Climate Change in Mexico:

Policy recommendations for adaptation and resilience in the fisheries and aquaculture sector

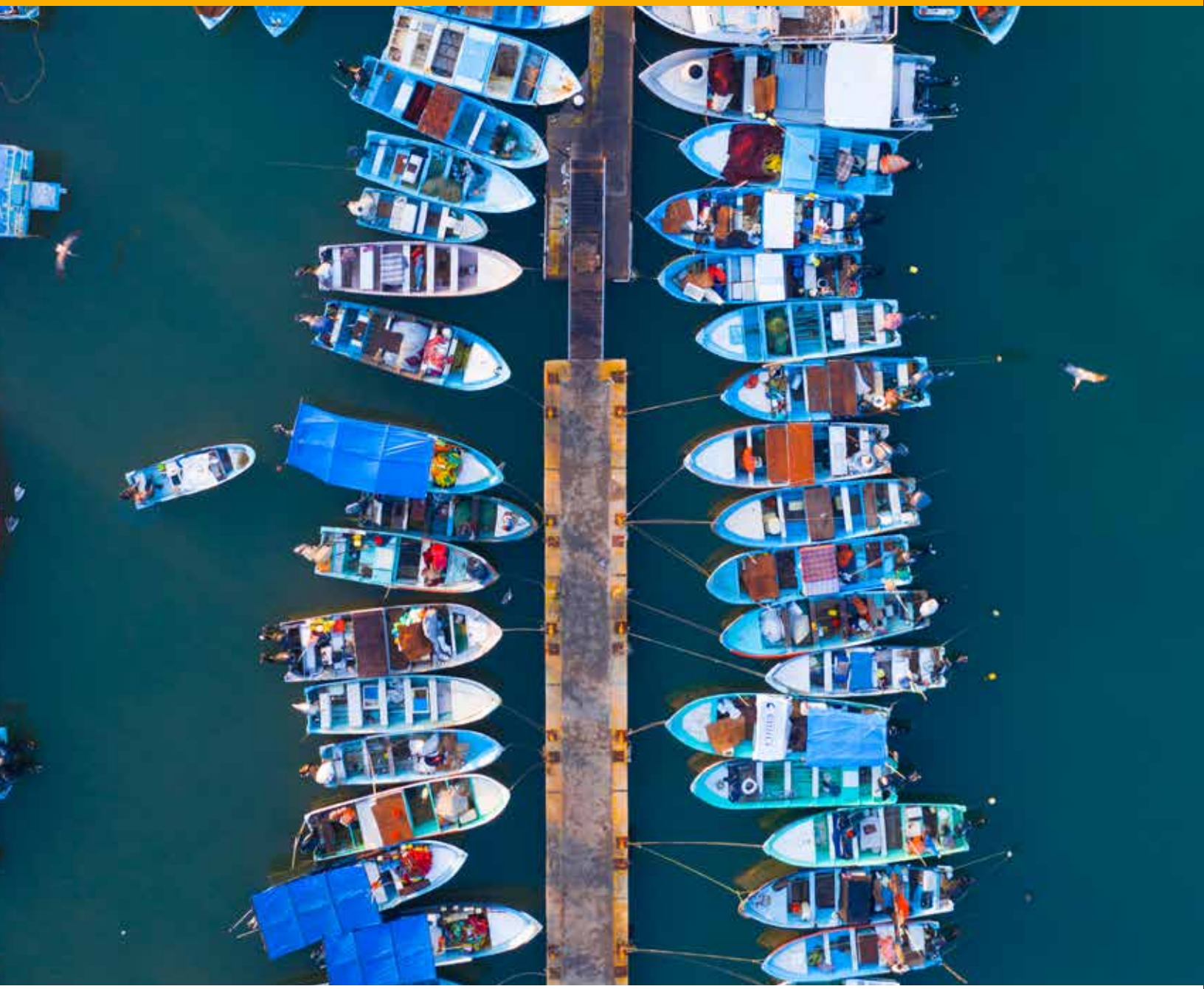

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TABLE OF CONTENTS

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Executive Summary

This document presents a detailed analysis of the current situation of the fisheries and aquaculture sector in Mexico in the face of the challenges posed by global climate change, from an environmental perspective and considering the existing legal framework that sets the path for adaptation to climate change in this particular sector. The first stage of the study conducted comprised extensive literature reviews, complemented with original content and interviews with experts. The last stage included a series of workshops and consultation rounds with the participation of authorities, producers, academia, and civil society organizations, which produced several resilience and climate change adaptation policy recommendations for the fisheries and aquaculture sector in Mexico.

These changes can have significant effects, particularly on commercial mollusk species.

Main Findings

The study shows that, according to the latest ocean-atmosphere models, the **main oceanographic changes** projected for the country are changes in sea temperature, more intense hurricanes, higher sea levels in states with huge lower ground areas, ocean acidification, and lower oxygen concentration. These changes can have significant effects, particularly on commercial mollusk species.

According to projections of Shared Socioeconomic Pathways (SSPs) scenarios for 2050, in the best-case scenario, a slight increase in primary productivity could be seen in all regions of the Atlantic, and a decrease in Pacific regions — with the exception of the Transitional Pacific of Monterrey, which would experience an increase of over 30% — while dissolved oxygen levels would decrease in all sea regions. In the worst-case scenario, all Atlantic regions would show an 11-15% reduction in primary productivity and a 0.1 to 2.1 mol.m-3 decrease in dissolved oxygen levels, while other regions could experience a slight increase in these variables. For both scenarios, temperature is expected to rise in all regions, particularly high in the Transitional Pacific of Monterrey (1°C to 2.9°C). Only in the worst-case scenario the region of the Gulf of California in the Pacific, and the Campeche Bank and northern coast of Yucatan in the southern part of the Gulf of Mexico, experience minimal cooling down. For 2100, the best-case scenario projects temperature and primary production changes slightly smaller than those for 2050, because this scenario takes into consideration that improved sustainability conditions may be achieved by the end of the century. In contrast, in the worst-case scenario temperatures keep rising in all regions (particularly in the Transitional Pacific of Monterrey and the Caribbean Sea) and primary productivity experiences significant reductions (between 50% and 80%) in the Middle American Pacific and the Gulf of California, as well as in the Atlantic regions. Finally, oxygen levels would decrease in both scenarios, particularly in the worst-case scenario, in the Atlantic zone. On the other hand, climate change scenarios towards 2050 show that current industrial fishing areas will experience an increase in temperature of less than 1°C, but primary productivity and dissolved oxygen levels will drop. By 2100, primary productivity may show a sharp decrease, with the exception of some areas of the Southern California Pacific coast, where it may increase, and dissolved oxygen levels

may experience a slight increase. However, the worst-case scenario shows a significant increase in temperature and a decrease in dissolved oxygen levels in most places.

On the other hand, by 2050 most mariculture sites will experience a drop in primary productivity, and 20-50% will experience a decrease in dissolved oxygen levels, as well as a temperature rise of up to 2°C in the worst-case scenario. Finally, by 2100 most of those sites will have low primary productivity levels in the best-case scenario and, although temperature anomalies could be lower than those for 2050, the expectation is that dissolved oxygen levels will decrease in all sites. In the worst-case scenario, all sites will record an 80% reduction in primary production levels and a temperature rise of up to 4.5°C by 2100. The places experiencing more severe reductions in primary production will show, in addition, decreased dissolved oxygen levels by up to 3 mol.m-3.

In the worst-case scenario, all sites will record an 80% reduction in primary production levels and a temperature rise of up to 4.5°C by 2100

Legal framework

The **legal framework analysis** concluded that Mexican laws, rules and regulations contain provisions that will allow to successfully address future problems. Mexico has in place a National Climate Change System (SINACC, for its Spanish acronym), headed by the President, which is in charge of fostering synergies and coordinating efforts to deal with the risks and vulnerabilities of our country, as well as defining priority actions to adapt to and mitigate climate change (CC), linking the needs of the agri-food industry. While the institutional operation of SINACC is solid, in practice it has apparently failed to produce the expected outcomes, given the lack of collaboration, consistency and convergence between the programs, actions and investment projects of the three levels of government and those of the Special Climate Change Program (PECC, for its Spanish acronym) (Velasco Ramírez and García Maning, 2019.) On top of that, the goals set for states and municipalities have also failed to be met; some of the country's most relevant states in the fisheries and aquaculture industry are relatively behind in the creation and application of policy instruments (INECC, 2019.) Given the importance of policy instruments in the application of the Climate Change General Act, we need to identify the challenges faced by the various states to design such policies, giving priority to those states more dependent on fisheries and aquaculture activities.

An updated regulation for the fisheries and aquaculture law is also vital, as climate policy instruments must be explicitly linked to actions described in the 2020-2024 National Fisheries and Aquaculture Program and the National Climate Change Strategy, and incorporate scientific advances as a basis for any changes and the creation of future laws and/or rules.

Finally, while the legal framework in place in Mexico to support climate change adaptation policies in the fisheries and aquaculture sector is solid and far-reaching, such policies should include international cooperation and a human rights approach. Moreover, incorporating a gender approach and the participation of young people into fisheries and aquaculture activities, combined with better education and training, will strengthen adaptation capacities in traditional fishing practices.

Impacts

The **analysis of vulnerabilities of Mexico's coastal communities** to pressures caused by climate change revealed that right now, northwestern states are in a worse position, but by 2050, if the growing concentration of greenhouse gases cannot be halted, the states along the southern coast of the Gulf of Mexico and the Peninsula of Yucatán may be drastically affected. Based on this analysis, the most vulnerable coastal communities of Mexico were identified for two (worst- and best-case) scenarios and two time-horizons (2050 and 2100). The states of Sonora, Sinaloa, and Baja California have the highest numbers of vulnerable communities. In the worst-case scenario, considering fossil-fueled development, more states have vulnerable communities.

Climate change-related environmental variations make the situation of fisheries and aquaculture even more complex. Failure to act in response to them, or taking inappropriate

steps, may result in substantial costs equivalent to an estimated 51 million USD annual loss (Mangin *et al.,* 2018).

Fisheries and aquaculture producers have varying adaptation capacities in response to unfavorable conditions as a result of climate change. As to fishing communities, their capacities depend on the infrastructure available and their level of social organization, as well as on the intensity and frequency of climate events (Nenadovic et al., 2018); in contrast, the aquaculture industry can determine in advance their level of risk, when making plans for the type of facilities, location, species to be cultivated, and infrastructure, which helps reduce both impacts and vulnerabilities (Monteforte, 2013).

The socioeconomic impact of climate change will also vary from one fleet to another (Seijo et al., 1998; Anderson and Seijo, 2010). In the case of traditional fishing, which does not receive significant funding each season, the more uncertain the availability of resources, the more intertemporal choices will be made or the more resources will be used immediately, leading to overfishing and heightened vulnerabilities and poverty in coastal communities with free access to resources. On the other hand, fewer intertemporal choices will be made in industrial fisheries, focused on conservative fishing management frameworks (e.g. limited vessel access) to foster investment and allow exploitation over a long period. This type of fleet may be more vulnerable, as searching for the resources requires higher investment, which may even drive fishermen to give up the activity entirely, leading ultimately to the loss of jobs.

It is necessary to consider the impacts of climate change on the agri-foods industry, incorporating and applying strategies to ensure food security in Mexico, fostering smart development taking into account the interaction between the various actors to prevent social conflict.

Conclusions

There is sufficient evidence of the phenomenon of climate change. In Mexico, it is already impacting the lives and wellbeing of thousands of people, particularly in the northwestern region of our country.

Among the main oceanographic changes that will be seen in Mexico according to the models used in this study, rising sea temperatures, more intense meteorological phenomena such as hurricanes, higher sea levels in states with huge lower ground areas, ocean acidification, and lower oxygen concentration, especially in the northwestern region, stand out.

The analysis of vulnerabilities of Mexico's coastal communities to pressures caused by climate change revealed that right now, northwestern states are in a worse position, but in the medium term (around 2050), in the worst-case scenario proposed by the UN Intergovernmental Panel on Climate Change (IPCC), the states along the southern coast of the Gulf of Mexico and the Yucatán Peninsula may be drastically affected.

The states of Sonora, Sinaloa and Baja California have the highest numbers of vulnerable communities

The legal framework upon which climate policies are based in Mexico is robust and, in general, acceptable. This framework provides a set of tools to deal with future disturbances, and is supported by a series of treaties and international agreements to which Mexico is a signatory. However, national rules and legal provisions are disconnected, therefore it is necessary to harmonize them in order to maximize their efficacy. Further, it was concluded that many coastal states are behind in the creation of laws and rules designed to mitigate and adapt to climate change.

Recommendations

As a result of our analysis, we propose a set of recommendations, to be applied locally and nationwide, seeking to enhance the ability of the fisheries and aquaculture sector to adapt in response to climate change in Mexico, particularly:

a) *Put in place a National Fisheries and Climate Change Program*: Preparing a climate change adaptation policy for the fisheries and aquaculture sector requires governance structures that take into consideration fishermen and their organizations. Adaptation requires fisheries resources and ecosystems in good health condition. For this reason, the tools described in the General Sustainable Fisheries and Aquaculture Act, which is the law designed for the fisheries sector, as well as fisheries management plans and the mechanisms for concessions and permits become legal instruments that are indispensable for resilience and climate change adaptation. During the process of preparation of the National Fisheries and Aquaculture Climate Change Adaptation Policy, steps will be taken to enable a dynamic implementation process of policies favoring resilient fishing resources and ecosystems and, above all, resilient, organized and strengthened communities able to face the challenges posed by global climate change. Furthermore, programs for the protection and restoration of coastal ecosystems important for fish species (mangroves, coastal lagoons, estuaries, coastal dunes, reefs, seagrasses, deltas and river mouths, among others) will be developed. Keeping fish stocks in good health is essential to strengthen the resilience of fish resources subject to exploitation.

b) *Create a Risk Atlas for the fisheries sector*: This instrument must incorporate the environmental pressures and adaptation capacities of the various communities and, at the same time, establish contingency plans to minimize any economic and social impacts, foster preventive activities and find options to protect people's infrastructure and property.

c) *Channel more investment to the generation of knowledge that may efficiently foresee and guide management strategies*: Invest in the creation of teams specialized in climate change, both in the public sector and in civil organizations and academia.

d) *Create direct communication channels between the government and fishing communities to jointly tackle the problem*: Invest more in knowledge generation and implement actions that make it possible to combine, identify, and validate the knowledge of every actor in the sector, to develop local scenarios and climate change adaptation strategies.

e) *Promote partnership building and coordination between ministries*: ensure proper transversal coordination between the various federal government departments, agencies and bodies, political subdivisions, sectors and actors connected with fisheries and aquaculture activities.

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Introduction

Our planet is going through a global warming period (Oreskes 2004), mainly attributed to the buildup of greenhouse gases (GHG) produced by human activities. According to the Intergovernmental Panel on Climate Change (IPCC), the buildup of greenhouse gases has resulted in a rise in Earth's temperature of 0.85 °C in the past century, including the ocean (0.11°C every 10 years). This phenomenon is part of a wider process called climate change, as a consequence of which significant sea features are being considerably transformed: sea surface temperature is increasing; marine geochemistry is changing; sea levels are rising; phytoplankton populations, which are the foundation of the trophic chain, are decreasing — impacting marine biodiversity — and extreme climate phenomena are becoming more frequent and intense, directly affecting human populations settled in coastal zones that depend on the sea. Mexico is no exception; its oceans and resources, along with Mexican coastal communities, are currently experiencing the effects of climate change mentioned above.

Significant sea features are being considerably transformed

The challenges posed by climate change require global cooperation and coordinated efforts of all states. Thus, climate change management should be understood as global and local governments working together to reduce global greenhouse gas emissions (mitigation) and actions to increase the resilience of socioecosystems to the impacts of this phenomenon (adaptation) now and in the future.

Owing to its physical, geographic, economic and social characteristics, as well as its biodiversity, Mexico is highly vulnerable to the impacts of climate change. This means that for Mexico it is vital to build capacities to understand the threats posed by climate change by assessing its repercussions on vulnerable communities, and to understand its impact on territories, ecosystems and economies, to reduce potential damages, take advantage of opportunities, and address its consequences. Although Mexico has made progress in climate governance efforts focused on many socioeconomic sectors and land ecosystems, more attention should be given to marine and coastal ecosystems, particularly to the fisheries and aquaculture sector.

