Migration Letters

Volume: 20, No: S7(2023), pp. 1197-1214

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)
www.migrationletters.com

Vulnerability and Adaptation of Fish Production to the Challenges of Global Change

Roberto Carlos Mori Zabarburú[1], Guido Ayay-Arista[2*], Armstrong Barnard Fernandez Jeri[3], Edwaldo Villanueva Pedraza[4], Noeidler Delgado Tuesta[5], Sebanias Cuja Quiac[6]

Abstract

Global climate change increasingly threatens fish production units and ecosystems, creating an uncertain future for both wild fish diversity and global fisheries. Understanding how fish growth responds to changing environments is essential for indicating and predicting the impacts of climate change on fish populations, communities and even aquatic ecosystems. This study aimed to review the state of current research by analyzing data on the environment, producing units, species and response patterns from 35 papers published in the ScienceDirect and Scopus database; 20 of them are analyzed under the approach of the characteristics of the Fishing Units, and the remaining 15 were analyzed according to factors of global change. The findings determine that coastal communities engaged in artisanal marine fisheries have been studied primarily, and fish from freshwater ecosystems were relatively less studied than their marine counterparts. Global change effects were shown mainly influenced by the temperature variable reflected in inadequate fish growth (physiology and health) with negative effects both globally and locally.

Keywords: *global change, climate change, mitigation, fishing units, fish production.*

INTRODUCTION

The physical environment, the non-living part of the world, lays the foundation for all living things. (Fé-Gonçalves et al., 2020). An important factor of the physical environment is climate, which ultimately determines water availability and thermal conditions. (Van et al., 2020). These two factors interact to determine how an astonishing variety of organisms are distributed in different parts of the world. (Mabe & Asase, 2020). Due to anthropogenic activities, climate changes and their impacts are felt worldwide; Changes such as global warming, the greenhouse effect, sea level rise, melting glaciers, warming oceans, migration of aquatic organisms, prolonged winter and summer, as well as habitat deterioration, pose a major threat to the aquatic ecosystem. (Ninawe et al.,

[1] Instituto de Investigación, Innovación y Desarrollo para el Sector Agrario y Agroindustrial de la Región Amazonas (IIDAA), Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas. Chachapoyas 01001, Perú. E-mail: roberto.mori@untrm.edu.pe ORCID: https://orcid.org/0000-0003-2203-0465

[2] Universidad Nacional Intercultural Fabiola Salazar Leguía de Bagua. Bagua 01721, Perú. E-mail: gayay@unibagua.edu.pe ORCID: https://orcid.org/0000-0002-5716-7376

[3] Facultad de Ingeniería y Ciencias Agrarias, Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, Chachapoyas 01001, Perú. E-mail: armstrong.fernandez@untrm.edu.pe ORCID: https://orcid.org/0000-0001-9476-1078

[4] Universidad Nacional Intercultural Fabiola Salazar Leguía de Bagua. Bagua 01721, Perú. E-mail: evillanueva@unibagua.edu.pe ORCID: https://orcid.org/0000-0002-9844-3509

[5] Universidad Nacional de Jaén, Jaén 06801, Perú. E-mail: nodeltu1961@gmail.com ORCID: https://orcid.org/0000-0002-0248-3339

[6] Universidad Nacional Intercultural Fabiola Salazar Leguía de Bagua. Bagua 01721, Perú. E-mail: spercuja82@gmail.com ORCID: https://orcid.org/0000-0003-3489-8720

2017). Both marine and freshwater aquatic ecosystems, including the organisms that inhabit them, are recognized as even more sensitive and vulnerable to climate change than their terrestrial counterparts. (Knouft & Ficklin, 2017). Projected extinction rates of aquatic biodiversity are generally higher than those of terrestrial biodiversity under both recent and future climate change scenarios, high vulnerability to environmental changes induced by climate warming results in an uncertain future for both wild fish diversity and global fisheries (Xenopoulos et al., 2005).

Global climate change is the phenomenon where other climatic factors change; The oceans and seas are mainly affected by the process of change caused by global warming, as they constitute a large part of our planet and have a rich biodiversity. (Ninawe et al., 2017). Water temperature occupies the first place in the list of the most determining factors, as it is essential for the reproduction of fish species and the formation of an ideal living environment. (Haugen et al., 2021). However, water temperature is one of the most important environmental factors affecting fish growth and survival. (Topal et al., 2021).

Changes in physiological factors in fish have been demonstrated as a result of climate change (Das et al., 2020). For example Ninawe et al. (2017), mentions that in the pre-adolescent stages called larva and juvenile, fish are quite susceptible to changes in water temperature; a fish population can tolerate temperature changes in the area where it is distributed in a certain time interval, if these changes are within a certain temperature limit and are slow, they usually provoke the migration of fish; Temperature takes important physiological phenomena as well as feeding, respiration, osmoregulation, growth and reproduction under control. If individuals in the population cannot adjust themselves according to sudden and strong changes in temperature, one or some of their metabolic activities may deteriorate and mass deaths may occur. (Campos et al., 2019).

Fish growth is an integral consequence of synergistic interactions between gene-determined growth potential and environmental conditions and is fundamentally important for successful recruitment; Alterations in growth are the most direct, immediate and common way for fish to respond to climate change (Rountrey et al., 2014). For example, the increase in the somatic growth rate of fish is directly due to temperature variation, including that of water and air induced by climate change. (Gamperl et al., 2020). Alterations in fish growth are likely to have predictable and long-lasting influences on population characteristics (e.g., age size structure, egg size, reproduction phenology), dynamics (e.g., hibernation mortality), and recruitment. (Carozza et al., 2019), and could then be transferred to higher levels of organization by connecting ecological processes (e.g., relationships between species and food webs) (Pilière et al., 2014).

Therefore, understanding how fish growth responds to changing environments is an essential and efficient step in predicting the impacts of climate change on populations, communities and even ecosystems. (Tao et al., 2018). Growth responses to climate change have been observed in marine and freshwater fish in a wide range of ecosystem types and climatic zones (Stefani et al., 2020). However, there are many findings and conclusions that disagree, including on fish growth responses to climate change across species and areas. (Nyboer et al., 2019). For example, temperatures were found to be the key factor driving variations in fish growth in most cases, however the relationship can be positive or negative (reflected in fish physiology and health), which could be attributed to species, climatic zones and ecosystem types; There was also no clear relationship between fish growth and environmental variables. (Huang et al., 2021).

On the other hand, the growing scientific evidence of global climate change and its expected impacts on the world's fisheries and fisheries livelihoods raises concerns. (Dzoga et al., 2018), on the resilience and ultimate well-being of such resource-dependent communities (Himes-Cornell & Kasperski, 2015). Rising sea surface temperature, acidification and deoxygenation are projected to affect marine fish production and species distribution, affecting maximum catch and income potential. (Badjeck et al., 2010). There is growing concern about the consequences of global warming for the food security and livelihoods of the world's 36 million fishers and the nearly 1.5 billion consumers who depend on fish for more than 20% of animal protein from their diet. (Andres et al., 2019).

