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# Small-Scale Fisheries in the Colombian Pacific: Understanding the Impact of Climate Change on Fishermen's Livelihoods

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**Abstract:** While few have contemplated the potential impacts of climate change on small-scale fisheries and fishermen in the Colombian Pacific, understanding these effects is crucial for devising effective adaptation strategies. This study presents the outcomes of a vulnerability assessment related to climate change for fishermen in the Colombian South Pacific. The assessment employed a multivariable model that considered the sensitivity of marine and coastal ecosystems that support fishing resources alongside fishermen's adaptability to changes in the biophysical environment. Socioeconomic factors were also scrutinized. The study revealed that 80% of the surveyed fishermen are at a medium to high level of vulnerability due to changes in the distribution of key commercial species, which influences the productivity of their traditional fishing sites. Their vulnerability is primarily attributed to low usage of fishing technologies, the boat engine's limited propulsion capacity, and a lack of diversity and sustainability in fishing gear. These elements increase their reliance on fishing sites close to the coast (approximately 3 km to 5 km from the shoreline), resulting in a low adaptive capacity for the fishermen. The dominant factor driving the sensitivity component was the economic significance of the fishing gear and the fact that the gear could be more diverse and durable. These findings provide a critical scientific basis for assessing the fishing sector's vulnerability to climate change and informing future collaborative decision-making in managing small-scale fisheries in the Colombian South Pacific Ocean.

**Keywords:** climate change; vulnerability; species distribution; Colombian Pacific; fishermen; small-scale fisheries

**Key Contribution:** This study serves as the first vulnerability assessment specifically focused on the interplay between climate change and fisheries in the region. It lays the groundwork for understanding how climate change could impact fishing communities in the Colombian Pacific. Our research reveals that small-scale fisheries are particularly susceptible to the effects of climate change. This vulnerability is due to their limited adaptive capacity, further hampered by a lack of economic resources and assets needed to expand their operational range into open waters. These findings provide a foundation for formulating and implementing adaptive strategies in future scenarios. They also inform governmental actions and cooperative efforts to benefit the territory and its communities.

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## 1. Introduction

The contribution of small-scale fisheries (SSFs) to the socioeconomic systems of coastal communities is widely recognized worldwide. For instance, they account for nearly half of the world's fish landings [1]. In Colombia, where artisanal, semi-industrial, and industrial fishing coexist, the Pacific region contributes 80% of the country's total catch volume through SSFs [2], accounting for 3% of the Gross Domestic Product (GDP) [3]. However, SSFs are highly vulnerable to climate change's impact on commercial species' geographical distribution. Global warming is altering the physical–chemical conditions of the oceans, thereby affecting the distribution, abundance, and productivity of phytoplankton and zooplankton—the primary levels of the trophic chain—and, consequently, other marine species that depend on them [4–6].

Small-scale or artisanal fishing is characterized globally by various factors such as the size of the vessel, the type of equipment used, the intended product, the distance from the coast where the fishing occurs, or a combination of these factors [7]. In Colombia, the primary criteria include the final destination of the catch and the fishing techniques and gear employed [8]. Specifically, communities in the Colombian Pacific mainly engage in fishing for economic and household sustenance. These communities typically operate within 12 nautical miles of the coastline, using wooden or fiberglass boats equipped with outboard motors ranging from 40 to 80 HP. Notably, they often rely on traditional knowledge of the fishing grounds rather than advanced geopositioning equipment such as GPS, radar, and echo sounders.

Artisanal and small-scale fisheries provide the primary marine resources on Colombia's Pacific coast, making them responsible for a significant proportion of the seafood consumed in the country. Castellanos-Galindo et al. [7] state that the gross revenues from this industry are in the range of US$10–20 million per year. For instance, the landings from artisanal and small-scale fisheries in the Pacific region in 2017 were valued at US$10.8 million, with Buenaventura (56.9%) and Tumaco (21.2%) accounting for the majority of the landings, as these two ports are the largest in the region [9].

The vulnerability to climate change has become a major worldwide topic of debate, as it provides key information on how the effects of climate change can disrupt an individual, community, or system. Its analysis has been conceived as a strategy to provide decision-makers with tools for integrated planning of adaptation measures to guide development [10]. The concept of climate change vulnerability was presented by the IPCC in its Fourth Assessment Report (AR4) as an integrated function of exposure, sensitivity, and adaptive capacity [11,12], and based on the definition of the "vulnerability context" in the Fifth Report (AR5) [13,14]. The first two assess the potential impact of climate change on ecosystems, while the third (adaptive capacity) assesses the response of the social system.

In the context of fisheries, exposure means the presence of people, lifestyles, species, ecosystems, ecosystem functions, services, resources, infrastructure, or cultural, economic, or social assets or goods in places and configurations that may be negatively affected by climate change [15]. On the other hand, sensitivity is related to how vulnerable the object or subject of study is. It shows how much a system responds to climatic influences and how climate changes may change its current form [16]. It can be thought of as the degree to which the fisheries sector will be affected by shocks and stresses due to its susceptibility. Adaptive capacity, finally, refers to the ability of individuals to respond to, cope with, and recover from the effects of changes or stressors. A system can adjust to climate change, including climate variability and extremes, in a way that minimizes damage, takes advantage of opportunities, or faces the consequences [17]. In this case, it is related to changes in the availability of biological resources and to the impact that fishing sector equipment, boats, and homes may have due to extreme events.

On the other hand, the concept of vulnerability context recognizes that socioeconomic conditions, such as policy trends, distribution of economic resources, and governance, play a significant role in exposing a system to climate-related hazards. The complexity of socioeconomic and policy dynamics in the fishing industry can make SSFs highly susceptible to environmental changes, reducing their adaptive capacity [18–20]. The vulnerability of SSFs in the Colombian South Pacific also depends on the types and diversity of fishing gear and boats used and their economic dependence on fishing [21].

In Colombia, vulnerability assessments have mainly been conducted in the social context to evaluate impacts on livelihoods and food security [22–24] and to manage risks from new weather conditions and extreme events [25–27]. Bejarano et al. [28] assessed the level of exposure, sensitivity, and adaptive capacity of marine resources, such as corals, in the Corales del Rosario and San Bernardo National Natural Park to climate change factors, including sea surface and air temperature, precipitation, and ocean acidification. Herrera-Montiel et al. [29] and Selvaraj, Rosero-Henao, and Cifuentes-Ossa [30] predicted changes in the distribution of pelagic fish species in the Colombian Pacific Ocean under different climate change scenarios using modeling software and satellite-derived environmental variables such as sea surface temperature, chlorophyll-a, and ocean currents. Few studies have examined the vulnerability of SSFs and fishermen to climate change in Colombia. Tilley et al. [2] predicted the vulnerability of SSFs in the Pacific region to management changes, offering insights into their sensitivity and adaptive capacity to external changes, such as new fishery policies.

This study aims to contribute to understanding the vulnerability of artisanal fishing and fishermen in the Colombian South Pacific to the effects of climate change. Recognizing and categorizing a community's vulnerability constitutes a baseline or starting point for designing, identifying, and implementing adaptation strategies to bolster their resilience capacity. The study applies a vulnerability assessment model to a sample of 150 fishermen in the Nariño department in the Colombian South Pacific, surveyed in 2020. The model assesses their sensitivity and adaptive capacity based on crucial information on household composition, demographic characteristics, and fishing activity performance. Additionally, exposure to climate change was evaluated by identifying changes in the distribution of 12 marine fish species. The community prioritized these species based on their local and ancestral knowledge and their significance for commercial fishing and food sovereignty in the region. Their importance is determined by local commercial interests, regional and national market demand, and their desirability among households. The model also predicts their future displacements under the Representative Concentration Pathway (RCP) 8.5 scenario by 2050 from traditional fishing grounds used by the surveyed fishermen. In conclusion, the model developed to identify and analyze the vulnerability of artisanal fishing on the Pacific coast of Nariño is based on the sensitivity of marine and coastal ecosystems supporting the fishing resource and the adaptability of fishermen to changes in the biophysical environment. It uses a multi-variable approach based on the results of a socioeconomic characterization process.

## 2. Methods

### *2.1. Study Area*

The study area corresponds to the Colombian South Pacific region, including the departments of Nariño and Cauca (Figure 1). This study area has been named the Nariño Economic Exclusive Zone (NEEZ) for the purpose of this study based on the area where the artisanal fishermen of Nariño carry out their fishing tasks. The Colombian Pacific has an Economic Exclusive Zone (EEZ) of 339,500 km$^2$ and a coastline that extends from the borders of Panama (7°13′21″ N, 77°53′25″ W) to Ecuador (1°27′48″ N, 78°51′43″ W) [31,32]. Its continental shelf encompasses almost five traditional fishing grounds where different types of species can be found (straddling stocks, whitefish stocks, and demersal species) that are harvested by industrial and small-scale fisheries [33].

The people of the Colombian Pacific are mainly Afro-descendants (>95%) who support their income and food supply through fishing, agriculture, and resource extraction activities such as that of timber and gold [34] and have a high dependence on natural resource extraction [35]. A significant portion of households depend on small-scale fisheries, which supply the local and national markets and represent between 15% and 40% of landings in the coastal zone, for their food and income [1,36].