Given that Mexico is a country with close ties to the ocean — key economic activities, such as the transportation of people and goods, depend on the sea — and tourism, fisheries and aquaculture, and as mentioned before, Mexican oceans and coasts are threatened by climate change, urgent work is required to strengthen climate management and governance in oceans and coasts, as well as the sectors depending on them. Particularly, the fisheries and aquaculture sector should be a focus of attention. Firstly, owing to its social relevance: The nutritional contributions of traditional and consumer fishing are crucial to food security and sovereignty in Mexico. Secondly, owing to its economic importance: The extraction and harvesting of marine organisms is the foundation of a production chain that benefits not only the residents of small fishing communities but even big marketers operating in the largest cities of Mexico, and even abroad. Thirdly, because of its cultural importance: Fishing shapes the world view of communities involved in that activity, and gives identity to the people living in coastal states of Mexico.

Fishing and aquaculture are priority sectors domestically, and are strategically relevant to guarantee the wellbeing of the Mexican society as a whole. The threats posed by climate change to this sector require solutions not only in the form of specific actions or steps taken by particular sectors, but

implemented with a holistic and comprehensive approach, well planned, given the sociocultural and economic relevance of fisheries in Mexico.

The purpose of this document is to summarize the problems caused by global climate change to fisheries and aquaculture activities in Mexican coasts, describing the legal tools available in our country to respond to these circumstances, and finally, offer a series of recommendations targeted to decision-makers, that may provide some pointers to build on the adaptation capacities of the sector facing the changes expected in decades to come.

This document is divided into three parts: The first one, comprised of 4 sections, provides a full diagnosis of current and future effects of climate change on Mexico's fisheries and aquaculture sectors (based on the framework used to analyze climate risks (IPCC, 2018), to help readers understand such climate threats, the impacts they would have on ecosystem services and resources, the socioeconomic impacts they would have on communities largely dependent on such services and resources, and the economic risks facing the sector at the federal level.

Urgent work is required to strengthen climate management and governance in oceans and coasts

Section 1, *Key oceanographic changes expected as a result of climate change in Mexican oceans*, introduces readers to the current and future situations in terms of climate variability and climate change nationwide, with their various expressions: This section is the result of an extensive review of data and literature dealing with the threats, risks and impacts of climate change to the seas, coasts and fishing activities, and presents hypothetical future situations modeled based on different climate change scenarios described by IPCC.

Section 2, *Origins, trends and potential disturbances of climate change directly impacting fisheries and aquaculture activities in Mexico*, seeks to explain the reasons behind the imminent adaptation of the fisheries and aquaculture sector in Mexico to climate change. This section makes a connection between climate risks and threats described in the previous section, and the seen and projected impacts on fisheries and aquaculture activities in Mexico.

Section 3, *Analysis of the vulnerabilities of coastal communities in Mexico*, establishes links between climate threats and socioeconomic characteristics in order to determine the exposure and sensitivity of coastal communities in Mexico to climate change, as well as their adaptation capacities, and analyze their vulnerability to this phenomenon.

Then, section 4, *Diagnostic analysis of the socioeconomic impact of climate change in Mexico*, looks deeper into the relationship between climate threats, impacts to resources, social vulnerability, and the economic implications of climate change.

The second part of this study, comprised of three sections, presents a diagnosis of governance and the legal framework, with the aim of clearly presenting the framework enabling the development and strengthening of policies, the regulatory tools, and planned climate change adaptation activities.

In this part of the study we find section 5, *Review of programs and projects providing a framework for Mexico's climate and aquaculture-fisheries governance*, section 6, *Legal framework for climate change adaptation in the fisheries and aquaculture sector in Mexico*, and finally, section 7, *Domestic and international experiences of climate change adaptation in fishing communities*, which exemplifies the operation of the socioeconomic, ecosystem, and climate interaction model in connection with climate change management efforts seeking to increase resilience and sustainability in the specific sector of interest.

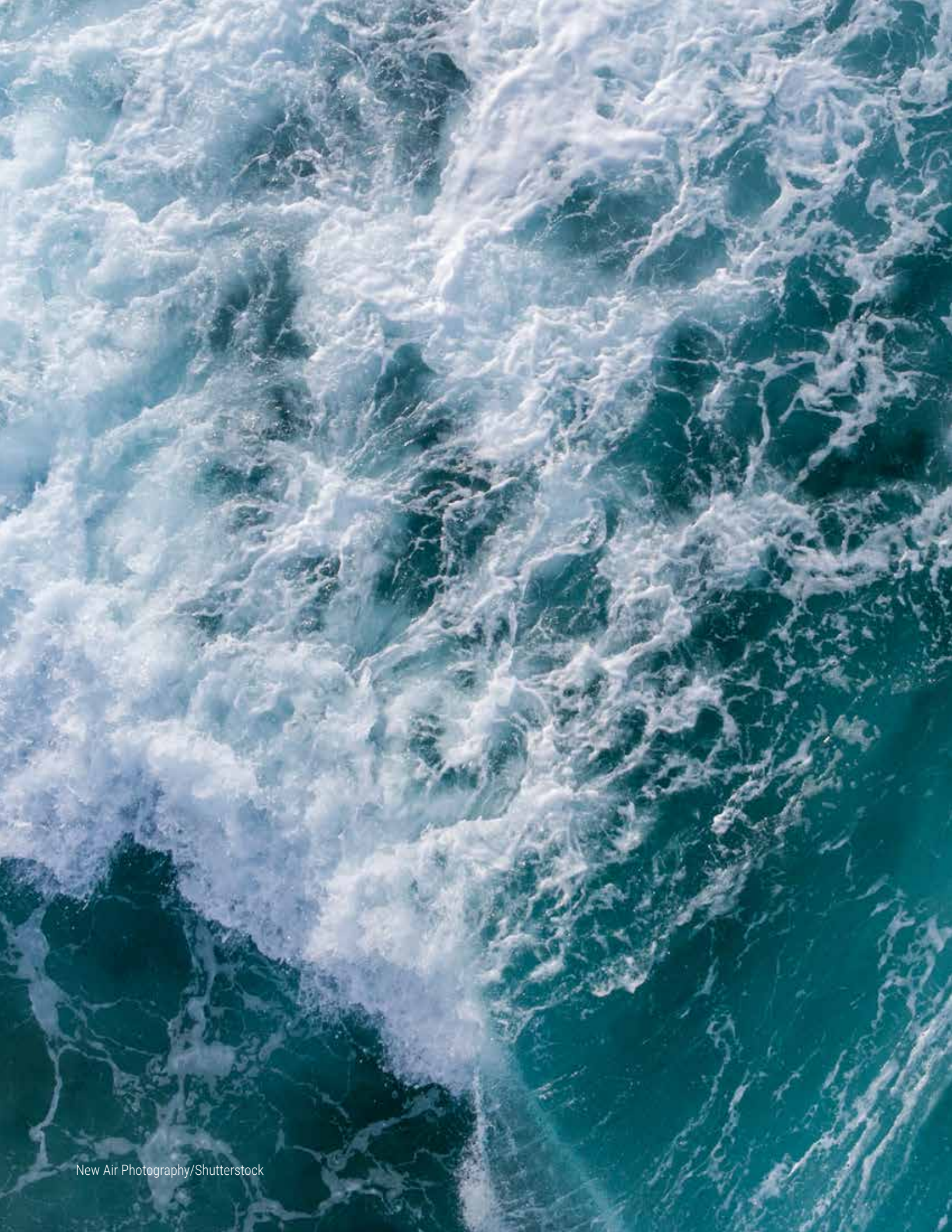
Finally, the third part of this document directly presents policy and governance recommendations that we think link, on the one part, the connection between territory and the local nature of adaptation activities, and on the other, the economic, social, and political needs of this sector to adapt to impacts of climate change already evident, vehemently acknowledging the complementary nature of economic growth and wellbeing, and environment and sustainability, for the fisheries and aquaculture sector in Mexico in view of climate change.

Despite the multiple challenges posed by climate change to fisheries socio-ecological systems, there are concrete actions that can be taken to minimize risks and take advantage of opportunities. This document represents a call to action to build resilience and sustainability in the fisheries and aquaculture sector in response to climate

change in Mexico, supported by extensive research of the most up-to-date scientific information available, but it is also firmly based on the opinions and recommendations of over 50 experts from government bodies, higher education institutions and civil organizations. It also incorporates direct opinions and describes experiences of members of well-organized groups of fishermen across Mexico.

It is our belief that this contribution is only the first among many other steps that all social sectors of Mexico should take to successfully address the challenge posed by climate change to the fisheries and aquaculture industry in Mexico.

There are concrete actions that can be taken to minimize risks and take advantage of opportunities



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Oceanographic changes expected as a result of climate change in Mexican oceans

Climate change projections have been useful tools in the design of proactive adaptation measures, as they give a glimpse into the future of oceans (Ojeda-Ruiz *et al*., 2020). In order to have better climate predictions, the UN **Intergovernmental Panel on Climate Change** (IPCC) developed the Shared Socioeconomic Pathways (SSPs) (See text box 1). SSP models outline possible social changes in the future and create five scenarios with various mitigation and adaptation challenges, ranging from the best case (SSP126) to the worst case (SSP585) (Riahi *et al*., 2017; Escoto-Castillo *et al*., 2017).

In order to estimate the variation in environmental conditions that the fisheries and aquaculture sector in Mexico will experience as a result of climate change, projections were made for spatial patterns of temperature change, primary productivity (PP) and dissolved oxygen in the ocean considering two time horizons (2040-2050 and 2090-2100) based on two scenarios: the best-case scenario (SSP126), with a premise of sustainable development management and, accordingly, low climate change mitigation and adaptation; and the worst-case scenario (SSP585), with a premise of continued fossil fuel-driven fast development, requiring high mitigation but low adaptation.

Text box 1: Shared Socioeconomic Pathways as a basis to model future scenarios.

The Scenario Model Intercomparison Project (*ScenarioMIP*) dealt with projections within the activities of Phase 6 of the Coupled Model Intercomparison Project (CMIP6). These scenarios were used as a basis for IPCC's Sixth Assessment Report. ScenarioMIP integrates a track of future emission projections with other developing social factors (Eyring *et al*., 2016), and includes five Shared Socioeconomic Pathways(SSPs), which are detailed scenarios examining the interaction between climate change in the physical environment and global socioeconomic futures (Grose *et al*., 2020). So, SSPs describe possible trends in societal and ecosystem development in the 21st Century (O'Neill *et al*., 2014). SSPs describe divergent narratives: SSP1 - sustainability, SSP2 - middle of the road, SSP3 - regional rivalry, SSP4 - inequality, and SSP5 - fossil-fueled development (O'Neill et al., 2014, Riahi *et al*., 2017). In addition to SSPs, ScenarioMIP also includes different Representative Concentration Pathways (RCPs) that provide examples of the physical results of climate change in the future and are based on the projected radiative forcing (W/m2) in 2100, in the tropopause, in contrast with preindustrial levels (O'Neill *et al*., 2016, Hayhoe et al., 2017). Scenario SSP5 (SSP585), reflecting fossil-fueled development, and SSP1 (SSP126), reflecting sustainability, were used. The mean for SST and primary productivity was computed in a radius of 50 km around each community.

The historical mean of each variable was used as a reference for current environmental conditions (Figure 3), and then was compared with both time horizons. This mean was computed for each of the following regions: **Transitional Pacific of Monterrey (TPM), Southern Californian Pacific (SCP), Gulf of California (GC), Mexican Pacific Transition (MP), Middle American Pacific (MAP), Northern Gulf of Mexico (NGM), Southern Gulf of Mexico (SGM) and Caribbean Sea (CS)**, in line with the marine ecoregions proposed by Wilkinson and colleagues (2009).

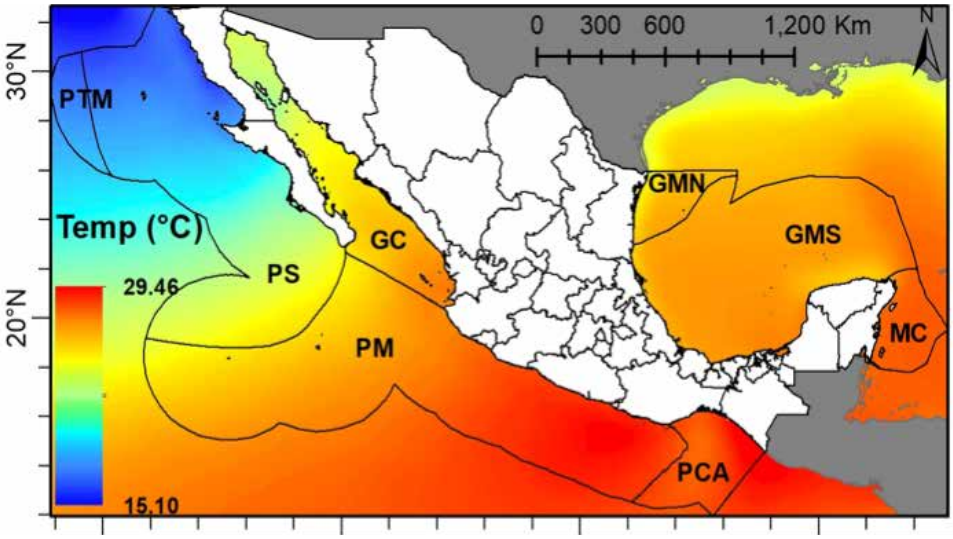
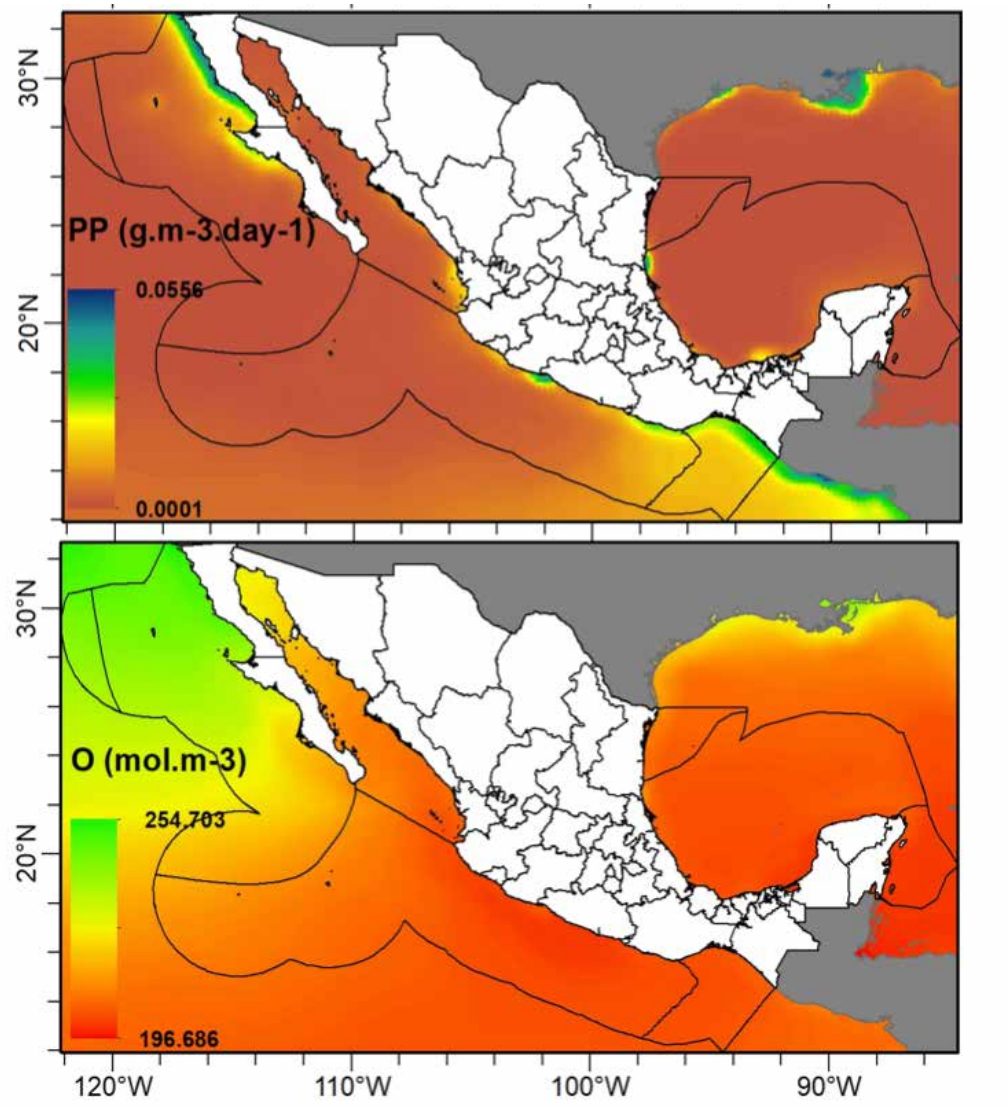


Figure 3. Historical temperature mean (Temp), primary productivity (PP), and oxygen (O).
Source: MODIS-Aqua sensors, University of Oregon and *World Ocean Atlas 2018*.