A deeper understanding of how societies respond to multiple stressors (climate and non-climate) is critical to the success of adaptation efforts in vulnerable sectors, such as fisheries. (Teh et al., 2019). These stressors refer to environmental and socioeconomic changes or events at the local, national or global level that make a system or group of people vulnerable. (O'Brien et al., 2009). Efforts to improve adaptive capacity often result in poor results, due to a poor understanding of the dynamics of the unique socio-economic factors that shape their vulnerability. (Koomson et al., 2020).

Currently, developing economies are becoming sources of global economic growth, but also of the emissions associated with the more intensive use of natural resources to drive their conventional economic growth patterns (OECD) (Hynes & Wang, 2012). The OECD added that by 2030 developing economies will have increased the economic benefits of the sustainable use and management of fisheries and aquaculture, in which sustainability indicators (SI) will be the backbone of monitoring progress towards the Sustainable Development Goals (SDGs) at local, national and global levels. In the search for the eradication of poverty in all its forms and dimensions, the United Nations resolution (2018) that speaks about the transformation of the world in 2030 has emphasized 17 (seventeen) Sustainable Development Goals (SDGs), of which three have significant relevance in the fisheries sector namely: Goal 1 (Eradicate poverty); Goal 2 (Zero hunger) and Goal 12 (Sustainable consumption and production); Therefore, taking into account the potential of the aquaculture - fisheries sector, it is possible to achieve the above objectives that will undoubtedly positively impact the health, happiness, prosperity and well-being of all citizens of a country. (Duarah & Mall, 2020).

According to the above, it is necessary to fully understand the concept of sustainability, understood as the balance that exists between a community and its environment to meet its needs. (Estrella & González, 2014). In this context, there are three scientific thoughts on the development of sustainability models related to fishing activity. 1) Analytical or traditional model, based on the natural sciences and focuses on analyzing phenomena from cause – state – effect and response; 2) Systemic model, which proposes a holistic vision between ecology – politics and economics. This analysis includes measurements such as the ecological footprint, global environmental impact indices, intensity of use of materials, among others; and finally we have the 3) Normative model, which has a multidimensional vision between the social-economic and environmental, integrating the indicators of cause-state-effect-response with the ecology-political-economic or systemic model. (Barrezueta, 2015).

Therefore, it is of utmost importance to have a comprehensive, comprehensive overview of existing research to have a further illustration on fish growth responses to different environmental environments associated with climate change. The present study aimed to analyze the impact of global change on fish production through literature analysis from the ScienceDirect and Scopus database to obtain the characteristics of fishing units in relation to global change and relationships between fish growth and environmental variables. The results of this study help to interpret in a more adequate way the effects of global change on fishing units, as well as on fish growth and increase knowledge related to the research topic.

MATERIAL AND METHODS

Data were obtained from ScienceDirect and Scopus, based on titles, abstracts and keywords, which were searched according to the following sentences: ((global change AND fish production) (climate change AND fish production) (climate change AND fish growth) (impact of climate AND fish) (fish production AND climate adaptation)). A total of 35 records were extracted. The time period of this investigation covered the months of April and August 2021. We used only records containing at least one search phrase mentioned above.

To obtain a deep understanding of the characteristics of fishing units in relation to global change, the information of each reviewed article was analyzed: (1) author(s) of the scientific article, (2) geographical context, (3) indicators worked, (4) segment to which the research belongs (fishing or aquaculture), (5) type of activity developed, (6) scale of production of each productive unit, (7) sustainability dimensions analyzed and (8) the most important results found.

Finally, in the case of findings related to the impacts of climate change on fish growth, the following information was extracted from each of the articles: (1) author(s) of the scientific article, (2) geographical context, (3) the variables that have been evaluated, (4) the quantity and/or type of species analyzed, (5) segment of fish investigated (fishing or aquaculture), (6) type of production (river/natural, fish farms, marine fishery) and finally the main results found in each study (7).

RESULTS AND DISCUSSION

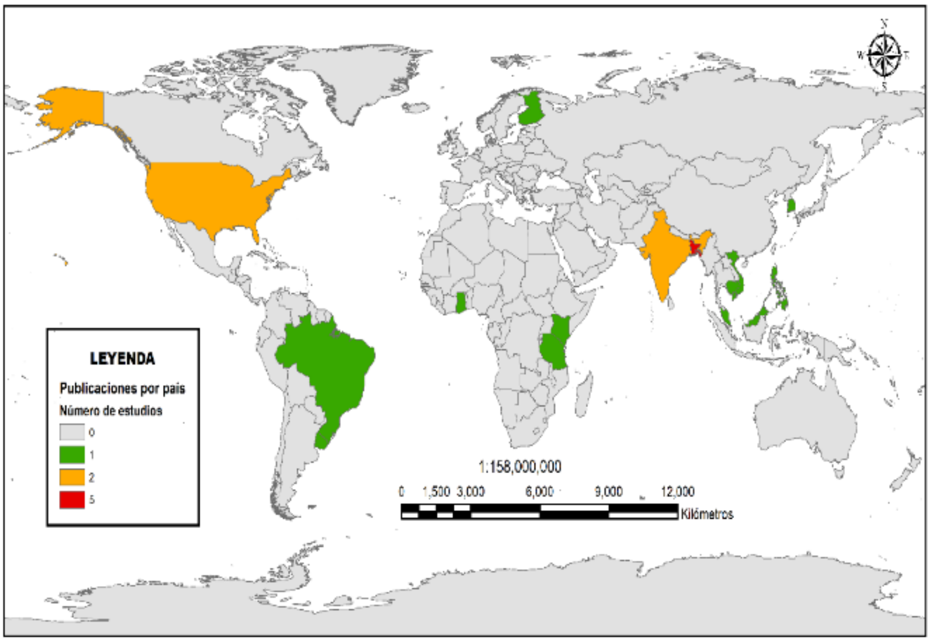
1. Results

1.1. Characteristics of the production units:

Table 1 shows different parameters selected from the 20 investigations analyzed in this study, which are related to the evaluation of the characteristics of fishing units in correlation to global change.

Regarding the geographical context, a frequency of 14 countries has been identified, among which 12 investigations are from Asia, 04 from America, 03 from Africa and 01 from Europe (Figure 1). The Asian continent leads in research, as well as in productive fishing activities for self-consumption.

Figure 1 Distribution of investigations by fishing units.



In relation to the indicators worked, it can be determined that they are oriented to: the variables generated by global change, physiological behavior of the fish and the type of activity they develop.

While it is true that the fishing activity is very broad, the segment to which the evaluation has been made is defined mainly in the term of fishing (90%), this because the areas under study have natural bodies of water, there are populations of native fish and it is also because it is an ancestral activity that has been inherited from generation to generation, displacing aquaculture (10%), since this activity requires greater technical knowledge, greater investment and adequate infrastructure. It is necessary to mention that within the fishing component, 03 segments can be identified: artisanal, small and medium. Artisanal fishing is mainly subsistence, while small fisheries are given for subsistence and small-scale sale, and medium fishing is mainly for sale. With regard to the type of activity, marine fishing occupies 80% unlike inland fishing (10%) and farms (10%).