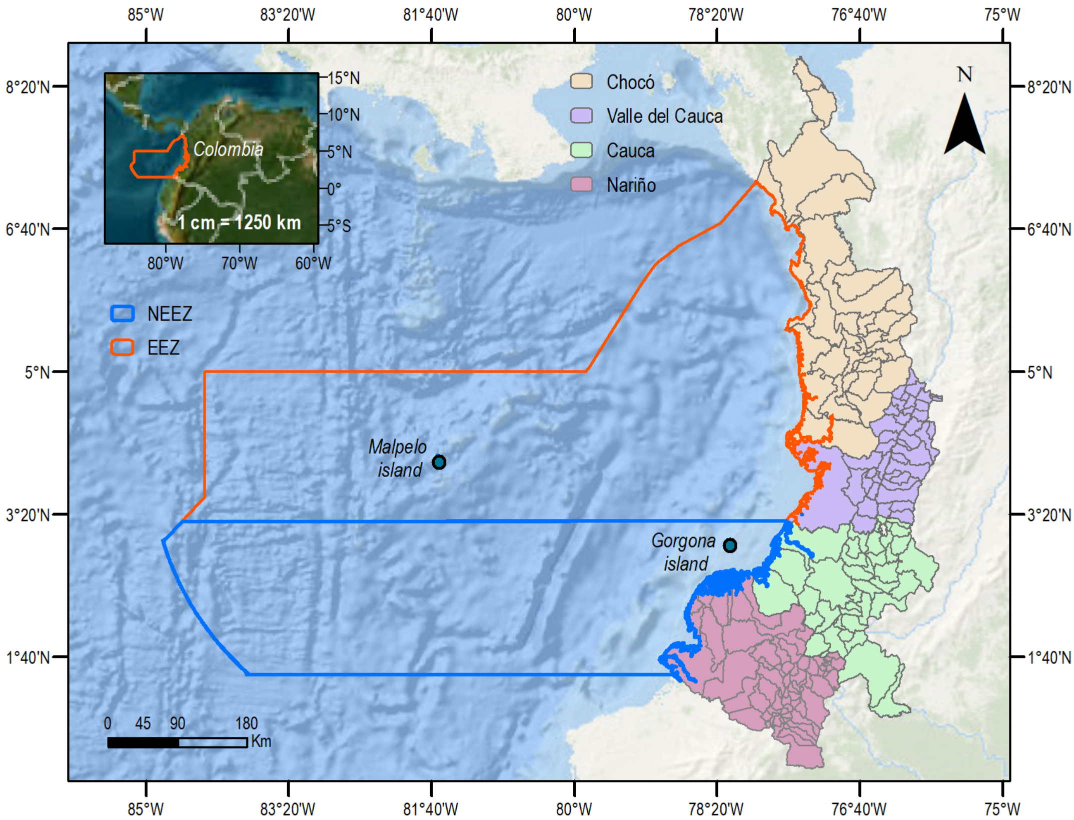


**Figure 1.** Study area: the Nariño Economic Exclusive Zone (blue polygon) in the Colombian South Pacific. Orange polygon shows the total Economic Exclusive Zone of Colombia in the Pacific.

### 2.2. Semi-Structured Survey

A semi-structured questionnaire was administered to a range of fishermen in the Colombian Pacific, from those involved in artisanal or small-scale fishing to those classified as semi-industrial. In this particular context, a semi-industrial fisherman is defined as someone who employs certain technological aids in their fishing activities, such as having multiple motors on their boat or using a radio, GPS, or sonar. Importantly, this designation does not imply that the fisherman operates on an industrial scale with a high fishing capacity; instead, they occupy a middle ground between artisanal and industrial fishing. The questionnaire was divided into four (4) main sections:

1. The sociodemographic profile of the fishermen and their households;
2. The characteristics of their fishing activity;
3. Information on the main fishing species of commercial interest and used for household food;
4. Fishermen's perception of the effects of climate change.

The questionnaire was designed to gather essential information directly from the fishermen regarding their fishing practices. This included details about which species they prioritize and where they typically fish them—i.e., their preferred fishing grounds and their distance from the coast—among other important data relevant to the broader objectives of the study, as elaborated below. Table 1 shows the details of each variable considered in the questionnaire. The surveys were performed in March and April 2020 in the District of Tumaco and nearby coastal municipalities in the department of Nariño. A total of 154 fishermen were asked to fill out the surveys.

Information from the survey was encoded and checked for errors, such as incomplete answers and missing details. However, after the initial data analysis, some entries were removed since the respondents only caught shrimp, which was not to be analyzed in this study. As a result, the vulnerability assessment was carried out with 150 respondents.

**Table 1.** Description of the semi-structured questionnaire.

| Sections in the Questionnaire | Summary of Information Obtained |
|---|---|
| **1. Sociodemographic information** | Residence location (urban or rural)<br>Household location (commune)<br>Age<br>Marital status<br>Family composition<br>Education level<br>Income level<br>Length of time living in the region |
| **2. Characteristics of Fishing Activity** | Duration of time working in the fishing activity<br>Details of the fishing boat and gear (materials, propulsion type, capacity)<br>Usage of technology in the fishing activity<br>Time invested in carrying out the fishing activity |
| **3. Commercially important and food-security-relevant species (marine fish)** | Presence of species in the fisherman's catch<br>Months of the year when the species is caught<br>Fishing gear used to catch the species<br>Depth at which the species is caught<br>Distance from the coast where the species is caught<br>Fishing ground used |
| **4. Fishermen's perception of the effects of climate change** | Changes in environmental variables (water temperature, tides, currents, rain)<br>Changes in frequency of extreme events (floods, storms, red tides, coastal erosion)<br>Opinion on the causes of climate change<br>Source of information on climate change<br>Opinion on the potential measures for adapting to climate change<br>Opinion on who should be managing climate change |

### *2.3. Climate Change Vulnerability Model*

The concept of vulnerability to climate change has undergone several adaptations as publications from the Intergovernmental Panel on Climate Change (IPCC) have emerged, making it a central theme in the climate change and development debate. For example, Raemaekers and Sowman [10] say that knowing how vulnerable people, communities, and systems are to climate change and its effects helps guide the development of adaptation strategies and actions that will help society in the long run. Vulnerability analysis methodologies have been classified into four types: (1) qualitative, based on qualitative information such as case studies or comparative analyses; (2) quantitative, those that combine social and economic information, such as statistics and climate models; (3) top-down, those applied to studies directly managed by scientists without direct information from beneficiaries, and (4) bottom-up, those that require participatory processes and interactions with stakeholder beneficiaries to obtain input information for analysis. Studies of resilience and assessments of how people and the environment interact have used these methods, such as stakeholder engagement, research actions, and community work [14].

The model used to determine how vulnerable fishermen are in the Colombian South Pacific is based on quantitative and bottom-up methods. It considers the connections between the ecological and social parts of the system by looking at the relationship between exposure, sensitivity, and the ability to adapt, using the IPCC's ideas as a starting point [11–13]. In particular, AR5 [14] emphasizes how important it is to understand exposure through the potential impact on the system or object of analysis (analyzed through components and sensitivity, which contribute to the sum in the vulnerability formula) and adaptation efforts (analyzed through adaptive capacity, which contributes to reducing the vulnerability to be identified, with a negative sign), taking equity and social justice into account, especially when dealing with vulnerable people. The variables that form part of each component in the vulnerability model (Figure 2) were selected from the data gathered through the survey.


**Figure 2.** Climate change vulnerability model and variables used to assess the vulnerability of the Colombian South Pacific fishermen.

In this respect, the vulnerability model developed for the fishing activity and artisanal fishermen of the Colombian South Pacific incorporates, through the exposure component, an analysis of the impact perceived, and potentially perceived, by the fishermen due to changes in the distribution of the leading 12 species of interest for commercial fishing and household food security. This analysis is of traditional and routine fishing sites in the region and their association with diversity and fishing capacity through equipment and fishing gear. Through the sensitivity component, the model analyzes how the sustainability of fishing gear and the economic dependence of the fishing household on the fishing activity could lead to a more significant impact and perceived vulnerability for the region's artisanal fishermen.

Finally, the adaptive capacity component groups the characteristics that allow the fisherman his autonomy and fishing capacity, such as the boat's material, propulsion, fishing technology, and access to or use of essential information for decision making in fishing planning.

### *2.4. Data Analysis*

Data processing was performed for all the answers collected from the questionnaire. For closed-ended questions, different answer options were assigned scores between "0" and "1". A score of "0" was the lowest, associated with a negative effect, and "1" was the highest score, associated with a positive effect. For the sensitivity component, for example, a "0" meant that the fishermen were very sensitive to the effects of climate change, while a "1" meant that they were less sensitive to the effects of climate change. Similarly, for adaptive capacity, "0" represented a lower adaptive capacity for the fishermen, while "1" represented a high adaptive capacity. Lastly, the answers to open-ended questions were put into groups and scored between "0" and "1" in the same way as the answers to the other questions.

We analyzed the exposure component to identify the shifts in the geographic distribution of 12 commercially significant marine fish species, which contribute to the food security and sovereignty of fishing households in the region (Table 2; Figure 3). Species distribution models (Figure 3) were developed using an ensemble of five machine learning models, Artificial Neural Network (ANN; [37]), Maximum Entropy (MaxEnt; [38]), Generalized Boosting Model (GBM, also known as Boosted Regression Tree or BRT; [39]), Random Forest (RF; [40]), and Classification Tree (CT; [41]), for the current scenario analysis, a 10-year climatology from 1979 to 2013. These models were built based on potential changes in the selected oceanographic variables acting as predictors of their habitat (temperature, salinity, net primary productivity, U currents, and V currents) under the RCP 8.5 climate change scenario (Representative Concentration Pathways) for the medium term (2050). In addition, we used an ensemble of four Global Circulation Models (GCMs) which included the Max Planck Institute for Meteorology Earth System Model (MPI-ESM-MR and MPI-ESM-LR; [42]), the Earth System Model employed by the Met Office Hadley Centre (HadGEM2-ES; [43]), and the Centre National de Recherches Meteorologiques Earth system model (CNMR-CM5; [44]). These were obtained from the Coupled Model Intercomparison Project Phase 5 (CMIP5), following the specific methodology more extensively detailed in a research article by the same authors, Selvaraj, Rosero-Henao, and Cifuentes-Ossa [30], to analyze the potential future distribution of the 12 prioritized species of marine fish. The RCP 8.5 represents the most unfavorable scenario concerning emissions, with a sustained increase to the end of the 21st century. The evaluation was performed at a depth associated with the biological preference of each species (Table 2).

