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(RESEARCH ARTICLE)

The impact of climate change on the reproductive biology and population dynamics of fishes: Implications for fisheries and food security

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Abstract

The purpose of this paper is to review and evaluate published literature on the impact of climate change on the reproductive biology and population dynamics of fishes. A systematic method was utilized to access published literature on "Impacts of Climate Change on fishes and fisheries". A total of fifty-two (52) research papers published between the years 1973 to 2024 were accumulated and used for this review. A subjective approach was used to select the topics: impact of climate change and fishes and fisheries. The physical and biological impacts of climate change on fisheries were evaluated. In addition, the role of fisheries in food security to combat the global hunger index of human beings was assessed in this review paper. Strategies to be implemented by fisheries to mitigate the effect of climate change was also presented in this review. The literature accessed revealed that fish is an important resource to the economies of many countries and a source of natural protein. As the average per capita food supply from fish and fisheries products continue to rise in developing nations, it is falling in underdeveloped nations. The published works of literature established that the global fisheries and fish population dynamics, reproductive biology, abundance and distribution are all affected by climate change. This review highlights the fact that more extensive studies on the impact of climate change on fishes and fisheries should be done in neotropical countries since there are gaps of such information on research and published data in these biodiversity rich regions.

Keywords: Climate change; Fishes; Fisheries; Food Security; Reproduction; Population Dynamics

1. Introduction

1.1. Climate Change and Fishes

As the most long-term threat to marine ecosystems, climate change is a harsh reminder of the impact humans are experiencing on the environment [11] [12] [13] [14] [15] [51] [124] [125] [126] [127]. These physio-chemical changes in aquatic conditions, coupled with overfishing, habitat degradation, and pollution, exacerbate the problem facing the world's fisheries resources [30] [60] [133]. Fishery resources across a range of biological scales, including individuals, populations, communities, food webs, and huge ecosystems, may be directly or indirectly impacted by climate change [45] [52] [73] [74]. The examination of fish communities' distribution patterns in light of climate change is a relevant topic in the field of international fisheries ecology [39] [103].

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The increase in atmospheric greenhouse gases, especially carbon dioxide, has caused a rise in average sea surface temperatures (SST), one of the numerous consequences of climate change [11] [12] [13] [14] [15] [51] [124] [125] [126] [127]. Fishes are ectotherms and as such are sensitive to temperature variations. Tropical marine fishes that reside near upper thermal limits in a habitat that is generally thermally stable are particularly susceptible to SST changes [85] [107]. Rising ocean temperatures have the potential to harm fish at all stages of their life cycle, as well as at all levels of their biological and ecological organization, including population, ecosystem, and community [85] [106] [109].

Growth and reproduction are two biological processes in fishes that typically respond favorably to modest rises in ambient temperature, but can also deteriorate at temperatures higher than the thermal optimum of a species [106] [107].

The main goal of this review is to illustrate how climate change may affect an already finite resource (fishes) that contributes to food security and poverty alleviation. The coastal zone is currently under physical, ecological, and socioeconomic stress, which will be made worse by climate change [69] [82] and the fisheries of several tropical developing nations are also seriously and permanently threatened by a changing climate. The expansion of fisheries and mass fish production have produced enormous benefits. Fisheries and aquaculture are vital to nutrition, revenue production, and food supply on a local and global scale [36] [82].

Approximately 43.5 million people work directly in the fishing industry worldwide, with the bulk of those employed in developing nations. When one accounts for fisheries workers in related supply, marketing, distribution, and processing businesses, the industry supports the livelihoods of around 200 million people [7] [82]. About 10 million people depend on the fishing industry for their livelihood, and 20% of the population gets their animal protein primarily or exclusively from it. As a result, the industry contributes significantly to increasing food availability and migrates threats to food security in a number of nations that are highly food-insecure. For instance, fish accounts for up to 75% of the protein in Senegal's diet [82] [90]; in Ghana, the average annual fish consumption per person is 22 kg, or 15% of the protein obtained from fish; and in Sierra Leone, fish accounts for 63% of the total animal protein consumed [6] [82].

One of the most traded food items in the geographical region is fish. The fish trade contributes to national food security and dietary diversity by bringing in food for local consumption, supporting national government operations, and serving as a significant source of cash flow for paying off foreign debt. However, national economic planning frequently minimizes or disregards the sector's advantages. This is mostly due to the fact that small-scale artisanal fisheries, which produce well over half of the fish produced, are frequently overlooked in national statistics and so do not show up as contributors to the economy or food security [82].

The significance of fisheries is sometimes underestimated, yet it is hard to overlook how climate change will affect this industry as well as coastal and riparian communities more broadly [7] [19] [54] [82]. In addition to numerous other concurrent pressures including overfishing, habitat degradation, pollution, introduction of new species, and other related issues, climate change poses serious dangers to fisheries [19] [82]. Around the world, 20% of targeted fishery resources are moderately exploited, 52% are fully exploited with no plans for further increases, 19% are overexploited, 8% are depleted, and 1% are recovering from previous depletion, in comparison to the level that would support maximum sustainable yield [54] [82]. The biophysical features of the aquatic environment changing and extreme events happening more frequently will have a big impact on the fish ecosystems. This will have a variety of effects on food security [70] [82] [108].

Initially, the loss of certain fish species will result in less fish available for local consumption. Additionally, the migration of many fish species to aquatic environments with ideal climates will have a significant impact on fishermen who are unable to pursue fisheries because of political (border) and economic constraints. Moreover, since small-scale fisheries provide the majority of the fish harvested for export in many developing nations, this will result in less fish produced and less money from fish export, which will reduce the ability to import food and exacerbate national food insecurity [7] [19] [54] [70] [82] [108].

2. Material and methods

The topic “impact of climate change on fishes and fisheries” was the subject of a systematic review using “Google Scholar,” a web-based search engine which provides a quick and easy way to search and access published literature from articles, journals and books. Thematic search terms such as impact, climate change, fishes, fisheries, food security, reproduction and population dynamics were used in the search.

The subjects that were evaluated in this research were chosen using an approach that involved assessing at the related works of literature. Publications between the years 1973 to 2024 were acquired for this review. However, not all of the articles that were reviewed, were used in this study because the major objective was to assemble data from recent research (past 10 to 20 years) on impact of climate change on fishes and fisheries. However, papers that contained relevant literature from as far back as the 1900's and the 2000's were also utilized for this review. Sixty-eight (68) research articles were retrieved and included in this review and literature from fifty-two (52) papers published between the years 1973-2024 were presented in this paper.

The search yielded different results: Some articles had all the thematic keywords and some were obtained that were specific to legislation measures and management approaches to mitigate the effects of climate change to be employed by fisheries, while others were specific on fishes' responses to environmental factors, Canadian and Antarctic perceptions of climate change on fishes and future predictions by climate models for the global fish population.

