment opportunities within local communities. Despite the potential positive impact, there are challenges in predicting future changes in ocean carbonate chemistry with certainty. The complexity of marine systems and the difficulties in monitoring long-term biological responses under experimental conditions contribute to this uncertainty. Finfish, especially marine species, are more vulnerable to the impacts of ocean acidification because they have calcium otoliths (Clements & Chopin, 2017)

Extreme Weather Events: The mention of IPCC warning indicates that climate models suggest that the risks associated with drought events are likely to be more severe under a 2°C warming scenario compared to a 1.5°C scenario. This underscores the importance of limiting global temperature rise to mitigate adverse impacts on water availability and aquaculture. Heavy rainfall can cause floods that lead to the loss of fish from ponds. Droughts can lead to water stress, scarcity, and degradation, all of this may negatively affect the productivity of aquaculture (Rutkayova et al., 2018). Climate change can cause water shortages, which can lead to conflicts among diverse groups, including agriculture, aquaculture, domestic and industrial users. Additionally, this may lessen producers' financial advantages and perhaps result in poverty in the impacted regions. Aquaculture, like other sectors, faces challenges related to competition for water resources. Increased demand for water from various sectors, such as agriculture, industry, and urban areas, can limit the availability of water for aquaculture. Climate change can influence rainfall patterns, potentially leading to changes in the availability of water resources. The availability of water for aquaculture can positively impact social and economic sustainability in the affected regions.

Diseases and harmful algal blooms: Warmer waters create favorable conditions for the proliferation of pathogens and harmful algae. Disease outbreaks in aquaculture, caused by parasitic, bacterial, fungal, and viral agents, are expected to be inclined by altering temperature administrations in random ways. It's anticipated that outbreaks of warm-water diseases would become more frequent, and concerns have been raised about the potential for new illnesses to emerge in light of climate change (Sae-Lim et al., 2017). Disease outbreaks, including those caused by warm water pathogens like sea lice, can significantly impact fish health and survival. Warm water pathogens, like sea lice in salmon culture, may pose increased challenges with further warming, requiring additional management and additional expenditures. The outbreak of epizootic diseases is identified as a significant limiting factor for aquaculture production systems globally (Maulu et al., 2019). The rise in diseases among aquaculture species is likely to reduce profits, can be detrimental to aquaculture production's social and economic viability. This shift in disease dynamics may have implications for the production of specific fish species.

Changing Ocean Currents: Changes in ocean currents can influence the distribution of plankton and other small marine organisms that serve as food for fish. This, in turn, can affect the migratory patterns of fish species, potentially impacting the livelihoods of fishing communities.

Anthropogenic activity's effects on climate changes

Anthropogenic activities can have significant effects on climate change, and these changes can, in turn, impact fish production and aquatic ecosystems.

Changing fishing practices and shifts in fishing grounds: This refers to anthropogenic activities, primarily the emission of greenhouse gases, deforestation, and other human-induced changes to the atmosphere. Physio-chemical alterations, such as changes in temperature, acidity, and oxygen levels, contribute to the complexity of challenges faced by global fishery resources. These alterations are influenced by climate change and other environmental factors. Overfishing, habitat degradation, and pollution are identified as additional stressors on fishery resources. These factors, in conjunction with physio-chemical alterations, further strain the resilience of aquatic ecosystems. Fisheries may need to adapt to the changing conditions by adjusting various aspects, including fishing seasons, gear types, and target species. Effective management and conservation strategies are crucial to addressing the challenges posed by these alterations (Gaines et al., 2018, Carozza et al., 2019). Changes in fishing patterns and practices can have economic implications for fishermen and the fishing industry. Fishing communities may experience social challenges as traditional ways of life are disrupted or altered. Fisheries administration must adapt to the interrelated problems of pollution, overfishing, loss of habitat, and physio-chemical changes in aquatic environments. It is essential to develop strategies that consider both the ecological sustainability of fishery resources and the socio-economic well-being of fishing communities. Integrated and well-planned approaches are crucial to address the complex and interrelated issues affecting global fishery resources (Pascual et al., 2022).

EFFECT OF CLIMATE CHANGE ON ECOSYSTEM AND BIODIVERSITY

The ecosystems of the Earth, those intricate tapestries of life and environment, are under obstruction. The relentless growth of the human population, the degradation of farmland, the buildup of CO_2 in atmosphere due to fossil fuel combustion, the gradual increase in the levels of various man-made pollutants and contaminants and global warming collectively result in significant alterations in our climate, known as climate change. These circumstances could set off unparalleled heat waves, droughts, firesand floods worldwide, and a decrease in Earth's biodiversity.