**Table 2.** Species and depths included in the vulnerability assessment.

| Biological Category | Species | | | Depths of Analysis |
|---|---|---|---|---|
| | Common Name | Scientific Name | Acronym | |
| Pelagic | Black skipjack | *Euthynnus lineatus* | El | 0 m |
| | Pacific sierra/seerfish | *Scomberomorus sierra* | Ss | 17 m |
| | Whitefin weakfish | *Cynoscion albus* | Ca | 0 m |
| | Pacific thread herring | *Opisthonema libertate* | Ol | 0 m |
| | Pacific anchoveta | *Cetengraulis mysticetus* | Cm | 0 m |
| Benthopelagic | Spotted rose snapper | *Lutjanus guttatus* | Lg | 17 m |
| | Pacific red snapper | *Lutjanus peru* | Lp | 17 m |
| | Flathead grey mullet | *Mugil cephalus* | Mc | 27 m |
| Demersal | Cachema weakfish | *Cynoscion phoxocephalus* | Cp | 27 m |
| | Red sea catfish | *Bagre pinnimaculatus* | Bp | 17 m |
| | Chilhuil sea catfish | *Bagre panamensis* | Bpa | 54 m |
| | Pacific bearded brotula | *Brotula clarkae* | Bc | 61 m |

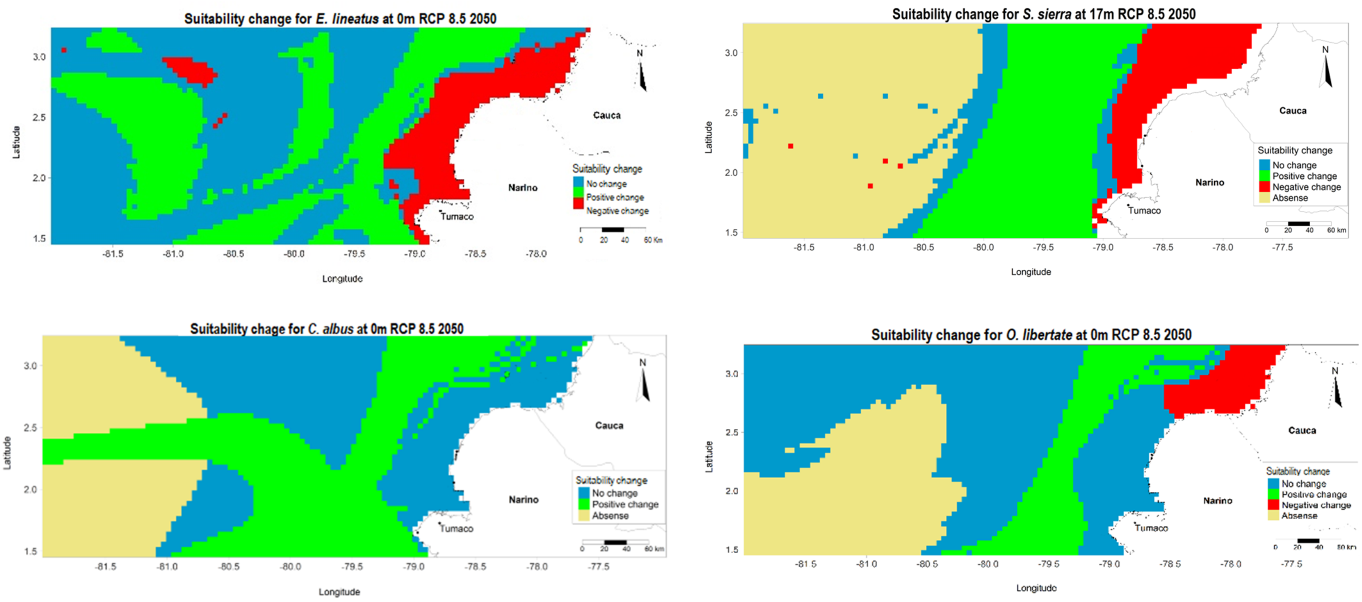


**Figure 3.** *Cont.*

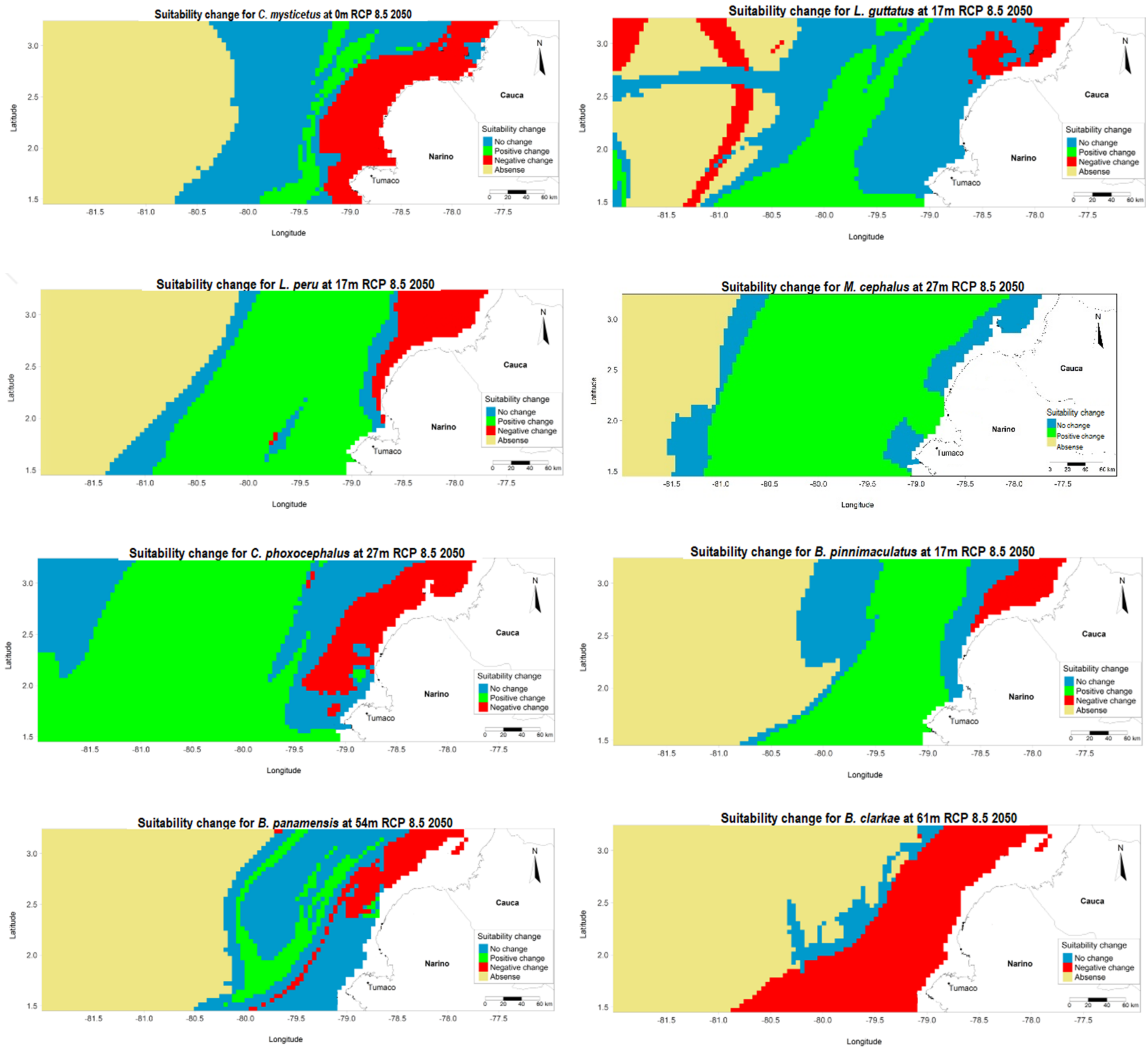


**Figure 3.** Change detection results in the distribution of the 12 species included in the study.

The fishing grounds and sites mentioned by the fishermen were added to these results to figure out how much the distribution of the species would be affected by climate change. Exposure is defined as the reduction in productivity of the fishing sites for the 12 species assessed in this study. Scores for the different fishing grounds and sites answered by the fishermen were assigned either "0" or "1", with "0" representing a fishing site that will be negatively affected in the future by the effects of climate change on the distribution of the species, and a score of "1" representing a fishing ground that will have a positive change or no change in the future in the distribution of the species. The evaluation criteria for the exposure component are detailed in Table 3.

**Table 3.** Definition of criteria for the qualification of the exposure component.

| Change Detection Classes | Criterion 1 | Criterion 2 | Criterion 3 |
|---|---|---|---|
| **No change** | If the fishing site is located in an area where the SDM result is "no change", the current distribution of the species should be evaluated to find out if it currently has a high or low probability of occurrence | If it has a low probability of occurrence (<50% probability), a value of "0" is assigned. If it has a high probability (>50%), a value of "1" is assigned | If the fishing site or the fishing area falls between two classes, the percentage of area occupied by said class over the area of influence of the fishing bank must be estimated to assign the class that comprises the largest area |
| **Positive change** | The fishing site is completely located within a zone of "positive change". A value of "1" is assigned | If the fishing site is partially located in a zone of "positive change" and another class, the percentage of area occupied by said class must be estimated to assign the value of "1" with respect to the area of influence of the fishing bank | |
| **Negative change** | The fishing site is located entirely within a zone of "negative change". A value of 0 is assigned | If the fishing site is partially located in a zone of "each class" and another class, the percentage of area occupied by said class must be estimated to assign the value of "0" with respect to the area of influence of the fishing bank | |
| **Absence** | The fishing site is located entirely within a zone of "absence". A value of "0" is assigned | | |
| **None** | The fishing site is located outside the change detection raster due to the evaluated depth | In this case, a value of "0" is assigned, because that fishing site does not have that depth. For example, when the fishing site is located near the coast and the evaluation of the species is being performed at a depth of more than 0 m (17 m, 27 m, 54 m, or 61 m) | If the fishing site is located outside the change detection raster, despite the fact that the evaluated depth is 0 m deep, the point must be included in the evaluation, assigning a score of "0" or "1" as appropriate in the evaluation change detection. For example, when the evaluation is performed at 0 m depth and the fishing site is located near the coast |

The sensitivity component was evaluated based on the capacity of each fisherman to capture a diversity of species, taking into account the type and number of fishing gear used. The greater the number and/or diversity of fishing gear used by the fisherman, the lower their sensitivity to the effects of climate change. The economic dependence of the fisherman on the fishing activity was also taken into account as measured by the level of income received from the fishing activity. So, the level of income of the surveyed fishermen was used to measure their financial ability to deal with possible adaptation measures and determine how much they depended on the money they made from fishing. In other words, the higher the income from fishing, the greater the fisherman's sensitivity to climate change's effects [20,45].

The diversity of fishing gear in this component serves as an indicator of the potential capacity of the fisherman to capture different types of species and reach greater depths if needed. The type of fishing gear used also indicates the fisherman's sensitivity to the sustainable use of fishing gear to conserve hydrobiological resources and habitats. Other studies have found that using non-sustainable fishing gear can not only affect the habitats of the species caught but can also increase the level of sensitivity of fishermen when new regulations are put into place that prohibits or restrict their use [46].

Each fisherman's gear was evaluated based on the international classification of fishing gear used by the Colombian National Authority for Aquaculture and Fisheries [47] (Table 4). Based on the FAO Fisheries Management Guide [48], a set of criteria was made to determine the fishing gear's sustainability. These criteria included the effects of the fishing gear on habitats, the selectivity of the fishing gear in terms of species size and type, and the number of accidental catches. A numerical rating was then assigned for each evaluated criterion to obtain a more objective assessment of the sustainability of the fishing gear. Finally, the scores for each criterion are added to obtain the final sustainability score. The higher the number, the greater the sustainability of the fishing gear, with a maximum score of 15 (Table 4).