3. Results

When searching "Google Scholar" for information on impact of climate change on fishes and fisheries, a total of 356,000 was retrieved. Among the results obtained from the search, a total of 28,700 were published within the years 2000-2023, 29,800 were published between the years 2010-2023 and 28,600 were published within the years 2015-2023. 40,200 publications between the years 2010-2023 presented information on the impact of climate change on fishes and 195,000 publications between the years 2010-2023 addressed the impact of climate change on fisheries.

However, not all the results retrieved for this research focused on both the impact of climate change on fishes and fisheries. While some focused solely on climate change on fishes, others examined climate change on fisheries as a separate topic. Some research papers were specific to legislative measures and management approaches to mitigate the effects of climate change to be employed by fisheries. Additionally, research ally focus on fishes' responses to environmental factors, Canadian and Antarctic perceptions of climate change on fishes and future predictions by climate models for the global fish population.

4. Discussion

4.1. Regulation of Fish Reproduction

The hypothalamic-pituitary-gonadal axis (HPG), which controls fish reproductive function, is modulated by seasonal variations in near-environmental parameters in terms of neuroendocrine and endocrine activity [23] [25] [135]. The ovaries produce estradiol-17β (E2) and 17,20β-dihydroxy-4-pregnen-3-one (17,20βP), while the testicles produce testosterone (T) and 11-ketotestosterone (11KT). The hypothalamus produces gonadotropin-releasing hormone (GnRH), which stimulates the pituitary's secretion of follicle-stimulating hormone (FSH) and luteinizing hormone (LH). The essential function that some enzyme complexes, including aromatase (P450aro) in females and 11β-hydroxylase (11βH) in males, play in steroidogenesis is a remarkable feature of teleost reproduction. As a precursor, T is converted to E2 in the ovaries by aromatase, while 11βH mediates the conversion of T to 11KT in the testicles [23] [25] [87] [135].

In both sexes, the gonads' production of sexual hormones promotes vitellogenesis and egg maturation in females and spermiation in males. In sequential hermaphrodite species, these hormones also regulate the development of secondary sexual traits and reproductive behavior [23] [25] [87] [135], as well as the physiological processes of gonad differentiation and sex change [23] [58] [64] [115].

4.2. Influence of Temperature on Fish Reproduction

The physiological influence of temperature on the regulation of fish reproductive activity, particularly in tropical species, remains largely unknown. At several critical points in the functioning of the HPG axis, temperature fluctuations most likely result in changes in the expression of genes that regulate the production of reproductive hormones and the enzymes that go along with them [23] [25] [77] [99]. Since these molecules are thermosensitive and thermolabile, temperature directly affects metabolic processes at the cellular level, influencing the synthesis, structure, and activity of the hormones, neurohormones, and enzyme complexes involved in steroidogenesis [23] [25] [77].

The reproductive processes of organisms can be adversely affected by temperatures above their thermal physiological tolerance range in three ways: (1) by suppressing the expression of the genes that regulate the synthesis of reproductive hormones and related enzymes; (2) by changing the levels of hormone activity in the bloodstream and the activity of gonadal enzymes; and (3) by changing the specific affinity of reproductive hormone receptor cells (as demonstrated in

Table 1) [23] [81] [98]. As a result, temperatures that are higher than ideal can have an impact on oocyte development and maturation, spawning and ovulation timing, egg quality, and female reproductive physiology [4] [23] [25] [77] [99].

Table 1 Impact of climate change on fish reproductive biology and population dynamics

Impacts	**Description of impacts**	**Author(s)**
Effect on Female's Reproductive Cycle	Endocrine alterations in the HPG axis of fish can be triggered by small temperature increases, especially in tropical regions. Temperatures over 30 °C have the potential to interfere with the endocrine processes involved in reproduction in these species. In general, a rise in temperature causes fish reproductive cycles to be mistimed e.g. red grouper (*Epinephelus morio*) in the western Atlantic, including the Gulf of Mexico and the Caribbean. According to the results from experimental research, this impact is more pronounced in females than in males. The reduction or inhibition of aromatase and E2 synthesis and activity when environmental temperature rises above a species' physiological thermal tolerance zone causes this mistiming in a female's reproductive cycle. The season in which the temperature rises in relation to the season in which a species reproduces will determine how off the timing is. The impacts of temperature will rely significantly on both the annual pattern of thermal change and the ambient temperature. High temperatures therefore have the potential to accelerate or shorten the reproductive season in spring or summer-spawning species and postpone it in fall-spawning species in temperate locations. Fish species often spawn for much of the year, if not all year, in tropical climates. In species that reproduce only after they cross a thermal threshold, temperature increases in certain areas can precede the start of the breeding season. As long as the temperature range that is compatible with reproduction does not surpass its upper limit, the reproductive season may continue longer than expected. During the reproductive season, ovulation and spawning may eventually be temporarily halted if the maximum temperature rises above the physiological tolerance limit of a tropical species. According to research in gonads of both sexes, high temperatures modify gonad development and prevent gamete emissions by suppressing the genes that code for steroidogenic enzymes. Since the date of hatching and the ideal environmental circumstances for larval survival are not aligned, mistiming fish reproductive cycles can result in detrimental effects on gamete quality and larvae development. The reproductive biology of the following populations of Campeche Bank and neotropical species were examined: red grouper between 1988 and 1993; black grouper (*Mycteroperca bonaci*) and gag (*Mycteroperca microlepis*) between 1996 and 2001; red snapper (*Lutjanus campechanus*) between 1999 and 2000; red hind (*Epinephelus guttatus*), tiger grouper (*Mycteroperca tigris*), and yellowfin grouper (*Mycteroperca venenosa*) between 2008 and 2010, as well as yellowtail snapper (*Ocyurus chrysurus*) and lane snapper (*Lutjanus synagris*), and hogfish (*Lachnolaimus maximus*) between 2011 and 2015. Although the ovaries best reflect the duration of fish spawning activity, the seasonality of spawning in this species was evaluated in the current study solely taking into account the female reproductive cycle. The reproductive season for groupers on the Campeche Bank is shorter (4–7 months) than that of snapper (*Lutjanus spp.* and *O. chrysurus*) and hogfish (*L. maximus*) (11–12 months). The female black grouper (*M. bonaci*), on the other hand, is sexually active year-round. All groupers, including black grouper, exhibit spawning maxima in winter and/or early spring, when temperature and photoperiod gradually	(Sadovy, 1996); (Brulé *et al.*, 1999); (Brulé *et al.*, 2003); (Brulé *et al.*, 2003); (Pankhurst & Porter, 2003); (Munday *et al.*, 2008); (Brulé *et al.*, 2010); (Pörtner & Peck, 2010); (Pankhurst & Munday, 2011); (Trejo-Martínez et al., 2011); (Caballero-Arango & Estrategia, 2013); (Caballero-Arango *et al.*, 2013); (Miranda *et al.*, 2013); (Nóh-Quiñones, 2017); (Dahlke *et al.*, 2020); (McKenzie *et al.*, 2021); (Trejo-Martínez et al., 2021); (Brulé *et al.*, 2022)

