Research article

The economic vulnerability of fishing households to climate change in the south Pacific region of Colombia

John Josephraj Selvaraj [a,*], Daniel Guerrero [b], Maria Alejandra Cifuentes-Ossa [b], Ángela Inés Guzmán Alvis [b]

[a] *Institute of Pacific Studies, Universidad Nacional de Colombia, Tumaco Campus, Kilómetro 30-31, Cajapí Vía Nacional Tumaco-Pasto, Tumaco, 528514 Nariño, Colombia*
[b] *Universidad Nacional de Colombia, Palmira Campus, Department of Engineering, Carrera 32 No. 12-00 Chapinero, Vía Candelaria, Palmira 763533 Valle del Cauca, Colombia*

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ABSTRACT

Climate change's direct and indirect effects on marine ecosystems and coastal areas mainly impact small-scale fishers, especially in developing countries, which present extreme poverty and high dependency on marine ecosystems as a source of food and sustenance for households. Understanding the vulnerability of fishing households and considering the associated socio-economic-political complexities is essential for preserving their livelihoods and maintaining their well-being. This study proposes a measure of economic vulnerability based on the capacity of fishing households in Tumaco, located on the southern Pacific coast of Colombia, to diversify their livelihoods. Different statistical procedures have been conducted to identify the most relevant strategies in reducing the economic vulnerability of households. The results indicate that reducing the vulnerability of fishing households depends on adaptation strategies such as occupational mobility, some elements of social capital, and reduced dependence on the fisheries resource. This study could constitute an input for creating public policy that guides efforts to achieve strategies for the generation of other livelihoods and the sustainability of fishing households that continue to choose fishing as their main economic activity.

1. Introduction

Vulnerability in the context of climate change is defined as the degree to which a system is susceptible to the adverse effects of climate variability and extreme events (IPCC, 2001). It is estimated as the result of three factors—exposure, sensitivity, and adaptive capacity to one or more disturbances (Adger, 2006; Gallopín, 2006; Smit and Wandel, 2006)—assuming that exposure and sensitivity generate vulnerability, while adaptive capacity offers direct inputs and strategies to reduce or respond to the potential impact (Moreno-Sanchez and Maldonado, 2014).

There is significant uncertainty when projecting the effects of climate change on marine fishery productivity on a global and local scale. However, efforts are mainly focused on estimating the potential decrease in diversity and variation in the relative abundance of species or the change of its potential distribution in response to the changing oceanographic conditions. Among the findings, a possible change in global marine catches is prominent—a fall of up to 40% in the specific case of

the tropics (Cheung et al., 2010), and consequently, a 35% decrease in the global revenues of sectors that depend on marine resources by 2050 (Lam et al., 2016), excluding the latent risk for the food security of coastal communities (Cheung, 2018). Consequently, communities and sectors dependent on marine ecosystems will be affected by their income, operating costs, and fisheries management effectiveness (Pitcher and Cheung, 2013). Furthermore, these changes interact with indirect global drivers, such as population growth, changes in the food supply, consumption patterns, and stresses on fishing efforts and effectiveness (Pörtner et al., 2014; Gattuso et al., 2015), which would not necessarily be alleviated by effective management of the fishing sector (Cheung et al., 2010).

Studies on climate change in Colombia have analyzed different expressions of the phenomenon on the elements of the biophysical environment; among them, the historical trends and forecasts of climatological variables —such as temperature and precipitation— (León-Aristizabal, 2000; Pabón and Hurtado, 2002; Poveda, 2009; MAVDT-IDEAM-PNUD, 2010) and the frequency and intensity of climatic

events extremes (Benavides et al., 2007; Mayorga et al., 2011). As a result, the researchers converge on various types of results that allow them to identify that, since the second half of the 20th century, the average air temperature has been increasing at a rate of 0.1–0.2 °C per decade and the maximum temperature by approximately 0.6 °C; while the behavior of the temperature presents variations between -4% and 6% per decade, with a generalized increase in the Colombian Pacific region.

Research highlights that the most robust expression of global warming and climate change in Colombian territory is reducing the area of mountain glaciers. However, in coastal areas, the primary evidence is associated with trends in the increase in mean sea level (Rangel and Montealegre, 2003; Pabón and Lozano, 2005), with additions for the Pacific of 3–5 mm/year. Referring to rainfall, the IDEAM (2001) indicates that, although the amount of rain has not changed drastically, the intensity of precipitation has been increasing, which coincides with the conclusions of the IPCC (2007): "increase in the intensity of rains and hurricanes worldwide." All this has implications for the population and the sectors at risk of natural disasters because, as a consequence, it is possible to perceive a more significant number of sudden floods, floods, and landslides; events generate 90% of the disasters that occur in the country.

The first national communication on climate change in Colombia (the year 2001) made it clear that global warming is causing various alterations in biotic and physical environments and the increasing likelihood of threats like flooding, drought, soil and water degradation, fires, and deterioration of ecosystems. With this as a precedent, it is considered that climate change constitutes an imminent social challenge, especially for the most vulnerable populations like the coastal communities -assuming that the level of vulnerability will depend mainly on the geographical location, the time, and the social, economic and environmental conditions of each region-. As a result, climate change fundamentally challenges the social structure of fishing communities and their interaction with the resource.

In this sense, the direct and indirect effects of climate change estimated and projected on marine ecosystems and coastal areas mainly impact small-scale fishers, especially in developing countries (Badjeck et al., 2010; Martins and Gasalla, 2018). This, in turn, presents borderline conditions of poverty and high dependence on the marine resource as a food source (Allison et al., 2009) and livelihood for households (Daw et al., 2009; Badjeck et al., 2010; Martins and Gasalla, 2020).

Artisanal fisheries also referred to as Small-scale fisheries, consist of fishing activity carried out along the coastal water with low technology and low capital by traditional/subsistence fishermen and represents a direct and indirect source of employment for inhabitants of the coastal zones, who oversee fishing, unloading, processing, distribution, and commercialization. A large part of the artisanal fishers allocates their catches in the first instance for self-consumption and, in some cases, if they generate surpluses, for commercialization. However, in cases where there are more significant production surpluses, the fishers usually depend on intermediaries to purchase their product since the limited economic resources, the scarce possibility of unionizing, and the difficult access to lines of credit, make it difficult for them to this type of activity exceeds the same subsistence. In this sense, artisanal fishing is experiencing a need to dignify the value chain to ensure decent economic income and an adequate quality of life.

Artisanal fisheries plays a fundamental role in the food security and household income of coastal fishing communities in Colombia and various world regions (Galappaththi et al., 2021; Ebn-Jalal et al., 2021; Sreya et al., 2021; Suresh et al., 2021). The Coastal fishing households lack 68.7% of the Unsatisfied Basic Needs Index - UBN among the country's population (National Administrative Department of Statistics, 2018). Their condition of poverty makes them more vulnerable to the adverse effects of climate change, and they have a lower capacity to cope with them (Eckstein et al., 2021). In addition, regional studies indicate that the increase in sea temperature alters the migration patterns of fish species, which may negatively affect fishers by increasing costs in operations (Herrera-Montiel et al., 2019). Therefore, understanding the vulnerability of fishing households, their strategies to mitigate and adapt to these impacts, and the socio-economic and political complexities associated with the activity (Morton, 2008) is essential for preserving their livelihood and maintaining their well-being (Kalikoski et al., 2010).

In general, the studies conducted worldwide on the effects of climate change on fishing households are mainly focused on identifying strategies to reduce vulnerability to climate change and simultaneously increase adaptive capacity at the global and local levels (Allison et al., 2009; Cinner et al., 2012; Mamauag et al., 2013). Recent findings agree that the adaptive capacity of low-income households will depend on: the degree of the associativity of individuals; programs to improve the adaptive capacity of families, including diversification of activities that generate sustainable income in the long term; improving education in households; gender equality due to the role played by the woman in the income of these households, being lower when they are women; appropriate policy and social interventions that improve the adoption of strategies by families against the impacts of climate change (Susaeta et al., 2017; Sreya et al., 2021; Suresh et al., 2021).