**Table 4.** Classification of the fishing gear obtained in the survey applied to the fishermen of Tumaco.

| **Classification of Fishing Gear Based on AUNAP (2014)** | | | **Criteria for the Evaluation of Sustainability Based on FAO (2002)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fishing Gear** | | | Effects of Fishing Gear on Habitats | | Selectivity of the Fishing Gear in Size of the Species | | Selectivity of the Fishing Gear in the Type of Species to Be Captured | | Bycatch Level | | Susceptibility of Fishing Gear Abandoned at Sea | | **Final Score** |
| International General Classification | Associated Fishing Gear [3] | Survey Responses «Local Name» | **Impact** | Score | **Impact** | Score | **Impact** | Score | **Impact** | Score | **Impact** | Score | |
| **Purse seine nets** | Purse seine net<br>Beach seine<br>Seine net without purse | «Ruche [1]»<br>«Red de barco»<br>«Red de cerco» | Medium | 2 | Low | 1 | Medium | 2 | Medium | 2 | Low | 3 | 10 |
| **Dragnet fishing nets** | Cast net | «Malla»<br>«Atarraya»<br>«Boliche de mano» | Medium | 2 | Low | 1 | Low | 1 | Medium | 2 | Low | 3 | 9 |
| **Trawling gear** | Trawl net<br>Boat dredges | «Riflillo [2]»<br>«Changa [2]»<br>«Chinchorro» | Alto | 1 | Low | 1 | Low | 1 | Alto | 1 | Low | 3 | 7 |
| **Gillnets or mesh nets** | Trammel (gill net)<br>Electronic trammel<br>Monofilament/ multifilament mesh | «Trasmallo»<br>«Red de Enmalle»<br>«Zangarreo o Calambuqueo» | Low | 3 | Medium | 2 | Low | 1 | Medium | 2 | Alto | 1 | 9 |
| **Fishing traps** | Traps | No registration in the survey | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **No Classification** | Dynamite | «Dinamita» | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **Hooks and lines** | Fixed or anchored handline or troll | «Línea de Mano»<br>«Correteo, Trolling, Curricán»<br>«Línea de mano fija o anclada»<br>«Palangre/Nylono Anzuelos» | Low | 3 | Low | 1 | Low | 1 | Medium | 2 | Medium | 2 | 9 |
| | Drifting longline or bottom-set longline | «Calandro»<br>«Espinel de fondo Palangre/Espinel de fondo» | Low | 3 | Medium | 2 | Medium | 2 | Medium | 2 | Low | 3 | 12 |
| | Longline or shallow longline | «Boyao»<br>«Palangre o Espinel somero» | Low | 3 | Medium | 2 | Medium | 2 | Medium | 2 | Low | 3 | 12 |

Applicable regulation: [1] [49] Resolution 2254 of 2015 (AUNAP). [2] [50] Resolution 2526 of 1981 (INDERENA) and [51] Resolution 695 of 2004 (INCODER). [3] [52] Law 13 of 1990 (Colombian Congress).

Finally, the qualification criteria used for the analysis associated with the fishing gear are summarized below (Table 5).

The adaptive capacity component was defined based on the characteristics of the boats, including the primary materials (Table 6) and mobility/propulsion system (Table 7) and the use of technology for the fishing activity (Table 6). The greater the capacity of the boats and use of advanced technologies, the greater the adaptive capacity of the fisherman. The materials of the boats were scored. In the same way, the adaptive capacity score was assigned for the use of technological aids in the fishing activity and to the variable of access and use of information on climatic conditions to plan or carry out their fishing work (Table 6).

**Table 5.** Criteria used to assess the sensitivity score of the fishing gear.

| | | | |
|---|---|---|---|
| **Diversity of fishing gear (total number of different types of fishing gear used by the fishermen)** | If the fishermen use only one (1) type of fishing gear, assign a score of "0" | If the fishermen use two (2) or three (3) types of fishing gear, assign a score of "0.5" | If the fishermen use four (4) or more types of fishing gear, assign a score of "1" |
| **Sustainability of the fishing gear (assessed according to the total number of fishing gear types that are considered as sustainable)** | If the amount of sustainable fishing gear is greater than the less sustainable fishing gear, a score of 1 is assigned in the sensitivity component for the sustainability of fishing gear | If the number of less sustainable fishing gear is greater than the number of fishing gear considered sustainable, we proceeded to assign the score as follows: | "0.5" if the fisher uses at least one (1) sustainable fishing gear |
| | | | "1" if among the fishing gear used, there are two (2) or more classified as sustainable |
| | | | "0" if the fisherman does not have any fishing gear considered sustainable |

**Table 6.** Classification of three (3) components of the adaptive capacity score assigned for the vulnerability analysis.

| Assigned Score | Boat Materials | Technological Aids Used for Fishing | Access and Use of Information on Weather Conditions |
|---|---|---|---|
| **0** | Wood only | Does not use any help | Does not access or use information on weather conditions for fishing activity |
| **0.5** | Combination of wood and fiberglass | Use some combination of compass and/or radio | Access information on weather conditions through newspapers, television, and/or radio |
| **1** | Combination of iron and fiberglass | Use some combination of GPS, web browser, sonar, compass, and/or radio | Access information on weather conditions through the port authority, weather stations, cell phone, and/or internet |
| | Fiberglass only | | |

**Table 7.** Classification of the vessels according to their total capacity for mobilization and the assigned adaptive capacity score.

| Sum of the Horsepower of the Engines | Assigned Score |
|---|---|
| No engines | 0 |
| Up to 15 HP | 0.2 |
| Up to 50 HP | 0.3 |
| Up to 75 HP | 0.5 |
| Up to 90 HP | 0.7 |
| Up to 120 HP | 0.9 |
| 121 HP or more | 1 |

After scoring all the answers from the variables in the model for each fisherman, an average score was calculated for each component to obtain a general vulnerability score. These scores were then categorized into five levels of vulnerability (Figure 4).

Finally, in the case of the "sensitivity" and "adaptive capacity" components, a Principal Component Analysis (PCA) was performed to identify the variables with the most significant weight or importance in the vulnerability analysis developed based on the previous experience [53,54] and using R software Version 4.1.2; R.studio, PBC;Boston, MA; United State (2022; https://www.r-project.org/; accessed on 1 February 2022).

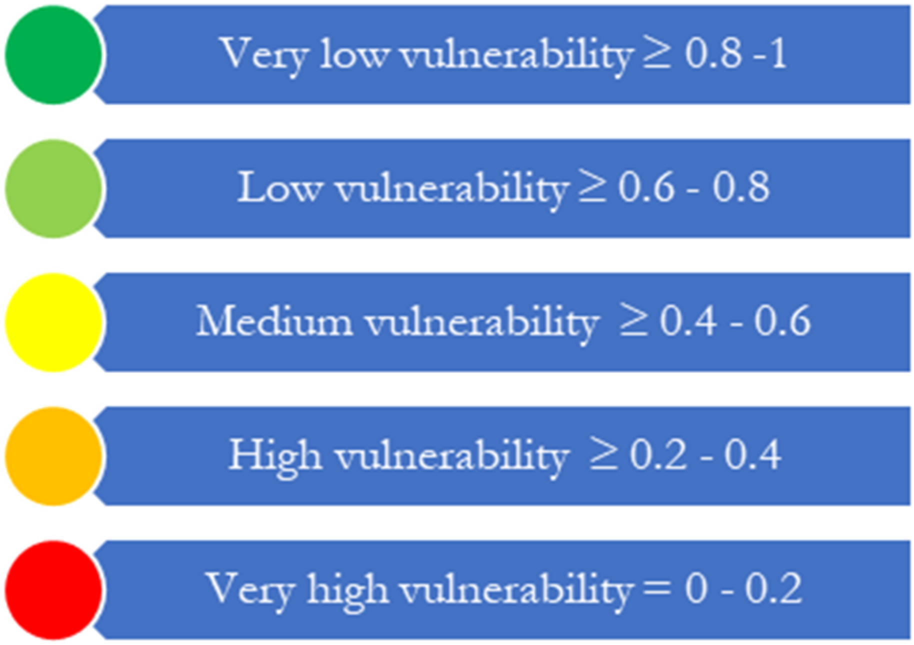


**Figure 4.** Vulnerability categories defined for the study.

### *2.5. Vulnerability by Distances from the Coast*

We also looked at how vulnerable fishermen were to climate change based on where their fishing spots were and how far away they were from the coast. The sensitivity and adaptability parts of the vulnerability model were added together to obtain a global rating for each fisherman. This rating was then used to divide the study area into four (4) zones based on how far away they were from the coast. These distance zones group the fishing sites and show how vulnerable fishermen are to the effects of climate change on the distribution of key commercial species and how far they can travel from the coast to the open sea with their boats and fishing gear. Four categories of distances were defined based on the fishermen's survey responses:

- Distance Zone 1 includes fishing sites less than 3 km from the coast and Tumaco Bay; it includes all the fishing spots in the estuaries of the rivers that flow into the coast and the fishing spots in Tumaco Bay
- Distance Zone 2 includes fishing sites between 3 and 5 km from the coast
- Distance Zone 3 includes fishing sites between 5 and 20 km from the coast
- Distance Zone 4 includes fishing sites located more than 20 km from the coast, including all those in the open sea.

## 3. Results and Discussion

The global vulnerability of the Colombian South Pacific's fishermen to climate change is generally high, with almost 80% of the fishermen surveyed scoring a medium to a very high level of vulnerability to the effects of climate change on the geographic distribution of the 12 key commercial species that were prioritized with the local community.

Figure 5 shows the global vulnerability of the surveyed fishermen to climate change. Since fishing is relied upon for personal consumption and economic subsistence, changes in key species could significantly impact the economic income of fishermen's households, leading them to abandon the activity and search for alternative sources of income (Among the main alternative activities, informal transport services, agriculture, the manufacture of handicrafts, and mining stand out.) [45]. This could result in increased economic hardship in the country due to a decreased fishing workforce and reduced fish production. Other authors [55] determined the country's economic vulnerability to climate change's impacts on fisheries. They identified Colombia as one of the most vulnerable countries due to its limited societal capacity to adapt to potential changes or opportunities. When establishing the relationship between the vulnerability categories analyzed and the level of monthly income received by artisanal fishermen due to the performance of the activity (Table 8), it was found that the highest proportion of fishermen categorized with high vulnerability stated that they received a net income lower than the current legal monthly minimum wage for the year of study.