	increase. Some groupers begin maturing in fall (red hind, red grouper, and gag), while others do so in winter (tiger grouper and yellowfin grouper). With the exception of black grouper, none of the species spawn in the fall when the temperature and photoperiod start to drop, or in the summer when the SST reaches its peak values between July and September. The spawning peaks of snapper and hogfish, on the other hand, occur in the spring and autumn, respectively, when temperature and photoperiod rise or fall. If the temperature of the water has the greatest influence on the time of reproductive cycles in tropical fish, then any increase in temperature that beyond the maximum threshold of their physiological thermal tolerances may cause mistiming. It is unknown what temperature above a certain point affects grouper, snapper, or wrasse reproduction. However, the heat suppression of reproduction usually manifests itself at 30 ∘C and above in certain tropical fishes. This temperature might be the present thermal tolerance limit for the study's species because they showed a range of spawning temperatures, either in the field or in captivity, that never went over 30°C.	
Effect on Sexual Determination	In many gonochoristic fishes, the determination of sex is influenced by either environmental (environmental sex determination-ESD) or genetic variables (genotypic sex determination-GSD). In fish species with GSD, genes typically found in the sexual chromosomes determine sex at conception. In ESD, the environment, particularly temperature at a critical phase of cell sensitivity (the embryonic or larval stage), determines sex following conception. Temperature sex determination (TSD) is the term used for this. However, in certain GSD species, environmental influences of exogenous elements (GSD + EE), particularly temperature effects (GSD + TE), might affect sex determination throughout embryo and larval development. The temperature may therefore finally orient phenotypic sex, or gonad differentiation, in species with GSD + TE in the other direction from that determined by genetics. The proportion of males in some thermosensitive gonochoristic species (TSD or GSD + TE) rises with temperature, leading to an imbalance in the sex ratio of the population. The suppression of the expression of thermosensitive genes that code for the production of aromatase (e.g., cyp19a1aingonads) may account for this increased proportion of males. Low aromatase activity inhibits the conversion of T to E2, resulting in an imbalance in sexual steroids favoring the 11-oxygenated androgens (e.g., 11-KT) and making undifferentiated individuals more masculine. Since E2 functions as a natural modulator of ovarian differentiation, aromatase activity may consequently play a crucial unidirectional role in determining sex. Regarding the effect of temperature on gonad development in hermaphrodite species, very little information is currently known. Although all undifferentiated gonads of some protogynous or protoandrous species first differentiate into immature ovaries, it is thought that ovarian differentiation may be the main status in sequential hermaphrodite fishes. Immature ovaries then differentiate to become mature ovaries or testicles. Snapper populations, like the red snapper from the Campeche Bank, typically display traits of gonochoristic species, such as balanced sex ratios, similar average sizes, and a similar size range between sexes. However, the monandric protogynous hermaphrodite sexuality of grouper and hogfish exhibits a bimodal size-frequency distribution and a biased ratio to females. Minor females have an average size smaller than average males (all secondary males); the size range of females barely	(Chan & Yeung, 1983); (Grimes, 1987); (Sadovy & Shapiro, 1987); (Baroiller *et al*., 1999); (Valenzuela *et al*., 2003); (Bruslé & Quignard, 2004); (Nakamura *et al*., 2005); (Ospina-Álvarez & Piferrer, 2008); (Penman & Piferrer, 2008); (Brulé *et al*., 2010) (Guiguen *et al*., 2010); (Kobayashi *et al*., 2012); (Wootton & Smith, 2015); (McKenzie *et al*., 2021); (Brulé *et al*., 2022)

	overlaps that of males, as seen in the case of the Campeche Bank's tiger grouper. In snapper, the decrease in aromatase activity imposed on by ocean warmth brought on by climate change may cause a greater percentage of undifferentiated individuals to become masculinized, hence reducing the proportion of females. This could lead to an imbalance in these populations' sex ratio, favoring males without significantly changing either sex's average size or range of sizes. Since it is believed that temperature changes have the same physiological effects on steroidogenesis as those seen in gonochoristic snapper, a reduction in or inhibition of aromatase activity may also contribute to the early masculinization of some undifferentiated individuals in monandric protogynous hermaphrodite groupers and hogfish. These would cause small-sized males (principal males) to emerge in the populations, which would reduce the overall percentage of females. In this scenario, depending on the degree of early masculinization, hermaphrodite species would show a less biased sex ratio towards females, or possibly a balanced one. The average male size would gradually decrease to match that of females, incorporating a mix of primary and secondary males. Consequently, the male size range would expand and eventually overlap the female size range. As a result, these protogynous hermaphrodite species' sexuality pattern may evolve from monandry, or only having secondary males, to diandry, or having both primary and secondary males, as a result of ocean warming brought on by climate change.	
Effect on Sex Change	The expression level of the genes involved in aromatase biosynthesis is a critical element in the physiological process of exchange in every hermaphrodite species. In these species, elevated blood levels of E2 are indicative of the functional female phase, whereas elevated serum levels of 11KT are indicative of the functional male phase. In protandrous animals, an increase in E2 levels brought on by aromatase gene activation promotes the transition from male to female sex. Alternatively, in animals that are protogynous, the inactivation of these genes results in a reduction of aromatase and E2 levels and, through a cascade effect, an elevation of 11βH and 11KT levels, which supports the transition from a female to a male sex. Despite the influence that social variables have over the process of sexual inversion, temperature rising may prevent or cause an exchange in sequential hermaphrodite species. In protandrous animals, high temperatures may prevent the development of the aromatase genes, which in turn prevents the sexual inversion from male to female. In animals that are protogynous, suppression of the expression of the aromatase gene may promote sexual inversion from female to male and cause sex to change at a younger age and smaller size. Ocean warming may prevent aromatase biosynthesis or activity in populations of monandric species like hogfish and grouper, which would cause an early shift in the sex ratio in favour of males. Consequently, the female-size range would narrow, the male size range would widen, and the average size of males and females would decrease. The early sexual inversion of females could further skew these ratios in favour of males, with smaller average sizes and a wider size range for males and even smaller average sizes and a narrower size range for females, assuming a hypothetical early masculinization in a fraction of the undifferentiated individuals.	(Baroiller *et al*., 1999); (Delvin & Nagahama, 2002); (Nakamura *et al*., 2003); (Frisch, 2004); (Nakamura *et al*., 2005); (Guiguen *et al*., 2010); (Pankhurst & Munday, 2011); (Miranda *et al*., 2013); (McKenzie *et al*., 2021); (Brulé *et al*., 2022)

4.3. Impact of climate change on fisheries

Fisheries and the effectiveness of their management have always been impacted by natural climate oscillations, especially those occurring on a medium (decadal) scale [61]. Over the next 50 to 100 years, the atmosphere and ocean will continue to warm, sea levels will rise as a result of thermal expansion of water and glacier melting, the pH of the ocean will decrease (becoming more acidic) as more carbon dioxide is absorbed, and circulation patterns may alter locally, regionally, and globally [17] [82] [83].