According to projections for 2050 (Figure 4) in the best-case scenario, a slight increase in primary productivity could be seen in all regions of the Atlantic, and a decrease in Pacific regions — with the exception of TPM, which would experience an increase of over 30% — while dissolved oxygen levels would decrease in all sea regions. In the worst-case scenario (SSP585), all Atlantic regions would show an 11-15% reduction in primary productivity and a 0.1 to 2.1 mol.m-3 decrease in dissolved oxygen levels, while other regions could experience a slight increase in these variables. For both scenarios, temperature is expected to rise slightly in all regions, particularly high in the TPM (1 to 2.9°C). Only in the worst-case scenario (SSP585), the region GC in the Pacific, and the Campeche Bank and northern coast of Yucatan in the SGM, experience minimal cooling down.

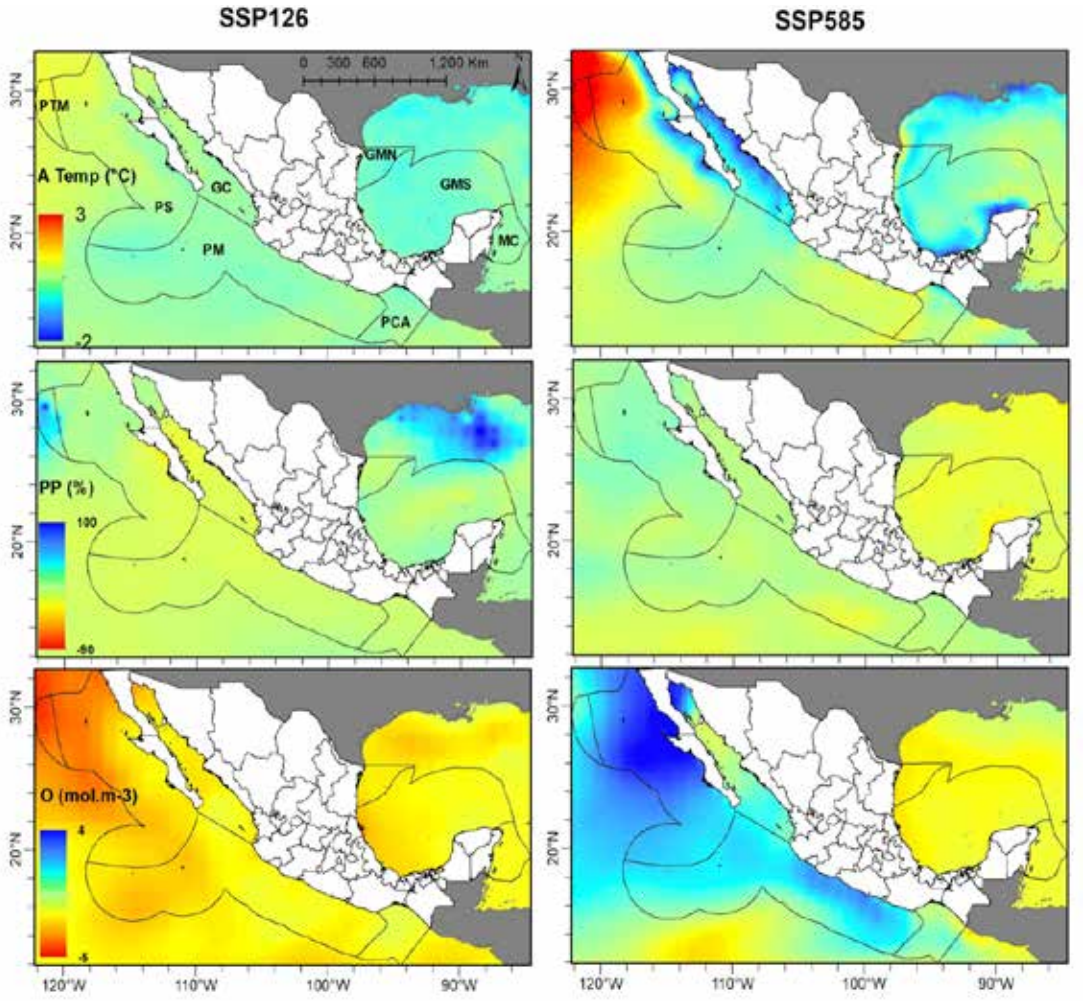


Figure 4. Climate trends based on scenarios SSP126 and SSP585 for 2050. For the temperature, the anomaly is considered (increase/decrease with respect to historical temperature). For primary production the percentage change in concentration is considered. Dissolved oxygen corresponds to the change in $mol.m^{-3}$.

Source: Prepared by the authors using IPCC data.

In the worst-case scenario temperatures keep rising and primary productivity experiences significant reductions in the MAP, GC and Atlantic regions.

For 2100 (Figure 5), the best-case scenario (SSP126) projects changes in temperature and primary production slightly smaller than those for 2050, because this scenario takes into consideration that improved sustainability conditions may be achieved by the end of the century. In contrast, in the worst-case scenario (SSP585) temperatures keep rising in all regions (particularly in the MTP and the CS), and primary productivity experiences significant reductions (between 50% and 80%) in the MAP and the GC, as well as in the Atlantic regions. Finally, oxygen levels would decrease in both scenarios, particularly in the worst-case scenario (SSP585), in the Atlantic zone.

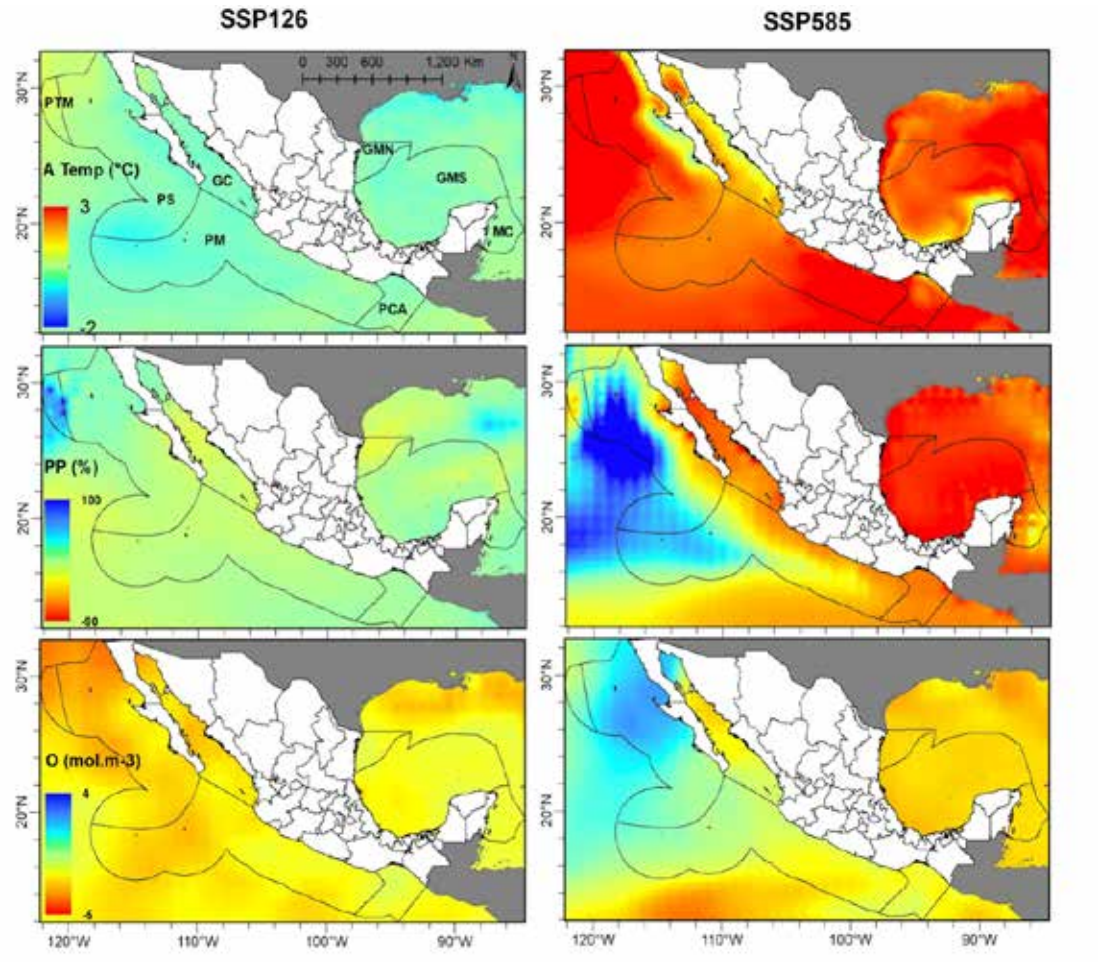


Figure 5. Climate trends based on scenarios SSP126 and SSP585 for 2100 compared to historical average. For the temperature, the anomaly is considered (increase/decrease with respect to historical temperature). For primary production the percentage change in concentration is considered. Dissolved oxygen corresponds to the change in $mol.m^{-3}$.

Source: Prepared by the authors using IPCC data.

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Origins, trends and potential disturbances of climate change directly impacting fisheries and aquaculture activities in Mexico

All marine regions in Mexico are in a climate change process and projections show this will continue, affecting each of them to different degrees. Climate threats derived from this process have been linked to various impacts on marine biota, which in turn pose a risk to fisheries and aquaculture activities (Table I).

Table I. Impacts on biodiversity and risks to fisheries and aquaculture activities associated with exposure to the main threats posed by climate change. Risks to the aquaculture sector are colored in blue.

Climate threat	Impact on biodiversity	Risk to fisheries and aquaculture activities
Changes in Sea Surface Temperature (SST)	Mass coral death.	Reduction and/or permanent loss of species dependent on the reef.
	Changes in the distribution of reef-building species.	Reduction and/or permanent loss of species dependent on the reef.
	Changes in the distribution of marine fauna causing impacts such as: - Alteration of ecosystem dynamics such as predator-prey. - Loss of ecosystems or endemic species. - Incorporation of exotic species.	Changes in the abundance and availability of populations subject to exploitation.
		Increased catches at higher latitudes and depleted catches at lower latitudes.
		Changes in target species, affecting the profitability and market value of catches.
		Increased levels of fishing efforts and, as a consequence, possible decreased yield.
		Depleted catches.
		Need to modify operations in the aquaculture sector, as well as the location of offloading, harvesting and preparation facilities.
	Algal blooms: If toxic, they impact fish, crustaceans and, to a lesser degree, mollusks.	Lower profitability or market value.
		Death of species harvested in bays, estuaries and open waters (fish, mollusks, and crustaceans).
		Depleted catches.
	Changes in seasonal behaviors (such as delayed or earlier start of reproductive seasons, migration and feeding sites.)	Changes in biomass production.
	Variation in sea primary production affecting the trophic chain.	Variation in catches.
	Disturbances to early stages in the life cycle of fish and consequently, demographic changes.	Modification of catches of affected species.
	Disturbance at a physiological level in fish.	Smaller average sizes.
		Increased propensity to disease and parasite load.
	Disturbance at a physiological level in decapods.	**Increased propensity to disease and risk of mass death.**
		Decreased growth rate.
	Disturbance at a physiological level in bivalves.	**Decreased larval settlement rate and, as a result, decreased production.**
		Increased propensity to disease and risk of mass death.
	Environmental conditions that favor the emergence of new pathogens, and consequently increase the frequency and intensity of disease outbreaks in key ecosystems for primary stages in the life cycle of commercial species, or directly in species of commercial importance.	Depleted catches.
		Mass death of harvested species.
		Lower profitability or market value.
Ocean acidification	Variations in coral accretion and structural integrity.	Reduction and/or permanent loss of species dependent on the reef.
	Changes in the growth and development of gastropods, bivalves, and echinoderms.	**Development problems and/or death of larvae and young species, particularly in bivalve harvesting sites.**
		Depleted production and catches of species categorized in these groups.

Climate threat	Impact on biodiversity	Risk to fisheries and aquaculture activities
Ocean deoxygenation	Physiological impacts on fish.	Smaller average sizes.
		Migration of commercial species.
	Physiological impacts on sessile species (mollusks, echinoderms, corals, etc.)	Decreased growth rate.
		Depleted production and catches of species categorized in these groups or dependent on these groups at any stage in their life cycles.
		Decreased larval settlement rate and, as a result, decreased production.
		Death of bivalves and harvest mollusks.
Sea level rise	Increased coastal erosion and reduced coastlines.	**Damage to aquaculture infrastructure.**
		Damage to offloading infrastructure for catches.
	Changes in salinity conditions in coastal ecosystems with impacts such as: - Alteration of ecosystem dynamics such as predator-prey. - New conditions favorable for exotic species and potentially pathogens. - Physiological impacts in euryhaline species.	Increased propensity to disease and risk of mass death in species of commercial importance.
		Decreased growth and reproduction rates.
		Changes in the abundance and availability of species subject to exploitation.
	Impact to coastal ecosystems such as mangroves.	Consequences in the recruitment of species dependent on mangroves in the early stages of their life cycle and, as a result, depleted catches of such species.
More and more frequent extreme weather events and rainfall	Physical damage to reefs and coastal ecosystems.	Reduction and/or permanent loss of species dependent on the reef.
	-	Fewer days in the high seas or harvesting.
	-	Damage to coastal infrastructure.
	-	**Destruction of aquaculture facilities (ponds and tubs) in zones likely to be impacted.**
	-	**Escape of organisms from harvesting areas as a consequence of the destruction of floating cages.**
	Disturbance at a physiological level.	Increased propensity to disease and risk of mass death in species of commercial importance.
		Decreased growth and reproduction rates.

Potential impacts on fisheries and aquaculture activities in Mexico

In order to minimize potential impacts derived from the above-mentioned threats in Mexican fisheries, awareness of potential future scenarios is important. For such purpose, the impact on fisheries and aquaculture activities was estimated, and environmental changes in the places where these activities are currently conducted were determined for the best-case (SSP126) and worst-case (SSP585) scenarios. These sites were identified based on industrial fishing effort data collected by Global Fishing Watch (GFW), georeferenced records of mariculture permits issued by Comisión Nacional de Acuacultura y Pesca (CONAPESCA), and the register of permits for smaller vessels issued by CONAPESCA in coastal municipalities. For each fishing and mariculture zone identified, values for variables such as temperature, primary productivity and dissolved oxygen were computed for both time horizons (2050 and 2100) as an indicator for possible climate change impact.

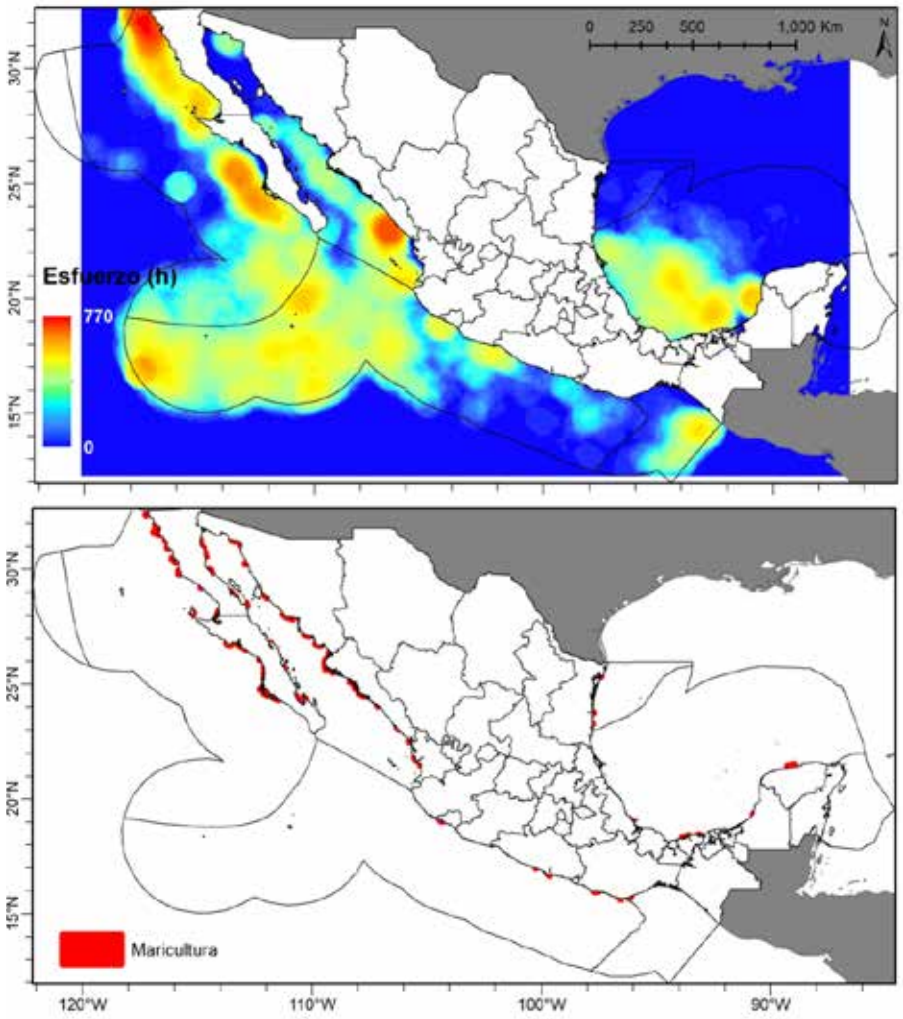


Figure 6. The effort in hours applied by the industrial fishing fleet for 2012-2016 (above) and current distribution of sites with mariculture activities (below).
Source: Global Fishing Watch and CONAPESCA.