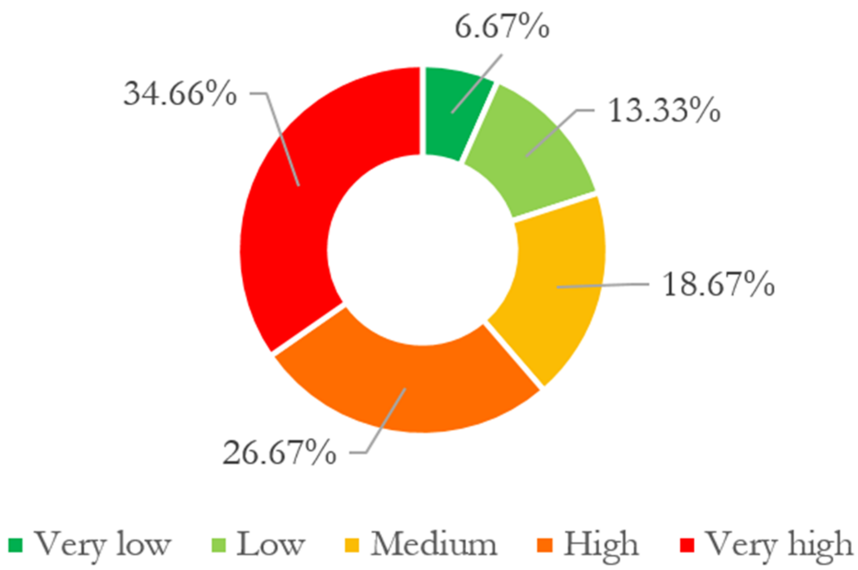


**Figure 5.** Global climate change vulnerability of the fishermen surveyed.

**Table 8.** Relationship in terms of proportion of fishermen between categories of vulnerability and the monthly legal income.

| **Vulnerability Analysis** | **Monthly Income from Fishing Activity** | | |
|---|---|---|---|
| | **Categories** | | |
| **Categories** | % Fishing household with the Colombian legal monthly minimum wage (2020) | % Fishing household with income above the Colombian legal monthly minimum * wage (2020) | % Fishing household with income below the Colombian legal monthly minimum * wage (2020) |
| **Very high** | 41.82% | 14.54% | 43.64% |
| **High** | 36.84% | 18.42% | 44.74% |
| **Medium** | 20% | 16.67% | 63.33% |
| **Low** | 22.22% | 5.56% | 72.22% |
| **Very low** | --- | ---- | 100% |

* The Current legal minimum monthly salary in Colombia, for the year 2020, corresponded to COP 877,802 (Colombian pesos) and USD 185.90 (American dollars—reference exchange rate of 03/10/2023).

### *3.1. Exposure*

In Figure 6, we observe the exposure levels of different species based on their quartile scores. Among the pelagic species, the Pacific anchoveta (Cm) had the highest exposure, with all fishermen reporting a "0" score for their fishing sites. Nonetheless, only 24% of the surveyed fishermen catch this species. The Pacific thread herring (Ol) ranked second in terms of exposure and is caught by 32% of fishermen. The seerfish (Ss) exhibited a high-to-medium level of exposure at the fishing sites used by 56% of surveyed fishermen, as indicated by a third-quartile score below 0.5. Similarly, in the benthopelagic species group, the flathead grey mullet (Mc) had the highest exposure, followed by the Pacific red snapper (Lp); both species had third-quartile scores below 0.5. Among the demersal species, the Pacific bearded brotula (Bc) showed the highest exposure but is only caught by 20% of the surveyed fishermen, likely due to its deep-water habitat. Lastly, the cachema weakfish (Cp), caught by 60% of surveyed fishermen, also demonstrated high-to-medium exposure levels, as evidenced by a third-quartile score below 0.5.

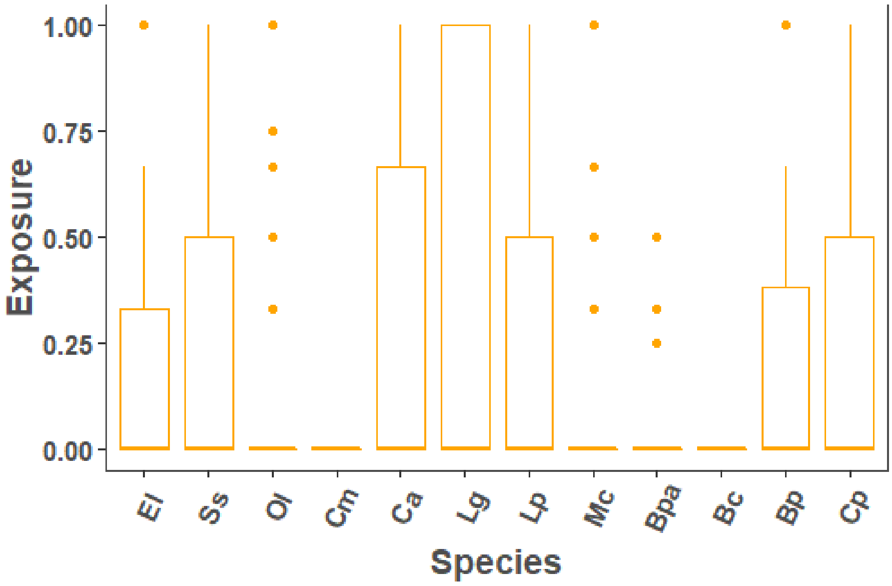


**Figure 6.** Scores of exposures of the fishing sites for each species assessed (species acronyms in Table 2).

These trends suggest a challenging future for small-scale fishermen. Many species, including the seerfish, Pacific anchoveta, Pacific red snapper, flathead grey mullet, Pacific bearded brotula, and cachema weakfish, are increasingly shifting to more remote off-coast areas. This shift poses challenges to small-scale fishermen, as it affects the majority of current fishing sites, as illustrated in Figure 3.

### 3.2. Adaptive Capacity

The Principal Component Analysis identified the most critical variables in the vulnerability assessment grouped into two principal components (Table 9). The first principal component is associated with the fishermen's adaptive capacity, in which fishing technologies become an important limitation, mainly because 64% of the surveyed fishermen do not have high-capacity technologies such as GPS and sonar. The most common tools fishermen use in the region are compasses and radios [56]. However, they often rely on recognizing specific symbols and landmarks in the territory to manage their location, as reported in the case of the fishermen of the Buenaventura coast in the Valle del Cauca department [57]. Based on their experience and ours, artisanal fishermen predominantly use identifying elements and landmarks in the territory (such as geographical features) as their most traditional and culturally ingrained navigation method. Approximately 24% of the surveyed fishermen use a combination of tools and technologies, including GPS and sonar, giving them a higher adaptive capacity to cope with changes in the distribution of commercial species.

**Table 9.** Principal components matrix with variables of importance for adaptive capacity and sensitivity. Variables highlighted in bold correspond to the important variables in the PCA. PC1 and PC2 explain 62% of the cumulative variance.

| | Variable | PC1 | PC2 |
|---|---|---|---|
| **Adaptive Capacity** | Use of technologies for fishing | **0.616** | |
| | Total engine capacity of the boats (sum of total HP of the engines) | **0.447** | |
| | Access to meteorological conditions for fishing | **0.338** | |
| | Construction materials of the boat | 0.159 | |
| **Sensitivity** | Total amount of fishing gear | | 0.013 |
| | Sustainability of fishing gear | | **−0.660** |
| | Monthly incomes from fishing | | **−0.556** |

Another critical variable in this first component (PC1) was the total engine size of the boats (in horsepower), which indicates the propulsion used by the fishermen. In many cases, propulsion is achieved by rowing, limiting their ability to move to new fishing grounds that could be located far from the coast. Moreover, 46% of the surveyed fishermen have low-capacity engines (less than 75 HP), and 23% have no engine at all, meaning their propulsion is achieved by rowing and their spatial range for fishing is limited. It was noted that several fishermen surveyed mentioned that they did not have a boat, as they fished from the bridges of the city of Tumaco. For these cases, a very high vulnerability is displayed, as they have no adaptive capacity to overcome changes in species distribution. Most species fished currently will no longer be present in Tumaco Bay, putting their subsistence at risk [29,30]. Other studies have also used this information as a variable to determine the adaptive capacity of fishermen, finding results well below the average for the Nariño Pacific region [54].

Regarding access to and use of information related to weather conditions, it was found that only 21% of the surveyed fishermen access and consult this type of information to plan their fishing operations, which would allow them to make increasingly informed decisions and anticipate potential risk situations [56,57].

### 3.3. Sensitivity

The second component (PC2) is related to sensitivity, where the sustainability of fishing gear and economic dependence on the fishing activity (monthly incomes from fishing) play a significant role in determining the vulnerability of the fishermen. Other studies have also found this [20,58].

Regarding the sustainability of fishing gear, the assessment found that about 40% of the fishermen use gillnets and trammel nets, which have a low sustainability index due to their impact on ecosystems [48] and, therefore, exhibit a high sensitivity to the effects of climate change. Furthermore, Tilley and Box [46] found that artisanal communities in Buenaventura commonly use gillnets as their sole fishing method, increasing their vulnerability to environmental and socio-political changes in the long term as they become restricted in their exploitation of alternative fishery opportunities and lack the capacity to adapt to changes in fishing regulations, particularly a ban on gillnets. The results of this study also identify the same risk for the surveyed fishermen of the Colombian South Pacific, as their fishing gear diversity is limited, and they often only use a gillnet or trammel net.

### 3.4. Vulnerability by Distances from the Coast

For the first category of distance—sites located within 3 km of the coastline—over 80% of the fishermen have a high to medium level of vulnerability. In this area, the most common fishing sites used by the surveyed fishermen are Salahonda, Tumaco Bay, Francisco Pizarro, "Barco Hundido" (sunken boat), and river estuaries. When analyzed by the species they catch, the Pacific bearded brotula (Bc), the black skipjack (El), and the cachema weakfish (Cp) presented the highest proportions of vulnerability among the fishermen (Figure 7). Based on projections of their future geographical distribution, these species will not be available in this coastal area. The species that would represent the least vulnerability for fishermen who carry out their tasks in this distance range would be the Pacific thread herring (Ol), the Pacific anchoveta (Cm), and the flathead grey mullet (Mc).