It is impossible to generalize about how climate change affects fisheries, but there is a good chance that it will cause variations in fish populations [19] [82]. Many disadvantaged communities and national economies that rely heavily on fisheries could face serious economic effects as a result of fluctuations in fish stocks [19] [82]. Physical and biological changes are in two categories of how fish stocks are affected by climate change. Ocean acidification, variations in salinity, sea level rise, and sea surface temperature rise are examples of physical changes [4] [23] [25] [77] [99]. The distribution of fish stocks and changes in primary output are examples of biological changes [4] [23] [25] [77] [99]. The already-stretched resource will suffer from the combination of these causes [82].

4.4. Physical Changes

4.4.1. Water Surface Temperature Rise

The global climate is mostly controlled by the oceans. Due to their significantly higher heat capacity (and thus net heat uptake) than the atmosphere [7] [82], they are able to absorb a sizable portion of the world's heat emissions. The dynamics of the region's aquatic habitats may alter as a result of these temperature variations in the ocean. Fish landings may decrease as a result of altered ocean dynamics, particularly in coastal fisheries, and fish migration patterns [3] [82]. For instance, rising sea temperatures may have an impact on upwelling in the Gulf of Guinea, rendering the ocean waters unfit for fishing and perhaps leading to a decline in fishing operations [3] [82] [128]. Additionally, susceptible to the effects of climate change, inland waters could also be significantly influenced [69] [82].

Water stress will rise sharply in areas that are already quite dry, according to the worldwide Dialogue on Water and Climate (2004). The rising sea surface temperature is one of the challenges that inland waters are dealing with [82]. The warming in Africa is most likely going to be greater than the global annual mean warming throughout the region and in all seasons, according to Christensen *et al.* (2007). Drier subtropical regions will warm more than the wetter tropics, which will lead to a decrease in rainfall [82].

The sea surface temperature rises and the patterns of ocean circulation that carry warm and cold water around the world shift as the oceans absorb more heat. Marine habitats can be affected by variations in sea surface temperature in a number of ways [125] 126] [127]. Biodiversity is also threatened by rising water temperatures. Fish typically have a predilection for heat that maximizes physiological functions [1] [82]. A species' existence is at jeopardy if the water temperature goes above its upper limit of tolerance. Since there are no fish in the majority of Bangwa Rivers, women in the Lebialem Highlands of Cameroon have taken to hunting tadpoles and frogs, as demonstrated in a study by Urama & Ozor (2010). But even the frog and tadpole populations have drastically decreased as a result of warmer rivers that have brought more predator fish to a region where they had never before lived [4] [23] [25] [77] [82] [99].

4.4.2. Sea Level Rise

Sea levels have already risen 10–20 cm globally during the 20th century, mostly as a result of thermal expansion. Based on the full range of 35 climate projection scenarios provided by the Intergovernmental Panel on Climate Change, a global rise in sea levels of 9–88 cm is anticipated by 2100 [34] [82] [93]. Sea level rise in coastal locations may change the salinity of estuarine habitats, submerge wetlands, and lessen or completely eradicate the amount of submerged vegetation [4] [23] [25] [77] [99]. These changes will have a negative impact on species that depend on these coastal habitats for recruitment and reproduction [66] [82].

Furthermore, due to rising sea levels, current fishing infrastructure such as jetties and fish storage centers situated on the coastal margins, just above the mean high tide line, would be more frequently inundated by storms and tidal waves. Sea level rise will therefore most certainly have a detrimental effect on fish landing, processing, and marketing facilities as well as fishery production (since salt affects the fish stock and its habitat [4] [23] [77] [82].

Studies evaluating the effects of sea level rise in the coastal regions are extremely rare. However, there is some data regarding the effects of sea level rise in several of the coastal towns with the highest population. For instance, Nigeria is vulnerable to seawater intrusion into coastal freshwater resources due to its 800 kilometers of low-lying coastline, which stretches from Lagos to Calabar. Aquaculture and inland fisheries will suffer as a result. Rising waters have ruined the livelihoods of many who formerly depended on fishing in coastal areas [4] [23] [34] [77] [82] [128].

Another United Nations Human Settlements Program (UN-HABITAT) assessment from 2008 states that because lowland marshes and lagoons predominate in the coastal zone, a sea level rise in Abidjan is projected to submerge 562 square kilometers of the region's coastline. According to the same assessment, Mombasa, which is located in the coastal region of East Africa, may see a 0.3-meter rise in sea level, rendering a sizable portion of its land untenable and decreasingly productive as a result of salt stress [4] [23] [34] [77] [82] [128].

4.4.3. Increasing Water Salinity

There are several ways in which climate change can raise or lower the salinity of water. Water nearer the poles have become fresher, whereas tropical waters are getting more and more salty. This emphasizes that, in comparison to seas in higher latitudes, tropical oceans are most likely to be more negatively impacted by possible increases in water salinity [4] [23] [25] [77] [82] [99].

The impact of alterations in water salinity varies based on the organisms' tolerance level and the habitat type, be it freshwater, marine, or estuarine. Anthropogenic climate change is expected to cause some freshwater ecosystems to become more salinous [68] [82]. Due to their detrimental effects on the organisms' capacity for osmoregulation, these physical alterations will damage the populations of plankton and larger prey fish species [82] [113].

Empirical research has demonstrated that salinity variations adversely affect zooplankton populations, especially in freshwater environments. Small increases in saline levels have a negative impact on the zooplankton communities found in low-lying coastal tidal lakes and wetlands [82] [113]. The biological functioning of these valuable but vulnerable ecosystems may be further disrupted by such changes in zooplankton abundance, they caution. Changes in the populations of zooplankton or other planktonic primary and secondary producers upset the food chain, as will be covered in more detail in the section that follows, and this has a detrimental effect on fisheries [82].

According to Marshall & Elliot (1998) and Abowei (2010), salinity is also thought to be one of the most significant factors affecting an organism's ability to survive in estuarine ecosystems. This can be achieved directly by damaging the organisms or indirectly by destroying their habitat, which includes their breeding and nursery grounds. Blaber (1997) reported that all estuary fish are euryhaline, or able to adjust to variations in salinity; however, the degree to which they can do so differs among species, which means that variations in salinity may have an impact on the distribution of these fish.