PHYSIOLOGICAL IMPACTS OF CLIMATE CHANGE ON AQUACULTURE

The effects of climate change have drastically changed global temperature trends, and these changes are predicted to persist and get stronger (Sarà et al., 2018). In reality, many of the most significant aquaculture-producing regions are also the most susceptible to adverse weather conditions (Reid & Gurney-Smith, 2019).

Response to an extreme temperature event

Fish express a great deal of catecholamines, corticosteroids, and hormones in their blood and tissues in response to both acute and chronic heat stress (Yada & Tort, 2016). Different stresses and species kinds elicited different neuroendocrine responses (Alfonso et al., 2021). Acute heat shock (13-25°C for 4 hours) causes rainbow trout, *O. mykiss*, to release substantial amounts of catecholamines, reduce arterial O_2, and increase CO_2 (Currie et al., 2013). When *O. niloticus*, were exposed to 13°C for three days after being at 25°C, their blood cortisol levels also increased (Panase et al., 2018). *Acipenserfulvescens* exposed to high temperatures 18°C showed a rise in cortisol levels throughout their bodies compared to fish at10°C temperature (Kim et al., 2017).

Metabolic and molecular stress responses

Enzymatic processes, metabolic rates and cellular respiration are temperature-dependent in ectotherms (Volkoff & Rønnestad, 2020). Modifications in metabolic rate are connected to both acute and long-term elevated thermal stress (Benítez-Dorta et al., 2017). High oxygen intake and respiratory rates aggravate these variations in metabolic rate even further (Araújo et al., 2018). Since blood glucose is closely related to metabolism, hyperglycemia is a typical sign of cold shock responses during wintertime cold stress exposure (Zhang et al., 2019). Majhi et al. (2013) found that in comparison to fish at 27 and 30°C, cold shock at 6 °C markedly raised the blood glucose levels in mahseer. When *P. olivaceus*, the olive flounder, was exposed to temperatures between 28 and 30°C for two weeks, there was a significant rise in HSP70 (Kim et al., 2019). HSPs are essential for long-term stress adaptation because they emerge after the initial stress exposure and shield tissues and cells against structural deterioration during future exposures (Reyes-López et al., 2018).

Changes in hematological and biochemical parameters

Lipid layer and energy storage alterations brought on by stress from temperature can also alter the quantity and form of blood cells. Climate-induced temperature events have been linked to anomalies in nuclear and erythrocytic cellular structure in several recent studies (Ashaf-Ud-Doulah et al., 2019). When exposed to temperatures between 16 and 24 degrees Celsius for ten to thirty days, European seabass, or *D. labrax*, showed a considerable rise in white blood cells (WBC) but an inverse trend in RBCs, hematocrit and hemoglobin (Islam et al., 2021). When exposed to 36 °C for seven days, striped catfish (*Pandasianodonhypothalamus*) significantly reduced their Hb and RBC levels at 28°C, when their WBCs showed conflicting trends (Shahjahan et al., 2018).

Immune responses

The immune system and fish's capacity to fight off infections are severely impacted by both acute and long-term temperature fluctuations outside of their ideal range (Makrinos & Bowden, 2016). Fish are more susceptible to disease when temperatures rise above the ideal thermal window. Proliferative kidney disease causes by pathogen *Tetracapsuloides bryosalmonae*, was found to impair the immunological function of rainbow trout, after they were exposed to 12-15°C for seven weeks. When stressed at 26°C, fish from largemouth bass (*M. salmoides*) showed significantly decreased levels of gill and liver lysozyme activity (Sun et al., 2020).

Changes in ionic balance

Varying temperatures in freshwater fish reduce ion inflow and cause net ion loss in saltwater fish, however, the opposite occurs. In general, fish lose electrolytes in freshwater and gain more ions in saltwater water (Vargas-Chacoff et al., 2018). In times of extreme heat, the fish body uses its metabolic energy to transfer ions instead of passively diffusing them from its environment which might result in osmotic failure (Evans & Kültz, 2020). Consequently, ionic imbalances impair the function of the central nervous system (CNS). For instance, a reduction in synaptic transmission efficiency causes fish to experience basic stress responses, which in turn impacts all of their physiological processes (Vargas-Chacoff et al.,2018). By decreasing Na+-K+ ATPase activity, temperature modifies gill flexibility Vargas-Chacoff et al. (2018) inspected that how saline and temperature affected the gill osmoregulatory proteins and osmo-tolerance in smolt Atlantic salmon, *Salmosalar*. In fresh and saltwater fish were exposed to warm stress for eight days at temperatures between 14 and 17, 20, and 24°C. While no mortality happened in any other group, fish exposed to 24°C and SW exhibited 100% mortality.