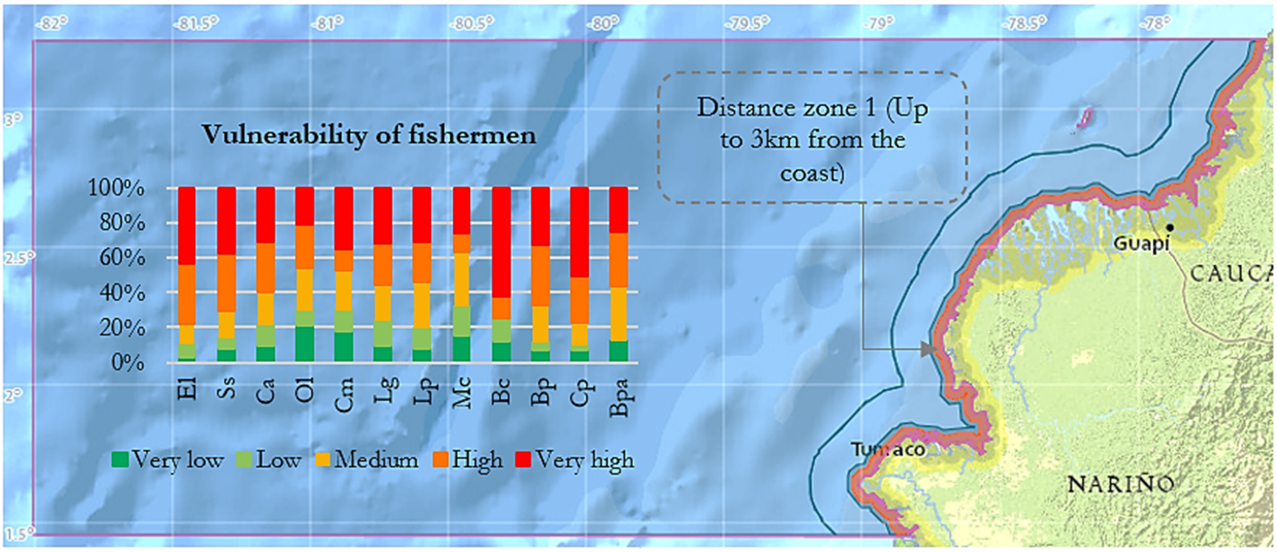


**Figure 7.** Distance area of 3 km from the coastline (red shading) with the vulnerability results by species (species acronyms in Table 2).

The second distance category includes fishing sites between 3 and 5 km from the coastline. The most common sites reported by the fishermen are Bocagrande, Majagual, and San Juan. In this area, the proportion of fishermen with high vulnerability slightly increases compared to the first distance category (85%). Regarding the species they catch, changes are observed with the flathead grey mullet and the seerfish (Ss), reducing the level of vulnerability of the fishermen who catch these species. On the contrary, the Chilhuil sea catfish (*Bagre panamensis*) will slightly increase the vulnerability level of the fishermen (Figure 8).

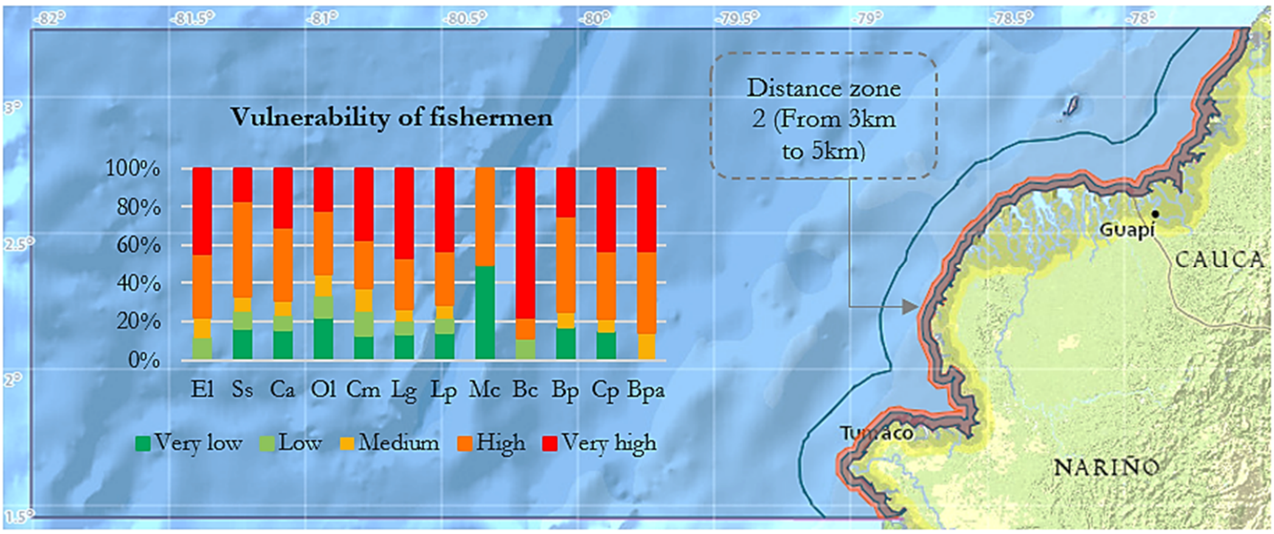


**Figure 8.** Distance area between 3 km and 5 km from the coastline (red shading) with the vulnerability results by species (species acronyms in Table 2).

For the third category of distance (fishing sites between 5 km and 20 km of the coastline), the high vulnerability of the fishermen increases to 96%. This area includes the fishing sites "Avión Hundido" (Sunken Plane) and "Ancla Hundida" (Sunken Anchor), which are commonly used by the small-scale fishers of the region. The vulnerability associated with the species they catch shows that 2 of the 12 are not caught in this area. In contrast, the vulnerability of the fishermen who catch the threaded herring, the Chilhuil sea catfish (Bpa), the spotted rose snapper (Lg), the black skipjack (El), and the seerfish (Ss) in this area is increased (Figure 9).

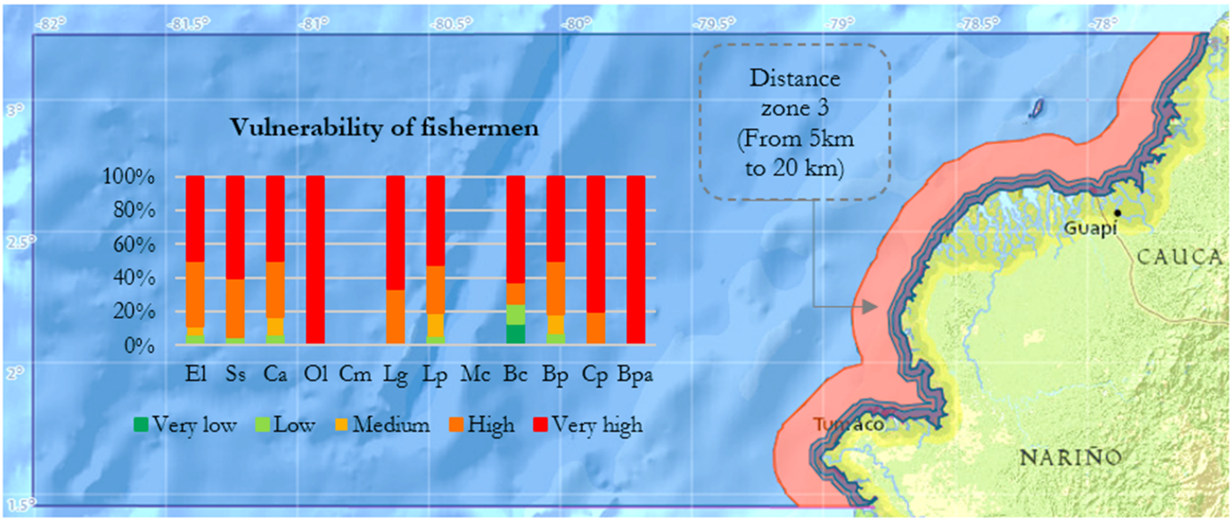


**Figure 9.** Distance area between 5 km and 20 km from the coastline (red shading) with the vulnerability results by species (species acronyms in Table 2).

In the last category of sites located over 20 km from the coast, the high vulnerability of the fishermen decreased to 84%. This area includes traditional fishing grounds such as "Banco Tumaco", "Banco Pasacaballos", "Boya de Tsunami", Gorgona Island, and "Banco la República". The vulnerability associated with the species these fishermen catch is also reduced for several of the 12 species assessed. However, the black skipjack (El) and the Pacific bearded brotula (Bc) continue to pose a high level of vulnerability to the fishermen who catch them (Figure 10).

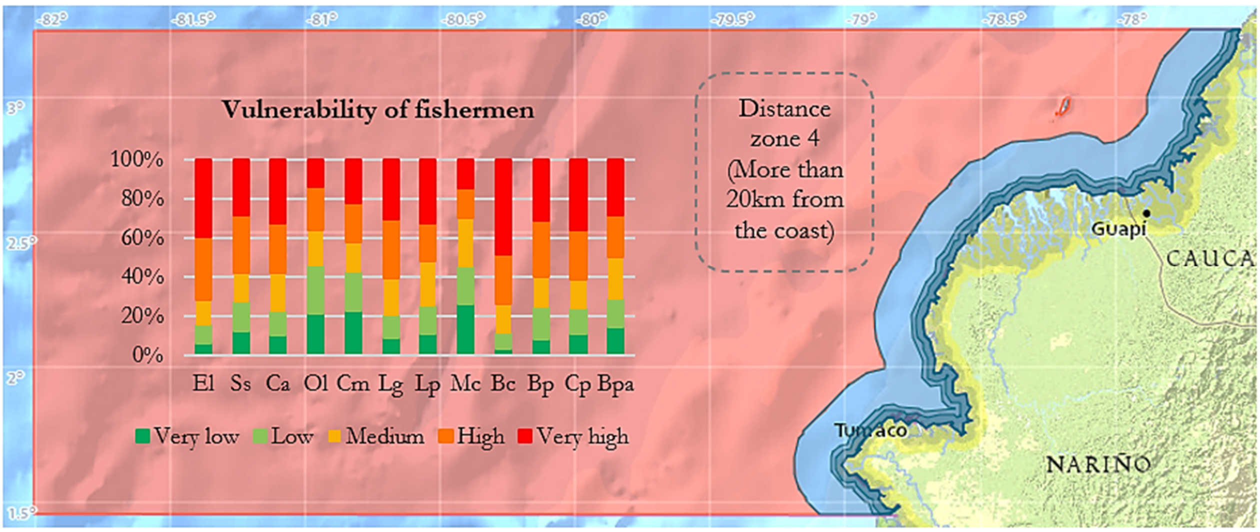


**Figure 10.** Distance area over 20 km from the coastline (red shading) with the vulnerability results by species (species acronyms in Table 2).

In addition to changes in the species under study, the researchers suggest shifts in the behavioral dynamics of both the resource and the communities that depend on or exploit it. Other alterations may occur within biological communities, which could favor locations closer to the coast based on biological preferences and evolving climate conditions. These changes can affect the expected distribution cycles of marine species and even alter perceptions and potential uses. Species that benefit from these changes may become promising options for local consumption and commercial marketing systems [59].