Industrial fishing effort (Figure 6) in the Pacific occurs mainly off the coast of Ensenada, Baja California and of Magdalena Bay, Baja California Sur, in SCP, and the area of Mazatlan, Sinaloa, in the GC, while in the Atlantic it is concentrated off the coast of Campeche and Tabasco. Further, 414 mariculture sites (Figure 6) were identified mainly distributed in the region of GC and SCP (87%). On the other hand, states in the northwest of Mexico have more permits and vessels for beach shore fishing (Figure 7), and among them Baja California and Baja California Sur stand out.

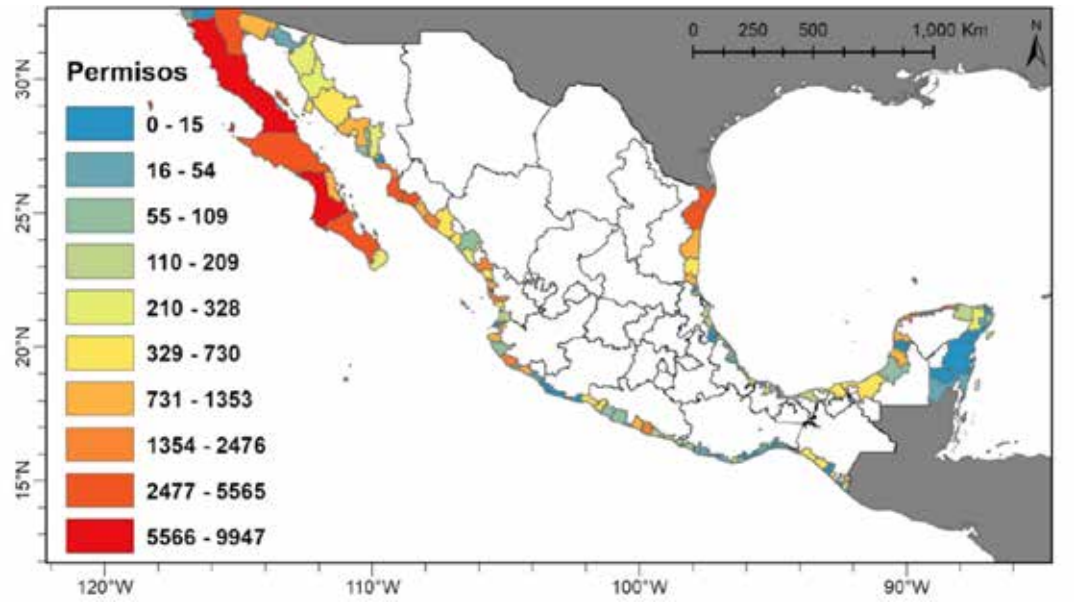


Figure 7. Fishing permits granted in coastal municipalities of Mexico.

Climate change scenarios (Figure 8) towards 2050 show that current industrial fishing areas will experience an increase in temperature of less than 1°C, but primary productivity and dissolved oxygen levels will drop. For 2100, primary productivity may show a sharp decrease, with the exception of some areas of the SCP, where it may increase, and dissolved oxygen levels may experience a slight increase. However, the worst-case scenario (SSP585) shows a significant increase in temperature and a decrease in dissolved oxygen levels in most places.

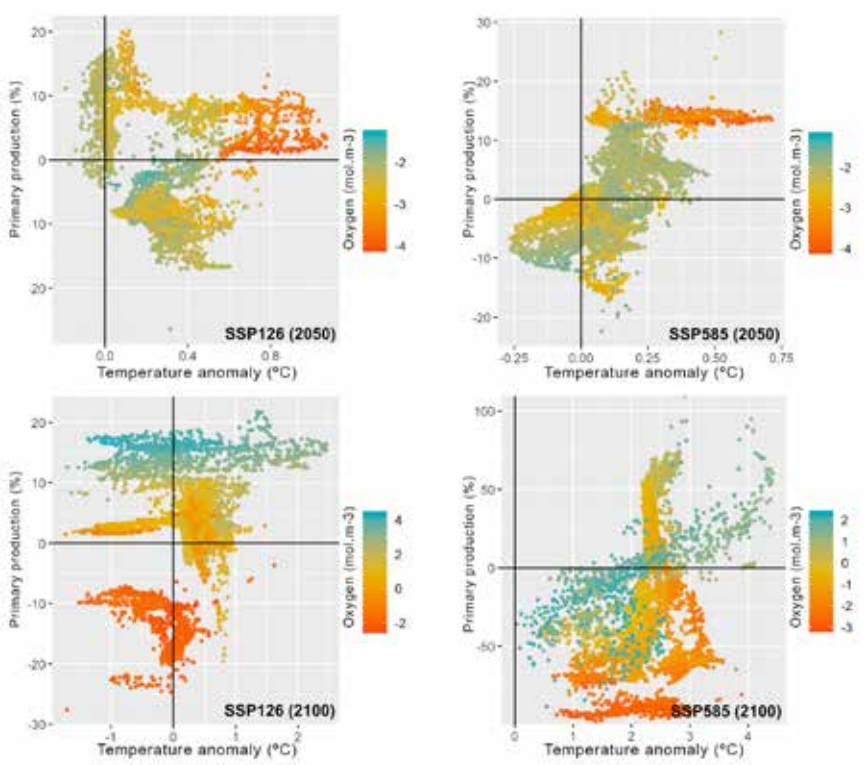


Figure 8. Estimation of environmental change in the sites where the industrial fishing fleet operates currently, for scenarios SSP126 and SSP585 in time horizons 2050 and 2100.

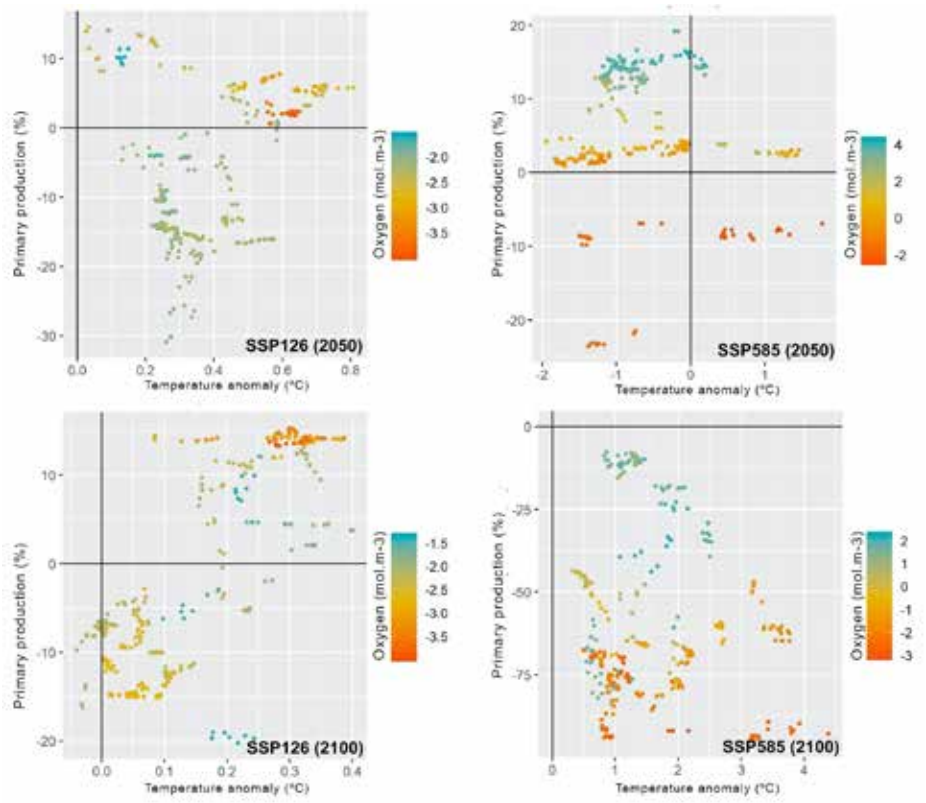
Source: Prepared by the authors.

On the other hand, by 2050 most mariculture sites (Figure 9) will experience a drop in primary productivity, and 20-50% will experience a decrease in dissolved oxygen levels, as well as a temperature rise of up to 2°C in the worst-case (SSP585) scenario. By 2100 most of those sites will have low primary productivity levels in the best-case scenario (SSP126) and, although temperature anomalies could be lower than those for 2050, the expectation is that dissolved oxygen levels will decrease in all sites. In the worst-case scenario (SSP585), all sites will record an 80% reduction in primary production levels and a temperature rise of up to 4.5°C by 2100. The places experiencing more severe reductions in primary production will show, in addition, decreased dissolved oxygen levels by up to 3 mol.m^{-3}.

Figure 9. Estimation of environmental change in current mariculture sites, for scenarios SSP126 and SSP585 in time horizons 2050 and 2100.

Source: Prepared by the authors.

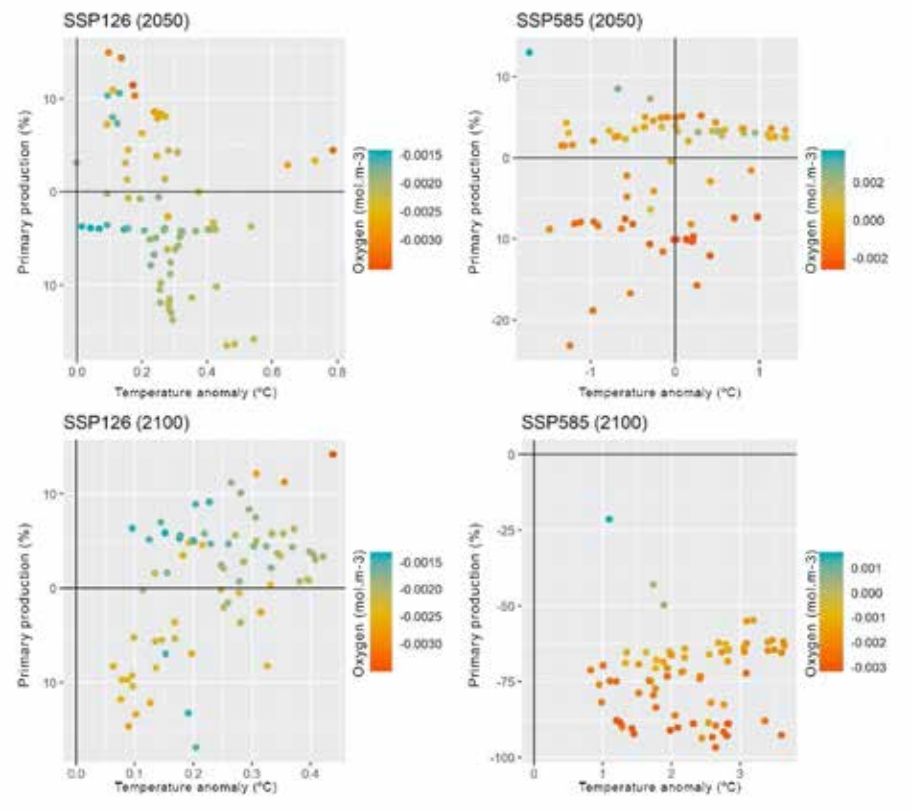
In the worst-case scenario all sites will record an 80% reduction in primary production levels and a temperature rise of up to 4.5°C by 2100



Finally, by 2050, in coastal zones where the smaller fleet operates (Figure 10), a ±10% change in primary productivity is expected with anomalies around 1°C. By 2100, changes for the best-case scenario (SSP126) are less significant; however, the worst-case scenario (SSP585) would involve a drop of more than 50% in primary productivity, with anomalies above 1°C and a decrease in dissolved oxygen.

These results show that fisheries and aquaculture sites are exposed to changes in environmental conditions that will cause changes in fish resources. Temperature rises and decreases in primary productivity and dissolved oxygen represent a risk for fisheries and mariculture activities , especially towards the end of the century; thus, we should focus on developing adaptive biodiversity management strategies so that resources, the production sector, and the human communities dependent on them are less sensitive.

Figure 10. Environmental changes in coastal zones where smaller vessels operate.
Source: Prepared by the authors.



Fisheries and aquaculture sites are exposed to changes in environmental conditions . Temperature rises and decreases in primary productivity and dissolved oxygen represent a risk for fisheries and mariculture activities.

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Brief analysis of the vulnerabilities of coastal communities in Mexico

Assessing the vulnerability of fishing communities to climate change and other cumulative anthropogenic factors is a necessary and important first step that will serve as a basis to propose management strategies, providing decision-makers with a cost-benefit analysis of management policies designed to make coastal communities more resilient (Perry et al., 2010, Cinner *et al*., 2012).

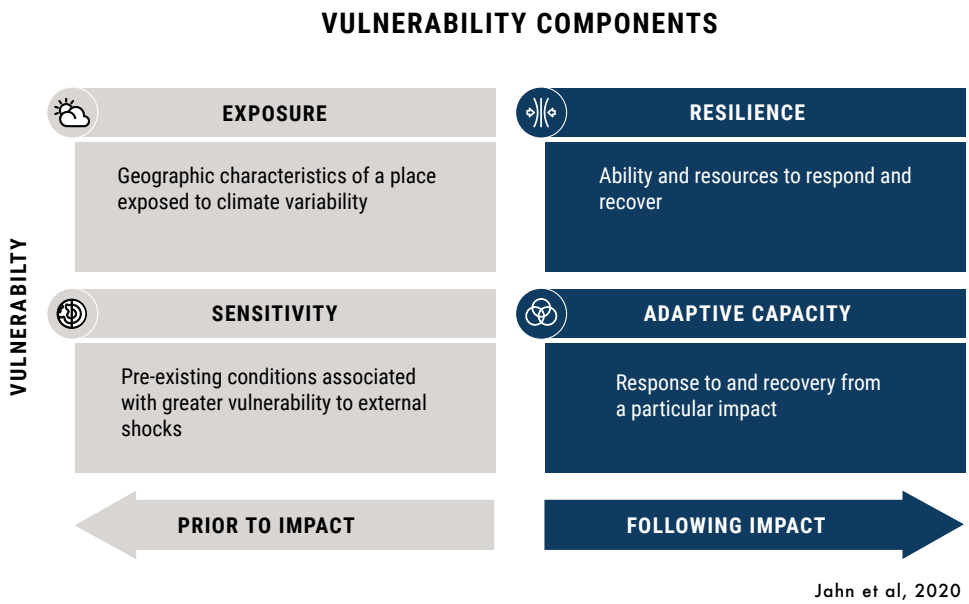

Figure 11. Vulnerability components.

Various research frameworks were developed to assess the vulnerability of traditional fishermen to environmental changes (Badjeck et al., 2010, Cinner et al., 2012, Jacob et al., 2013, Himes-Cornell & Kasperski, 2015). The vulnerability of coastal communities was assessed based on the methods proposed by Morzaria-Luna (Morzaria-Luna et al., 2014). Initially, "coastal communities" were defined as communities settled within a band of 30 km from the coast, based on the coastline contour (http://www.conabio.gob.mx/informacion/gis/) and for which census data were available. Based on these criteria, 12,985 communities were identified (Figure 12).