Previous experiences of applying these initiatives to fishing communities have brought contributions to the scientific literature. They have served to inform communities on developing skills to anticipate projected disturbances, even from a hypothetical view. These experiences have also made it easier for decision-makers to identify needs and prioritize actions when the budget is limited. However, there are several conflicting objectives (Moreno-Sanchez and Maldonado, 2014) and aligning private sectors' interests with environmental commitments (Rodríguez, 2014). However, there has been little research on Colombian fishing households' vulnerability and livelihood-based adaptive capacity for climate change. More specifically, San Andrés de Tumaco (hereinafter, Tumaco), a municipality located in the southern Pacific of Colombia, has been impacted by four tsunamis in the last century and is susceptible to future natural disasters (Colombian Red Cross, 2011). Therefore, this study contributes to the literature by analysing how the possible loss of livelihood conditions influences the vulnerability of fishing households in the municipality of Tumaco and the strategies they employ to alleviate their condition.

2. Adaptive capacity and livelihoods

Adaptive capacity comprises a set of strategies that define the ability of a system to face, prepare, adjust to disturbances, and take advantage of opportunities (Gallopín, 2006; IPCC, 2007; Boillat and Berkes, 2013). This concept has been developed and used mainly to measure the possible adaptation of communities to the effects caused by climate change and natural disasters (Lacambra et al., 2008). Hence, vulnerability results from the difference between exposure to a climatic phenomenon and adaptive capacity (Gallopín, 2006). Therefore, vulnerability has an inverse relationship with adaptive capacity—as the adaptive capacity of a household increases, its vulnerability decreases—.

Some studies focused on coastal fishing communities indicate that adaptive capacity varies between communities and households. This can be attributed mainly to differences in asset distribution, participation in community organisations (Faraco, 2013), local knowledge (Martins and Gasalla, 2020; Zanmassou et al., 2020; Chepkoech et al., 2020), and the role in regional institutions. The latter is considerably important as they facilitate the adaptation of households and the ability to anticipate the effects of climate change (Yomo et al., 2020) and correct market failures through reciprocity, trust, and solidarity (Agrawal and Perrin, 2009).

Given the consequences at different levels of climate change for marine systems and associated social systems, the options to address these challenges must also be multidimensional and depend on global mitigation systems or local adaptation strategies. At the local level in marine fishing communities, climate change adaptation could be improved through interventions based on four principles: (i) reduce the impact factors of climate change at the local level; (ii) limit non-climatic

human factors to reduce the sensitivity of ecosystems of marine species; (iii) support species diversity to facilitate adaptation to environmental change; (iv) facilitate species migration and movement to areas with adequate environmental conditions to maintain their viability (Miller et al., 2017). However, to make these principles viable at the community level, it is necessary to increase the human capital of fishing communities by increasing access to education and generating more livelihood opportunities to diversify their income (Cheung, 2018). Thus, households with access to social, human, physical, and financial capital and economic and social support systems to secure their livelihoods during adverse periods can adapt more efficiently and reduce their vulnerability (Ellis, 2000; Chepkoech et al., 2020; Zanmassou et al., 2020).

Therefore, livelihood diversification, which includes employment in multiple income-generating activities, occupational mobility, geographic mobility, and diversification outside of fishing (Badjeck et al., 2010), aims to find the stability and sustainability of households for maintaining minimum subsistence conditions and as an adaptation strategy to the effects of climate change (Osbahr et al., 2010). The adaptation strategies must be a combination of understanding the social capacities of the fishing community, its sociocultural roots, and its empirical learning in different adverse situations (Deb and Haque, 2016). Thus, these strategies must seek to generate sources of income that allow households to be less dependent on natural resources and indirectly grant them access to more markets and better infrastructure (Choden et al., 2020; Yomo et al., 2020).

However, various discussions contend that there is a propensity to be caught in fishing due to different socio-economic and institutional reasons. These discussions propose two approaches. The first—*endogenous approach*—is based on a Malthusian belief that overexploitation of the resource leads to a poverty trap in fishing communities. The logic of this approach reveals that the 'open access' nature of fisheries allows an increasing number of people to enter the fishing industry, leading to economic and ecological overexploitation of resources. Therefore, poverty originates as a consequence of this overexploitation (Béné, 2003). This approach has also been labelled as the 'old paradigm of poverty' in small-scale fishing. It also demonstrates that once families enter the fishing industry, they cannot usually abandon it even living on the fringes of subsistence (Copes, 1989).

The second –*exogenous approach*– focuses on the socio-institutional dimension of poverty and has attempted to address the problem of poverty in the fishing industry based on the argument that a lack of income options is a key factor contributing to a low-level life span in small-scale fisheries (Smith, 1979; Panayotou, 1982). This approach argues that poverty originates outside the fishing sector, considering that the low income of fishers is not due to the level of exploitation of resources or the dissipation of rent but because of the economic situation outside the productive activity (Cunningham, 1993). Furthermore, it considers that fishing plays a part in wealth redistribution because its open access nature offers the poorest people a livelihood through fishing activities. Therefore, small-scale fishing is positioned as an employer of last resort for the poor, and in turn, poverty is caused by the lack of alternative income outside of fishing (Ikiara and Odink, 1999). In summary, it is considered that fishers decide to continue fishing even if they earn significantly less than their opportunity costs (Panayotou, 1982). Thus, various diversified economic activities and community solidarity and trust are developed as survival strategies to alleviate poverty (Wekke and Cahaya, 2015).

When comparing these approaches, it can be inferred that fishing generates a poverty trap from which it is extremely difficult to escape due to either overexploitation or the lack of opportunities outside the activity itself. Hence, the decision to exit fishing is conditioned by socio-economic and institutional factors that reduce the occupational mobility of fishers and the diversification of livelihoods outside of fishing.

Given this context, this study aims to understand some of the challenges that climate change poses to the economic system of Tumaco's marine fishing households and analyse the diversification of livelihoods as a strategy to face and adapt to climate change and guarantee their subsistence. The results may constitute an important input for developing strategies, programmes, and policies that seek to preserve the livelihoods of communities (Kalikoski et al., 2010), design actions to reduce vulnerability to climate change (Cinner et al., 2012), promote and increase the resilience of coastal communities (Perry et al., 2010; Cinner et al., 2012; Morzaria-Luna et al., 2014), and recover their functional status after a disturbance (Buckle, 2000).

3. Methods

3.1. Study area

Tumaco is located in the extreme south of the Colombian Pacific (Figure 1), at 7m above sea level. It has a humid tropical climate with an average temperature of 26 °C and a total annual rainfall of 3,762mm (Climate-data.org, 2021). Tumaco is a port city characterised by beaches, estuaries, mangroves, deltas, and lagoons.

Among the coastal processes intensified by climate change and those that affect communities are the floods of spring tides that have increased in elevation and recurrence, the gales that affect many exposed towns, as well as earthquakes, tsunamis, and subsidence. The loss of land on the coast is associated with the scouring of rivers or the migration of sandy barriers to mangrove swamps. Tumaco presents vulnerability indices between medium, high, and extremely high due to the town's exposure to the dynamic natural changes of the barrier islands and estuaries, the institutional absence of the government, the low primary conditions of well-being, to isolation, the precarious economic conditions, and the deficiencies of the health and disaster response system (Ricaute-Villota et al., 2018).

Tumaco's population is mainly Afro-descendant and indigenous, and their economy is based on extractive activities such as mining, fishing, agriculture, livestock, commerce, and port activities. In the agricultural sector, the mono-extensive cultivation of African palm, cocoa, banana, and coconut stands out. Tuna, shoal, and shrimp are among the principal species caught, and the fishing activity includes the artisanal, semi-industrial, and industrial. However, according to an estimate of the economic impacts of climate change on the fishing sector, overall fish landings will decrease by 2100 (Herrera et al., 2015).

According to data from the National Administrative Department of Statistics (2018), the quality of life in the households in Tumaco, compared to the rest of Colombia, presents an unfavourable situation. The Unsatisfied Basic Needs with the most significant impact on families are inadequate services, economic dependency, and overcrowding in homes. Likewise, the Incidence rate of Multidimensional Poverty (MPI) in the municipality is high (53.7%), indicating deprivation in the households mainly of informal work, low educational attainment, low access to an improved water source, and inadequate excreta disposal. According to the MPI the population is extremely vulnerable to multiple socio-economic variables, motivating the government to develop a few programmes in the territory to overcome extreme poverty (Tumaco District Mayor's Office, 2020).