Growth and reproductive performance

Temperature fluctuations in the environment affect an ectotherm's ability to consume, digest, absorb, and assimilate food (Volkoff & Rønnestad, 2020). It has been found that under temperature stress, there is growth inhibition as well as alterations in reproduction efficiency and sex ratio (Geffroy & Wedekind, 2020). Elevated body temperature (eustress) causes increased energy and metabolic processes, as well as faster rates of absorption and assimilation and physiological activation, all of which contribute to increased growth rate (Sotoyama et al., 2018). Conversely, investigations conducted under controlled laboratory conditions have shown that temperature can exceed the point at which growth performance is negatively impacted (Bögner et al., 2018). Temperature stress frequently results in decreased development, feed intake, and food conversion efficiency. *S. salar*, an Atlantic salmon, showed poorer development performance throughout the five-month trial at temperatures of 17 and 22 °C relative to 10 °C (Wade et al., 2019).

Reproduction

It has been documented that phenology, sexual maturity, sex differentiation, spawning, and reproduction are all impacted by changes in ambient water temperature since these changes can disrupt the processes of steroidogenesis and gametogenesis (Chang et al., 2018). By disrupting hormones, temperature fluctuations can either speed up or slow down gametogenesis and maturation (Mateus et al., 2017). During gametogenesis in Atlantic salmon, *S. salar*, elevated temperature exposure was found to impede gonad steroid synthesis, change hepatic estrogen dynamics, and produce less vitellogenin in the liver. Exposure to high temperatures throughout several stages of gonadal development lessens the gonads steroid production and delayed or stops the pre-ovulatory transition. The salmon aquaculture sector in Norway is experiencing severe output losses and a rise in the frequency of intense heat waves (Calado et al., 2021).

UNCERTAINTIES AND RESEARCH GAP IN CLIMATE CHANGE

Regional variability

While climate models provide valuable insights into global trends, there is still uncertainty regarding the precise regional impacts of climate change. Understanding how specific regions will be affected is crucial for effective local adaptation and mitigation strategies (Wakatsuki et al., 2023).

Extreme events

The incidence and severity of severe weather phenomena, such as scorching temperatures, storms and droughts remain uncertain. Improved predictions of these events are essential for developing resilient infrastructure and response strategies (Bolles et al., 2019).

Ocean dynamics

Predicting the sea rising at a pace is challenging due to uncertainties in understanding complex Ocean dynamics, ice sheet behavior and the possibility of quick ice melt in Polar Regions (Park et al., 2023).

Carbon cycle dynamics

Uncertainties exist regarding the capacity of land and oceans to continue absorbing carbon dioxide. An understanding of carbon cycle dynamics is crucial for predicting future atmospheric CO2 concentrations (Crisp et al., 2022).

Ecosystem responses

Ecosystems' reactions to warming temperatures, such as changes in the distribution of species, biodiversity loss, and ecosystem services, are still not fully understood. More research is needed to anticipate and manage these changes effectively (Grimm et al., 2013).

Paleoclimate understanding

Understanding past climate variations through paleoclimate data is essential for contextualizing current changes. Further research in this area can enhance our understanding of natural climate variability (Cronin, 2009).

Interactions between climate change drivers

Investigative the synergistic properties of multiple climate change drivers, such as temperature increases, ocean acidification, and changes in precipitation patterns, is crucial for assessing cumulative impacts on ecosystems (Grimm et al., 2013).

Public perception and behavior

Understanding public perception, behavior, and the factors influencing climate change adaptation and mitigation efforts is vital for developing effective communication strategies and policies (Sullivan et al., 2021).