Changes in salinity can negatively affect estuary fish species indirectly, even if they may not directly affect them [82]. For instance, 60% of Senegal's mangrove regions have been destroyed as a result of rising salinity in the water [11] [69]. Parkins (2000) calculated that the loss of marine harvest amounts to 300 kg for every acre of mangrove forest removed. Therefore, changes in the salinity of the water will have a disastrous effect on the fisheries in the area, endangering the lives of numerous coastal communities who are already disadvantaged [82].

4.4.4. Ocean Acidification

Most of the CO_2 emissions caused by human activity are thought to be able to be absorbed by the oceans [29] [82]. In water, CO_2 dissolves and reverts to carbonic acid. The waters are becoming dangerously acidic due to this chemical reaction [47] [82]. Although this helps to slow down global warming, ocean ecosystems are negatively impacted by increasing acidity brought on by dissolved CO_2 in saltwater. Since various species respond differently to different pH changes at different periods of their life cycles, it is difficult to estimate the influence on the ecosystem [82]. As stated by Dupont & Thorndyke (2009), research on ocean acidification is still in its early stages, and while the field is expanding quickly, high-quality data is still hard to come by. Le Quesne & Pinnegar (2011) stated that despite the weak knowledge base, it is imperative to offer prompt advice and a fair assessment of potential effects on marine fisheries.

Evaluating the direct and indirect chemical impacts on important marine ecosystem services, such fisheries, is necessary in order to quantify the implications of ocean acidification on human communities [38] [82]. Le Quesne & Pinnegar (2011) state that modifications to physiological processes, such as otolith formation, decreased growth of calcified structures, and successful fertilization, are examples of direct consequences. In the end, they might have direct effects on the entire organism, such as decreased growth and reproductive productivity, increased predation and mortality, changed feeding patterns and behaviors, lowered immunocompetence, and decreased heat tolerance [4] [23] [25] [77] [82] [99]. Modifications in nutrient recycling, impacts on biogenic ecosystems like coral reefs, and variations in predator or pray numbers are examples of indirect effects [4] [23] [25] [77] [82] [99].

Fish eggs and larvae may not be as fortunate as adult fish, which appear to be well-adapted to cope with low pH environments or greater CO_2 levels in seawater [97]. For instance, elevated CO_2 levels in the water may cause male gametes to narcotize, suggesting that acidification may worsen sperm restriction issues and hinder fertilization, with catastrophic consequences for marine life [26] [82]. The growth of bottom-of-the-food-chain invertebrates and plankton may be slowed by ocean acidification. Hence, acidification has the potential to change productivity at specific trophic levels, upsetting the intricate aquatic environment food chain and affecting fishery production [82].

A decline in the numbers of calcifying creatures, including mollusks, is one of the most likely socio-economic effects of ocean acidification. This could have major socioeconomic repercussions in the following ways: (1) decreasing export revenues for net mollusk exporting countries; (2) eliminating jobs for numerous fishermen engaged in mollusk farming and harvest; or (3) raising mollusk prices that may drive away marginal consumers, thus widening the wealth and protein divide between the rich and the poor [4] [23] [25] [77] [82] [99]. According to a 2011 study by Cooley *et al*. assessing national vulnerability to declines in mollusk harvests caused by ocean acidification, the most vulnerable countries will be those with low flexibility, significant reliance on mollusks for economic or nutritional purposes, and quickly expanding populations. The $1 billion U.S. shellfish sector is vulnerable to ocean acidification, and a 2015 study identified hot locations for this vulnerability, including the Pacific Northwest, Long Island Sound, Narragansett Bay, Chesapeake Bay, Gulf of Mexico, and places off Maine and Massachusetts. The fisheries of Alaska, which provide over 100,000 employment and around 60% of the commercial fish catch in the United States, are also under jeopardy [91].

4.5. Biological Changes

According to Taucher & Oschlies (2011) and Sumeila *et al*. (2011), fish distribution and primary production are already shifting as a result of climate change's impact on the trends of several significant biological processes. Food security is negatively impacted in many tropical coastal states by changes in fish stock distribution and primary production brought on by climate change. Fish are essential to aquatic biogeochemical processes, ecosystem architecture, and food web functioning because they are the most varied vertebrates, with over 35,000 species, and because they spend their whole life in water [41] [58] [59]. The future of neotropical and global fisheries and the diversity of wild fish is uncertain due to their great susceptibility to environmental changes brought on by climate change [37] [57] [137].

The great majority of fish responses to climate change are biological, such as changes in phenology and growth [44] [86] [118], extinctions, such as mass mortality [120] [137], and distribution range shifts, such as migration [102] [130] [138]. As a result, aquatic ecosystems are affected at all levels of ecological organization, i.e., from individuals to the ecosystems [30] [134].

4.5.1. Changes in Primary Production

According to Dulvy *et al*. (2010), one of the main obstacles to fish and fisheries production will probably be the connection between climate change and future ocean primary output. The availability of adequate and suitable food is regarded to be a major factor in fish larvae's survival during the planktonic stage. Therefore, in addition to the effects of production changes, recruitment and fish stock production may also be impacted by climate-induced changes in the phenology and distribution of fish larvae and their prey [19] [82]. There has been relatively little research conducted in the tropics, despite several studies evaluating the effects of climate change on the primary production of aquatic habitats in high latitude seas. The Lake Tanganyika instance is among the relatively few studies that are now available [19] [82].

One of the most productive pelagic fisheries in the world has historically been sustained by Lake Tanganyika. In recent years, the fishery has produced an annual harvest of 165,000 to 200,000 metric tons, accounting for 25–40% of the animal protein supplied to the populations of the surrounding countries [82] [83]. Increased water column stability has limited mixing, deep-water nutrient upwelling, and diffusion into surface waters because to a rise in surface water temperature and a localized drop in wind velocity [82] [95]. Over the last 80 years, this has resulted in a 20% decline in primary production [9] [82].

Fish yields can decrease by about 30% in response to a 20% decline in primary productivity, according to O'Reilly *et al*. (2003). The detachment from ecological processes caused by the weakening of hydrodynamic patterns is suggested by the breakdown of the catch's formerly robust seasonal rhythms, which coincided with the reduction in catch. These alterations in the pelagic fishing are in line with a change in the ecosystem's functioning over the entire lake [19] [82].

The rise in surface temperature is one of the principal factors influencing primary production in aquatic environments, while there are other aspects as well. According to O'Reilly *et al*. (2003), there will be significant increases in thermal stability and decreases in production in these huge lakes if air temperature rises by the 1.7 degrees that are expected for the next 80 years. They also caution that part of the world, where big lakes are vital natural resources for local economies, the human consequences of such subtle but progressive environmental changes could be disastrous.