Regarding the dynamics of the fishing activity, marine fishing in the country is carried out on both the Caribbean and Pacific coasts, within Exclusive Economic Zone (EEZ) except for tuna fishing and similars carried out in international waters (AUNAP, 2019). Industrial and artisanal fishing fleets constitute marine fisheries on the Pacific coast. The former tend to orient towards exportation. The latter sustains the food security of the local communities and the national market (Puentes and Moncaleano, 2012). Precisely, artisanal fishing constitutes one of the main lines of the economy in Tumaco and the Pacific subregion of Nariño, contributing between 50-60% of the total volume sold. In general terms, production exceeds 4,500 tons/year on average, without considering a significant portion of the catches consumed in local and border
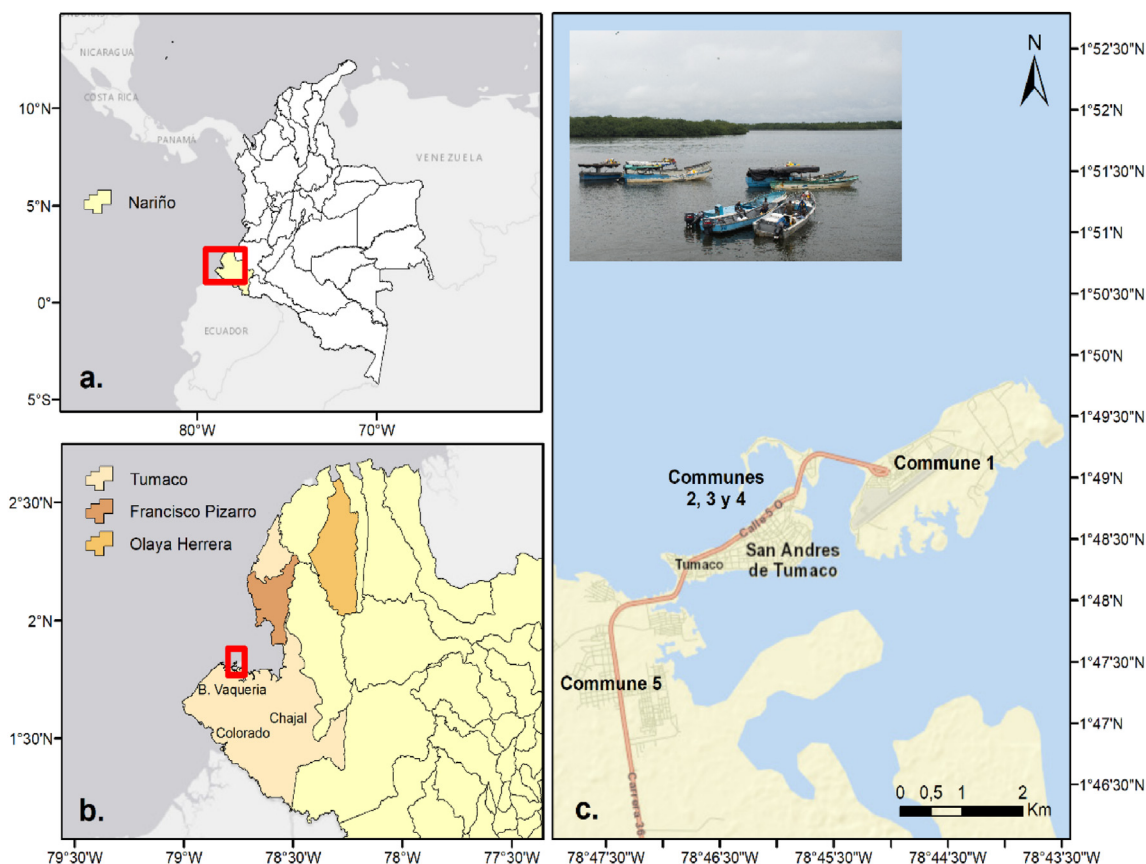
Figure 1. Sampling sites and study area location. **a.** Location of the Department of Nariño in Colombia. **b.** Coastal municipalities with surveyed population and rural Tumaco trails. **c.** Tumaco urban, distribution of communes.

markets, without any registration (Tumaco District Mayor's Office, 2016). This activity represents a direct and indirect source of employment for an estimated 12,000 families on the Pacific coast of Nariño. They deal with the development of capture, landing, processing, transport, and marketing of fish species.

The costs incurred by artisanal fishing activity depend on the fishing boat/equipment, the distance to the fishing grounds, and the time dedicated to its execution; along with the costs of supplies such as ice, bait, provisions, gasoline, oils, and supplies for repair or maintenance of the fishing gear. On average, it is estimated that a fishing trip lasting between one to three days costs a capital of COP $300,000 to $500,000[1].

On the other hand, in the context of the Colombian Pacific, artisanal fishing is usually characterized as an activity with little access to information and technology: for the location of fish, seamanship techniques, navigation, communications, and rescue; that as a whole end up reducing the performance and effectiveness of the productive activity. Also, the local fishing sector faces a series of persistent social, economic and environmental problems, which limit its growth and sustainability; which includes the changing climate, the shortcomings in the port and coastal infrastructure, the decrease in resources in the traditionally known fishing banks (from the practical experience of the fishers), the weaknesses of the productive chain and the commercialization models, and the deficiencies in the fisheries policies with local and national jurisdiction (Ministry of Agriculture and Rural Development Republic of Colombia, 2012; RIMISP, 2017).

3.2. Sampling

Drawing on previous studies on the impact of climate change on national and global fishing communities, we built a digital instrument for collecting data from the target community—the artisanal and semi-industrial fishers of Tumaco—which was implemented on electronic devices (Carlos-Gómez and Moreno-Sanchez, 2015; Cheung et al., 2010; Cheung, 2018).

The instrument was divided into three sections. The first section collected information on the components of the Adaptive Capacity Index (ACI). The second was designed to obtain information on the fishing activity and the most frequent or lucrative alternative household activity. It collected data on the resources available, the efforts made, the costs incurred, and the obtained income, among other information. Specifically, to determine the possibility of households switching between economic activities, they were consulted about their willingness to leave the fishing activity in a hypothetical scenario of a decline in fishing production and income. The third section collected information on some sociodemographic characteristics of the household, such as its composition and how they make decisions with the presence of a head of household. Thus, information was obtained from a total of 130 marine fishing households[2] distributed in the five communes of the head of Tumaco, the rural area, and two neighbouring coastal municipalities in the Pacific of Nariño (Francisco Pizarro and Olaya Herrera) (Figure 1).

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[1] The exchange rate for February 13, 2021 is 3,925.99 Colombian pesos/US dollar.

[2] We made an open call using word-of-mouth in neighborhoods where fishers live and congregate to obtain this sample. We received different types of fishers, associated and independent, willing to participate in the study. We built a database and contacted them once the fieldwork started. However, due to possible selection bias, we performed a statistical test reported in Section 4.3.

In general, from the target population is recognized that most (over 90%) of the marine fishers are male, with a specific age group of 40 and 60 years. However, the fishing activity also includes manual harvesting of shellfish, carried out almost entirely by the household women —with a more common age distribution between 20 and 40 years— and sometimes in the corporation of their children. The family composition of the surveyed fishers reflects that the majority (76%) have a stable partner and large families (41% with more than three children). 43% live with 4–5 people in their home, and 24% with six people or more, often economically dependent on fishing. It is noteworthy that 47% of fishers do not own a boat. The overall capacity of engines using artisanal vessels typical of the region is low to medium power (between 40-75 HP). About using technological tools to support the fishing activity, more than half of the fishers do not use any device to support their decision-making regarding navigability and guarantee their safety on the route. The relevant socio-demographic information of this sample is reported in Table 3.