Table 1 Description of the characteristics of the fishing units.

Author (s) and year	Geographical context	Indicators worked on	Segment	Type of activity	Production scale	Dimensions covered
Gianelli et al. (2021)	South Atlantic Ocean (Brazil – Uruguay)	• Ocean warming and changes in wind patterns. • Mass mortalities and adaptive actions.	• Fishing	• Marine fishery	• Handcrafted	• Environmental. • Social
Seung et al. (2021)	South Korea Gyeong-Nam Province	• Regression for anchovy supply function and economic impact. • Anchovy capture and processing predictions.	• Fishing	• Marine fishery	• Small	• Economic
Das et al. (2020)	India Parganas North and South District	• Change in temperature. • Fishing productivity. • Fishing model.	• Fishing	• Marine fishery	• Small	• Economic • Social • Environmental
Duarah & Mall, (2020)	India Cachar District of Assam.	• Species diversification	• Aquaculture	• Farm	• Small	• Economic
Hoang et al. (2020)	Vietnam Prov. of Thua Thien Hue.	• Livelihood vulnerability index.	• Fishing	• Inland fishery	• Small	• Economic • Social • Environmental

Author (s) and year	Geographical context	Indicators worked on	Segment	Type of activity	Production scale	Dimensions covered
Koomson et al. (2020)	Ghana	• Variability of temperature and local precipitation. • Impact of climate change. • Vulnerability of the home.	• Fishing	• Marine fishery	• Small	• Economic. • Environmental.
Silas et al. (2020)	Tanzania	• Perceptions of artisanal fishing. • Fishermen's perception of the decrease in catches. • Adaptability.	• Fishing	• Marine fishery	• Small	• Environmental. • Economic.
Hasan & Kumar (2019))	Bangladesh Districts of: Kutubdia, Koyra and Kalapara	• Vulnerability index (exposure, sensitivity and adaptive capacity).	• Fishing	• Marine fishery	• Small	• Environmental • Economic
Lomboy et al. (2019)	Philippines	• Economic resilience.	• Fishing	• Marine fishery	• Handcrafted	• Economic • Environmental
Seung & Ianelli (2019))	Alaska	• Regional economic effects. • Impacts of alternative policies.	• Fishing	• Marine fishery	• Small	• Economic
Teh et al. (2019)	Cambodia Tonle Sap	• Economic Evaluation.	• Fishing	• Inland fishery	• Handcrafted	• Economic • Environmental
Dzoga et al. (2018)	Kenya Lower Tana	• Ecological vulnerability. • Climate variability.	• Fishing	• Marine fishery	• Handcrafted	• Economic • Environmental
Finkbe	Pacific	• Climate	• Fishi	• M	• Hand	• Econo

Author (s) and year	Geographical context	Indicators worked on	Segment	Type of activity	Production scale	Dimensions covered
iner et al. (2018)	Islands	change and human rights. • Response to climate change.	ng	arine fishery	crafted	mic • Social • Environmental
Lauria et al. (2018)	Bangladesh / India / Ghana	• socio-economic context. • Employment and gender.	• Fishing	• Marine fishery	• Handcrafted	• Economic • Social • Environmental
Dasgupta et al. (2017)	Bangladesh	• Current and future aquatic salinity. • Incidence of poverty.	• Fishing	• Marine fishery	• Median	• Economic • Social • Environmental
Shaffril et al. (2017)	Malaysia	• Strengthening of social relations. • Adaptation to climate change.	• Fishing	• Marine fishery	• Handcrafted	• Social
Silvenius et al. (2017)	Finland	• Climate impact. • Eutrophication.	• Fishing	• Marine fishery	• Handcrafted	• Economic • Environmental
Ahmed & Diana (2015))	Bangladesh Bagerhat District	• Impacts of climate change on shrimp farming.	• Aquaculture	• Farm	• Median	• Environmental. • Economic
Himes-Cornell & Kasperski (2015))	Alaska	• Biophysical effect of climate change. • Adaptability	• Fishing	• Marine fishery	• Median	• Environmental
Ahmed et al. (2013)	Bangladesh	• Climate variables. • Climate variations.	• Fishing	• Marine fishery	• Handcrafted	• Economic • Social • Environmental

Likewise, in the scale of production it is observed that the highest percentage is artisanal fishing (45%), followed by small (40%) and finally the medium with 15%, demonstrating in this way that artisanal fishing is the predominant worldwide, since it is a subsistence fishing. On the other hand, the indicators evaluated in each study are related to the analysis and measurement of the impact of global change on fishing units.

Similarly, the indicators evaluated cover the social, economic and environmental dimensions, of which 01 belongs to the social aspect, 03 to the economic aspect and 01 to the environmental aspect. There are also related investigations between social-environmental (01), economic-environmental (06), and social-economic-environmental (08). It is necessary to mention that the indicators have been evaluated with respect to a context of adaptation to climate change, general knowledge of the community, water use and the main economic activity of each unit evaluated. From what has been analyzed, it is shown that these variables are closely related. Following the same scheme, in the case of the dimensions of sustainability we find that the greatest weight is found in the analysis of the economic-environmental dimension (85%).

Table 2 Description of the most important results of the characteristics of fishing units

Author(s) and year	Results
Gianelli et al. (2021)	The study provided strong evidence on regional climate change and the extent of ecological impacts stemming from an ocean warming hotspot. By using a mixed-method approach and spatio-temporal cross-scale analysis, we document long-term environmental changes.
Seung et al. (2021)	The results indicate that estimates of economic impacts for the two regions will be skewed if we consider only quantity change (harvest) when calculating economic impacts without taking into account the effects of price responses.
Das et al. (2020)	The study showed that net primary productivity in the Indian Bengal Delta and Mahanadi Delta was more influenced by temperature than nutrient loading.
Duarah & Mall (2020))	The result of this research has proposed that a novel farming practice of small, high-value native species with negligible investment will improve the income of fish farmers.
Hoang et al. (2020)	This study indicates that livelihood strategies and food availability are the most critical factors in determining the vulnerability of livelihoods in the TG-CH lagoon.
Koomson et al. (2020)	The results show that the factors that contribute to shaping the vulnerability of fishing households differ depending on which household categorization is used. It demonstrates that an intersectional understanding of vulnerability to climate change is essential to improve the design, planning and implementation of adaptation projects.
Silas et al. (2020)	Records of long-term trends in fish landings showed a remarkable reduction of ~50% in terms of catch per vessel and catch per fisherman from 1984 to 2016. Due to the general perception that nearshore areas have suffered a significant reduction in fish stocks, while offshore areas were still considered productive.
Hasan & Kumar (2019))	Coastal communities are exposed to multiple stresses and environmental shocks that affect their ability to survive. These fishing communities are more vulnerable to cyclonic effects than floods.
Lomboy et al. (2019)	An economic resilience strategy was developed that builds resilience through enhanced domestic assets to reduce risks and vulnerabilities.
Seung & Ianelli (2019))	More conservative policies work best from an economic impact perspective.
Teh et al. (2019)	We find that, at present, the highest net income was earned by those involved in fishing only; However, they are likely to experience an overall loss of net income in all future scenarios of socio-economic and environmental change.
Dzoga et al.	The ecosystem of Ungwana Bay and the Lower Tana Delta experiences high