Figure 12. Coastal communities identified.

For each coastal community identified, susceptibility, adaptive capacity, and exposure indexes were computed. To compute the susceptibility index, the share of the population 12 years old and over without an occupation (an indicator of a person's economic situation), the number of fishing businesses (economic units) registered per town, and the proportion of individual households without basic services, electric power, water and sewage mains connections were determined.

Variations in all three vulnerability components, susceptibility, exposure, and adaptive capacity are illustrated with the results for the worst-case scenario (SSP585) in 2050 by state (Figure 13).

Generally speaking, Baja California, Baja California Sur, Veracruz and Michoacán were the states with the largest variability in level of susceptibility for their coastal communities; while Veracruz and Oaxaca are the states with the most municipalities with high susceptibility. Adaptive capacity is higher in Baja California, Baja California Sur and Quintana Roo. Veracruz, Chiapas and Oaxaca are the states with the most municipalities with low adaptive capacity.

In current conditions, the states along the Pacific are more exposed than those in the Gulf of California and the Pacific coast in the Baja California Peninsula. Guerrero and Oaxaca are the states with the most municipalities with high exposure. When considering future climate change scenarios, changes in the spatial distribution of zones subject to more exposure are observed.

In the best-case scenario (SSP126), the communities in the southern region of the Baja California Peninsula and Southern Pacific show a higher increase in exposure between 2050 and 2100. In Baja California and Sonora, more coastal communities experience an increase in exposure in the best-case scenario (SSP126) in 2050, while Sonora, Sinaloa and Baja California show the highest increase in exposure in 2100 with respect to current conditions.

In Quintana Roo, Tamaulipas and Chiapas more communities experience a reduction in their exposure in the best-case scenario (SSP126) in 2050; in 2100, exposure decreases in Oaxaca, Chiapas, Quintana Roo and Guerrero. In the worst-case scenario (SSP585), communities in the Gulf of Mexico show a higher increase in exposure between 2050 and 2100. In Campeche, Yucatán and Baja California, more coastal communities experience an increase in exposure in the worst-case scenario (SSP585) in 2050, while Campeche, Tamaulipas and Sonora show an increase in exposure in more communities in 2100 with respect to current conditions.

In Chiapas, Guerrero and Oaxaca more communities have reduced exposure in the worst-case scenario (SSP585) in 2050 with respect to current conditions. While in 2100, exposure decreases in Chiapas, Guerrero and Michoacán. Finally, Oaxaca, Veracruz and Yucatán have the most municipalities with highly vulnerable communities in the SSP585 scenario.

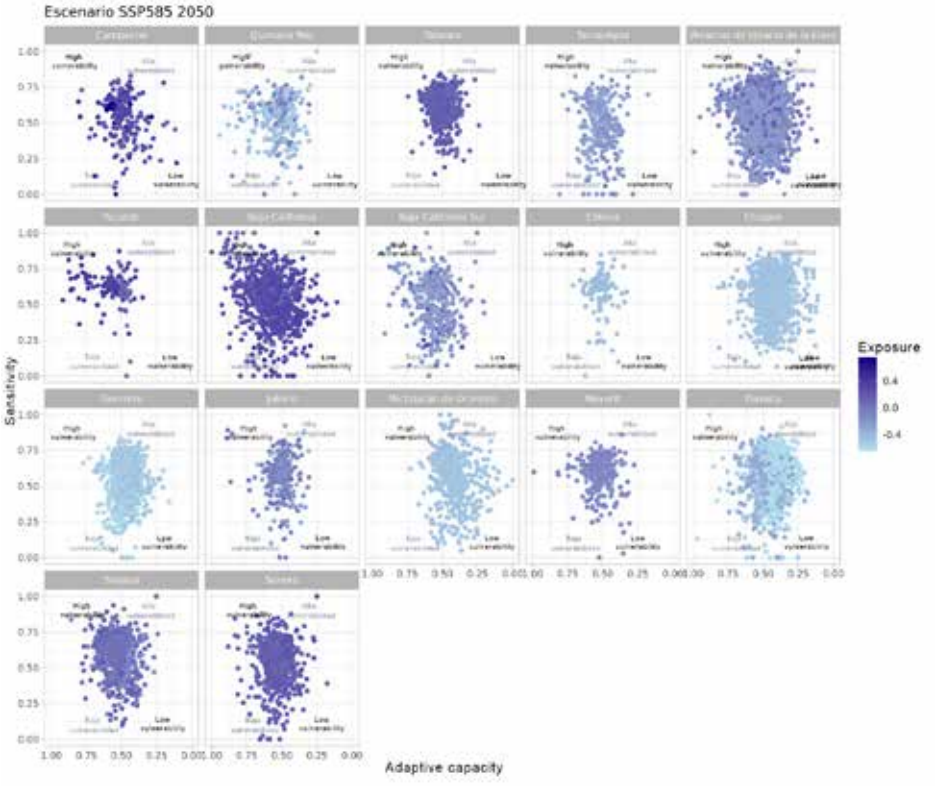

Figure 13. Vulnerability components for scenario SSP585 in 2050 by state.

Based on the three components, the most vulnerable coastal communities nationwide were identified for both scenarios and horizons (2050 and 2100; Figure 14). The states of Sonora, Sinaloa, and Baja California have the highest numbers of vulnerable communities. In the worst-case scenario (SSP585), considering fossil-fueled development, more states have vulnerable communities.

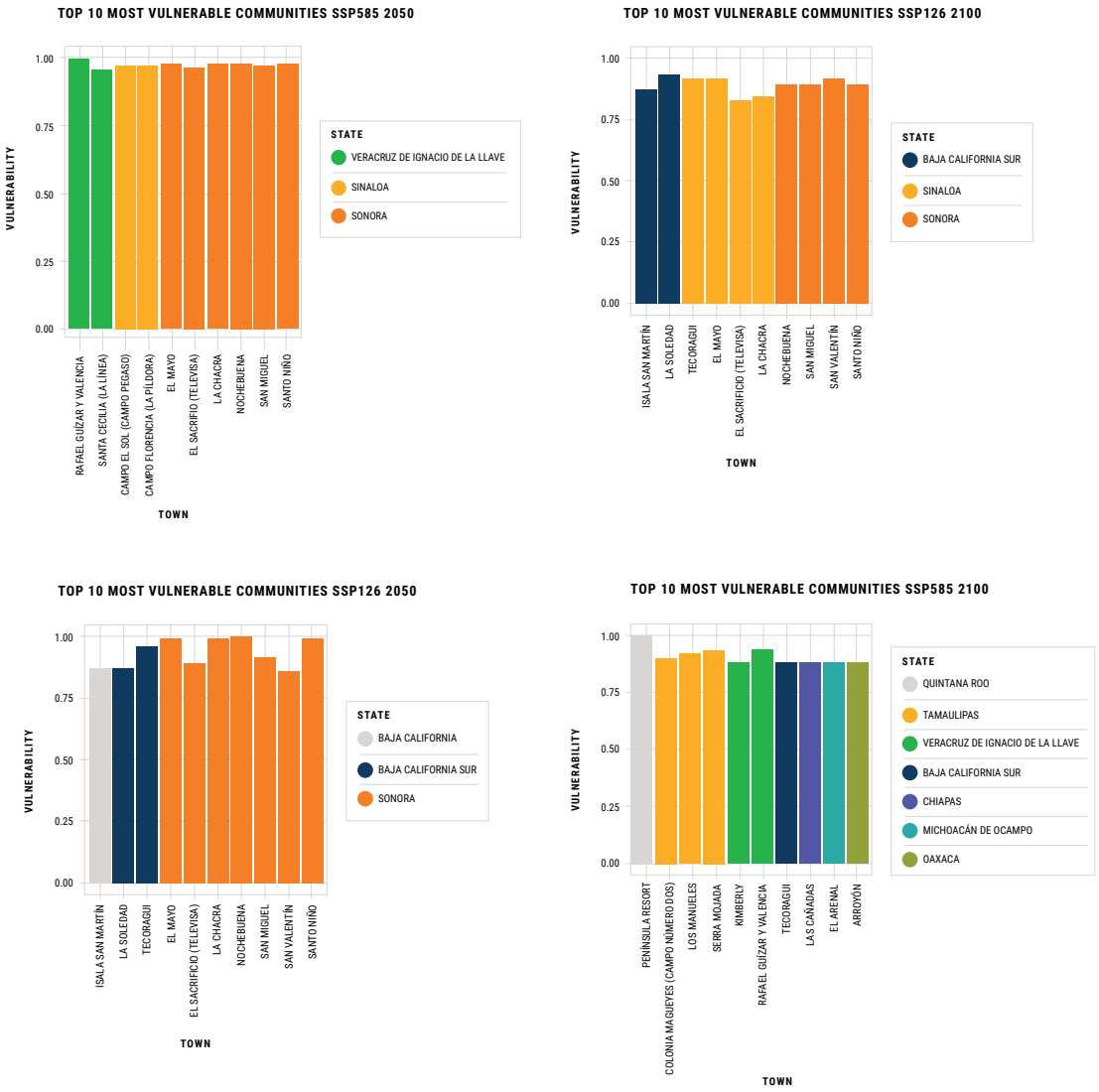

Figure 14. The top ten most vulnerable communities in Mexico for each scenario, SSP126 and SSP585, in 2050 and 2100.

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Diagnostic analysis of the socioeconomic impact of climate change in Mexico

The fisheries and aquaculture sector in Mexico

Mexico is one of the 20 countries responsible for supplying 74% of the total volume of fish and shellfish consumed worldwide (~80 million tons per year) (FAO, 2020). Catch and harvesting activities happen in every single state, particularly in the 17 coastal states, and especially those in the northwest of the country, which have a 70% share in terms of volume and a 60% share in terms of value of total national production (CONAPESCA, 2018; 2020). The fisheries and aquaculture sector is described in Table 2.

Category	Value	Source
Fishing population	213246**	INEGI
Fisheries and aquaculture companies	22,820	CONAPESCA
Industrial vessels	2,027	CONAPESCA
Processing plants	412	CONAPESCA
Aquaculture population	56250*	CONAPESCA
Aquaculture production units	9,320	CONAPESCA
Indirect jobs	>2,000,000	Consejo Mexicano para el Desarrollo Rural Sustentable
Average national fish production (2016-2018) in millions of tons	1.77	Prepared by the authors [a]
Average national aquaculture production (2016-2018) in tons	238,400	Prepared by the authors [a]
Aquaculture production value (millions of Pesos)	$15,376.51	Prepared by the authors [a]
Fish production value (millions of Pesos).	$23,753.46	Prepared by the authors [a]

* Data estimated by CONAPESCA in the Statistical Yearbook 2018
** Data provided by INEGI in the 2019 economic census
a With data of statistics CONAPESCA yearbooks (2005-2018)

Table 2. Fisheries and aquaculture in Mexico in numbers

Mexico is one of the 20 countries responsible for supplying 74% of the total volume of fish and shellfish consumed worldwide

Although the fisheries sector has access to over 600 species of fish and invertebrates, only 25 of them are responsible for 70% of the annual production volume (Cisneros-Mata, *et al*., 2019; D.O.F., 2018). In the aquaculture sector, over 60 species of fish, plants, algae, amphibians and mollusks are harvested for commercial purposes (Federal Gazette, 2013; CONAPESCA, 2018).

Most of the population involved in these activities is found along the Pacific coast, and Sinaloa and Sonora are the states with more people recorded (Figure 15A) and those with an annual share of almost 50% of the volume of fish and aquaculture production nationwide (Figure 15B). In the region of the Gulf of Mexico, Veracruz has the highest number of people recorded as being involved in aquaculture activities, while among landlocked states the State of Mexico and Morelos stand out (CONAPESCA, 2018) (Figures 15A and 15C). Almost the same number of people works in the aquaculture sector in coastal states and landlocked states, which is indicative of how important freshwater species farming is (Figure 15C).

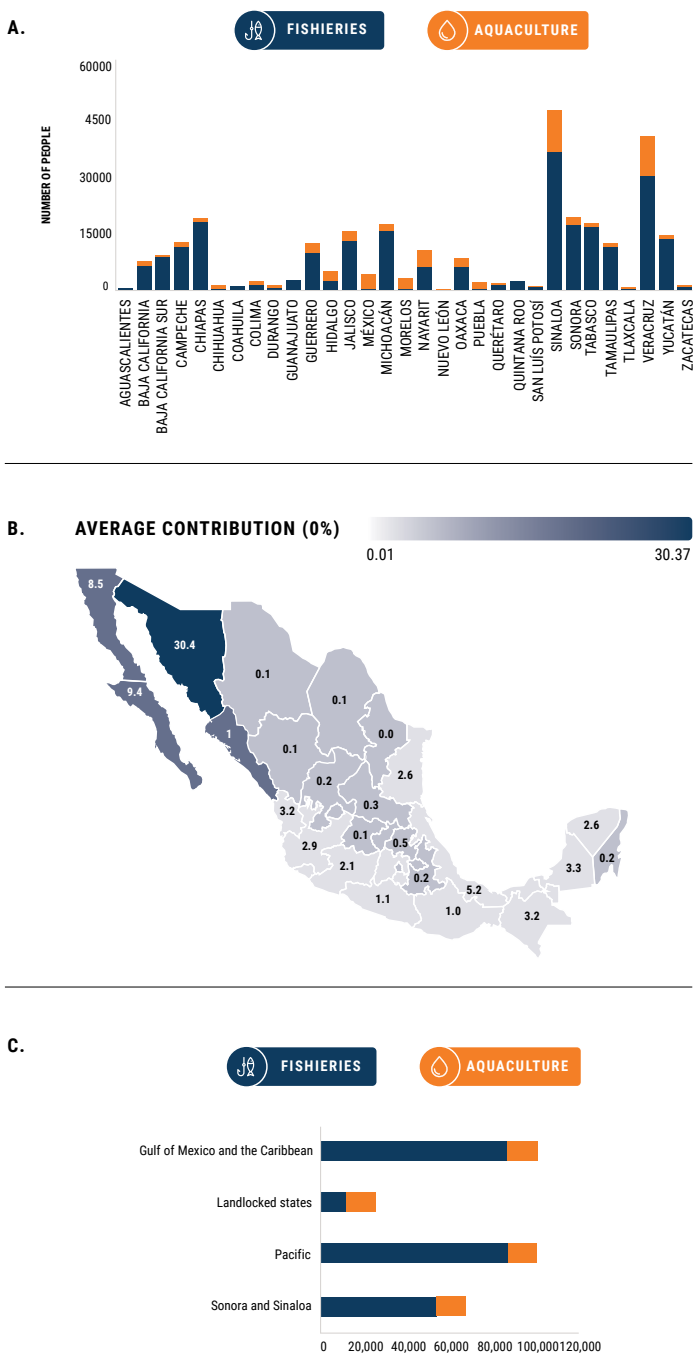

Figure 15. A. Number of people registered in the fisheries and aquaculture sector by state. B. Average annual share (2014-2018) of national volume (%) by state. C. Number of fishermen and aquaculturists grouped by region (Sinaloa and Sonora are grouped for comparison purposes). Prepared based on data from the National Fisheries and Aquaculture Registry (CONAPESCA, 2020).
Source: Prepared by the authors

Fisheries and aquaculture subsidies

In Mexico, although most subsidies promoting fishing activities stopped in 2019 (Federal Gazette, 2019), the government announced in 2020 that support would be provided in two components (Federal Gazette, 2020b): 1) Support for the Wellbeing of Fishermen and Aquaculturists (direct transfer equivalent to $7,200 Pesos per recipient) and 2) Support for the acquisition of Genetic Aquaculture Resources.

In the first case, the implications in connection with climate change are ambiguous (its effects have not yet been determined) because, although the amount is small, it could be put towards feeding the family or buying fishing gear, which would indirectly support the continuity of traditional fishing. In contrast, genetic aquaculture resources are potentially subject to being affected by climate change owing to the location of the farm and the physiological differences between species, affecting survival and harvest yields. In the absence of technical capacities regarding specific harvests, this program will not be successful.

Another type of subsidy that could help is that for marine protected areas, although its effect given the impact of climate change has not been clearly determined for Mexican fisheries. For example, a change in the distribution of species towards sites lacking protection would mean they would be vulnerable to fishing, thus reducing the conservation effect of such areas and making more vulnerable both the resource and the social environment.