3.3. Calculation of economic vulnerability

The present vulnerability analysis is based on the criterion of sustainable livelihoods within the concept of climate change defined by The IPCC, in its fourth assessment, in which report vulnerability as the exposure of a system to a change, its sensitivity to change, and its capacity to adapt (IPCC, 2007); and taking into consideration the impacts of climate change on fishing activity in Colombia (Herrera et al., 2015; CEPAL & European Union, 2015; Ministry of Environment and Sustainable Development of Colombia, 2017) in this case, the fisheries sector will be affected by changes or stressors (Koomson et al., 2020) due to its susceptibility. Essentially, the household's vulnerability to climate change occurs when it does not have sufficient benefits to compensate for the well-being it had before the exposure to the extreme weather event. Vulnerability then refers to the inability to maintain a livelihood based on a concept that is most often applied in development assistance and poverty alleviation. To calculate appropriate measures of economic vulnerability, we took as reference the principles proposed by Adger (2006) to ensure capturing relativity and severity in its redistribution.

First principle: The vulnerability measure should determine various forms of impact on well-being, including changes in income or wealth. A generalised measure must consider the severity of the vulnerability and be a relative measure, in addition to incorporating broadly defined well-being.

Second principle: The vulnerability measure considers the dimensions of the temporal dynamics of risk. Suppose the vulnerability is a transitory phenomenon associated with exposure to specific risks or a chronic state. Subsequently, vulnerability assesses a parameter—income mobility—which, in turn, measures whether the population categorised as 'poor' can escape its vulnerability state over time.

Third principle: The vulnerability measure must be sensitive to the distribution of risk, even if the total vulnerable population remains the same.

Accordingly, we propose a vulnerability measure that classifies at different levels the relative benefits that a household obtains between an alternative economic activity and fishing by diversifying their livelihoods. First, we based on the assumption that a household abandons fishing due to the possible decrease in revenues caused by the effects of climate change, making fishing an unprofitable activity. Therefore, the household engages in an alternative activity that yields incomes (*IS*) and assumes costs (*CS*). Accordingly, we calculated the daily benefit of its most frequent or representative alternative activity, resulting from the difference between income (*IS*) and its cost (*CS*) per day (weekly frequency of engagement in the alternative activity). Later, we divided it by the daily benefit from fishing, which is obtained from the difference between its income (*IP*) and its cost (*CP*) per day (weekly frequency of performing fishing) (Equation 1).

$$Recovery\ of\ Benefits = ((IS-CS)/\text{frequency})/((IP-CP)/\text{autonomy}) \quad (\text{Equation 1})$$

Following this expression (Equation 1), we obtained the proportion of the recovered livelihood from diversification. This proportion ranges from 0% up to more than 100%. With this proportion, we classified the household into five levels of vulnerability: Level 1. A household recovers more than 100% of its daily benefit by engaging in an alternative activity; Level 2. A household that recovers more than 50% but less than 100% of its daily livelihood by engaging in an alternative activity; Level 3. A household recovers more than 25% but less than 50% of its benefit by engaging in an alternative activity; Level 4. A household that recovers more than 0%, but less than 25% of its daily benefit by engaging in an alternative activity; Level 5. A household that does not recover from its daily benefit or does not have any alternative activity. In summary, the vulnerability levels are defined according to the proportion of benefits that the household manages to recover (Table 1).

This classification provides a relative measure that impacts the household's well-being in the event of temporary or chronic exposure to a possible natural phenomenon that prevents families from obtaining income from fishing. Likewise, it enables one to measure the diversification of household livelihoods to reduce the risk of loss of fishing benefits.

3.4. Adaptive capacity index (ACI)

The ACI calculated in this study centres its conceptual bases on the one proposed by Moreno-Sanchez and Maldonado, 2014, which was initially applied to measure the fishing communities' adaptive capacity when implementing marine protected areas. This index was later adapted by Carlos-Gómez and Moreno-Sanchez, 2015 to measure the adaptive capacity of indigenous communities to climate change.

The dimensions proposed by Moreno-Sanchez and Maldonado, 2014 were considered, emphasising the strategies implemented at the household level to replace income in Tumaco. These dimensions—socio-economic (*SN*), institutional (*SI*), and socioecological (*SE*) (Table 2)—comprise a diversity of sub-indices that provide information on the livelihoods of a household, its institutional networks, and its relationships with the ecological environment. By combining these three dimensions with their subscripts, the complexity of each household's decisions to reduce its vulnerability can be measured (Table S1).

The *Socio-economic Dimension (SN)* calculates the social and economic capacity to cope with the anomalies generated by climate change. This dimension is divided into poverty (*POV*) and occupational characteristics (*OCC*). The *POV* index is broken down into two sub-indices: self-perception of poverty (*POV1*) and material lifestyle (*POV2*). The first indices measure the household's self-perception of well-being considering the income and expenses that come together over time. The second index measures the physical capital that a family faces considering the potential impacts of climate change and comprises a set of household infrastructure characteristics according to the most common options in the municipality, which are valued according to their resistance.

Occupational characteristics (*OCC*) measure the flexibility of households in generating income through occupational diversity (*OCDI*), which corresponds to the proportion of people in the family who conduct some economic activity from which they receive remuneration. Occupational mobility (*OCMO*) is also measured, which estimates the

Table 1. Levels of economic vulnerability.

Vulnerability level	Proportion of benefits recovered
1	Recovery >100%
2	50% < Recovery ≤100%
3	25% < Recovery ≤50%
4	0 < Recovery ≤25%
5	They fail to recover

Table 2. Indices and sub-indices of each dimension of the ACI.

Dimension	Index	Subscript
Socio-economic (SN)	Poverty (POV)	Self-perception of poverty (POV1)
		Material lifestyle (POV2)
	Occupational characteristics (OCC)	Occupational diversity (OCDI)
		Occupational mobility (OCDM)
Institutional (SI)	Structural social capital (SSC)	Organisational density (SSC1)
		Expectation of support networks in the face of natural shocks (SSC2)
		Expectations on support networks in the face of community shocks (SSC3)
		Household collective action (SSC4)
	Cognitive social capital (CSC)	Solidarity (CSC1)
		Cooperation (CSC2)
		Trust (CSC3)
	Perception of actions against climate change (CCP)	Perception of community preparedness (PCC1)
		Perception on the preparation of government entities (PCC2)
		Perception of support from government entities (PCC3)
	Institutionality around climate change (ICC)	Presence of community early warning (ICC1)
		Existence of actions to face natural disasters (ICC2)
		Existence of facilities to face natural disasters (ICC3)
Socioecological (SE)	Resource use dependency (RUD)	
	Local ecological knowledge (CEL)	Local climate knowledge (CLCC)
		Local knowledge about the various species (CLCE)
	Ability to anticipate change (AAD)	

Source: Adapted from Moreno-Sanchez and Maldonado, 2014.

proportion of households who believe that they can easily change their economic activity and continue to receive income.

The *Institutional Dimension (SI)* estimates the formal and informal rules between households, their external relationships, and their relationship with the fishing resource. It includes structural social capital (*SSC*), cognitive capital (*CSC*), the perception of actions against climate change (*PCC*), and institutionalism against climate change (*ICC*).

This index is broken down into organisational density (*SSC1*) that estimates the proportion between the number of people in the household over 15 years of age who belong to a community organisation and the total number of people in the household over 15 years of age. Precisely, the SSC measures observable social structures such as associations, support networks, and protocols that enable households to cope with climate change events. The expectation on support networks for natural disasters (*SSC2*) captures the perception of networks and mutual support at the local level to solve problems caused by climate change that affect all households in general. Expectations about support networks in the face of community shocks (*SSC3*) capture the anticipation of homes to obtain support from various local organisations and the community itself to solve a problem that affects only some families in the community. Finally, the collective action of the household (*SSC4*) examines the participation of homes in community spaces designed to coordinate and conduct activities to face common problems.

Cognitive social capital (*CSC*) measures the different intangible structures that coordinate the behaviour of households and their relationships with the rest of their community. This sub-index is made up of three values:

- Solidarity (*CSC1*) captures the manifestations of detailed support for specific households facing critical situations due to shocks or other factors.
- Cooperation (*CSC2*) captures the willingness to participate in possible joint practices between households for the same purpose, given specific opportunities or circumstances.
- Confidence (*CSC3*) captures the firm hope that families have in their community to overcome certain situations.

The perception of actions against climate change (*PCC*) measures the household's perception of the activities that its community implements in terms of possible climate change events. It comprises the perception of community preparedness (*PCC1*), that of the preparation of government entities (*PCC2*), and that of the household's trust in the help that government entities can provide in the case of facing the effects of climate change (*PCC3*).