4.5.2. Changes in Fish Distribution

One of the most frequently documented ecological responses of marine species is a shift in fish distribution [116]. It is thought that certain fish species adjust their latitudinal and depth ranges in response to environmental changes, such as rising water temperatures. Fish landings may decline as a result of shifting ocean dynamics, particularly in the coastal fisheries of several nations [3] [82] [128]. Given the significance of marine fisheries as a source of food, shifts in the overall quantity or geographic distribution of fish that are accessible for capture may have an impact on food security [32] [82].

Changes in the distribution of fish stocks have different effects at different latitudes. In an effort to find habitats with the ideal water temperature, certain fish species would travel directly north, which could lead to an increase in fish harvest in latitudes higher than average. Conversely, counties at lower latitudes, will probably lose some fish stocks and species. According to Cheung *et al.* (2009), changes in fish-stock distribution could occur anywhere from a 30–70% increase in high latitude areas to a 40–50% decrease in tropical areas. This is a significant obstacle for the majority of artisanal fishermen, primarily due to the high cost of following the fish stock, which means being limited to economic exclusive zones. Thus, the distribution of benefits and costs associated with fisheries will shift as a result of these changes in fish stock distribution, with some people benefiting and others losing [4] [23] [25] [77] [82] [93] [99].

4.6. Implications of climate change and effects on fisheries

4.6.1. Food security

Food security is a significant social and global concern due to the expanding population and persistent issues of hunger and malnutrition that plague many communities [61] [82]. "When all people at all times have access to sufficient, safe, and nutritious food to maintain a healthy and active life" is the commonly accepted definition of food security [56] [82]. Food quality, accessibility, and availability can all be impacted by climate change. Reduced agricultural output, for instance, might be the result of predicted temperature rises, altered precipitation patterns, altered extreme weather events, and decreased water availability [126] [127] [128]. In many areas throughout the world, aquatic foods are essential in the fight against hunger and food poverty. They are rich in vital minerals like as iron, calcium, zinc, iodine, vitamin A, and vitamin D. They are also high in Omega-3 fatty acids [114]. The loss of marine species and habitats can result from abrupt temperature increases and acidity. The distribution of fish stocks and the structure of ecosystems are changing as a result of shifting ocean currents and warming seas [78].

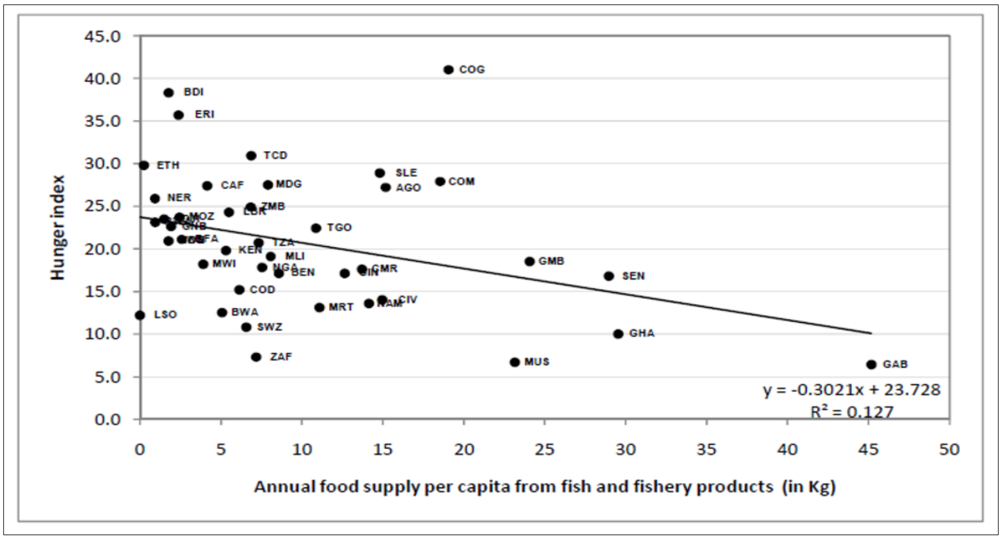
In most countries, population increase and the resulting strain on resources, water scarcity and recurrent droughts, inadequate rural infrastructure and services, and weak governance are the main causes of food insecurity [65] [82]. Climate change is most likely to make these worse.

Moreover, it is anticipated that in the upcoming years, food insecurity would worsen in many of the nations' due to persistently high food price spikes, which are partially caused by decreased food production, as well as related economic instability and climate change susceptibility [82]. The majority of countries depend on food aid due to their extremely low foreign exchange reserves for food imports. The majority of food aid that is sent to nations is not scheduled appropriately, failing to provide a buffer against food crises and frequently resulting in price and availability volatility. Therefore, increasing food production and addressing the possible effects of climate change on food production systems are necessary for governments to address food insecurity [82].

4.6.2. Fish and Food Supply

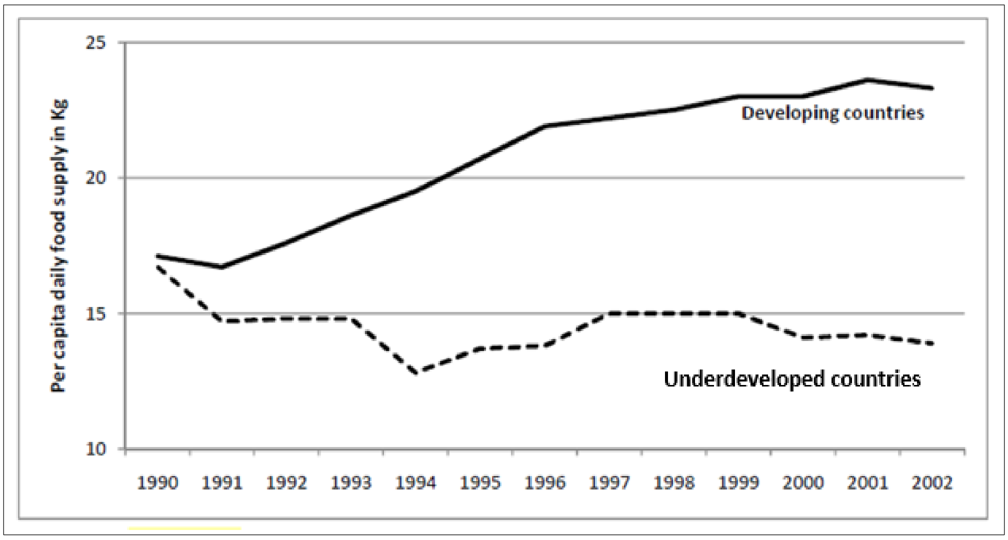
An additional attempt is made to investigate if the per capita food supply derived from fish and fisheries products played a role in reducing poverty. According to FAO FISHSTAT (2007), the amount of freshwater and marine fish, seafood, and goods derived from fisheries that are accessible to each individual for human consumption throughout the year is known as the annual food supply per capita from fish and fishery products [54]. According to Esteban & Crilly (2011), the FAO calculated this by adding up the fish production of a nation, subtracting exports, subtracting the amount of fishery production that is used for purposes other than food (such as reduction to meal, etc.), and adding or subtracting variations in stocks, also referred to as "apparent consumption." To determine the per capita food supply, the value is divided by the nation's total population.