## 4. Conclusions

The study determined the general vulnerability to climate change faced by fishermen in the Colombian South Pacific due to changes in the distribution of key commercial species that are categorized as the most important for the security and food sovereignty of the coastal household by the local community's perception. The study also identified the species that will contribute to a higher level of vulnerability because of their reduced productivity in the fishing grounds currently used by the fishermen. This information provides the first assessment of its kind in the fisheries sector for this region of the country, which is crucial for understanding climate change vulnerability and designing effective adaptation strategies.

A significant proportion of the fishermen were found to have a high level of vulnerability, with the main components playing an important role being the low use of technology in fishing, low diversity and sustainability of fishing gear, and high economic dependence on fishing. The species that are likely to be most affected by these changes are the Pacific bearded brotula (Bc), the black skipjack (El), and the cachema weakfish (Cp).

Since most of the analyzed species will likely move towards open/deeper water in the future due to climate change, the fishermen will need help catching and marketing them, as their adaptive capacity is generally low. This is due to their inability to travel long distances from the coast to find new fishing grounds. As a result, these fishermen will be forced to look for other potential species to catch in their current area of influence, adapt their boats and fishing gear to reach deeper and other fishing grounds, or find alternative economic activities.

Other possible adaptation strategies in the face of the identified vulnerability include making the scientific information available to the community to enable an analysis of the impacts and effects of climate change and contribute to more informed decision-making processes. In this regard, the project in which this research was carried out improves implementation through a participatory approach to a geographic information system for public access called "Geovisor Geopesca-Tumaco 1.0". This system uses a geographic process to make the results described here available to artisanal fishermen and decision makers in Tumaco and the Nariño Pacific subregion.

Although this study primarily focuses on assessing the vulnerability to climate change in fishing activity due to changes in species distribution and, as a result, the livelihood of the fishermen, other drivers of vulnerability to climate change were also identified, such as those related to the safety and integrity of the fishermen and their fleets during extreme ocean events. This type of vulnerability was not directly assessed in this study, but it does provide an idea of the robustness of the fishermen's equipment, such as the construction materials of their boats, and their ability to cope with extreme events, which can help understand how they will be affected by these risks. This information was integrated into the model through the adaptive capacity component with variables such as the construction materials of the boats and the propulsion method used.

In the context of fisheries management, and to contribute to the sustainable management of renewable natural resources as well as achieve the Sustainable Development Goals (SDGs) of zero hunger (Goal 2), climate action (Goal 13), and life below water (Goal 14), responsible fishing should prioritize decision-making that takes into account the social and economic characteristics of communities. These communities inhabit and utilize the relevant territories and ecosystems. Accordingly, the primary need for artisanal or small-scale fishing households is to establish and sustain their trade. This is crucial for generating employment and income opportunities and making significant contributions to food and nutritional security, especially in the coastal areas of the Colombian Pacific coast.

**Author Contributions:** J.J.S.: project management, conceiving the experiments, developing the analyses, and writing the article. L.V.R.-H.: design of the experiments, development of the analyses, community communication activities, and writing of the article. M.A.C.-O.: designing the experiments, coordinating the survey processes, developing the analyses, participating in community communication activities, and writing the article. All authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement:** Ethical review and approval were waived for this study because the survey with human subjects consisted of non-invasive items.

**Informed Consent Statement:** Informed consent was obtained from all the subjects involved in the study.

**Data Availability Statement:** The data presented in this research are not publicly available due to participant privacy.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Herrón, P.; Castellanos-Galindo, G.A.; Stäbler, M.; Díaz, J.M.; Wolff, M. Toward Ecosystem-Based Assessment and Management of Small-Scale and Multi-Gear Fisheries: Insights from the Tropical Eastern Pacific. *Front. Mar. Sci.* **2019**, *6*, 17. [CrossRef]
2. Tilley, A.; Herrón, P.; Espinosa, S.; Angarita, J.L.; Box, S. Predicting vulnerability to management changes in data-limited, small-scale fisheries. *Mar. Policy* **2018**, *94*, 39–45. [CrossRef]
3. Boyd, C. Fisheries Sector. In *Importance of Biodiversity and Ecosystems in Economic Growth and Equity in Latin America and the Caribbean: An Economic Valuation of Ecosystems*; Alpizar, F., Bovernick, A., Schnell, C., Eds.; United Nations Development Programme (UNDP). Technical Report, 1–44; UNDP: New York, NY, USA, 2010; pp. 1–327. Available online: https://www.undp.org/sites/g/files/zskgke326/files/publications/Report_ENG.pdf (accessed on 13 March 2022).
4. Pörtner, H.-O. Oxygen- and capacity-limitation of thermal tolerance: A matrix for integrating climate-related stressor effects in marine ecosystems. *J. Exp. Biol.* **2010**, *213*, 881–893. [CrossRef]
5. Jennings, S.; Collingridge, K. Predicting Consumer Biomass, Size-Structure, Production, Catch Potential, Responses to Fishing and Associated Uncertainties in the World's Marine Ecosystems. *PLoS ONE* **2015**, *10*, e0133794. [CrossRef]
6. Lotze, H.K.; Tittensor, D.P.; Bryndum-Buchholz, A.; Eddy, T.D.; Cheung, W.W.L.; Galbraith, E.D.; Barange, M.; Barrier, N.; Bianchi, D.; Blanchard, J.; et al. Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 12907–12912. [CrossRef] [PubMed]
7. Panayotou, T. *Management Concepts for Small-Scale Fisheries: Economic and Social Aspects [Conceptos de Ordenación para las Pesquerías en Pequeña Escala: Aspectos Económicos y Sociales]*; Documentos técnicos de pesca; FAO: Rome, Italy, 1983; Volume 228, 60p.
8. National Code of Renewable Natural Resources and Environmental Protection. 1993. Available online: https://cvc.gov.co/sites/default/files/Normatividad/Nacional/Leyes/Decreto-Ley2811-74-Codigo-Recursos-Naturales-Renovables-y-Proteccion-Medio-Ambiente.pdf (accessed on 20 December 2022).
9. Castellanos-Galindo, G.A.; Chong-Montenegro, C.; Baos, R.A.; Zapata, L.A.; Tompkins, P.; Graham, R.T.; Craig, M. Using landing statistics and fishers' traditional ecological knowledge to assess conservation threats to Pacific goliath grouper in Colombia. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2018**, *28*, 305–314. [CrossRef]
10. Raemaekers, S.; Sowman, M. *Community-Level Socio-Ecological Vulnerability Assessments in the Benguela Current Large Marine Ecosystem*; FAO Fisheries and Aquaculture Circular No. 1110.; FAO: Rome, Italy, 2015; pp. 1–127; ISBN 978-92-5-108908-8. Available online: https://www.fao.org/documents/card/es/c/38f3dc32-08e6-4d5a-bce4-da9135729756/ (accessed on 10 November 2021).

11. IPCC. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Parry, M., Canziani, O., Palutikof, J., Van der Linden, P., Hanson, C., Eds.; Cambridge University Press: Cambridge, UK, 2007; 976p. Available online: https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf (accessed on 10 November 2021).
12. IPCC. *Managing the Risks of Extreme Events Disasters to Advance Climate Change Adaptation*; Field, C.B., Barros, T.F.V., Stocker, D., Qin, D.J., Dokken, K.L., Ebi, M.D., Mastrandrea, K.J., Mach, G.-K., Plattner, S.K., et al., Eds.; Cambridge University Press: Cambridge, UK, 2012; 582p. Available online: https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/ (accessed on 10 November 2021).
13. IPCC. *Climate Change 2014: Impacts Adaptation Vulnerability Summaries Frequently Asked Questions Multi-Chapter Boxes Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Barros, D.J.V.R., Dokken, K.J., Mach, M.D., Mastrandrea, T.E., Bilir, M., Chatterjee, K.L., Ebi, Y.O., Estrada, R.C., Genova, B., et al., Eds.; World Meteorological Organization: Geneva, Switzerland, 2014; 200p. Available online: https://www.ipcc.ch/site/assets/uploads/2018/03/WGIIAR5-IntegrationBrochure_es-1.pdf (accessed on 10 November 2021).
14. FAO. *Assessing Climate Change Vulnerability in Fisheries and Aquaculture: Available Methodologies and their Relevance for the Sector, by Cecile Brugère and Cassandra De Young*; FAO Fisheries and Aquaculture Technical Paper No. 597.; FAO: Rome, Italy, 2015. Available online: https://www.fao.org/documents/card/es/c/3a200d99/ (accessed on 15 January 2022).
15. Cinner, J.; McClanahan, T.; Wamukota, A.; Darling, E.; Humphries, A.; Hicks, C.; Huchery, C.; Marshall, N.; Hempson, T.; Graham, N.; et al. *Social–Ecological Vulnerability of Coral Reef Fisheries to Climatic Shocks*; FAO Fisheries and Aquaculture Circular No. 1082.; FAO: Rome, Italy, 2013; 63p. Available online: https://www.fao.org/3/ap972e/ap972e.pdf (accessed on 15 January 2022).
16. Koomson, D.; Davies-Vollum, K.S.; Raha, D. Characterising the vulnerability of fishing households to climate and environmental change: Insights from Ghana. *Mar. Policy* **2020**, *120*, 104142. [CrossRef]
17. Gallopín, G.C. Linkages between vulnerability, resilience, and adaptive capacity. *Glob. Environ. Chang.* **2006**, *16*, 293–303. [CrossRef]
18. Morton, J.F. The impact of climate change on smallholder and subsistence agriculture. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19680–19685. [CrossRef]
19. Martins, I.M.; Gasalla, M.A. Perceptions of climate and ocean change impacting the resources and livelihood of small-scale fishers in the South Brazil Bight. *Clim. Chang.* **2018**, *147*, 441–456. [CrossRef]
20. Martins, I.M.; Gasalla, M.A. Adaptive Capacity Level Shapes Social Vulnerability to Climate Change of Fishing Communities in the South Brazil Bight. *Front. Mar. Sci.* **2020**, *7*, 481. [CrossRef]
21. Badjeck, M.-C.; Allison, E.H.; Halls, A.S.; Dulvy, N.K. Impacts of climate variability and change on fishery-based livelihoods. *Mar. Policy* **2010**, *34*, 375–383. [CrossRef]
22. Eitzinger, A.; Läderach, P.; Bunn, C.; Quiroga, A.; Benedikter, A.; Pantoja, A.; Gordon, J.; Bruni, M. Implications of a changing climate on food security and smallholders' livelihoods in Bogotá, Colombia. *Mitig. Adapt. Strat. Glob. Chang.* **2014**, *19*, 161–176. [CrossRef]
23. Martínez, C.I.P. Climate Change in Colombia: Trends and Perspective to Achieve Sustainable Development. *Eur. J. Sustain. Dev.* **2018**, *7*, 247–254. [CrossRef]
24. Roncancio, D.; Cutter, S.; Nardocci, A. Social vulnerability in Colombia. *Int. J. Disaster Risk Reduct.* **2020**, *50*, 101872. [CrossRef]
25. McMartin, D.W.; Merino, B.H.H.; Bonsal, B.; Hurlbert, M.; Villalba, R.; Ocampo, O.L.; Upegui, J.J.V.; Poveda, G.; Sauchyn, D.J. Limitations of Water Resources Infrastructure for Reducing Community Vulnerabilities to Extremes and Uncertainty of Flood and Drought. *Environ. Manag.* **2018**, *62*, 1038–1047. [CrossRef]
26. Coca-Domínguez, O.; Ricaurte-Villota, C. Validation of the Hazard and Vulnerability Analysis of Coastal Erosion in the Caribbean and Pacific Coast of Colombia. *J. Mar. Sci. Eng.* **2019**, *7*, 260. [CrossRef]
27. Berrouet, L.; Villegas-Palacio, C.; Botero, V. Vulnerability of Rural Communities to Change in an Ecosystem Service Provision: Surface water supply. A Case Study in the Northern Andes, Colombia. *Land Use Policy* **2020**, *97*, 104737. [CrossRef]
28. Bejarano, A.; Toline, C.; Horsman, J.; Zarza-González, E.; Cogollo, K. A climate change vulnerability framework for Corales del Rosario y San Bernardo National Natural Park, Colombia. *Clim. Res.* **2016**, *70*, 18. [CrossRef]
29. Montiel, S.A.H.; Coronado-Franco, K.V.; Selvaraj, J.J. Predicted changes in the potential distribution of seerfish (*Scomberomorus sierra*) under multiple climate change scenarios in the Colombian Pacific Ocean. *Ecol. Inform.* **2019**, *53*, 100985. [CrossRef]
30. Selvaraj, J.J.; Rosero-Henao, L.V.; Cifuentes-Ossa, M.A. Projecting future changes in distributions of small-scale pelagic fisheries of the southern Colombian Pacific Ocean. *Heliyon* **2022**, *8*, e08975. [CrossRef]
31. DIMAR (General Maritime Directorate of Colombia). *Bol. Inf.* **1988**, *2*, 1–3.
32. Correa, I.; Morton, R. Pacific Coast of Colombia. In *Encyclopedia of the World's Coastal Landforms*; Springer: Dordrecht, The Netherlands, 2010; pp. 193–198. [CrossRef]
33. Díaz-Merlano, J.M.; Vieira-Betancourt, C.A.; Melo-Saldarriaga, G.J. (Eds.) *Diagnóstico de las Principales Pesquerías del Pacífico Colombiano*; Fundación Marviva: Bogotá, Colombia, 2011; 242p. Available online: https://marviva.net/wp-content/uploads/2021/11/pesquerias_baja.pdf (accessed on 20 February 2023).