Author(s) and year	Results
(2018)	exposure to climate variability and increased anthropogenic pressure on fishery resources.
Finkbeiner et al. (2018)	Pacific island fishing communities are critically vulnerable to the effects of climate change.
Lauria et al. (2018)	The analysis provided in this paper highlights the importance of implementing fisheries management plans at the regional level.
Dasgupta et al. (2017)	Water salinization can have a particularly negative impact on poor households in the region. Estimates indicate that areas with poor populations losing species are about six times more prevalent than areas gaining species.
Shaffril et al. (2017)	Climate change has been consistently shown to reduce fishers' productivity, endanger their lives, damage their physical infrastructure, expose them to health problems and diminish their food supply.
Silvenius et al. (2017)	Allocation was found to be critical when calculating the environmental impacts of seafood and in this study economic allocation was preferred.
Ahmed & Diana (2015))	The practice of shrimp farming in the Bagerhat area off the coast of Bangladesh is vulnerable to climate change. There is overwhelming evidence that different climatic variables have severe effects on the ecosystem of shrimp farms, as well as on shrimp production.
Himes-Cornell & Kasperski (2015))	Alaskan communities are experiencing impacts of unprecedented climate change related to the geographic distribution and abundance of marine resources, increases in the frequency and ferocity of storm surges in the Bering Sea, as well as changes in sea ice distribution and thickness, and increases in river erosion.
Ahmed et al. (2013)	The study found that climate change has a severe impact on the post-larval shrimp fishery.

1.2. Global changes in fish physiology

Table 3 shows the different parameters established based on the 15 investigations analyzed, related to the impact of global change on the physiological characteristics of fish. In relation to the geographical context, a frequency of 11 countries has been identified, within which 04 belong to Europe, 03 to America, 03 to Asia and 01 to Africa of the total research (Figure 02). For this case, the one that leads the investigations is the European continent.

Figure 2. Distribution of studies on the impacts of global change on the physiological characteristics of fish.

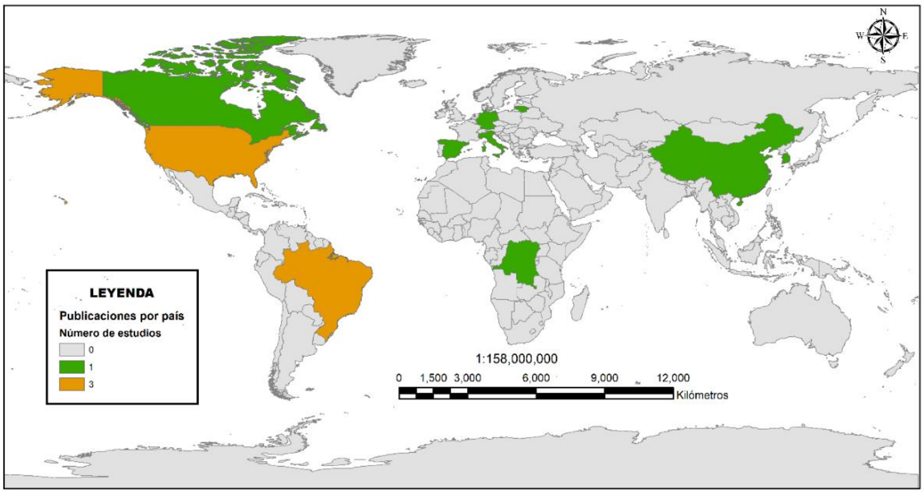


Table 3. Impacts of global change on the physiological characteristics of fish.

Author(s) and year	Geographical context	Variables evaluated	Species	Segment	Type of production
Ahmed & Turchini (2021)	U.S.	• Recirculating aquaculture systems. • Impacts and adaptation to climate change.	Fish farming	Aquaculture	Fish farm
Huang et al. (2021)	China	• Spatio-temporal distribution pattern. • Characteristics of the species • Relationships between fish growth and environmental variables	309 species	Fishing	Marine fishery.
Tsang et al., (2021)	USA.	• Air temperature and precipitation • Climate measurements associated with thermal and hydrological metrics.	26 species	Fishing	Rivers /Natural
Da Costa & Custódio (2020))	Brazil	• Haematological indicators. • Parasitological analysis. • Total RNA extraction. • Analysis of gene expression by PCR.	Colossoma macropomum	Aquaculture	Fish farms
Fé-Gonçalves et al. (2020)	Brazil	• RNA-seq transcriptome analysis.	Colossoma macropomum	Aquaculture	Fish farms
Servili et al. (2020)	Spain	• Effects of global change on the sensorineural system, reproductive behavior, sex determination and differentiation.	---	Fishing	Marine fishery.
Spurgeon et al. (2020)	U.S. Nebraska	• Growth response to changing climatic conditions in three types of water bodies: well lakes, reservoirs and power generation.	Channel catfish Ictalurus punctatuses	Fishing	Rivers /Natural
Stefani et al. (2020)	Italy	• Temperature increase. • Intensity of invasion of exotic fish • Degradation of habitat quality.	31 fish communities.	Fishing	Rivers /Natural
Van Treeck et al. (2020)	European lampreys	• Maximum length, type of migration, mortality, fertility, age of maturity and generation time	168 species of fish	Fishing	Rivers /Natural
Campos et al. (2019)	Brazil	• Metabolic and oxidative stress. • The response rate of integrated biomarkers.	03 Amazonian species	Fishing	Rivers /Natural
Dudgeon (2019))	Anthropocene	• Regulation of flow, dams and water catchment. • Land use change in watersheds. • Global climate change.	-----------------	Fishing	Rivers /Natural
Kriaučiūnienė et al. (2019))	Lithuania	• Water temperature, river hydrology and fish.	-----------------	Fishing	Rivers /Natural
NYboer et al., (2019)	Africa	• Climate change vulnerability assessments.	2793 species	Fishing	Rivers /Natural

Author(s) and year	Geographical context	Variables evaluated	Species	Segment	Type of production
Pandit et al. (2017)	Canada	• Spatial distribution: current and future. • Change of latitude and range of species distribution.	Carmine shiner	Fishing	Marine fishery.
Kwon et al. (2015)	Korea	• Climatic and geohydrological data. • Species distribution models (SDM).	22 species	Fishing	Rivers /Natural

On the other hand, in relation to the variables evaluated in the research, it has been identified that they cover two important aspects. The first, related to the physiological evaluations of fish in 4 investigations, and the second, related to the influence of climatic factors on fish behavior with 6 studies. In the same way, there are interactions between the physiological factor of fish and the climatic influence on them (5 studies). These variables have been evaluated in a context of influence of global change on the physiology and behavior of fish, mainly for species in their natural state, being related to the studies in Table 1, which shows that the main type of activity is subsistence fishing.