Socioeconomic aspects of the fisheries and aquaculture sector and climate change impact

In Mexico, there are considerable differences between sectors (fisheries and aquaculture) and between fleets. For example, in terms of salary and social security, the aquaculture sector (considering all farming types) is better off (SAGARPA-IICA, 2018; Fernández et al., 2011). With respect to fleets, industrial vessels have historically been the focus of attention and received more support from the government in the form of subsidies (Federal Gazette, 2020a; Pescando datos, 2021); in contrast, although the fleet working along the coast accounts for the most part of the work force, it has not been a national priority and its importance is only acknowledged as part of the political discourse (IMCO, 2013).

Variations make the situation of fisheries and aquaculture even more complex

Climate change-related environmental variations make the situation of fisheries and aquaculture even more complex. Failure to act in response to them, or taking inappropriate steps, may result in substantial costs equivalent to an estimated 51 million USD annual loss (Mangin et al., 2018).

Fisheries and aquaculture producers have varying adaptation capacities in response to unfavorable conditions derived from climate change. As to fishing communities, their capacities depend on the infrastructure available and their level of social organization, as well as on the intensity and frequency of climate events (Nenadovic et al., 2018); in contrast, the aquaculture industry can determine in advance their level of risk, when making plans for the type of facilities, location, species to be grown, and infrastructure, which helps reduce both impacts and vulnerabilities (Monteforte, 2013).

The socioeconomic impact of climate change will also vary from one fleet to another (Seijo et al., 1998; Anderson and Seijo, 2010). In the case of traditional fishing, which does not receive

significant funding each season, the more uncertain the availability of resources, the more intertemporal choices will be made or the more resources will be used immediately, leading to overfishing and heightened vulnerabilities and poverty in coastal communities with free access to the resources. On the other hand, fewer intertemporal choices will be made in industrial fisheries, focused on conservational fishing management frameworks (e.g. limited vessel access) to foster investment and allow exploitation over a long period. This type of fleet may be more vulnerable, as searching for the resources requires higher investment, which may even drive fishermen to give up the activity entirely, leading ultimately to job losses.

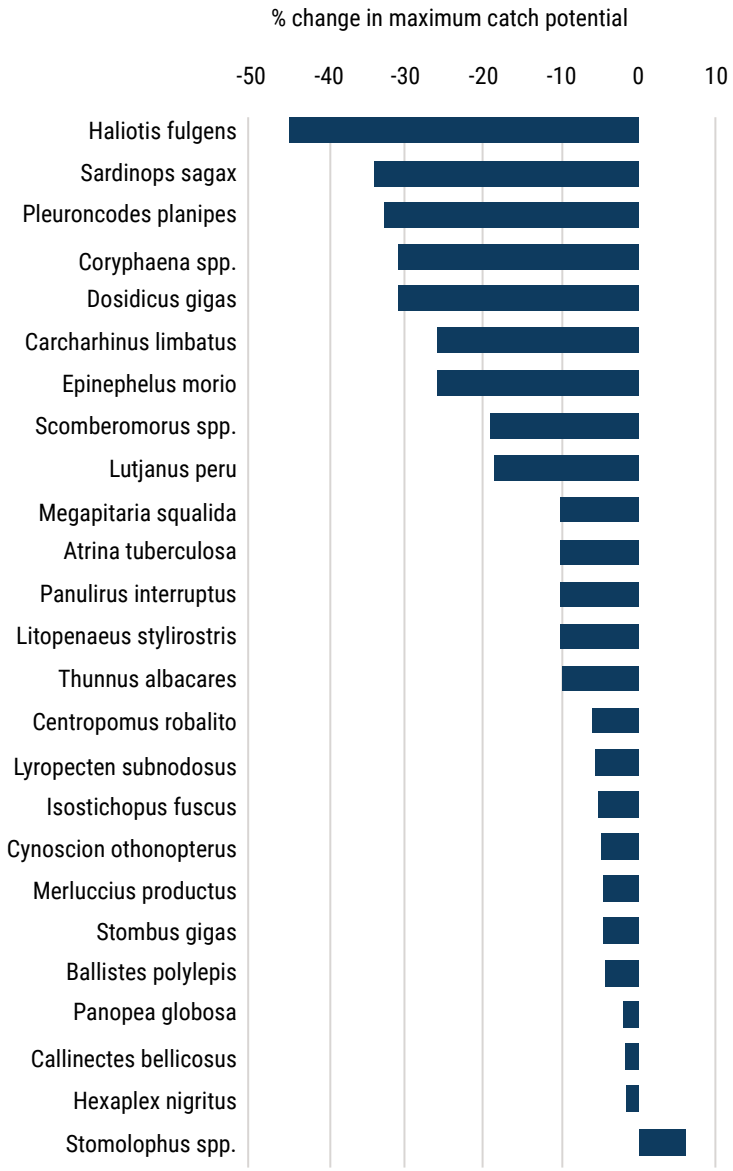

Figure 16. Climate change impact on the main fish species in Mexico.
Source: Adapted from Cisneros-Mata *et al*., 2019.

In sequential fisheries such as shrimp or red grouper, where two fleets compete for different components of the population (adult and young), competition for the resource gets tighter under the influence of climate change, affecting the resilience of the population as a consequence of recruitment problems and/or a drop in the breeding stock so that, with time, the costliest fleet will be removed. Also, according to projections, climate change will negatively impact the potential maximum catch of 21 out of the 25 main fisheries in Mexico (Cisneros-Mata et al., 2019; Figure 16).

Aquaculture areas are vulnerable to floods as a result of rising sea levels

With respect to aquaculture, although the effects of climate change vary from one species, type of farming and location to another, aquaculture areas are vulnerable to floods as a result of rising sea levels, mainly in southern Tabasco and Campeche, and in the Gulf of Tehuantepec (Flores-Nava, 2010).

It is crucial to consider the impacts of climate change on the agri-foods industry, incorporating and applying strategies to ensure food security in Mexico, fostering smart development taking into account the interaction between the various actors to prevent social conflict.

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Review of programs and projects providing a framework for Mexico's climate and aquaculture-fisheries

Institutional framework

Government institutions are key players in the implementation of adaptation measures for the fisheries-aquaculture sector in response to climate change. Mexico's institutional infrastructure is comprised of 21 federal administration ministries; of these ministries, the ones in charge of overseeing matters related to the environment and the fisheries and aquaculture sector are the Ministry of Agriculture and social Development (SADER), which manages the access and exploitation of agricultural, fisheries and aquaculture resources, and the Ministry of the Environment and Natural Resources (SEMARNAT), which deals with the protection and conservation of natural resources (Federal Gazette, 2000).

Mexico has in place a National Climate Change System (SINACC, for its Spanish acronym) headed by the president, which is in charge of fostering synergies and coordinating efforts to deal with the risks and vulnerabilities of our country, as well as defining priority actions to adapt to and mitigate climate change, linking the needs of the agri-food industry.

Legal frameworks and policies designed to address climate change

13 years have passed since the creation of the General Sustainable Fisheries and Aquaculture Law, and there is no regulation in effect

National laws have a hierarchical order as follows: At the top we find the Constitution of Mexico, which recognizes the three levels of government: federal, state, and municipal. Within this framework, the relevance of international treaties and agreements must be placed at the same level as the Constitution when it comes to conflicts in connection with human rights (SCJN, 2011). Some of the international agreements dealing with climate change that Mexico has signed are the United Nations Framework Convention on Climate Change, the Kyoto Protocol (the second commitment period of which concluded recently), and the Paris Agreement (Cámara de Diputados, 2019).

Current fisheries and aquaculture laws are governed by the General Sustainable Fisheries and Aquaculture Law, approved in 2007. This law sets forth a number of obligations for CONAPESCA, including to a) Promote, regulate, drive and implement climate change adaptation and mitigation actions; b) Coordinate with the federal government, other states and municipalities, the implementation of such actions; and c) Use scientific and technological research as a basis for the sustainable exploitation of fisheries and aquaculture resources, and the implementation of actions related to sustainable fisheries and aquaculture (Federal Gazette, 2007). But, 13 years have passed since the creation of the General Sustainable Fisheries and Aquaculture Law, and there is no regulation in effect, so its purposes cannot be achieved owing to the lack of regulation necessary to demand that the authorities fulfill their obligations, which places at risk the sustainability of marine and coastal resources (Vázquez-Vera, et al., 2021).

The pillars of climate policy in Mexico are solid because they consider vital elements necessary to design programs and policies oriented towards promoting a climate change culture that places Mexico in a good international position (Figure 17).

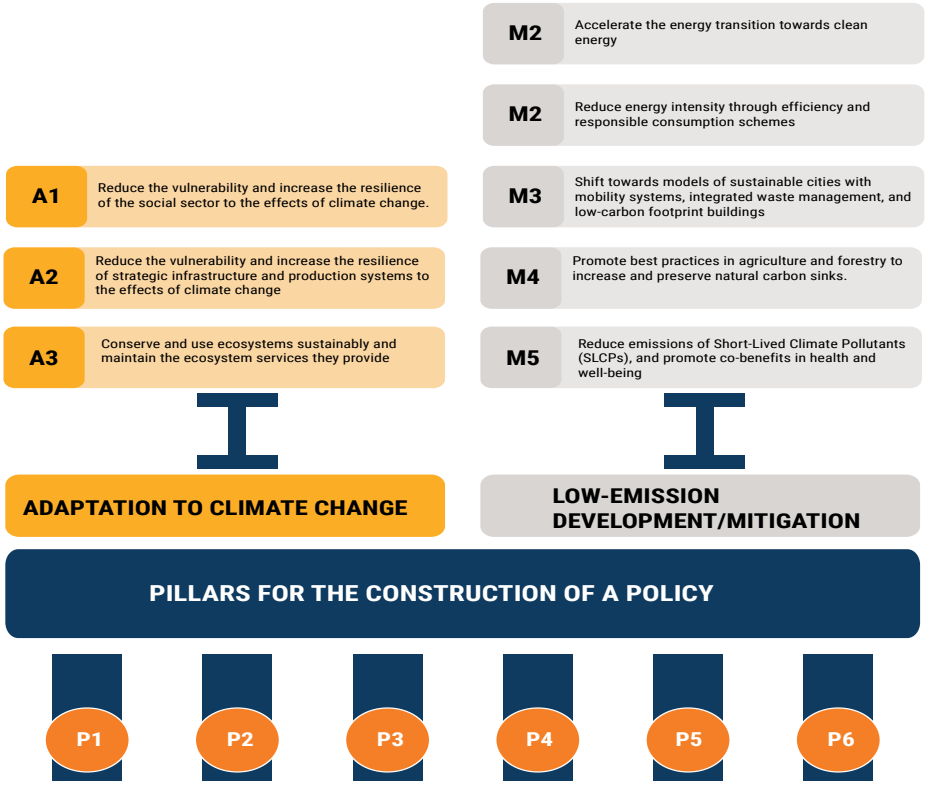


Figure 17. Pillars of National Climate Change Policy in Mexico. **Source:** House of Representatives, 2019

- **P1** Have in place cross-cutting, articulated, coordinated and inclusive climate policies and actions
- **P2** Develop climate-specific fiscal policies and economic and financial instruments
- **P3** Implement a research and innovation platform to develop suitable climate technologies and strengthen institutional capacities
- **P4** Promote the development of a climate culture
- **P5** Implement mechanisms for Measurement, Reporting, and Verification (MRV) and Monitoring and Evaluation (M&E)
- **P6** Strengthen strategic cooperation and international leadership

The organizational structure of SINACC is also robust (Figure 18). Among its components, the Congress and the Climate Change Council (C3) stand out, as they provide clear opportunities to promote the recommendations from the sector. Congress has a Fisheries and Aquaculture Commission both in the House of Representatives and the Senate, where consultation and social participation forums are organized to meet sector needs and promote a common and participatory agenda including the various voices of sector stakeholders regarding climate change. In turn, C3 has academic researchers, representatives of civil society organizations and entrepreneurs from this sector. There is also an opportunity to influence states and municipalities by taking part in the preparation of climate policy instruments described in the General Climate Change Law, and in policies for the sector (Aranceta-Garza et al., 2021).

The pillars of climate policy in Mexico are solid because they consider vital elements necessary to design programs and policies oriented towards promoting a climate change culture

While the institutional structure and operations of SINACC are robust, in practice it has apparently failed to produce the expected outcomes, given the lack of collaboration, consistency and convergence between the programs, actions and investment projects of the three levels of government and those of the Special Climate Change Program (PECC, for its Spanish acronym) (Velasco Ramírez and García Maning, 2019.) On top of that, the goals set for states and municipalities have also failed to be met; some of the country's most relevant states in the fisheries and aquaculture industry are relatively behind in the creation and application of policy instruments (Figure 19) (INECC, 2019.) Given the importance of policy instruments in the application of the General Climate Change Law, we need to identify the challenges faced by the various states to design such policies, giving priority to those states more dependent on fisheries and aquaculture activities.

An updated regulation for the fisheries and aquaculture law is also vital, as climate policy instruments must be explicitly linked to actions described in the 2020-2024 National Fisheries and Aquaculture Program and the National Climate Change Strategy, and incorporate scientific advances as a basis for any changes and the creation of future laws and/or rules.

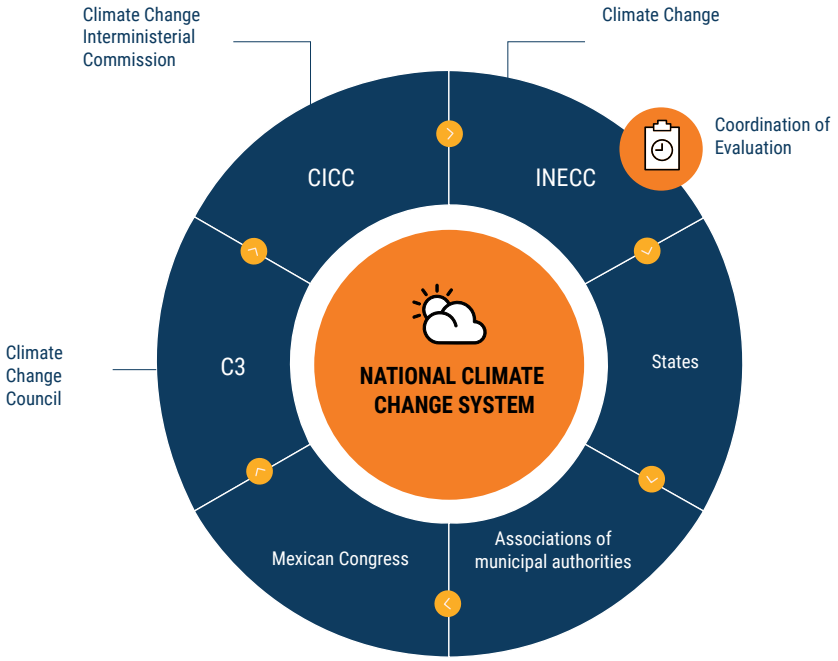
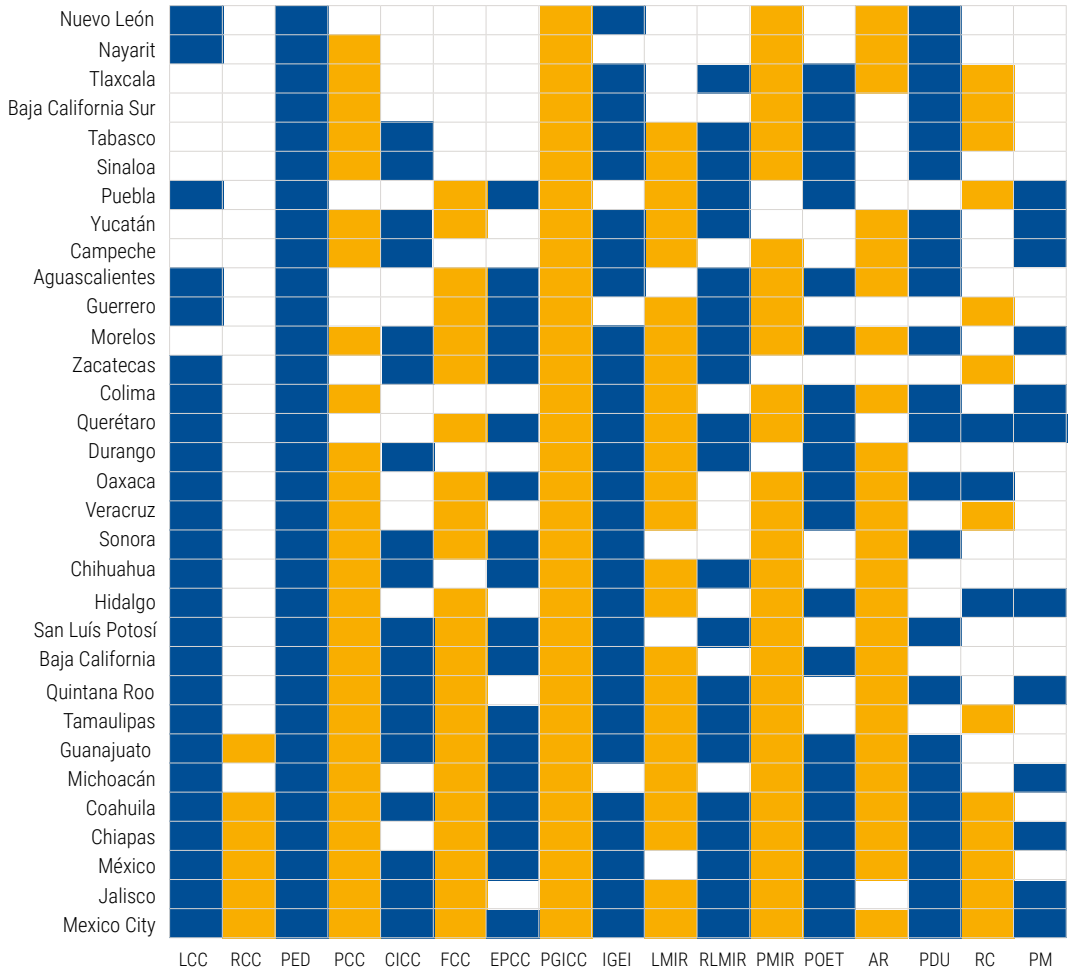


Figure 18. Chart of coordinated efforts of SINACC to comply with the General Climate Change Law.