ECONOMIC EFFECTS OF CLIMATE CHANGE ON FISHERIES

In light of the rising demand for food resources worldwide (Barange et al., 2014) and our increasing knowledge of the experimental (Weatherdon et al., 2016) and expected (Gaines et al., 2018) effects of climate change on fisheries, we need innovative methods to evaluate fisheries' capacity and sustainability for adaptation through various scales and systems (Thiault et al., 2019). A lot of people's lives could be negatively impacted by factors like anthropogenic climate change, which can have an impact on worldwide change (e.g., mobility or employment) or changes in demand from wealth and population growth. These factors run the risk of significantly altering sustainable yields or significantly raising fish product prices (Golden et al., 2016).

Since 1990, the official estimate of the world's marine fisheries landings has ranged from 80 to 85 million, with a same average yearly gross income that fluctuate around $100 billion a year (Swartz et al., 2013). A current study assessed the probable "true" yearly worldwide fastening to be approximately 130 million (Pauly & Zeller, 2016), accounting for unreported captures. Between 660 and 820 million people depend on the worldwide fishing industry for their livelihoods, either directly or indirectly. When the dependents of fishermen are included, this amounts to roughly 10–12% of the global population. In addition to being an essential source of micronutrients, fish offer 20 percent of the animal protein required by over 2.9 billion people worldwide (Golden et al., 2016).

However, climate change is understood as a huge experimental that determination profoundly impact the forthcoming of worldwide fisheries, beside through additional non-climatic causes such as changes in marketplaces, overexploitation and demographics. In the short term, fisheries may be more affected by these non-climatic pressures and management regime changes than by climate change (Eide, 2007), according to several studies, but in the long run, global fisheries are seriously threatened by rising climate uncertainty (O'neill et al., 2017).

The range of marine species' distribution, the temporal correlation of biological processes, and main subordinate output, (O'neill et al., 2017) are all affected by variations in ocean conditions, which include sea ice extent, temperature and O_2 levels and salinity, pH (Pinsky et al., 2013). Marine fish's maximum body sizes may also drop as a result of warmer temperatures (Cheung et al., 2013). The world's redistribution of MCP is anticipated to result from the mutual effects of the projected distributional changes and shift (Beaugrand et al., 2015) in ocean productivity due to climate change. MCP is predicted to rise in high latitudinal regions and decrease in tropical regions (Cheung et al., 2010) will be accompanied by changes in species composition. Fisheries contribute significantly to the global economy, and these changes will have a significant impact on those who depend on fish for money and food (Barange et al., 2014).

According to Lam et al. (2012), a significant decline in fish protein availability and a fall in marine fish output is anticipated in West Africa by the 2050s as a consequence of climate change. According to this study, climate change may also result in a 21% decrease in annual landed value, a 50% decrease in jobs associated with fishing, and an overall yearly loss of US$311 million for West Africa's entire economy.

Specifically, East Asian fisheries and the fishery industry would be impacted by climate change. As far as we know, Asia is home to 85% of the world's fishers and fish farmers, with China having the highest concentration (5.0 million fish farmers and 9.6 million fishers). China is the greatest fish producer, contributing 35% of the worldwide fish output in 2018 (FAO, 2020). Therefore, Fisheries are negatively impacted by climate change will unavoidably influence fishermen's livelihoods and fishing communities, especially in Asia.

Global fisheries productivity has already decreased due to ocean warming; since the 1930s, some locations have seen losses in the maximum sustainable yield (MSY) of significant fish populations of up to 35% (Free et al., 2019). Rich shellfisheries throughout the US Pacific coast have been jeopardized by ocean acidification, resulting in a significant loss of income and employment (Barton et al., 2015). Increasing ocean-shifting water temperatures and acidification are putting at risk tropical coral reef-linked fisheries, which are frequently crucial for local food security (Doney et al., 2020). As revealed by the "Blob," a marine heat wave that occurred in the Pacific Northeast between 2014 and 2016 and had a significant negative impact on fisheries on the US West Coast due to a sharp decline in ocean productivity (Fisher et al., 2021).

Government subsidies resulting from climate change, which total US$35.4 billion yearly worldwide, are a contributing factor why threats to marine capture populations continue (Sumaila et al., 2019). In already heavily capitalized fisheries, where the number of boats is currently treble that of the 1950s and commercial fishing is sustained even when stock levels decrease, these subsidies encourage inefficient, unproductive fishing tactics (Rousseau et al., 2019).