The institutional framework around climate change (*ICC*) evaluates whether the household identifies the strategies that its community environment implements to face climate change. It is subdivided into three components:

- The presence of community early warning (*ICC1*) measures whether the household is aware of the existence and operation of appropriate means and mechanisms that inform about the occurrence of possible natural disasters.
- The actions to face natural disasters (*ICC2*) measure whether the household is aware of procedures that allow it to act in the face of these disasters.
- The facilities to face natural disasters (*ICC3*) measure whether the household is aware of community organisations and processes to attend for those affected by an event related to a natural disaster.

The *Socioecological Dimension (SE)* measures the different relationships that fishing households have with the exploited resource. It comprises resource use dependency (*RUD*), local ecological knowledge (*CEL*), and the ability to anticipate change (*AAD*).

RUD measures how many household members have a job or some activity related to fishing and receive income from it. *CEL* includes two components on the knowledge of the available resources that households have explicitly focused on the fishing resource: the number of climatic conditions that the fisher considers when conducting the tasks (*CLCC*) and the number of species that the fisher usually fishes (*CLVE*). Finally, *AAD* measures the ability of a household to act in the face of the possible effects of an event or natural catastrophe that leaves it without the possibility of having an income.

Finally, to obtain the ICA, we calculated a simple average between the three dimensions (Equation 2):

$$ACI = (SN + SI + SE)/3 \qquad \text{(Equation 2)}$$

Having calculated the vulnerability and the ACI per household, we proposed to estimate two ordered discrete choice models: *Oprobit* and *Ologit*. The baseline is latent continuous metrics of the ACI influencing the order and variability of the household vulnerability. These models estimate the log-likelihood of a household moving from one level of vulnerability to another, based on each element of its adaptive capacity.

Additionally, we added control variables with socio-demographic characteristics of the household. The first one measures if the household owns a boat. This variable was incorporated as a proxy for the access to private capital that each household possesses. The second one measures if the household has a leader or head and was added to determine if the household considers it a strategy to alleviate resource allocation conflicts. This figure constitutes a social norm with which profit distributions, food security, and important financial decisions are managed (Munoz-Boudet et al., 2018). Eq. (3) expresses this estimate:[3]

$$P\,(vulnerability = n\,|X) = a_0 + a_{1k}\,[ICA_k] + a_2\,boat + a_3\,leader + \mu \quad \text{(Equation 3)}$$

Where n = 1, 2…5.

The above indicates that vulnerability is the result of an autonomous component a_0 and the variability of each of the k components of the ACI. Each of the a_{1k} estimates the log-likelihood that a household moves from one vulnerability level to another. The expected sign of each of these $a1k$ is negative. The coefficient a_2 that accompanies the boat variable was expected to be negative as access to private capital was expected to decrease household vulnerability. Finally, the coefficient a_3 that accompanies the leading variable was expected to be negative because, as a hypothesis, a household with this institution has fewer resource allocation problems, and therefore, a lower vulnerability condition.

Notably, the results of these estimates do not calculate the probability that a household changes its vulnerability level given the components of the ACI. Instead, these results are restricted to analyzing each element's relationship (direct or inverse) with the vulnerability levels.

3.5. The possible scenario of going out of fishing

To identify if there is a propensity of Tumaco's fishers to be caught in fishing, we proposed a conceptual framework to explain the different socio-economic and institutional reasons that prompt households to decide to go out of fishing due to the possibility of a decrease in incomes. On the one hand, the *endogenous* or *old paradigm approach*, indicates that the origin of poverty in fishing communities is because of the overexploitation of the resource leads to a trap and rent dissipation (Béné, 2003); on the other hand, the *exogenous* or *socio-institutional approach*, poverty origins from the lack of income opportunities outside fishing (Smith, 1979; Panayotou, 1982; Cunningham, 1993). Both approaches indicate a poverty-related decision to exit or continue performing the activity, which is conditioned by the combination of socio-economic and institutional factors. Accordingly, we measured the willingness to *go out* of fishing due to a hypothetical scenario of decrease in fish by asking fishers the following dichotomous question: If

the production of fish/shellfish/shrimp were lower, and your income declines:[4]

a. Would you continue fishing?
b. Would you leave fishing and change permanently to another activity?

Following these two poverty approaches, we estimated the relationship between the willingness to *go out* of fishing and their *self-perception of poverty* –measured by *POV1*– and household's *alternative activities*. Additionally, we estimated the influence of the opportunity cost of fishing to decide to leave, since the evidence argues that this indicator is an important driver ever time it is very low for most fishers; so, the opportunity cost of other activities is relatively higher (Copes, 1989; Ikiara and Odink, 1999; Doulman 2004). Thus, fishers resist leaving the activity, leaving other livelihood alternatives less developed or for sporadic employment.

Based on this conceptual framework, we proposed to estimate a discrete choice model to explain the decision to stay or go out of fishing and how this decision variates according to the different socio-economic variables of the households; we also considered the influence of poverty and the opportunities to obtain income outside of fishing. In the first place, the self-perception of poverty depends on the material and social capital of the household. This made it necessary to estimate a model that controls the endogeneity of these variables and identifies a consistent relationship between the decision to go out of fishing, the self-perception of poverty, and the accumulation of material and social capital. Therefore, a two-stage *IVprobit* probabilistic model with instrumental variables was estimated. Equation 4 expresses this estimate:

$$P\,(go\ out = 1|X) = \beta_0 + \beta_1(POV1 = f\,(CSC1,\ CSC2,\ CSC3)) + \beta_{2k}[AC_k]$$
$$+ \beta_3\ recovery + \beta_3 boat + \beta_4 leader + \upsilon \qquad \text{(Equation 4)}$$

The first stage estimated the self-perception of poverty (*POV1*) as an instrumented variable. As instrument variables, the variables of solidarity (*CSC1*), cooperation (*CSC2*), and trust (*CSC3*) were introduced as proxies of the household's social capital. The second stage estimates the decision to change the activity to go out of fishing as a dependent variable. Finally, as independent variables, the alternative household activities Services/remittances, Mining, Agriculture, and Moto-taxis (*ACk*) were estimated as the variable that indicates the proportion of income recovered in other recovery activities and the occupational mobility of the household (*OCMO*).

4. Results and discussion

Of the surveyed households, 51.53% stated that they have an alternative economic activity that they simultaneously engaged in or combined with marine fishing to generate income for the household (Table 3).

The alternative activities that households conduct to diversify their income are land transportation by motorbike (hereinafter referred to as moto-taxis), agriculture, handicraft manufacturing, mining and related activities, employment in services (mostly informal, including activities of domestic service, night surveillance of commercial premises, and sporadic sales in warehouses), teaching, and cultural activities (Table 4). Two of the households stated that they receive remittances from family or friends once a week. The activities in which the highest proportion of households are employed are agriculture, moto-taxis, and handicraft manufacturing.

4.1. Economic vulnerability estimation

The average daily benefit from fishing calculated for the fishers of Tumaco and the neighbouring coastal municipalities surveyed was $111,116.9 Colombian pesos ($CI_{(95\%)}$: $86,780.24 $\leq$ *ben_day* $\leq$ $135,453.6). Regarding the average daily benefit of the alternative

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[3] Given the possibility of selection bias, a Heckoprobit model was also estimated to identify an endogeneity problem in the estimation. This estimate reveals consistency with that presented in Table 8. The results are shown in Table S2.

[4] This question was designed to measure the likelihood of leaving the fishing activity because of their own will and possibilities outside the activity. Due to this, we omitted to mention causes such as climate change which generates a negative connotation and somehow an enforced leaving that could bias our analysis.

Table 3. Socio-economic information of the surveyed fishing households.

Variable	Average indicator
Fishing activity frequency	3.97 days/week
Days of autonomy of the activity	1.75 days/week
Average number of members of the household	4.85 people/home
Number of fishers in the household	1.33 people/home
Head of household	36.15%
Average formal schooling of head of household	2.7 years
Boat owner	22.31%
Alternative activity/other sources of income	51.53%
Average weekly frequency of employment in alternative activities	1.78 days/week

Table 4. Alternative economic activities of the surveyed fisher's households.