Figure 19. Legal and planning instruments in climate matters.

Some of the country's most relevant states in the fisheries and aquaculture industry are relatively behind in the creation and application of policy instruments



1. Climate Change Law (LCC), **2.** Climate Change Regulation (RCC), **3.** State Development Plan (PED), **4**. Climate Change State Program (PCC), **5.** Climate Change Interministerial Commission (CICC), **6.** Climate Change State Fund (FCC), **7.** Climate Change State Policy Assessment (EPCC), **8.** Integral Air Quality Management Program (PGICC), **9.** State Inventory of Greenhouse Gas and Compound Emissions (IGEI), **10.** Integral Waste Management State Law (LMIR), **11.** Waste Management State Law Regulation (RLMIR), **12.** Waste Management and/or Final Disposal State Program (PMIR), **13.** Territorial Ecology Legislation State Program (POET), **14**. State Risk Atlas (AR), **15.** Urban Development Plans or Programs (PDU), **16.** Construction Regulation (RC), **17**. State Mobility Plan or Program (PM). INECC data, 2019.

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Legal framework for climate change adaptation in the fisheries and aquaculture sector in Mexico

The legal framework in place in Mexico to support climate change adaptation policies in the fisheries and aquaculture sector is robust and far-reaching. Its sources include national and international law. Any climate change law should consider international cooperation and a human rights approach. Incorporating a gender approach and the participation of young people into fisheries and aquaculture activities, combined with better education and training, will strengthen adaptation capacities in traditional fishing practices.

As to international law, it is indispensable to keep in mind the following legal instruments:

1. Universal Declaration of Human Rights.
2. UN System Chart.
3. United Nations Framework Convention on Climate Change.
4. Paris Agreement.
5. Law of the Sea (CONVEMAR).
6. International Covenant on Economic, Social and Cultural Rights (ICESCR).
7. Optional Protocol of ICESCR.
8. International Covenant on Civil and Political Rights.
9. Convention on Biological Diversity (CBD).

10. New York 1995 Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks
11. Code of Conduct for Responsible Fisheries.
12. FAO's International Plans of Action (IPOAs).
13. Climate change and other environment related matters, FAO COFI-2018
14. The State of World Fisheries and Aquaculture 2020: Sustainability in action.
15. Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (SSF), FAO, 2018.
16. Fisheries and aquaculture in the face of climate change. FAO - UNDP - UNESCO - UNISDR - ICES - CBD - OECD - OSPesca - World Bank - SPC - Globec - PICES - NACEE - Benguela - ICFA - EBCD - FIDA.
17. Fisheries, aquaculture and COVID 19 issues and Policy Responses, OECD.
18. Impacts of climate change on fisheries and aquaculture, FAO, TECHNICAL PAPER 627.
19. Resolution adopted by the General Assembly of the United Nations, A/RES/75/239. Oceans and the law of the sea.
20. Resolution adopted by the General Assembly of the United Nations, A/RES/74/18: Sustainable fisheries.
21. Resolution adopted by the General Assembly of the United Nations A/RES/73/284. United Nations Decade on Ecosystem Restoration.
22. Resolution adopted by the General Assembly of the United Nations A/RES/75/216. Sustainable development: Disaster risk reduction.
23. GEO-6 (Global Environment Outlook 6), UNEP 2020.
24. Making peace with nature, UNEP 2021.
25. The Escazú Agreement, 2021.
26. Building a New Future, ECLAC, 2021.
27. The Outlook for Oceans, CEPAL-ECLAC, 2020.
28. Deep Decarbonization Pathways in Latin America and the Caribbean: challenges and opportunities.
29. 2030 Agenda and UN's SDGs.
30. Addis Ababa Action Agenda, Ethiopia, 2015. Financing for Development.
31. Resolution adopted by the General Assembly of the United Nations A/RES/75/204. International financial system and development.
32. Outcomes of the Third International Conference on Financing for Development, Addis Ababa, Ethiopia, 13-15 July 2015.
33. Laudato Si' Encyclical Letter, Pope Francis, 24 May 2015.

In terms of national laws, rules and regulations, the following documents are mandatory references:

1) Mexican Constitution.
2) General Environmental Equilibrium and Protection Law (LGEEPA).
3) General Climate Change Law (LGCC).
4) General Law for Sustainable Fisheries and Aquaculture (LGPAS)
5) State laws in the following matters: Environment and environmental equilibrium, fisheries and aquaculture, climate change.
6) National Development Plan, 2019- 2024.
7) National Fisheries and Aquaculture Program, 2020-2024.
8) National Environment and Natural Resources Program, 2020-2024.
9) National Climate Change Strategy..
10) PECC, 2020-2024.
11) Fisheries sustainability in Mexico. 2020.
12) Mexico climate transparency report. 2020.
13) Mexican Official Standards in connection with fisheries and aquaculture.
14) Content and scope of human rights to a healthy environment. Constitutional Studies Center (CEC) of Mexico's Supreme Court (SCJN).
15) Rights of indigenous peoples and communities to own land, territories and natural resources. Constitutional Studies Center (CEC) of Mexico's Supreme Court (SCJN).

Preparing a climate change adaptation policy for the fisheries and aquaculture sector requires governance structure

The preparation of a National Climate Change Adaptation Policy for Fisheries and Aquaculture should be based on agreements reached in State Fisheries and Aquaculture Councils, the National Fisheries and Aquaculture Council, and the Interministerial Climate Change Commission (notice of which should be given to the Climate Change Council), separately in accordance with their internal regulations, and ratified at a joint meeting of the Interministerial Commission and the Council. The National Climate Change System incorporates all states into the analysis and promotion of the application of policy instruments described in the law. For their implementation, an ad hoc work group will be created. Such group will prepare an agenda and take into consideration the input of coastal states and municipalities via the mechanisms described in the General Climate Change Law and the General Sustainable Fisheries and Aquaculture Law, and the contents of state laws applicable to fisheries, aquaculture and climate change in connection with social participation in both matters. Conducting information and debate meetings in fishing communities, having an open dialog with fishing cooperatives, federations and confederations, as well as with the National Chamber of Fisheries and Aquaculture Industries, will be indispensable to prepare a climate change adaptation program effective in the long run.

The National Climate Change Adaptation Policy for Fisheries and Aquaculture will use as guidelines the adaptation principles and provisions in the General Climate Change Law (IV), chapters 1 and 2. All information provided by climate change researchers and experts in fisheries activities in Mexico should help to prepare updated regional and local diagnostic analyses which can be used to adopt

As well as fisheries management plans and the mechanisms for concessions and permits become legal instruments that are indispensable for resilience and climate change adaptation.

adaptation measures that are appropriate for the fisheries and aquaculture sector considering the geographic, economic, social and political characteristics that make up the various realities faced by fishing communities in the Pacific coast, the Gulf of Mexico and the Caribbean, and the differing conditions prevailing in the northwestern and southern regions of the Pacific and between the communities in the Gulf of Mexico that take into consideration fishermen and their organizations. Adaptation requires fish resources and ecosystems in good health conditions. For this reason, the tools described in the General Sustainable Fisheries and Aquaculture Law, which is the law designed for the fisheries sector, as well as fisheries management plans and the mechanisms for concessions and permits become legal instruments that are indispensable for resilience and climate change adaptation.

The General Climate Change Law empowers states, pursuant to Article 8(II), to "formulate, regulate, drive and implement climate change adaptation and mitigation actions in accordance with the National Strategy and the Program in the following respects: [...] c) Agriculture, livestock, rural development, fisheries and aquaculture." And the same Article 8, in subsection IV, empowers them to: "Prepare and implement a climate change program, promoting social participation, taking into account the views and needs of the public and private sectors, and the society at large."

LThe General Sustainable Fisheries and Aquaculture Law can incorporate concepts and provisions to promote a better management of fisheries and aquaculture resources in a climate change scenario, for example: ecosystem approach, adaptation and mitigation, risk, vulnerability, impacts, sensitivity, exposure, precautionary principle, joint management, adaptive management, small-scale fishing, marine-coastal spatial planning. The time will come when Congress will be required to intervene and update legislation as necessary.

Local congresses must develop an updating and harmonization process for state fisheries and aquaculture, climate change, and environment and ecological equilibrium laws, with the clear purpose of strengthening the adoption of a consolidated and robust climate change adaptation policy, with solid participation mechanisms and appropriate sectorial governance mechanisms.

During the process of preparation of the National Fisheries and Aquaculture ClimateChange Adaptation Policy, steps will be taken to enable a dynamic process of implementation of policies favoring resilient fishing resources and ecosystems and, above all, resilient, organized and strengthened communities able to face the challenges posed by global climate change. Programs for the protection and restoration of coastal ecosystems important for fisheries species: mangroves, coastal lagoons, estuaries, coastal dunes, reefs, seegrasses, deltas and river mouths, among others will be developed. Keeping fish stocks in good health is essential to strengthen the resilience of fisheries resources subject to exploitation.

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Domestic and international experiences of climate change adaptation in fishing communities

Global climate change adaptation measures designed for fisheries and aquaculture must be included as part of an adaptive management system to improve the conditions of socioecological systems (SES) in fisheries (MSC, 2018). These measures are mainly focused on five lines of action (Smit and Pilifosova, 2003; Shelton, 2014; Brander et al., 2017; Tolentino-Arévalo et al., 2019): 1) biology, 2) climate actions with early warning data, 3) ex ante protection measures, 4) links to public policy, and 5) promotion of domestic and international trade.

Climate change adaptations proposed by each fishery and aquaculture SES subsystem are included in Table VI

Table VI. Scope of climate change adaptation in the international context of fisheries and aquaculture (Brander et al., 2017).

Adaptations for capture fisheries
• Assessment of cases in context and reduction of ecosystem stressors. • Full implementation of the code of conduct for responsible fisheries.
• Restricted only to changing fishing methods, fisheries infrastructure and markets.
Social and economic adaptation in fisheries
• Incorporate strategies based on an ecosystem services framework. • Include actions to increase the resilience of fisheries-dependent social groups, based on maximizing new opportunities, adopting multi-sector strategies, ensuring a public policy environment that allows for productivity and occupational flexibility, and ensuring the accessibility of insurance for vulnerable groups.
Adaptations in governance and management of fisheries
• Foster a precautionary policy and ecosystem approach, taking into account uncertainties and the effect of management and adaptation actions..
• Apply adaptive measures in response to climate-induced changes in resources.
Adaptations in aquaculture
• In the planning of the sector, include consideration of the potential effects of climate change, establishing ex ante planning that can include aquaculture zoning to minimize risks, better-adapted seed stock and/or selectively bred strains, improved feeds, and reducing pressure and reliance on feed resources.

Keeping fish stocks in good health is essential to strengthen the resilience of fisheries resources subject to exploitation.

Domestic and international experiences in the application of climate change adaptation measures

There are many examples of international fisheries and aquaculture efforts to fight the impact of climate change in contexts similar to that of Mexico or related to it. While some of them could be adapted for their application in Mexico, the main focus is on generating our own state-of-the-art tools to determine which adaptations are applicable in each case. These adaptations include fostering robust government-academia-producers partnerships under climate change-specific trusts, which are the basis for successful actions in the US, Europe and Australia in terms of research and application of mitigation strategies. Similarly, solid management supported by Strategic Climate Change Action Programs specific for the fisheries sector and funded by national and international funds, as done by Chile and Peru, could be replicated here.

The case of Mexico

In Mexico, any management measure to be implemented should address three main challenges (Mangin et al., 2018): 1) to generate information, 2) improve the precarious socioeconomic conditions of most traditional fishermen, and 3) strengthen institutional capacities. In addition, for any management measure to succeed, it is necessary to plan for the long term and include both the communities and the fisheries industry. At the same time, it will be essential to build capacities in the community to promote governance, joint management regimes and sustainable fishing (Espinosa-Romero et al., 2014).

Adaptive capacities in fishing communities

The attitude fishermen have towards risk and uncertainty, whether in the form of cooperation or competition, is specific to the context of each SES, so we need to understand their particular dynamics to be able to select strategies that may enable them to build successful adaptation capacities in response to climate change. For fisheries governance to be effective, it is important to formulate policies based on users' common interests and to minimize asymmetries in the decision-making process.

Programs for the protection and restoration of coastal ecosystems important for fisheries species.

Local experiences, implemented voluntarily by actors of the fisheries sector

Many national climate change adaptation strategies have been implemented voluntarily by coastal communities seeking to improve the sustainability of their resources. In this sense, communities have established surveillance committees (for example, lobster in Punta Allen, Quintana Roo; red lobster and abalone in Baja California); Advisory Boards in the management plans of protected natural areas (por example octopus, sea cucumber and drum in Bahía de los Ángeles); marine reserves in the Gulf of California (GC); biology monitoring (Baja California: Micheli *et al*., 2012; Sian Ka'an Reserve: Méndez-Medina *et al*., 2020); adjustment of exploitation rates following negative climate events (Finkbeiner *et al*., 2018).

Initiatives of the federal government to provide information and improve decision-making in the context of climate change

Mexico has organized forums — such as the Climate Change and Aquaculture Forum (INAPESCA-Instituto Nacional de Ecología, 2008) — and taken part in initiatives — such as the Ocean Panel initiative for 2030 in 2018 — with the purpose of preparing climate change adaptation and mitigation agendas for fisheries activities and the transition towards a sustainable ocean economy. Such meetings have provided the elements necessary for the aforementioned agenda (Table VII) and have made a commitment to apply measures of mitigation and coast resilience promotion.

Table VII. Elements for the climate change research agenda of the fisheries sector (INAPESCA, 2008).

Priority 1:	Priority 2:
• **Manage** and establish a fund with the purpose of funding climate change research for the fisheries and aquaculture sector. • **Strategies** and programs of adaptation to ecological, social and economic impacts, including territorial considerations. • **Design** a legal framework and appropriate and dynamic administrative structures allowing for the preparation of climate change adaptation strategies. • **Communication** and interaction between academia and the government and fisheries and aquaculture actors regarding climate change and their participation in any solution mechanism.	• **Model** the physical environment. • **Model** the biomass of resources supporting fisheries and aquaculture. • **Create** climate change scenarios for fisheries and aquaculture. • **Incorporate** models in oceans and coasts. • **Model** the economy in connection with climate change. • **Model** social impacts associated with climate change.

Marine PNAs do not have an assessment and monitoring plan for their resources and environment

The role of protected natural areas (PNAs) and climate change

PNAs increase the biological resilience of a population by protecting zones that are important for their biology and genetic diversity (Roberts et al., 2017), making it more likely for populations to succeed in their climate change adaptation efforts, combined with the management and sustainable use of resources by communities in the PNA. However, marine PNAs do not have an assessment and monitoring plan for their resources and environment which could enable truly sustainable management, assessing goals and management outcomes.