34. Escobar, A. *Territories of Difference: Place, Movements, Life, Redes*; Duke University Press: Durham, NC, USA, 2008. Available online: https://books.google.com.co/books?id=v2ttzsWSEpEC&printsec=frontcover&dq=Territories+of+difference:+place,+movements,+life,+redes.&hl=es&sa=X&ved=2ahUKEwi94dmswd3sAhVizlkKHROmDN8Q6AEwAHoECAQQAg#v=onepage&q=Territories%20of%20difference%3A%20place%2C%20movements%2C%20life%2C%20redes.&f=false (accessed on 10 January 2023).
35. Castellanos-Galindo, G.A.; Padilla, L.A.Z. Small-Scale Fisheries on the Pacific Coast of Colombia: Historical Context, Current Situation, and Future Challenges. In *Viability and Sustainability of Small-Scale Fisheries in Latin America and The Caribbean*; Salas, S., Barragán-Paladines, M., Chuenpagdee, R., Eds.; MARE Publication Series (19); Springer: Cham, Switzerland, 2019; pp. 79–100. [CrossRef]
36. De La Hoz, J.; Narváez, J.; Manjarrés, L.; Nieto, L.; Rivera, R.; Cuello, F.; Alvarez, T. *Boletín Estadístico Enero—Diciembre 2013*; Autoridad Nacional de Acuicultura y Pesca (AUNAP): Bogotá, Colombia, 2013; p. 60.
37. Ripley, B.D. *Pattern Recognition and Neural Networks*; Cambridge University Press: Cambridge, UK, 2014; pp. 1–403. [CrossRef]
38. Phillips, S.J.; Anderson, R.P.; Schapire, R.E. Maximum entropy modeling of species geographic distributions. *Ecol. Model.* **2006**, *190*, 231–259. [CrossRef]
39. Elith, J.; Leathwick, J.R.; Hastie, T. A working guide to boosted regression trees. *J. Anim. Ecol.* **2008**, *77*, 802–813. [CrossRef] [PubMed]
40. Breiman, L. Random forests. *Mach. Learn.* **2001**, *45*, 5–32. [CrossRef]
41. Breiman, L.; Friedman, J.H.; Olshen, R.A.; Stone, C.J. *Classification and Regression Trees*; Taylor Francis: Abingdon, UK, 2017; pp. 1–358.
42. Zanchettin, D.; Rubino, A.; Matei, D.; Bothe, O.; Jungclaus, J.H. Multidecadal-to-centennial SST variability in the MPI-ESM simulation ensemble for the last millennium. *Clim. Dyn.* **2013**, *40*, 1301–1318. [CrossRef]
43. Jones, C.D.; Hughes, J.K.; Bellouin, N.; Hardiman, S.C.; Jones, G.S.; Knight, J.; Liddicoat, S.; O'Connor, F.M.; Andres, R.J.; Bell, C.; et al. The HadGEM2-ES implementation of CMIP5 centennial simulations. *Geosci. Model Dev.* **2011**, *4*, 543–570. [CrossRef]
44. Voldoire, A.; Sanchezgomez, E.; Y Mélia, D.S.; Decharme, B.; Cassou, C.; Senesi, S.; Valcke, S.; Beau, I.; Alias, A.; Chevallier, M.; et al. The CNRM-CM5.1 global climate model: Description and basic evaluation. *Clim. Dyn.* **2013**, *40*, 2091–2121. [CrossRef]
45. Selvaraj, J.J.; Guerrero, D.; Cifuentes-Ossa, M.A.; Alvis, I.G. The economic vulnerability of fishing households to climate change in the south Pacific region of Colombia. *Heliyon* **2022**, *8*, e09425. [CrossRef]
46. Tilley, A.; Box, S. *Análisis de Vulnerabilidad de las Pesquerías Artesanales del Municipio de Buenaventura, Pacífico Colombiano (USAID, BIOREDD+). Reporte del Subcontrato (BR-SUBK-FP-029)*; Programa BIOREDD+; USAID Colombia: Bogotá, Colombia, 2014. [CrossRef]
47. AUNAP (National Authority of Aquaculture and Fisheries of Colombia); UNIMAGDALENA. *Characterization of the Main Fishing Gear in Colombia and Consolidated Report of the Type and Number of Gear, Vessels and UEP's Used by Fishermen Linked to the Fishing Activity. [Caracterización de los Principales Artes de Pesca de Colombia y Reporte del Consolidado del Tipo y Número de Artes, Embarcaciones y UEP's Empleadas por los Pescadores Vinculados a la Actividad Pesquera]*; Contract for the Provision of Services No. 190, signed between the National Authority of Aquaculture and Fisheries and the University of Magdalena; AUNAP: Santa Marta, Colombia; Bogotá, Colombia, 2014; 72p.
48. FAO. *A Fishery Manager's Guidebook—Management Measures and their Application*; Fisheries Technical Paper 424; FAO: Rome, Italy, 2002; ISBN 92-5-10473204. Available online: http://www.fao.org/3/y3427e/y3427e00.htm#Contents (accessed on 13 January 2023).
49. AUNAP (National Authority of Aquaculture and Fisheries of Colombia). *Resolution 2254 of 2015*; AUNAP: Bogotá, Colombia, 2015.
50. INDERENA (National Institute of Renewable Natural Resources and the Environment of Colombia). *Resolution 2526 of 1981*; INDERENA: Bogotá, Colombia, 1981.
51. INCODER (Colombian Institute of Rural Development). *Resolution 695 of 2004*; INCODER: Bogotá, Colombia, 2004.
52. Colombian Congress. *Law 13 of 1990*; Colombian Congress: Bogotá, Colombia, 1990.
53. Uddin, N.; Islam, A.S.; Bala, S.K.; Islam, G.T.; Adhikary, S.; Saha, D.; Haque, S.; Fahad, G.R.; Akter, R. Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis. *Appl. Geogr.* **2019**, *102*, 47–57. [CrossRef]
54. Macusi, E.D.; Macusi, E.S.; Jimenez, L.A.; Catam-Isan, J.P. Climate change vulnerability and perceived impacts on small-scale fisheries in eastern Mindanao. *Ocean Coast. Manag.* **2020**, *189*, 105143. [CrossRef]
55. Allison, E.H.; Perry, A.L.; Badjeck, M.-C.; Adger, W.N.; Brown, K.; Conway, D.; Halls, A.S.; Pilling, G.M.; Reynolds, J.D.; Andrew, N.L.; et al. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish Fish.* **2009**, *10*, 173–196. [CrossRef]
56. Espinosa-Corrales, C.A. "We live from this, this is our work": Artisanal fishing methods and arts in The Valley Corregimiento, Solano Bay (Chocó). ["Nosotros de esto vivimos, este es nuetro trabajo": Métodos y artes de pesca artesanal en el corregimiento El Valle, Bahía Solano (Chocó)]. *Boletín Científico CIOH* **2021**, *40*, 59–65.
57. Aroca-Araújo, A. Spatial orientation forms of fishermen Buenaventura, Colombia [Las formas de orientación espacial de los pescadores de Buenaventura, Colombia. *Rev. U.D.C. A Actual. Divulg. Científica* **2012**, *15*, 457–465.

58. Murciano, M.G.; Liu, Y.; Ünal, V.; Lizaso, J.L.S. Comparative analysis of the social vulnerability assessment to climate change applied to fisheries from Spain and Turkey. *Sci. Rep.* **2021**, *11*, 13949. [CrossRef]
59. Ojea, E.; Lester, S.E.; Salgueiro-Otero, D. Adaptation of Fishing Communities to Climate-Driven Shifts in Target Species. *One Earth* **2020**, *2*, 544–556. [CrossRef]