Variable	Number of households	Average weekly frequency of employment
None	63	-
Moto-taxis	19	4.47
Agriculture	14	2.4
Handicraft manufacturing	14	3.29
Mining and related activities	8	2.88
Employment in different informal services	6	3.5
Teaching in different areas	3	5
Remittances	2	1
Cultural activities	1	1

activity to fishing that households perform, the one that generates the greatest benefit was teaching[5], although only three of the surveyed households conduct it for five days a week. Further, it cannot be defined as a generalised or free-standing activity for an average household in the area. The second most lucrative activity and the second most frequent was agriculture (Table 5).

The general average indicates that households could recover up to 29.57% of their fishing profit by performing alternative activities. Some households can recover more than 100% of their fishing profit with another economic activity, indicating a possible welfare gain if the fishing household faces a climatic event that impedes fishing (Table 5). However, jobs such as teaching and cultural activities are not considered easily accessible because they commonly require proof of educational training, which explains the lack of mobility between these activities.

Nevertheless, employment in informal services, mining and related activities, moto-taxis, and handicraft manufacturing do not allow a 100% recovery of the benefits generated by fishing (Table 5). This reflects a possible loss of well-being, given the scenario that these households could not conduct their main economic activity due to an adverse situation. In the case of remittances and handicrafts, households reflect compensation for their well-being by having these complementary sources of income; however, remittances are not necessarily a frequent source of livelihoods. In mining, it is unknown if the activity is legal, constant, or temporary; therefore, employment in this activity can be considered sporadic and without guarantees.

Based on the level of recovery classification, we found that 8.46% (11 of the households surveyed) have a level 1 vulnerability—they recover more than 100% of their fishing benefits with an alternative activity. At the other extreme, 53.08% of households (69 of those surveyed) that cannot recover their fishing income belong to level 5 (0% recovery; according to Table 1), including households without any complimentary

activity to fishing and those that conduct alternative actions. The remaining 38.46% is between levels 2 and 4. Activities per vulnerability level are disaggregated in Table 6.

To indicate the relationship between the vulnerability level and alternative economic activity, cultural, teaching, informal services and remittances were grouped into the same category (called *Services/Remittances*; Figure 2), for the following reasons. First, these services usually do not require a direct and explicit cost to perform and are activities with the least number of households employed in them. Further, this category and mining are activities that allow a higher level of recovery of benefits and are demonstrated to categorise a significant proportion of households in level 1 of vulnerability.

Agriculture, handicraft manufacturing, and moto-taxis are activities that generate the highest levels of vulnerability, as less than 25% of households have a level 1 vulnerability. However, none of the households employed in agriculture has a vulnerability level of 5—it is the only activity that reduces the risk of a total loss of well-being in the face of a climatic event that prevents the household from being employed again in fishing. Finally, not having an alternative activity generates 100% vulnerability—households that do not diversify their income face a greater risk of a total loss of well-being in the face of a climatic event that prevents them from returning to employment in fishing (Figure 2). This level of vulnerability also includes two households that obtain zero (0) benefits from their alternative activity.

4.2. Adaptive Capacity Index estimation

The Poverty Index obtained (POV = 48.05) allows us to infer that most fishing households perceive themselves to be relatively poor. The infrastructure of their homes is often not resistant to possible adverse climatic events (Table 7). Furthermore, the occupational characteristics index (OCC = 45.41) indicates that, on average, households have considerably little labour mobility and do not tend to diversify their sources of income.

The structural social capital (SSC = 43.64) indicates that fishing households recognise few support networks and local protocols to deal with climate change events. However, the cognitive social capital index (CSC = 55.59) reflects that families tend to perceive different favourable intangible structures that coordinate behaviour and their relationships with the rest of their community. The index of perceptions of climate change (PCC = 44.28) indicates an unfavourable perception of households on the actions that their communities implement in terms of possible events of climate change. Nevertheless, actions regarding climate change (ICC = 63.58) show that, on average, households identify strategies implemented in their community to face climate change and natural disasters in general (Table 7).

The resource dependency index (RUD) value reveals a relatively high dependency on the fishing resource—the average proportion of people per household who obtain income from fishing tends to be considerably high. Conversely, the index of local ecological knowledge obtained (CEL = 34.33) indicates a relatively low knowledge about the climatic conditions and associated environmental information that would allow them to support their decision-making regarding fishing. The ability to anticipate change demonstrates that, in general, households have a relatively good ability to predict the possibility of being left without income because of the effects of climate change (Table 7)[6].

4.3. Econometric analysis: relationship between vulnerability and adaptive capacity

Two ordered discrete choice models estimated (*Oprobit* and *Ologit*) how the ACI components influence the variability of household vulnerability. These models estimate the log-likelihood of a household moving

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[5] This study accounted for only three households that perform teaching as an alternative activity. This teaching is mainly formal elementary schooling, including math, social sciences, natural sciences, and sports.

[6] Table S1 summarises the results of the ACI sub-indices.

Table 5. Daily benefits of alternative activities and proportion of benefits recovered.

Alternative activity	Average daily benefits		Recovery proportion
	(Colombian pesos)	Std dev.	
Teaching in different areas	$223,333.33	(80,829)	184%
Agriculture	$110,255.56	(12,7031.15)	57%
Remittances	$100,000	(14,1421.36)	100%
Employment in different informal services	$86,847	(13,6896.7)	63%
Cultural activities	$50,000	(0)	143%
Mining and related activities	$27,375	(18,534.77)	97%
Moto-taxis	$27,053	(14,926)	4%
Handicraft manufacturing	$24,821	(17,411)	23%
None	—	—	0

Table 6. Proportion of fishing households and activity by the vulnerability level.

Vulnerability level	None	Employment in different informal services	Remittances	Mining and related activities	Agriculture	Teaching	Cultural activities	Moto-taxis	Handicraft manufacturing	Total (Proportion of fishing households)
1	—	1	1	2	2	2	1	1	1	11
	—	16.67%	50%	25%	14.29%	66.67%	100%	5.26%	7.14%	**8.46%**
2	—	3	—	1	2	1	—	7	2	16
	—	50%		12.5%	14.29%	33.33%		36.84%	14.29%	**12.31%**
3	—	2	—	1	4	—	—	2	3	12
	—	33%		12.5%	28.57%	—	—	10.53%	21.43%	**9.23%**
4	—	—	—	3	6	—	—	7	6	22
	—	—		37.5%	42.86%	—	—	36.84%	42.86%	**16.92%**
5	63	—	1	1	—	—	—	2	2	69
	100%	—	50%	12.5%	—	—	—	10.53%	14.29%	**53.08%**

from one level of vulnerability to another, based on each element of its adaptive capacity. The vulnerability was taken as a categorical dependent variable that takes values from 1 to 5, and each of the ACI indices in Table 7 was included as an independent variable.

To incorporate the two socio-demographic controls, we created two discrete variables. The first one —boat— takes the value one if the household owns one or more boats; otherwise, it takes 0. The second variable —leader— takes the value of 1 if the household has a leader or head; otherwise, it takes 0. To estimate these models, we referred to Equation 3.[7]

Due to the scope of this analysis going as far as the description of these relationships and their implications, we focused only on the estimation of log-likelihood and signs. Results of these estimations are shown in Table 8.[8]

The results indicate that both models (*Oprobit* and *Ologit*) are consistent in terms of the symbols of each independent variable. The statistically significant variables are the same for both models and the coefficients of the estimates without controls (*Oprobit* n.c y *Ologit* n.c) by the household for both methods. However, the difference in both models is found in the estimates of the models with household controls. This difference arises because the coefficients for the *Ologit* model are higher, and sometimes their magnitude is double that of the *Oprobit* coefficients. However, the Hausman test indicates no systematic differences in the coefficients (chi^2 (11) = 8.90; p-value = 0.63). The signs of the coefficients of the independent variables are as expected, except those of the coefficients that accompany the *ICC* and *leader*.

These estimates reveal that the household's occupational characteristics (*OCC*) have a negative and significant relationship with its vulnerability, indicating that households with diversification strategies and the possibility of employment in different activities outside of fishing are more likely to decrease its level of vulnerability. Additionally, consistency is emphasised with the arguments that indicate that diversification in income sources generates less dependence on natural resources, guaranteeing livelihoods (Choden et al., 2020; Yomo et al., 2020). These results are consistent with those found by Martins and Gasalla (2020), arguing that a household dependent on the fishing resource has lower livelihoods, and therefore, more negligible income diversification. This, in turn, prevents the household from accessing social, human, physical, and financial capital, consequently generating a lower perception of wealth.