Research in connection with climate change impacts on commercial fisheries

An action proposed to fight overfishing, which exacerbates the negative effects of climate change on resource resilience, is to adapt the inspection system to inter-institutional or shared surveillance (Ortiz-Gallarza *et al*., 2020a), examples of which can be found in the communities of BC and Quintana Roo (for example, Arroyo-Mina *et al*., 2016; Audefroy and Sánchez, 2017; Finkbeiner *et al*., 2018; Fulton *et al*., 2015; Micheli *et al*., 2012).

For some industrial and traditional fisheries, management with an ecosystem focus taking into account climate change impacts is already in place (Lehodey *et al*., 2013; Morgan *et al*., 2015; Ortiz-Gallarza *et al*., 2020b). However, this kind of management is really complex and, in order to face such complexities, three lines of action have been proposed oriented towards research, governance and attention to the social component.

Including bioeconomic analyses makes it possible to establish a connection between the economic behavior of a fisherman and the condition of the resource under uncertain natural circumstances (for example, climate change). Then, it is possible to estimate an optimal effort level based on bioeconomic points of reference, such as the maximum sustainable or economic yield under different climate scenarios.

For aquaculture, adaptations for climate variability have been provided by private companies linked to academia and with a focus on the biology (Ibarra *et al*., 2017) or technology of the harvest. However, the cost of using recirculating aquaculture systems (RAS) makes it impossible to implement them in rural zones.

In conclusion, according to the five general lines of action for climate change adaptation mentioned above, it was found that: 1) In terms of biological resilience, Mexico must have specific measures involving the society, academia, the government and civil society organizations that may allow them to improve the current conditions of fish stocks; 2) Environmental information is still limited and public access to information platforms in order to create early warning projections is also limited; 3) Not one case of ex ante protection measures specifically applied to fisheries in response to climate change was found; 4) There is no clear link between management and specific climate change adaptation measures established by region, community and species. At the same time, governance should be strengthened by promoting schemes of cooperation and participation in the decision-making process of all stakeholders. 5) Governments (at a federal, state and municipal level) must work on commercial strategies for marine products incorporating user equality and inclusion.

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Conclusions

- There is sufficient evidence of the phenomenon of climate change.
- In Mexico, it is already impacting the lives and wellbeing of thousands of people, particularly in the northwestern region of our country.
- Among the main oceanographic changes that will be seen in Mexico according to the models used in this study, rising sea temperatures, more intense meteorological phenomena such as hurricanes, higher sea levels in states with huge lower ground areas, ocean acidification, and lower oxygen concentration, especially in the northwestern region, stand out.
- The analysis of vulnerabilities of Mexico's coastal communities to pressures caused by climate change revealed that right now, northwestern states are in a worse position, but in the medium term (around 2050), in the worst-case scenario proposed by the UN Intergovernmental Panel on Climate Change (IPCC), the states along the southern coast of the Gulf of Mexico and the Yucatán Peninsula may be drastically affected.
- The legal framework upon which climate policies are based in Mexico is robust and, in general, acceptable.
- This framework provides a set of tools to deal with future disturbances, and is supported by a series of treaties and international agreements that Mexico has agreed to apply. However, national rules and legal provisions are disconnected, so it is necessary to coordinate them in order to maximize their efficacy. Further, it was noted that many coastal states are behind in the creation of laws and rules designed to mitigate and adapt to climate change.

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Policy recommendations for climate change adaptation in Mexico's fisheries and aquaculture sector

Based on the information presented here, and on a series of workshops to collect the comments and opinions of members of all the sectors involved in fishing activities in Mexico (federal government, fishermen organizations, academic institutions, civil organizations, members of international agencies specialized in fisheries, and the society), more than 30 recommendations for climate change adaptation strategies in the fisheries sector were prepared, ranging from the local to the national level. This initial set was subject to a first filter to select the most relevant recommendations, taking into account the following: a) Relative importance of the strategy according to the experts; b) Feasibility of application of the recommendation, considering the legal framework in effect in Mexico; c) The likelihood that the respective recommendation could be applied in the short term, and d) The existence of social groups (government, fisheries organizations, academic institutions, industrial groups or civil organizations) that may implement them.

The final recommendations are divided into three categories: General strategies (applicable nationwide), Strategic considerations and Practical recommendations (regional and local focus).

Priority recommendations

1. Develop and implement a **National Fisheries and Climate Change Program** at the federal level, widely present in the territory and with active interdisciplinary public participation, i**ncorporating the views of actors in the various stages of the sector's productive chain**. This must be based on **inter-sector coordination and public consultations** opening up communication channels and collaborative work opportunities for agencies in the three levels of government, as well as the creation of partnerships with other sectors with connections to the fisheries sector. This program must include an ongoing assessment system to evaluate the success of all strategies applied, assigning value to the results and at the same time allowing for sufficient flexibility.

2. Create the **National Risk Atlas for the fisheries sector**, incorporating environmental pressures and the adaptation capacities of the various communities and, at the same time, establish contingency plans to minimize any economic and social impacts, foster preventive activities, and find options to protect people's infrastructure and property.

3. Invest more in **knowledge generation** and implement actions that make it possible to combine, identify, and validate **the knowledge of every actor** in the sector, to develop local scenarios and climate change adaptation strategies. It is also important to **invest in forming teams specialized** in climate change, in **government, civil organizations and academia**.

4. The legal framework governing fisheries and aquaculture activities was created in a different context of ideas and social conditions, which can limit its applicability. Our recommendation is to harmonize legal tools related to climate change and ecosystem management, both at the federal and state levels, and particularly update: National Fisheries Charter (Carta Nacional Pesquera), National Aquaculture Charter (Carta Nacional Acuícola), Mexican Official Standards and Management Plans in connection with fisheries resources.

5. Recognizing that vulnerabilities to climate change are by no means equal for every member of a social group, we recommend that a gender approach should be included in vulnerability analyses of the fisheries sector, so that these aspects can be mainstreamed to the preparation and implementation of adaptation measures.

Strategic recommendations

1. Strategies and legal reforms should be promoted to allow **State Fisheries and Aquaculture Councils** to participate in resource management decision-making processes, and deal concretely with community needs. Also, **Interstate Fisheries Councils** should be created with the purpose of preventing any problems that may arise among communities owing to the possible migration of resources towards other regions.

2. These councils could create or activate **policies designed for small scale fishing, using a community approach** and including not only those who work in the fisheries and aquaculture sector, but the entire society with which they interact. This will help to build an adaptation community that shares territory and problems, and builds its own adaptation model jointly and collaboratively.

3. Conduct an integral analysis of the possible situations the various links in the value chain could live, and **establish strategies to help catch, harvest, storage, management, industrialization, transportation and marketing systems** to adapt to the new environmental and social contexts that may be caused by climate change.

4. Review and promote the implementation of **international treaties that may allow an appropriate management of transboundary resources, and pay attention to exports markets**, which represent strategic revenue-generating streams for the country

5. We recommend that the federal government should organize the creation of a c**entralized data base on ocean conditions, operating in real time** and built with the support of various sectors, so that they can relate to the goal.

6. A necessary piece of key scientific information is to r**eview changes prompted by the new conditions that affect primary production**, sea production, **key demographic parameters for fisheries management** (season and maturity age, natural mortality and growth rate, etc.) **catch volume**, and the **spatial distribution** of target species. This will allow us to support communities by foreseeing possible changes in capture site, fishing gear and resource type.

7. A program should be established to **efficiently communicate to all sectors and through various media messages regarding the dangers, opportunities and forms of adaptation** we face. This will make everyone more aware of the situation and favor the application of adaptation measures at different levels, from local to federal.

8. With respect to aquaculture, we recommend that **activities should be diversified** (for example, with polycultures), **research and the development of infrastructure** (better seed production laboratories) should be promoted, and **genetic lines should be improved**, to optimize the quality of harvested species and favor their adaptation capacities to the new ocean conditions.

9. Any plans to adapt the aquaculture sector to climate change should consider the **scenarios and inputs available in the INECC-UNAM Climate Change Atlas** to ensure that water resources are managed well, the integrated management of basins and the quality of water. These elements are essential, as multiple aquacultural resources depend on salty zones or breed or are recruited in sites with freshwater influence such as mangroves.

ROADMAP FOR THE RECOMMENDATIONS

Recomendaciones prioritarias				
Recommendation	**Leader**	**Collaborators**	**Potential funding**	**Timescale**
National Climate Change, Fisheries and Aquaculture Program	SADER	INAPESCA, GE, OP, PI, CP, AC, OSC	Federal funds, international agencies	Short
National Atlas of Risks for the Fisheries Sector	INECC	CONAPESCA, AC, OSC	Federal funds, international agencies	Short
Discovery of knowledge and improvement of capacities	AC	INAPESCA, OSC, CP, PI	Federal funds, international agencies, foundations	Short
Analysis of harmonization and update mechanisms for legal tools	SADER	CONAPESCA, INAPESCA, OSC	Federal funds, foundations	Medium
Include a community and gender focus in the measures		Todos los sectores	Not required	Short
Strategic recommendations				
Recommendation	**Leader**	**Collaborators**	**Potential funding**	**Timescale**
Creation or strengthening of State and Inter-state Fisheries and Aquaculture Councils.	CONAPESCA	INAPESCA, GE	Federal funds	Medium
Review and implementation of international treaties on transboundary resources and export species.	SADER	CONAPESCA, INAPESCA, GE, PI	Federal funds	Medium
Creation of centralized data base on oceanographic conditions and operating in real time	INECC	CONABIO, AC, OSC, OP, PI	Federal funds, international agencies, foundations	Medium
Analysis of the effects of climate change on the biology and distribution of resources.	AC	INAPESCA, INECC, OSC	Federal funds, international agencies, foundations	Short
Program for the dissemination of information on threats and adaptation possibilities of the sector, targeting multiple social actors.	OSC	AC, CONABIO	Federal funds, international agencies, foundations	Short

Diversification of aquaculture activities and improvement of the quality and adaptive capacities of harvested species.	INAPESCA	CONAPESCA	Federal funds, international agencies	Largo

List of abbreviations: INAPESCA: Instituto Nacional de Pesca y Acuacultura (National Fisheries and Aquaculture Institute.) AC: Academia. CONABIO: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (National Commission for the Knowledge and Use of Biodiversity.) CONAPESCA: Comisión Nacional de Pesca y Acuacultura (National Fisheries and Aquaculture Commission.) FC: Fishing communities. SG: State governments. INECC: Instituto Nacional de Ecología y Cambio Climático (National Institute of Ecology and Climate Change.) FO: Fisheries organizations. CSO: Civil society organizations. IF: Industrial fishing. SADER: Secretaría de Agricultura y Desarrollo Rural (Ministry of Agriculture and Rural Development.)

Timescale: C: Short (1 to 3 years), M: Medium (4 to 6 years), L: Long (> 6 years.)

RECOMMENDATIONS AT A REGIONAL LEVEL, SUGGESTED DURING COLLABORATIVE WORKSHOPS

Recommendation	Nortwestern Mexico	Gulf of California	Tropical Pacific	Gulf of Mexico	Mexican Caribbean	Key stakeholders
Create models that highlight the relevance of huge spatial scale effects, such as El Niño, or changes in ocean circulation patterns and winds.			X	X	X	AC, CSO
Correct blanks for information on climate threats in the region of the Gulf of Mexico-Caribbean Sea.				X	X	AC, FG, SG, CSO
Analyze expected demographic changes in coastal cities, based on state development plans and population projections prepared by INEGI.		X			X	FG, SG, AC, CSO
Support the development of academic capabilities to create groups of specialists with a local and direct application perspective.			X	X	X	AC, FG, SG
Develop differential climate effect diagnostic analyses for the industrial and traditional sectors, and at a regional level.	X	X		X		AC, FG, SG, CSO, TF, IF
Promote investment in education to use new methods for catching species and to update, improve and replace fishing gear. Also support	X	X		X		FG, SG, AC, CSO

List of abbreviations for the column of key stakeholder recommendations: FG: Federal government, SG: State governments. AC: academia, CSO: Civil society organizations, TF: Traditional fishing, IF: Industrial fishing.

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Glossary of terms

Climate change (CC) means "a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods of time" (United Nations, 1992).

The greenhouse effect occurs when solar radiation is trapped in the atmosphere because of the presence of greenhouse gases (GHG). These gases can occur naturally or result from human activity, which can modify the concentrations of some of them in the atmosphere and cause, for example, a constant rise in the average temperature of the planet and the oceans, known as global warming, altering the natural conditions of ecosystems (Barbieri et al., 2020; IPCC, 2018).

In the context of CC, **threats** or dangers refer to two kinds of events: 1) Extreme weather events which are sudden (for example, intense rainfall), and 2) Gradual changes that can take some time (for example, changes in mean rainfall or temperature regimes, or coastal erosion.) If these threats or dangers affect social systems, they may result in impacts, generally linked to economic loss, usually as a consequence of increased exposure, that is, an increase in the presence of people, communities, natural resources and environmental services, or infrastructure, among others, in places that could be affected by the weather.

Vulnerability determines the degree to which a system is susceptible or lacks the capacity to cope with the adverse effects of alterations in climate variability, and defines the extent of damage a natural event can cause. Influencing the level of vulnerability are **sensitivity,** which is the degree to which the system is affected by stimuli related to climate, and **adaptation capacity or resilience**, which is the capacity systems have to cope with a hazardous event, trend or disturbance responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for learning and transformation (IPCC, 2014b).

Risk refers to the potential adverse consequences of a climate-related danger or the adaptation or mitigation responses to such danger (IPCC, 2018), and its visible expressions are **disasters**.

To manage disaster risks means to focus on working to reduce **vulnerability and exposure**, as well as on developing steps to live with the risk.

Measures in response to climate change: mitigation and adaptation

Mitigation refers to efforts to reduce the contributions causing CC by reducing or limiting GHG emissions or boosting the natural removal of such gases (IPCC, 2014a).

CC **adaptation** refers to measures and adjustments to human or natural systems in response to climate stimuli or their effects, in order to limit the damage or take advantage of any beneficial aspects (General Climate Change Law, moved section Federal Gazette 13-07-2018). Adaptation measures seek to create **resilient systems** to the impacts of CC; such measures can occur as an autonomous process **(reactive),** that is, responses by the communities without any explicit planning, or in advance **(proactive),** oriented towards anticipating future CC impacts and reducing potential risks. The latter involve planning and the participation of communities, the private sector and/or the government. In addition, such measures will be **structural** if they derive into tangible results, or **non-structural**, if they are aimed, for example, at developing capacities in the people affected by a threat.

Ecosystem-based adaptation (EbA) is an approach to adaptation that integrates the use of biodiversity and ecosystem services to enhance the adaptation capacities of various systems (CBD, 2009).

A community-based approach to adaptation (CbA) is an approach to adaptation that champions the permanent participation of local actors, seeking to build measures and strategies based on locality-specific characteristics that may help create a sense of belonging and generate awareness and commitment to change or adjust usual practices to anticipate impacts and improve their life conditions (SAyDS, 2013).

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

PNA: Protected natural areas

CC: Climate change

CONAPESCA: Comisión Nacional de Acuacultura y Pesca (National Fisheries and Aquaculture Commission)

CONEVAL: Consejo Nacional de Evaluación de la Política de Desarrollo Social

GC: Gulf of California

GHG: Greenhouse gases

GFW: Global Fishing Watch

NGM: Northern Gulf of Mexico

SGM: Southern Gulf of Mexico

IPCC: Intergovernmental Panel on Climate Change

IPP: Instruments of public policy

GLA: General lines of action

LGCC: General Climate Change Law

LGPAS: General Law for Sustainable Fisheries and Aquaculture

CS: Caribbean Sea

OSC: Civil society organizations

MAP: Middle American Pacific

PECC: Special Climate Change Program

MP: Mexican Pacific Transition

PNPA: National Fisheries and Aquaculture Program

PP: Primary productivity

SCP: Southern Californian Pacific

TPM: Transitional Pacific of Monterrey

RCP: Representative Concentration Pathway

RNPA: National Fisheries and Aquaculture Registry

SADER: Secretaría de Agricultura y Desarrollo Rural (Ministry of Agriculture and Rural Development.)

SEMARNAT: Secretaría de Medio Ambiente y Recursos Naturales (Ministry of Environment and Natural Resources)

SEPADA: Secretaría de Pesca, Acuacultura y Desarrollo Agropecuario (Ministry of Fisheries, Aquaculture and Agriculture Development)

SINACC: National Climate Change System

SSP: Shared Socioeconomic Pathways

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