In reference to the number of species analyzed, we can differentiate two large groups, those related to freshwater fish and saltwater fish; In both parts it is evident that there is a considerable sample of species studied. On the other hand, in relation to the fish segment, 80% corresponds to the fishing segment, while 20% corresponds to aquaculture, which is influenced by the behavior of fish in their natural state, since in the aquaculture sector the climatic and physiological variables can be manipulated with the aim of having a better production performance.

Following the same logic, in the case of production types it was possible to show that 60% corresponds to fish found in rivers or lakes and that are naturally. Of the remainder, 20% refers to fish produced in fish farms and the other 20% to marine fisheries. From which, it can be analyzed that the fish that are in their natural habitat are the ones that have been studied the most. From this, it is demonstrated that there is a direct relationship between fish in their natural state and the indicators raised in the studies analyzed, since they are influenced by global change in relation to their distribution, characteristics, morphological and genetic factors mainly.

Table 4. Results of impacts of global change on the physiological characteristics of fish.

Author(s) and year	Results
Ahmed & Turchini (2021))	• The RAS can be considered for adaptation to climate change due to its operation in a terrestrial, closed and controlled environment.
Huang et al. (2021)	• The overall effects of climate change (mainly temperature variables) on fish growth (reflected in physiology and health) were negative on both global and local scales.
Tsang et al. (2021)	• The results greatly improve our ability to describe habitat changes at a stream scope scale over large regions, and may help prioritize management strategies to adapt to climate change at local and regional scales.
Da Costa & Custódio (2020))	• The results suggest that extreme climate changes cause a rapid increase in parasitism leading to severe stages of inflammation, such as in the expression of analyzed pro-inflammatory genes that decrease host immunity, which can cause production losses.
Fé-Gonçalves et al. (2020)	• Our findings reveal the signatures of promising candidate genes involved in the regional plasticity of each tambaqui population to cope with upcoming climate changes.
Servili et al. (2020)	• Variations in temperature and photoperiod regimes strongly affect sexual differentiation and the timing and phenology of the spawning period in various fish species.

Author(s) and year	Results
Spurgeon et al. (2020)	• Establishing relationships between climate and growth variables for a freshwater generalist with a plastic diet and wide temperature tolerance serves as an indication of the breadth of possible responses for freshwater fish under global changes in climatic conditions.
Stefani et al. (2020)	• The impact of the increase in temperature and alien species on the functional diversity of the fish was effective, idiosyncratic and mediated by the scale of analysis and by the intensity of the pressures and determined the increase in functional dispersion and uniqueness.
Van Treeck et al. (2020)	• Our approach is based on the analysis and compilation of resilience traits and provides a species-specific classification score of adult mortality sensitivity from a population.
Campos et al. (2019)	• Amazonian fish species are susceptible to climate change as they showed an increase in metabolic rate and oxidative stress.
Dudgeon (2019))	• Freshwaters are global hotbeds of biodiversity, but they are also hotbeds of danger. The same environmental factors that cause the initial pattern of wealth are responsible for the susceptibility of this biodiversity to anthropogenic threats.
Kriaučiūnienė et al. (2019)	• The present study was designed to assess the response of fish assemblages in Lithuanian rivers to changes in temperature and hydrological regime, as well as the uncertainty of the response.
NYboer et al. (2019)	• We found that nearly 40% of African freshwater fish are vulnerable to climate change, mainly due to the many species with highly specialized habitat and life cycle requirements, and the numerous anthropogenic stressors they face.
Pandit et al. (2017)	• Carmine shiner may be highly vulnerable to a warm climate and suggest that management actions, such as assisted migration, may be necessary to mitigate the impacts of climate change.
Kwon et al. (2015)	• The results revealed that five species have a high probability of becoming extinct in their respective habitable sub-basins by the 2080s due to climate change.

Finally, according to the studies analyzed, it can be affirmed that global change influences the characteristics of fish, mainly in: the mortality rate, gene modification, habitat changes, increased parasitism, anthropogenic stress, phenology of the spawning period and in some cases, the extinction of vulnerable species.

2. Discussions

2.1. Characteristics of production units

Most of the studies analyzed have studied global change mainly in coastal communities engaged in artisanal marine fisheries (Table 1). Badjeck et al. (2010), states that small-scale fishers and fish farmers are particularly vulnerable to climate change. Sustainable sources of livelihoods for artisanal fishers depend heavily on the sustainability of ecosystem services, including the provision of fishery resources (Tol, 2005). Therefore, understanding the vulnerability of ecosystems to climate variability is critical to ensuring the food security of communities that depend primarily on natural resources, particularly coastal and marine resources. (Mabe & Asase, 2020). Fishery resources tolerate specific environmental conditions appropriate to their biological functioning (Saunders & Harry, 2014).

When talking about global change in fishing units (Table 1), it is necessary to start from its evaluation, using environmental indicators for specific species. (Pecl et al., 2014). However, the functioning of ecosystems is affected by both natural and anthropogenic factors. Metcalf et al. (2015) He noted that it is necessary to capture important socio-economic factors that directly affect fishery resources for sensitivity assessment. These factors were identified and analyzed in the present study.

The degree to which individuals, households, communities, societies or nations can respond to climate change is determined by the assets available, the rights granted to them and their relative agency to access and leverage these assets and rights. (Finkbeiner, 2015). The resulting latent quality, responsiveness, also defined as a broad set of development-related resources that can be mobilized in the face of risk, describes the ability to mitigate the impacts of climate change and adapt to impacts experienced or anticipated. (Tol, 2005). Responsiveness is linked to real decisions and actions by sociocultural factors such as risk perception and access to information (Burch & Robinson, 2007). Ensuring resilient inland fisheries that can continue to support present and future livelihoods requires enforceable fisheries laws and regulations on illegal and destructive fishing gear, and restricting the 'open access' status of current fisheries, among others. (Ninawe et al., 2017). Achieving these outcomes encompasses various management interventions, such as marine spatial planning, building community support and improving equality of access and distribution. (Ratner, 2006).

2.2. Global changes in fish physiology

Further warming of terrestrial and aquatic ecosystems (Table 3) threatens global biodiversity at all levels (Mackay, 2008), leading to altered species distribution and population structure and, in the worst case, extinction of endemic species (Bellard et al., 2012). Freshwater biota is particularly vulnerable to expected global warming, and many resident species have a limited ability to disperse as the environment changes. (Woodward et al., 2010).