The graphs below illustrate the negative correlation between the annual food supply per capita derived from fish and fisheries products and the hunger index. Figure 1 illustrates that hunger index values in nations with limited annual fish food supplies per capita are higher than the "alarming" threshold. Unless significant steps are taken to increase the number of fish that is consumed per person, these trends are quite likely to continue and will likely be made worse by climate change. While the average per capita food supply from fish and fisheries products is rising in developing nations, it is falling in underdeveloped nations (Figure 2) [82].



Source: FAO FISHSTAT (2007) & Mohamed & Uraguchi (2013)

Figure 1 Annual food supply from fish and fishery products and hunger index



Source: FAO FISHSTAT (2007) & Mohamed & Uraguchi (2013)

Figure 2 Per capita food supply from fish and fishery products in developing countries and underdeveloped countries

For instance, in Ghana, a 10,000 metric ton decrease in fish production (mostly as a result of climate change) would result in a moderate to severe rise in the prevalence of hunger and food insecurity. The similar decrease in the catch level in Kenya might push Ethiopia and Kenya from their current serious levels to highly alarming and alarming, respectively. Thus, the region, which already faces non-climatic challenges like overfishing and habitat destruction, may see an increase in food insecurity as a result of a potential influence of climate change and the ensuing decrease in fish supplies [82].

4.6.3. Fish Production and Poverty

The sustainable management of fishery resources for future global food security has drawn substantial attention from the public policy community. Fisheries resources are an important source of proteins, vitamins, and micronutrients, especially for many low-income communities in rural areas [61] [82]. Sustainable fisheries have the potential to alleviate poverty by creating income and wealth, acting as a social and economic booster in local communities and fostering economic expansion countrywide [82]. This section aims to illustrate the connection between poverty nations and total fish production.

The aggregate production from aquaculture and capture of all aquatic plants, fish, mollusks, crustaceans, and other aquatic animals in both inland and marine environments is referred to as the "total for all species." The Global Hunger Index (GHI) is a stand-in for the degree of poverty. The International Food Policy Research Institute (IFPRI) creates the index annually with the goal of measuring and tracking hunger on a global, national, and regional scale [62] [82].

The importance of fisheries should be highlighted by the association between the level of fish output and the hunger index. As a result, the industry should be given top priority when developing adaptation policies, and adequate funding should be allocated to sustainably raise fish production in these areas [82].

4.7. Investments to Climate-Proof Fisheries

In light of climate change, conservation of fisheries entails three key objectives: (1) lessening the demand on already-strained fishing resources; (2) permitting fish species to effectively adapt and settle; and (3) boosting the adaptive capacity and resilience of fisher communities. The effects of climate change on fisheries may have an impact on the four dimensions of food security: changes in habitats, stocks, and species distribution will affect the availability of aquatic foods; changes in seasonality, increased ecosystem productivity variance, and increased supply variability and risks will affect supply stability; changes in livelihoods and capture or farming opportunities will affect access to aquatic foods; and changes in utilization of aquatic products, such as the need for some societies and communities to adapt to species not traditionally utilized [4] [7] [23] [25] [77] [82] [99]. Increased and sustained investments in market development, fisheries governance, and the provision of economic incentive mechanisms are essential to reducing the potential effects of climate change on fisheries and food security and enhancing the resilience of many impoverished fisher communities [82].

4.7.1. Market Development

One of the strategic policy interventions that the majority of nations should create, implement, and further integrate into national economic planning frameworks is market development through private sector engagement and development. Artisanal fisheries provide more than 60% of the fish supplied to both domestic and international markets [54] [82]; in certain countries, this percentage might reach 90%. This is anticipated to strengthen the potential of fisheries as a means of promoting local economic development and the welfare of households and communities engaged in the sector (in terms of production, income, and consumption). It is possible to identify two strategic issues as the main focus of initiatives [82].

Investments to Support Sustainable Artisanal Fisheries Businesses

In the majority of nations, artisanal or small-scale fishing enterprises are highly active. They could be a long-term source of investment. It is possible for fishermen to sell their catch at competitive prices on a local, regional, and national scale while also preserving enhanced fish production systems that tackle overfishing, excessive water consumption, and environmental damage. In addition, mechanisms must be able to reduce operating expenses and fuel consumption, use less expensive technology, have a smaller environmental impact, and have a larger potential for creating jobs [82].

These are seldom used opportunities, however. For a variety of reasons, getting into larger and more promising markets and, consequently, greater prices, continues to be difficult. At landing sites, producers more frequently sell their goods to middlemen. They are unable to invest in long-term, profitable ventures due to the low prices they ultimately receive. Because the fishermen are poorly organized, they do not sell their products collectively or purchase inputs in large quantities, which would lower production costs and raise sales prices. The lack of coordination between small-scale fisheries and other private sector entities places them in a weak competitive position [82].

Small-scale fishermen also face difficulties obtaining loans; the amounts granted are frequently insufficient, and the repayment terms are not tailored to the cash flow of the enterprise. Many small firms must begin with small loans because larger loans require collateral or strong creditworthiness as requirements. They thus survive off of their meager savings. Furthermore, as most of these enterprises have seasonal revenue, the weekly payback plans are frequently not tailored to the cash flow of the company. Since there is more risk for lenders, seasonal loans are scarce in many of the nations where they are available. One may witness the common issue of the "missing middle" in the majority of the nation [82].

The ability to deploy low-cost fishing technologies suitable for different commercial species is another thing that artisanal fisheries lack. Modernizing fishing operations and practices with improved fishing boats, fishing gear, and post-harvest equipment is one example of adopting low-cost technologies. At a higher level, fish processing technologies that raise product value can be introduced to boost income and competitiveness. All of them require effective extension services to turn subsistence fishing into a sector capable of producing large economic opportunities. them services include research and advisory, business development, regulatory and quality-ensuring standards, information, and training [82].

Market Infrastructure to Address Post-Harvest and Income Losses

Three categories of losses are identified by an evaluation of post-harvest losses in artisanal fishing. First, fish that are thrown away or disposed of physically cause loss. Second, improper handling can result in physical damage or change, which lowers the value of fish. This is known as quality loss. Third, abrupt shifts in the market lead fishermen to reduce the price at which they can sell their catch [82] [131].

Fresh fish is more profitable for the majority of SSA's artisanal fishermen than cured fish, or dried fish. Nonetheless, infrastructure for setting up marketing space, insulated storage facilities, ice and refrigeration availability, efficient transportation facilities, access from landing sites to main roads, potable water supply wells, pumps, and fish reception and cleaning are all necessary for supplying large quantities of fresh fish. According to estimates [5] [82], post-harvest losses in nations range from 20 to 25 percent.