DEVELOPMENT IN LEGISLATION AND POLICIES

Regarding the legal management of fisheries and climate change, here are two different but related authorized systems in accordance with worldwide regulation. The former is governed by the United Nations Framework Convention on Climate Change (UNFCCC), although the second is under the jurisdiction of the UN Convention on the Law of the Sea (LOSC). The two groups of laws share certain certified ideas, even if they are overseen by two distinct legal systems. It is agreed that while the majority of the Law of the Sea instruments do not specifically address climate change, both the customary law and LOSC in this area contain regulations that are pertinent to the issue (Zou, 2021). It is still uncommon to find explicit mentions of change in climate in the mainstream of contemporary marine pollution instruments (Boyle, 2012).

According to the text, the UNFCCC seeks to attain a balance of greenhouse gas emissions level in the atmosphere that shield the planet from damaging human interference with its climate. This means preventing detrimental effects on Earth's climate system brought on by human activity by stabilizing the amounts of greenhouse gases in the atmosphere. UNFCCC, have obligations and responsibilities to help accomplish the declared objective. Among these responsibilities include encouraging sustainable administration and participating in preservation and improvement.

The precautionary approach mandates states to take action even in the absence of concrete scientific indication of possible harm to a specific natural area, weather or fishing. The Straddling Fish Stocks Agreement (1995), also recognized as the United Nations Fish Stocks Agreement (UNFSA), is a noteworthy international agreement that addresses the protection and administration of highly wandering and spanning fish species in regions outside of national borders. The precautionary approach is a key principle embedded in this agreement, emphasizing the need for caution in fisheries management to prevent overfishing and ensure the maintainable use of marine resources.

The North Pacific Fishery Management Council (NPFMC) takes by state policy prohibited commercial fishing in certain areas of the ocean due to scientific data uncertainty resulting from weather change. Similarly, the Arctic Management Zone remains off-limits to marketable fishing till adequate data becomes available to start the planning process for the development of commercial fisheries. North Pacific Anadromous Fish Commission's (NPAFC) Working Group on Salmon Marking (WGSM) to enhance research on salmon populations, migration patterns, and of climate changes impacts. To better understand how climate change may affect the ecosystems of the far eastern seas and Pacific salmon productivity and neighboring Pacific waterways, Russia proposes to carry out surveys in the Bering Sea, Okhotsk Sea and northwest Pacific Ocean (https://npafc.org/wp-content/uploads/ Public-Documents/2020/AR2020.pdf).

The Asia-Pacific Fishery Commission's (APFIC)member states have undertaken a variety of measures to adapt to and mitigate the effects of climate change, such as implementing climate-smart management techniques and developing environmentally conscious fishing to ensure adequate nutrition in the long run. For instance, Bangladesh's development plan includes fisheries that are robust to climate change. Several nations, such as the Philippines, Malaysia, Nepal, and Cambodia, are attempting to set up early-warning and communication systems about climate change that are aimed at specific communities (Wongbusarakum et al., 2017).

Fixed quota allocation, or fixed quota shares, is a principle used in fisheries management to determine how the total allowable catch (TAC) is divided among different fishing entities, often countries or specific groups of fishers, amongst EU member nations, is one of main tenets of European Union's Common Fisheries Policy (CFP; 1970) (Sobrino & Sobrido, 2017).

Climate-adaptive management strategies are already incorporated into Australia's fisheries governance to increase the fishing industry's resistance to climate change. The Climate Adaptation Program spent AUD 9 million on preparatory research between 2010 and 2014 (Creighton et al., 2016). 2018 saw the completion of an assessment of climate sensitivity and updated fisheries predictions, and throughout the previous two years, an Australian Commonwealth fisheries climate adaptation handbook (Fogarty et al., 2021) was created.

Using an ecosystem-based approach, the auxiliary Marine Strategy Framework Directive (MSFD) objectives to "promote sustainable use of the seas and conserving marine ecosystems" (Article 251, 4) by harmonizing current environmental protection, management, and legislation, such as the Habitats Directive and Common Fisheries Policy (CFP) (European Commission, 2020; European Union, 2008). It is still not possible for member states to attain MSFD's lofty goal of attaining Good Environmental Status by 2020–2024 (Korpinen et al., 2021).

NOAA Fisheries' adoption of the Climate Science Strategy in 2015 is indeed a significant step in recognizing and tackling how climate change is affecting marine resources and related management regimes. The Climate Science Strategy reflects NOAA Fisheries' commitment to a proactive approach in understanding and responding to climate-related challenges. The inclusion of seven objectives in NOAA Fisheries' Climate Science Strategy reflects a comprehensive and forward-thinking approach to providing decision-makers with critical information to address the challenges posed by changing ocean conditions (Busch et al., 2016). The use of Customized Regional Action Plans to oversee the implementation of NOAA Fisheries' Climate Science Strategy is premeditated approach to tailor the strategy to specific regional contexts and challenges. This approach recognizes the diversity of ecosystems, fisheries, and stakeholders across different regions, allowing for targeted efforts to address the impacts of climate change (NMFS, 2021).