In the face of recent climatic conditions, evolutionary processes can substantially influence the patterns and response rates of individuals, populations or species. (Walther et al., 2002). Most fish species have a narrow range of optimal temperatures related to their basic metabolism and the availability of food organisms. (Tol, 2005). On shorter timescales of a few years, rising temperatures can lead to changes in temperature distribution, recruitment, and abundance. (Ninawe et al., 2017). On timescales ranging from a few years to a decade, changes in distribution, recruitment, and abundance of many species can be acute. (Belton et al., 2014). If individuals in the population cannot adjust themselves according to sudden and strong changes in temperature, one or some of their metabolic activities may deteriorate and mass deaths may occur. (Ninawe et al., 2017).

CONCLUSIONS

Fishery resources are important for the livelihoods of many coastal communities, especially in tropical developing countries. However, these resources continue to face unprecedented pressure due to the impacts of climate change, affecting productivity and more broadly to fish catch, generating impacts on household economies, which have been considerably reduced in the last 4 years, attributable to an interaction of climatic and non-climatic factors.

To mitigate and adapt to changing climatic conditions, fishery resources need to be properly managed and regulated. Social and economic policies are needed to increase people's adaptive capacity and build community resilience so that they have the capacity and opportunity to diversify livelihoods. This can be done through a variety of approaches, for example, focusing on human capital creation (education and health, etc.), improving market benefits (e.g. increasing value added to the fish supply chain) or economic development (urbanization). It also suggests the need to improve current governance systems around land tenure and fisheries access rights to achieve more equitable access and distribution of resources.

Although we are at an early stage in understanding global warming trends and their impacts on future biodiversity, changes in the fitness components of species (behavior, survival, growth and reproduction) to current climate change are already clearly visible in their natural habitat, in both freshwater and saltwater species. as they are more susceptible to climatic variations.

THANKS

To the National University Toribio Rodríguez de Mendoza de Amazonas for the financing of this study through the Public Investment Project: "Creation of research, innovation and technology development services for the agricultural and agroindustrial sector of the UNTRM headquarters Chachapoyas, Chachapoyas province, Amazonas region", with C.U. N° 2313205.

References

Ahmed, N., & Diana, J. S. (2015). Coastal to inland: Expansion of prawn farming for adaptation to climate change in Bangladesh. Aquaculture Reports, 2, 67–76. https://doi.org/10.1016/j.aqrep.2015.08.001

Ahmed, N., Occhipinti-Ambrogi, A., & Muir, J. F. (2013). The impact of climate change on prawn postlarvae fishing in coastal Bangladesh: Socioeconomic and ecological perspectives. Marine Policy, 39(1), 224–233. https://doi.org/10.1016/j.marpol.2012.10.008

Ahmed, N., & Turchini, G. M. (2021). Recirculating aquaculture systems (RAS): Environmental solution and climate change adaptation. Journal of Cleaner Production, 297, 126604. https://doi.org/10.1016/j.jclepro.2021.126604

Andres, K. J., Chien, H., & Knouft, J. H. (2019). Hydrology induces intraspecific variation in freshwater fish morphology under contemporary and future climate scenarios. Science of the Total Environment, 671, 421–430. https://doi.org/10.1016/j.scitotenv.2019.03.292

Badjeck, M. C., Allison, E. H., Halls, A. S., & Dulvy, N. K. (2010). Impacts of climate variability and change on fishery-based livelihoods. Marine Policy, 34(3), 375–383. https://doi.org/10.1016/j.marpol.2009.08.007

Barrezueta, S. (2015). Agrarian Sustainability: with a focus on systems and indicators (U. T. de Machala (ed.); 2015th ed.).

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. In Ecology Letters (Vol. 15, Issue 4, pp. 365–377). John Wiley & Sons, Ltd. https://doi.org/10.1111/j.1461-0248.2011.01736.x

Belton, B., van Asseldonk, I. J. M., & Thilsted, S. H. (2014). Faltering fisheries and ascendant aquaculture: Implications for food and nutrition security in Bangladesh. Food Policy, 44, 77–87. https://doi.org/10.1016/j.foodpol.2013.11.003

Burch, S., & Robinson, J. (2007). A framework for explaining the links between capacity and action in response to global climate change. Climate Policy, 7(4), 304–316. https://doi.org/10.1080/14693062.2007.9685658

Campos, D. F., Braz-Mota, S., Val, A. L., & Almeida-Val, V. M. F. (2019). Predicting thermal sensitivity of three Amazon fishes exposed to climate change scenarios. Ecological Indicators, 101(January), 533–540. https://doi.org/10.1016/j.ecolind.2019.01.051

Carozza, D. A., Bianchi, D., & Galbraith, E. D. (2019). Metabolic impacts of climate change on marine ecosystems: Implications for fish communities and fisheries. Global Ecology and Biogeography, 28(2), 158–169. https://doi.org/10.1111/geb.12832

Da Costa, J., & Custódio, L. A. (2020). Extreme climate scenario and parasitism affect the Amazonian fish Colossoma macropomum. Science of the Total Environment, 726, 138628. https://doi.org/10.1016/j.scitotenv.2020.138628

Das, I., Lauria, V., Kay, S., Cazcarro, I., Arto, I., Fernandes, J. A., & Hazra, S. (2020). Effects of climate change and management policies on marine fisheries productivity in the north-east coast of India. Science of the Total Environment, 724. https://doi.org/10.1016/j.scitotenv.2020.138082

Dasgupta, S., Huq, M., Mustafa, M. G., Sobhan, M. I., & Wheeler, D. (2017). The Impact of Aquatic Salinization on Fish Habitats and Poor Communities in a Changing Climate: Evidence from Southwest Coastal Bangladesh. Ecological Economics, 139, 128–139. https://doi.org/10.1016/j.ecolecon.2017.04.009

Duarah, J. P., & Mall, M. (2020). Diversified fish farming for sustainable livelihood: A case-based study on small and marginal fish farmers in Cachar district of Assam, India. Aquaculture, 529(June), 735569. https://doi.org/10.1016/j.aquaculture.2020.735569

Dudgeon, D. (2019). Multiple threats imperil freshwater biodiversity in the Anthropocene. In Current Biology (Vol. 29, Issue 19, pp. R960–R967). Cell Press. https://doi.org/10.1016/j.cub.2019.08.002

Dzoga, M., Simatele, D., & Munga, C. (2018). Assessment of ecological vulnerability to climate variability on coastal fishing communities: A study of Ungwana Bay and Lower Tana Estuary, Kenya. Ocean and Coastal Management, 163(August), 437–444. https://doi.org/10.1016/j.ocecoaman.2018.07.015

Estrella, M. V., & González, A. (2014). Sustainable development. A new tomorrow. Grupo Editorial Patria, S.A.