Other authors (Chepkoech et al., 2020; Martins and Gasalla, 2020; Yomo et al., 2020; Zanmassou et al., 2020) have studied the diversification of livelihoods in rural households as a fundamental strategy to alleviate the effects of climate change, which coincide with those as mentioned earlier. However, it is necessary to investigate the role of local and governmental institutions in guiding actions to mitigate the climatic effects that these most vulnerable fishing households face. It could be suggested that these households, although less privately adapted, could entrust their survival and resilience to government institutions, perceiving them as fundamental agents for their support in the region. Although the results indicated that institutionality is not decisive for fishing households, it may decrease their vulnerability levels, possibly due to a low perception of the actions taken by the institutions or as an effect diluted by the lack of trust that households have towards them.

Regarding cognitive social capital (*CSC*), a negative and significant relationship with the household's vulnerability was observed, revealing that informal institutions of reciprocity, solidarity, and cooperation are important to reduce the vulnerability of fishing households. These results
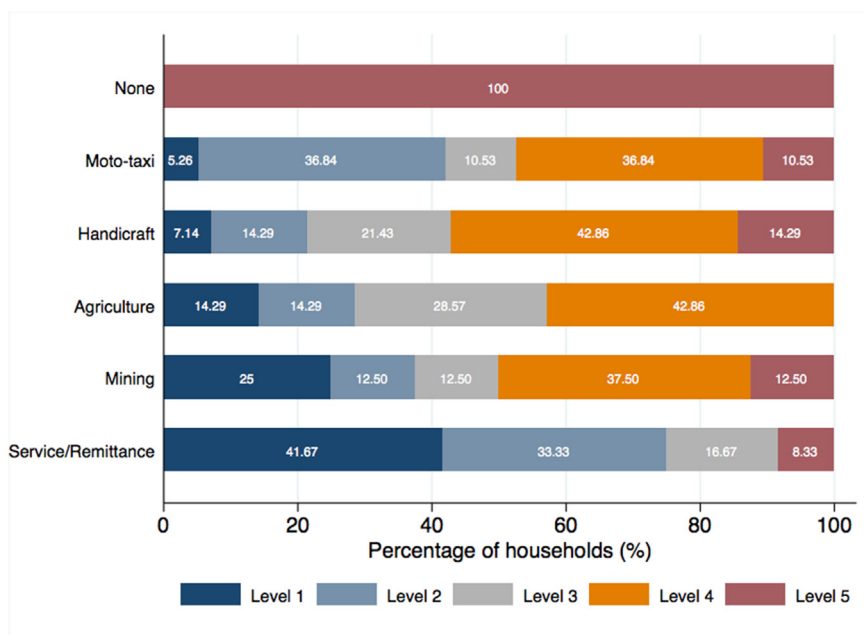
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[7] Given the possibility of selection bias, a Heckoprobit model was also estimated to identify if there is an endogeneity problem in the estimation. This estimate reveals consistency with that presented in Table 8. The results are shown in Table S2.

[8] The marginal effects are shown in Table S3 and S4.

Figure 2. Economic vulnerability of households by alternative activity.

Table 7. Average values of the ACI indices, according to their dimension.

Dimension	Index	
	Description	Average value
Socio-economic (*SN*)	Poverty (*POV*)	48.05
	Occupational characteristics (*OCC*)	45.41
Institutional (*SI*)	Structural social capital (*SSC*)	43.64
	Cognitive social capital (*CSC*)	55.59
	Perception of actions against climate change (*PCC*)	44.28
	Institutionality around climate change (*ICC*)	63.58
Socioecological (*SE*)	Resource use dependency (*RUD*)	22.61
	Local ecological knowledge (*CEL*)	34.33
	Ability to anticipate change (*AAD*)	70.96

are consistent with the arguments of Agrawal and Perrin (2009) and Wang et al. (2013).

The results of the estimates on resource dependence (*RUD*) are consistent with the arguments of Martins and Gasalla (2020) as they reveal that fishers who rely on marine resources to obtain income and guarantee their livelihoods have greater probabilities of having higher vulnerability levels.

The estimates on the institutional framework around climate change (*ICC*) and vulnerability indicate that these two variables have a direct relationship. The coefficient is positive and statistically significant in all the estimates. Therefore, it was not possible to verify the hypothesis that the institutional framework around climate change (which measures whether the household identifies alarms, strategies, and infrastructure to deal with possible natural disasters) reduces the household's vulnerability. This result indicates that the greater the institutional framework around climate change in the household, the more vulnerable it is—the households that most recognise these strategies have the highest levels of vulnerability. This is because they are the ones who need them the most; also, it indicates that these households are the poorest. The marginal effects (Table S3 and S4) of these estimates suggest that the probability of being at vulnerability level 5 increases when the *CCI* is higher—those households that most identify this type of strategy in their environment

are more likely not to recover their income. This may be a consequence of the history that Tumaco has with natural disasters from 1868 to 1983, when the municipality suffered four tsunamis, affecting thousands of homes (Colombian Red Cross, 2011), including environmental, health, and social damages. Thus, the *ICC* acts more as a consequence of vulnerability than as a mitigation strategy—the more procedures and infrastructure households identify, the more vulnerable they are to these phenomena.

The coefficients that accompany the other model variables, such as *POV, SSC, PCC, CEL, AAD*, and *boat*, have the expected signs; however, they are not statistically significant. Therefore, the evidence does not allow conclusions to be drawn about their influence on the vulnerability level of the fishing households of Tumaco.

4.4. Econometric analysis: the possible scenario of going out of fishing

The results obtained indicate that the proportion of fishers willing to change their main economic activity is 41.54%. In comparison, the remaining 58.46% declare that they would continue fishing if faced with a decline in the income from marine fishing. Therefore, we estimated the two-stage *IVprobit* probabilistic model with instrumental variables using Equation 4.

We used the proportion of fishers filling to change their economic activity – go out –. This variable takes value 1 if the household is willing to leave the fishin case this one becomes unprofitable; takes value 0 otherwise. As independent variables we estimated the set of alternative activities and the opportunity cost; finally we introduce the control variables *boat* and *leader*.

The variable *Services/remittances* takes the value 1 when someone from the household is employed in commercial activities, private surveillance, cleaning services in domestic or commercial premises, cultural services, teaching activities, or receives remittances; otherwise, it takes the value 0. The *Mining* variable takes the value 1 when the household is employed in gold extraction activities or other activities related to mining and 0 otherwise. *Agriculture* takes the value 1 when the household is employed in the cultivation and commercialisation of agricultural goods and 0 otherwise. *Moto-taxis* takes the value 1 when someone from the household uses this activity and 0 otherwise. Finally, the variable *Handicraft manufacturing* takes the value 1 when someone in the household manufactures and/or markets handicrafts and 0 otherwise.

Table 8. Vulnerability of fisher's households according to their adaptation capacity.