DIRECTION FOR FUTURE RESEARCH

During a period when the demand for food resources worldwide is rising (Barange et al., 2014), observed knowledge (Weatherdon et al., 2016) and predictable (Gaines et al., 2018) due to the worldwide effects of global warming on fisheries, new methods must be used to evaluate their capacity for sustainability and adaptability across a wide range of systems and sizes (Thiault et al., 2019). Anthropogenic (human-induced) climate change has far-reaching impacts that extend beyond environmental consequences. It influences various aspects of human societies, economies, and lifestyles. These factors run the risk of causing significant adjustments to sustainable yields or large increases in the price of fish products, which could have a detrimental impact on the health, well-being, and dietary requirements of a large number of people (Golden et al., 2016). How to thoroughly assess fisheries sustainability to successfully foresee and prevent dangers to fisheries economies and livelihoods under climate change is a major challenge. Unfortunately, due to a lack of information on fishing efforts and exogenous factors (such as weather, expenses, and prices) that affect fishing, this condition is frequently left untreated (Lam et al., 2016).

The absence of clear financial and legal incentives for adapting to climate change, especially in fisheries rules. It is nevertheless difficult to include specific techniques for adapting to changing climates into the legal and financial frameworks pertaining to marine governance, even in spite of the growing political recognition of the role that healthy seas play in reducing the effects of climate change (Lindegren & Brendar, 2018; Tittensor et al., 2019). This can result in the implementation of actual adaptation measures being insufficient or nonexistent. A greater amount of focus and funding will probably be required to assist the fishing industry in adjusting to current and upcoming climate change. Because it is linked to food security, an inability to adapt and a decline in fisheries production have an impact on both the sector and the world's expanding population (Béné et al., 2016; Loring et al., 2019).

It has been challenging to convert knowledge regarding the consequences of global warming into information that can be put into practice, mostly because of the system's increased uncertainty and probabilistic representation (Sillmann et al., 2021; Skern-Mauritzen et al., 2018). Building climate-resilient fisheries requires setting adaptive and climate-informed specific population restrictions determined on assessments of stocks that take into account new observations rather than historical ones. Enhancing specific components within the climate-enhanced ecosystem-based fisheries management (EBFM) strategy to ensure efficient climate adaptation. Focusing on the improvement of ecosystem indicators and ecological risk assessments, along with the integration of climate vulnerability assessments (CVAs), is a strategic approach.

Hare et al. (2016) and Hobday et al. (2011) emphasize the role of Climate Vulnerability Assessments (CVAs) in determining priorities for Ecosystem-Based Fisheries Management (EBFM). The assessments, as outlined by these studies, focus on evaluating the likelihood that various ecosystem features and fisheries components affected by climate change. The importance of climate-aware system-level indicators within the framework of climate-enhanced Ecosystem-Based Fisheries Management (EBFM). These indicators play a crucial role as they provide a foundation for management initiatives such as control rules or ecosystem-based harvest limitations. (Williams et al., 2021).

A critical aspect of fisheries management in the context of a rapidly changing ocean due to climate change. The need for grounded research, regular monitoring, and adaptive strategies is crucial for ensuring the sustainability of living marine resources. In an ideal world, this would mean deploying integrated ocean observation systems, sophisticated sampling techniques (underwater drones, gliders, sail drones, and eDNA) and open ecosystem status updates to expand the survey's temporal and geographical coverage (Link et al., 2023).

CONCLUSION

Climate change is causing substantial impacts on marine life and fisheries, primarily through alterations in fish distributions, abundance and migratory patterns. Warming oceans are resulting in fewer productive fish species, as changing predator-prey interactions hinder species from keeping up with favorable conditions. Fish stocks are shifting pole ward, creating challenges for fisheries management, especially when fish move across international borders or require significant reductions in catch. Although some species may expand their ranges, overall fish biomass is expected to decrease, potentially exacerbating overfishing. Adaptive management strategies and international cooperation are necessary to maintain sustainable fisheries in the face of climate change.

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