Fé-Gonçalves, L. M., Araújo, J. D. A., Santos, C. H. dos A. dos, Val, A. L., & Almeida-Val, V. M. F. de. (2020). How will farmed populations of freshwater fish deal with the extreme climate scenario in 2100? Transcriptional responses of Colossoma macropomum from two Brazilian climate regions. Journal of Thermal Biology, 89(July 2019). https://doi.org/10.1016/j.jtherbio.2019.102487

Finkbeiner, E. M. (2015). The role of diversification in dynamic small-scale fisheries: Lessons from Baja California Sur, Mexico. Global Environmental Change, 32, 139–152. https://doi.org/10.1016/j.gloenvcha.2015.03.009

Finkbeiner, E. M., Micheli, F., Bennett, N., Ayers, A., Le Cornu, E., & Doerr, A. (2018). Exploring trade-offs in climate change response in the context of Pacific Island fisheries. Marine Policy, 88(October 2017), 359–364. https://doi.org/10.1016/j.marpol.2017.09.032

Gamperl, A. K., Ajiboye, O. O., Zanuzzo, F. S., Sandrelli, R. M., Peroni, E. de F. C., & Beemelmanns, A. (2020). The impacts of increasing temperature and moderate hypoxia on the production characteristics, cardiac morphology and haematology of Atlantic Salmon (Salmo salar). Aquaculture, 519, 734874. https://doi.org/10.1016/j.aquaculture.2019.734874

Gianelli, I., Ortega, L., Pittman, J., Vasconcellos, M., & Defeo, O. (2021). Harnessing scientific and local knowledge to face climate change in small-scale fisheries. Global Environmental Change, 68(October 2020), 102253. https://doi.org/10.1016/j.gloenvcha.2021.102253

Hasan, M. K., & Kumar, L. (2019). Comparison between meteorological data and farmer perceptions of climate change and vulnerability in relation to adaptation. Journal of Environmental Management, 237(August 2018), 54–62. https://doi.org/10.1016/j.jenvman.2019.02.028

Haugen, B. I., Cramer, L. A., Waldbusser, G. G., & Conway, F. D. L. (2021). Resilience and adaptive capacity of Oregon's fishing community: Cumulative impacts of climate change and the graying of the fleet. Marine Policy, 126(January), 104424. https://doi.org/10.1016/j.marpol.2021.104424

Himes-Cornell, A., & Kasperski, S. (2015). Assessing climate change vulnerability in Alaska's fishing communities. Fisheries Research, 162, 1–11. https://doi.org/10.1016/j.fishres.2014.09.010

Hoang, H. D., Momtaz, S., & Schreider, M. (2020). Assessing the vulnerability of small-scale fishery communities in the estuarine areas of Central Vietnam in the context of increasing climate risks. Ocean and Coastal Management, 196(October 2019), 105302. https://doi.org/10.1016/j.ocecoaman.2020.105302

Huang, M., Ding, L., Wang, J., Ding, C., & Tao, J. (2021). The impacts of climate change on fish growth: A summary of conducted studies and current knowledge. Ecological Indicators, 121(March 2020), 106976. https://doi.org/10.1016/j.ecolind.2020.106976

Hynes, W., & Wang, S. (2012). Green Growth and Developing Countries A Summary for Policy Makers.

Knouft, J. H., & Ficklin, D. L. (2017). The Potential Impacts of Climate Change on Biodiversity in Flowing Freshwater Systems. Annual Review of Ecology, Evolution, and Systematics, 48, 111–133. https://doi.org/10.1146/annurev-ecolsys-110316-022803

Koomson, D., Davies-Vollum, K. S., & Raha, D. (2020). Characterising the vulnerability of fishing households to climate and environmental change: Insights from Ghana. Marine Policy, 120(November 2019), 104142. https://doi.org/10.1016/j.marpol.2020.104142

Kriaučiūnienė, J., Virbickas, T., Šarauskienė, D., Jakimavičius, D., Kažys, J., Bukantis, A., Kesminas, V., Povilaitis, A., Dainys, J., Akstinas, V., Jurgelėnaitė, A., Meilutytė-Lukauskienė, D., & Tomkevičienė, A. (2019). Fish assemblages under climate change in Lithuanian rivers. Science of the Total Environment, 661, 563–574. https://doi.org/10.1016/j.scitotenv.2019.01.142

Kwon, Y. S., Bae, M. J., Hwang, S. J., Kim, S. H., & Park, Y. S. (2015). Predicting potential impacts of climate change on freshwater fish in Korea. Ecological Informatics, 29(p2), 156–165. https://doi.org/10.1016/j.ecoinf.2014.10.002

Lauria, V., Das, I., Hazra, S., Cazcarro, I., Arto, I., Kay, S., Ofori-Danson, P., Ahmed, M., Hossain, M. A. R., Barange, M., & Fernandes, J. A. (2018). Importance of fisheries for food security across three climate change vulnerable deltas. Science of the Total Environment, 640–641(May), 1566–1577. https://doi.org/10.1016/j.scitotenv.2018.06.011

Lomboy, C. G., Belinario, F., Pomeroy, R., Pedrajas, J., Tirona, R. S., Box, S., Domondon, P. R., & Balbido-Ramirez, K. (2019). Building household economic resilience to secure a future for near shore fishers in the Philippines. Marine Policy, 99(November 2018), 334–342. https://doi.org/10.1016/j.marpol.2018.11.013

Mabe, F. N., & Asase, A. (2020). Climate change adaptation strategies and fish catchability: The case of inland artisanal fishers along the Volta Basin in Ghana. Fisheries Research, 230(December 2019), 105675. https://doi.org/10.1016/j.fishres.2020.105675

Mackay, A. (2008). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Journal of Environmental Quality, 37(6), 2407–2407. https://doi.org/10.2134/jeq2008.0015br

Metcalf, S. J., van Putten, E. I., Frusher, S., Marshall, N. A., Tull, M., Caputi, N., Haward, M., Hobday, A. J., Holbrook, N. J., Jennings, S. M., Pecl, G. T., & Shaw, J. (2015). Measuring the vulnerability of marine social-ecological systems: A prerequisite for the identification of climate change adaptations. Ecology and Society, 20(2). https://doi.org/10.5751/ES-07509-200235

Ninawe, A. S., Indulkar, S. T., & Amin, A. (2017). Impact of climate change on fisheries. In Biotechnology for Sustainable Agriculture: Emerging Approaches and Strategies. Elsevier Inc. https://doi.org/10.1016/B978-0-12-812160-3.00009-X

Nyboer, E. A., Liang, C., & Chapman, L. J. (2019). Assessing the vulnerability of Africa's freshwater fishes to climate change: A continent-wide trait-based analysis. Biological Conservation, 236(February), 505–520. https://doi.org/10.1016/j.biocon.2019.05.003

O'Brien, K., Quinlan, T., & Ziervogel, G. (2009). Vulnerability interventions in the context of multiple stressors: lessons from the Southern Africa Vulnerability Initiative (SAVI). Environmental Science and Policy, 12(1), 23–32. https://doi.org/10.1016/j.envsci.2008.10.008