As a result, small-scale fisheries' onshore fish handling practices are in poor and chaotic condition, and they frequently employ antiquated and labor-intensive techniques such employing buckets and other locally manufactured materials to scoop fish out of boats. The vast quantities of fish left in shoddy sheds for open market auctions make this much more hazardous due to contamination. Elevated temperatures lead to a decline in the quality of fish sold, which in turn limits the potential of artisanal fisheries as a reliable source of high-quality products and income. Because fish has a high content of unsaturated fatty acids, it is more likely to oxidize free radicals when exposed to external circumstances for extended periods of time. Conventional fish preservation techniques, such as salting, sub-drying, and smoking, increase post-harvest losses because to bacterial deterioration, color changes, mold and insect infestation, and animal and bird pilferage [82].

4.7.2. Governance Structure

Many scientists are concerned about how fisheries and fish populations may be affected by global climate change, but not much has been done to mainstream fisheries governance into adaptation plans or incorporate observed changes or event-based thinking into management models [35] [82]. In order to efficiently manage fisheries resources, the government collaborates with many stakeholders such as communities, civil organizations, and the private sector through the development of policy tools and regulatory measures known as fisheries governance. It is essential for figuring out whether or not fisheries will continue to help the economy, way of life, and food security, and whether or not the possible negative effects of climate change on the sector can be avoided. According to Pinstrup-Andersen and Pandye-Lorch (1998), governments should support food security for all households and individuals by fostering a social and economic environment that gives everyone the chance to secure their own food security rather than by physically delivering the food that is required for all citizens. The same case can be made for improving community resilience to climate change's effects and supporting the ecological and economic sustainability of fishery resources [82].

Adaptation is a dynamic social process in which a society's capacity to act collectively plays a role in determining its ability to adapt [2] [82]. In aquatic environments, co-management, also known as cooperative management, can support local communities' efforts to become more resilient to climate change by distributing decision-making and resource management responsibilities among a variety of stakeholders [67] [82]. As the main asset of the impoverished, governments must invest in enhancing and utilizing the social capital of fishing communities. This could establish the framework for fishermen to actively participate in the development of adaptation policies and manage their resources by actively participating in the implementation and oversight of regulatory measures intended to enhance their standard of living [82].

Communities that heavily depend on fisheries for animal protein are typically impoverished and malnourished. As a result, initiatives must be taken to lessen the reliance of fishing villages on the industry and to diversify their sources of income. Communities will be less vulnerable to future, unprecedented effects of climate change as a result of these initiatives. This can be achieved by governments investing more and more in their nations to promote co-management of fisheries and by giving communities financial incentives to lessen the strain on the resource [82].

4.7.3. Economic Incentive Mechanisms

Economic incentives have been advocated for by many, mainly as a workable way to internalize environmental costs in cases when the efficacy of regulatory actions has been inadequate [10] [82]. Economic incentive systems, commonly referred to as payments for ecosystem services (PES), compensate for the advantages lost by adhering to specific natural resource use regimes or reward resource users for better practices in the use of natural resources.

There have been recent attempts to apply the same methodology to coastal and marine environments. A few current examples are the "defeso" program in southeast Brazil, which provides alternative livelihoods and no-take areas in Kubulan, Fiji, and compensates communities for losing income during the off-season (spawning or reproductive period) and the creation of marine protected areas [10] [82]. Another example is the community development fund that safeguards the habitat of grey whales in Laguna San Ignacio, Mexico.

The use of incentive mechanisms in aquatic environments can be quite difficult, in contrast to terrestrial ecosystems. Because aquatic ecosystems and resources are mobile, it can be difficult to adopt, monitor, and execute laws pertaining to them because ownership and property rights are frequently, if not usually, ill-defined and unrecognized. Nevertheless, by assisting them in diversifying their sources of income and offering improved community services like the advancement of post-harvest technology and value addition, these mechanisms can play a vital role in encouraging fishing communities to co-manage and restore their fisheries resources [82].

In order to enhance their standard of living, fishermen can participate in the management of their fisheries through co-management at the community level. However, experiences to date suggest that current co-management arrangements have mainly concentrated on the conservation and management of fish resources, rather than on utilizing them to support the economic development of fishing communities or as a means of reducing poverty, according to Sunde & Isaacs (2008). As a result, there have been multiple instances where the co-management approach to fisheries has failed miserably. Offering fishing communities financial incentives could be the solution to the issue. Fisher communities may receive financial incentives to make up for the short-term losses resulting from reduced fishing activity. This could provide livelihood benefits in addition to encouraging communities to preserve their fishing resources, so addressing the issue of food insecurity [82].

5. Conclusion

A nutritious, well-balanced diet should include fish [94]. In addition to being a major dietary source of heart-healthy omega-3 fatty acids, they also offer a substantial supply of protein and vitamins [94]. Along with vitamins A, D, and B, fish also contains important minerals like calcium, phosphorus, zinc, iron, selenium, and iodine. These nutrients help to lower the risk of noncommunicable diseases and malnutrition, which can occur when a high energy diet is combined with an unbalanced diet [49]. Consumed fish also carries nutrients across geographic borders, connecting various ecosystems. In nutrient-poor settings, fish's role as distributors and active or passive carriers of resources and energy can improve primary production [16] [75]. For most vulnerable and impoverished populations, fishing is a key source of livelihood. In addition to being one of the most traded food items in the area, the fisher sector employs a large number of men and women. Fish trade contributes to national food security and dietary diversity by funding national government operations, financing international debt service payments, and bringing in significant amounts of cash for the trade of goods into developing nations. However, the region's fisheries are seriously threatened by climate change. Physical and biological changes are the two main ways that climate change may affect fisheries. Physical changes include rising sea levels, increasing salinity, and acidification of the ocean and biological changes include adjustments to primary production and distribution of fish stocks. Such alterations may result in the loss of habitat, a reduction in the amount of food available and the balance between prey and predator, damage to coastal fish landing areas, danger to processing and marketing sites, and disturbances to the food chains of aquatic flora and wildlife. When these detrimental effects are added together, they will negatively affect the already-strained resource and lower fish productivity. However, decision-makers continue to pay little attention to the sector's benefits when it comes to formulating policies for food security and climate change adaptation. This is mostly due to the fact that small-scale or artisanal fisheries, which generate more than half of the fish produced, are not included in national statistics and therefore their contribution to the economy and food security is hidden. Based on the findings of the literature review, many of the published literatures that provided information on countries external to the neotropics. Therefore, there is a need for more research to be done in relation to climate change on fishes and species as well as possible strategies to mitigate its effect on global fish resources since there is a limited and dearth of data in this biodiversity rich region.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors hereby declare that this manuscript does not have any conflict of interest.

Statement of informed consent

All authors declare that informed consent was obtained from all individual participants included in the study.

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