Pandit, S. N., Maitland, B. M., Pandit, L. K., Poesch, M. S., & Enders, E. C. (2017). Climate change risks, extinction debt, and conservation implications for a threatened freshwater fish: Carmine shiner (Notropis percobromus). Science of the Total Environment, 598, 1–11. https://doi.org/10.1016/j.scitotenv.2017.03.228

Pecl, G. T., Ward, T. M., Doubleday, Z. A., Clarke, S., Day, J., Dixon, C., Frusher, S., Gibbs, P., Hobday, A. J., Hutchinson, N., Jennings, S., Jones, K., Li, X., Spooner, D., & Stoklosa, R. (2014). Rapid assessment of fisheries species sensitivity to climate change. Climatic Change, 127(3–4), 505–520. https://doi.org/10.1007/s10584-014-1284-z

Pilière, A., Schipper, A. M., Breure, A. M., Posthuma, L., De Zwart, D., Dyer, S. D., & Huijbregts, M. A. J. (2014). Comparing responses of freshwater fish and invertebrate community integrity along multiple environmental gradients. Ecological Indicators, 43, 215–226. https://doi.org/10.1016/j.ecolind.2014.02.019

Ratner, B. D. (2006). Community management by decree? Lessons from Cambodia's fisheries reform. In Society and Natural Resources (Vol. 19, Issue 1, pp. 79–86). Taylor & Francis Group . https://doi.org/10.1080/08941920500323344

Rountrey, A. N., Coulson, P. G., Meeuwig, J. J., & Meekan, M. (2014). Water temperature and fish growth: Otoliths predict growth patterns of a marine fish in a changing climate. Global Change Biology, 20(8), 2450–2458. https://doi.org/10.1111/gcb.12617

Saunders, T., & Harry, A. V. (2014). Implications of climate change on fisheries resources of northern Australia. Part 1: Vulnerability assessment and adaptations. https://www.researchgate.net/publication/272158690

Servili, A., Canario, A. V. M., Mouchel, O., & Muñoz-Cueto, J. A. (2020). Climate change impacts on fish reproduction are mediated at multiple levels of the brain-pituitary-gonad axis. General and Comparative Endocrinology, 291(February), 113439. https://doi.org/10.1016/j.ygcen.2020.113439

Seung, C. K., & Ianelli, J. N. (2019). Evaluating alternative policies for managing an Alaska pollock fishery with climate change. Ocean and Coastal Management, 178(May), 104837. https://doi.org/10.1016/j.ocecoaman.2019.104837

Seung, C. K., Kim, D. H., Yi, J. H., & Song, S. H. (2021). Accounting for price responses in economic evaluation of climate impacts for a fishery. Ecological Economics, 181(December 2020), 106913. https://doi.org/10.1016/j.ecolecon.2020.106913

Shaffril, H. A. M., Abu Samah, A., & D'Silva, J. L. (2017). Adapting towards climate change impacts: Strategies for small-scale fishermen in Malaysia. Marine Policy, 81(March), 196–201. https://doi.org/10.1016/j.marpol.2017.03.032

Silas, M. O., Mgeleka, S. S., Polte, P., Sköld, M., Lindborg, R., de la Torre-Castro, M., & Gullström, M. (2020). Adaptive capacity and coping strategies of small-scale coastal fisheries to declining fish catches: Insights from Tanzanian communities. Environmental Science and Policy, 108(April), 67–76. https://doi.org/10.1016/j.envsci.2020.03.012

Silvenius, F., Grönroos, J., Kankainen, M., Kurppa, S., Mäkinen, T., & Vielma, J. (2017). Impact of feed raw material to climate and eutrophication impacts of Finnish rainbow trout farming and comparisons on climate impact and eutrophication between farmed and wild fish. Journal of Cleaner Production, 164, 1467–1473. https://doi.org/10.1016/j.jclepro.2017.07.069

Spurgeon, J. J., Pegg, M. A., Pope, K. L., & Xie, L. (2020). Ecosystem-specific growth responses to climate pattern by a temperate freshwater fish. Ecological Indicators, 112(August 2019), 106130. https://doi.org/10.1016/j.ecolind.2020.106130

Stefani, F., Schiavon, A., Tirozzi, P., Gomarasca, S., & Marziali, L. (2020). Functional response of fish communities in a multistressed freshwater world. Science of the Total Environment, 740, 139902. https://doi.org/10.1016/j.scitotenv.2020.139902

Tao, J., Kennard, M. J., Jia, Y., & Chen, Y. (2018). Climate-driven synchrony in growth-increment chronologies of fish from the world's largest high-elevation river. Science of the Total Environment, 645, 339–346. https://doi.org/10.1016/j.scitotenv.2018.07.108

Teh, L. S. L., Bond, N., KC, K., Fraser, E., Seng, R., & Sumaila, U. R. (2019). The economic impact of global change on fishing and non-fishing households in the Tonle Sap ecosystem, Pursat, Cambodia. Fisheries Research, 210(October 2018), 71–80. https://doi.org/10.1016/j.fishres.2018.10.005

Tol, R. S. J. (2005). Adaptation and mitigation: Trade-offs in substance and methods. Environmental Science and Policy, 8(6), 572–578. https://doi.org/10.1016/j.envsci.2005.06.011

Topal, A., Özdemir, S., Arslan, H., & Çomaklı, S. (2021). How does elevated water temperature affect fish brain? A neurophysiological and experimental study: Assessment of brain derived neurotrophic factor, cFOS, apoptotic genes, heat shock genes, ER-stress genes and oxidative stress genes. Fish & Shellfish Immunology, 115, 198–204. https://doi.org/10.1016/J.FSI.2021.05.002

Tsang, Y., Infante, D. M., Wang, L., Krueger, D., & Wieferich, D. (2021). Conserving stream fishes with changing climate: Assessing fish responses to changes in habitat over a large region. Science of the Total Environment, 755, 142503. https://doi.org/10.1016/j.scitotenv.2020.142503

Van, R., Van, J., & Wolter, C. (2020). Fish species sensitivity classification for environmental impact assessment, conservation and restoration planning. Science of the Total Environment, 708, 135173. https://doi.org/10.1016/j.scitotenv.2019.135173

Walther, G. R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., Fromentin, J. M., Hoegh-Guldberg, O., & Bairlein, F. (2002). Ecological responses to recent climate change. In Nature (Vol. 416, Issue 6879, pp. 389–395). Nature Publishing Group. https://doi.org/10.1038/416389a

Woodward, G., Perkins, D. M., & Brown, L. E. (2010). Climate change and freshwater ecosystems: Impacts across multiple levels of organization. In Philosophical Transactions of the Royal Society B: Biological Sciences (Vol. 365, Issue 1549, pp. 2093–2106). Royal Society. https://doi.org/10.1098/rstb.2010.0055

Xenopoulos, M. A., Lodge, D. M., Alcamo, J., Marker, M., & Kerstin, S. (2005). Scenarios of freshwater fish extinctions from climate change and water withdrawal. Global Change Biology, 11, 1557–1564. https://doi.org/10.1111/j.1365-2486.2005.01008.x