Variables	Oprobit	Oprobit (n.c.)	Ologit	Ologit (n.c.)
POV	-0.00632	-0.00760	-0.0191	-0.0191
s.e.	(0.0101)	(0.00961)	(0.0177)	(0.0164)
OCC	-0.00909*	-0.00889*	-0.0168*	-0.0162*
s.e.	(0.00528)	(0.00528)	(0.00955)	(0.00940)
SSC	0.00572	0.00491	0.0104	0.00986
s.e.	(0.00548)	(0.00554)	(0.00911)	(0.00956)
CSC	-0.0291**	-0.0285**	-0.0521**	-0.0512**
s.e.	(0.0126)	(0.0129)	(0.0230)	(0.0233)
PCC	-0.0141	-0.0129	-0.0196	-0.0189
s.e.	(0.0101)	(0.00985)	(0.0184)	(0.0180)
ICC	0.00882*	0.00823**	0.0191**	0.0172**
s.e.	(0.00456)	(0.00408)	(0.00816)	(0.00740)
RUD	-0.00774**	-0.00778**	-0.0136**	-0.0139**
s.e.	(0.00375)	(0.00371)	(0.00638)	(0.00629)
CEL	0.00121	0.000135	-0.000436	-0.00127
s.e.	(0.00640)	(0.00656)	(0.0110)	(0.0114)
AAD	-0.00511	-0.00487	-0.00818	-0.00728
s.e.	(0.00450)	(0.00447)	(0.00804)	(0.00785)
leader	-0.209	-	-0.201	-
s.e.	(0.295)	-	(0.519)	-
boat	0.218	-	0.469	-
s.e.	(0.251)	-	(0.419)	-
Constant cut1	-4.207***	-4.287***	-7.430***	-7.532***
s.e.	(1.129)	(1.131)	(2.223)	(2.223)
Constant cut2	-3.579***	-3.664***	-6.256***	-6.371***
s.e.	(1.128)	(1.129)	(2.221)	(2.219)
Constant cut3	-3.248***	-3.335***	-5.668**	-5.786***
s.e.	(1.125)	(1.127)	(2.206)	(2.207)
Constant cut4	-2.714**	-2.805**	-4.740**	-4.868**
s.e.	(1.120)	(1.121)	(2.176)	(2.180)

[a] Dependent variable: *vulnerability*. N = 130.
[b] *Oprobit* model estimated without controls per household.
[c] *Ologit* model estimated without controls per household.
Significance: *** 1%; ** 5%; * 10%. Marginal effects in Table S3 y Table S4.

Additionally, an alternative estimation was made with the dichotomous variable *activity* that groups all alternative sources of livelihoods; this variable takes the value 1 if the household reports any activity or alternative source of income that allows it to diversify its livelihoods; otherwise, it takes the value 0. This alternative estimation uses one variable to capture the aggregate effects of having alternative livelihoods, instead of estimating the disaggregation of the effects by each alternative activity such as *Services/Remittances, Mining, Agriculture, Moto-taxis* and *Handicraft manufacturing*.

The variable *recovery* is introduced as an index of the opportunity cost of the household when going out of fishing. This variable is considered decisive as the evidence indicates that the opportunity cost of fishing for most fishers is meagre; hence, the opportunity cost of other activities is relatively higher (Copes, 1989; Ikiara and Odink, 1999; Doulman, 2004). Thus, it is conceived that fishers usually choose to develop fishing as their main economic activity, renouncing other less developed alternative activities or leaving them for sporadic employment (Table 9).

[9] Other instruments of structural capital stock were estimated (*SSC1, SSC2, SSC3,* and *SSC4*) that turned out to be insignificant. Additionally, the Wald test indicated that they are not a good instrument for this estimation (chi² (1) = 2,11; *p-value* = 0,1461); hence, they were omitted. Models with the aggregate indices (*POV, CSC,* and *SS*C) were also estimated; however, they did not reveal consistency.

The Wald tests indicate that the estimates of the social capital of the household (*CSC1 CSC2* and *CSC3*) allow the *IVprovit* model to be consistent, indicating that these variables are good instruments to control the model's endogeneity. The estimates of the first stage of the model reveal that the relationship between this social capital and the self-perception of poverty is not clear for the variables of solidarity (*CSC1*) and trust (*CSC3*), and the coefficients in all its estimates are statistically non-significant[9]. However, the variable that estimates household cooperation has a positive and meaningful relationship with self-perception of poverty, indicating that when a fishing household perceives cooperation in its fishing operation, it perceives itself as less poor. This social capital measures the existing links between the household members or the community and represents a mechanism for the redistribution of resources. Therefore, social capital can alleviate poverty; however, its accumulation does not necessarily allow it to be overcome.

Nevertheless, the coefficient that accompanies the variable *boat* is only significant in the *IVprobit* model, identifying that it is perceived as less poor when a household owns at least one boat. This accumulation of material capital motivates fishers to conduct the activity as capitalists rather than as workers. They have incentives to obtain higher incomes and thus reward their opportunity costs. In this case, the households that own a boat have a direct investment with which they reference whether the activity is profitable. Hence, these owners perceive fishing as a business and not as a subsistence activity; these results coincide with those presented in other studies (Panayotou, 1982).

The estimates of the coefficients that accompany the *leader* variable allow us to identify that the figure of the head of household is not necessarily a strategy for those households that perceive themselves as poorer. In other words, this figure that, according to authors, co-helps alleviate resource allocation conflicts, income distributions, food security, and important financial decisions (Munoz-Boudet et al., 2018) tends to be more of a figure to alleviate the poverty burden and not a consequence of it.

The coefficient that accompanies the occupational mobility of the household (*OCMO*) was found negative and significant in all the estimates, indicating that the higher the occupational mobility of the household, the poorer it is self-perceived. In other words, those households that have less occupational mobility perceive greater security and stability in their income by not considering occupational mobility as a strategy to alleviate poverty. Similarly, those households that perceive themselves as poorer may perceive themselves with less income stability; therefore, increasing their occupational mobility is considered a strategy to alleviate poverty.

To mention a specific example, households with the highest occupational mobility, according to the results, tend to be employed alternately in agriculture (*OCMO* = 78.7) and mining (*OCMO* = 83.33.); tasks that tend to be informal and with fewer needs for specialised labour in the local context. Correspondingly, these two activities tend to accumulate households that recognise themselves as poorer (*POV1* (agriculture) = 29.44); *POV1* (mining = 37.5). However, based on this inference, future research could be conducted on the relationship between poverty and intragenerational occupational mobility. This is because the studies conducted in this regard in developing countries present significant differences due to the methodologies with which these are indicators measured (Iversen et al., 2019).

The coefficients that accompany the variables that relate to the activities or alternative sources of household income were not significant in any estimation for both the disaggregated activities and for those grouped in a single dichotomous variable. However, it is possible to establish that the diversification of activities and sources of income is not necessarily a strategy that allows fishing households in Tumaco and the other coastal municipalities considered in this study to perceive themselves as less poor. With this as a reference, for the second stage of the probabilistic model, it was estimated that self-perception of poverty is a determining factor in deciding to go out of fishing (Table 10).

Table 9. Estimation of the first stage: *Self-perception of poverty.*

Variables[a]	IVprobit[b]	IVprobit (n.c.)[c]	IVprobit (grouped activities)[d]	IVprobit (grouped activities; n.c.)[e]
Services/Remittances	3.040	4.478	-	-
s.e.	(5.169)	(5.219)	-	-
Mining	5.811	4.693	-	-
s.e.	(6.423)	(6.446)	-	-
Agriculture	-5.782	-5.824	-	-
s.e.	(4.489)	(4.564)	-	-
Moto-taxis	5.535	4.578	-	-
s.e.	(3.978)	(3.979)	-	-
Handicraft manufacturing	-1.767	-1.220	-	-
s.e.	(4.344)	(4.411)	-	-
activity	-	-	0.687	0.679
s.e.	-	-	(2.985)	(3.017)
recovery	1.143	1.841	1.646	2.393
s.e.	(2.261)	(2.276)	(2.182)	(2.172)
OCMO	-0.109***	-0.102***	-0.107***	-0.101***
s.e.	(0.0300)	(0.0295)	(0.0302)	(0.0295)
boat	6.538**	-	-1.179	-
s.e.	(3.233)	-	(2.825)	-
leader	-2.182	-	5.954*	-
s.e.	(2.823)	-	(3.248)	-
CSC1	0.00408	-0.00134	0.00848	0.00692
s.e.	(0.0306)	(0.0390)	(0.0357)	(0.0391)
CSC2	0.194	0.223*	0.244*	0.246*
s.e.	(0.138)	(0.134)	(0.129)	(0.130)
CSC3	-0.0822	-0.0701	-0.0928	-0.0787
s.e.	(0.0595)	(0.0643)	(0.0664)	(0.0700)
Constant	22.77*	19.88	17.88	17.66
s.e.	(12.83)	(12.88)	(12.26)	(12.40)
rho	-1.703**	-1.408**	-1.473**	-1.337**
s.e.	(0.747)	(0.685)	(0.587)	(0.599)

Significance: *** 1%; ** 5%; * 10%.

[a] Dependent/instrumented variable: self-perception of poverty *POV1*. N = 130.

[b] Instruments: *Services/remittances, Mining, Agriculture, 'Moto-taxis', recovery, OCMO, boat, leader, CSC1, CSC2, CSC3*. Wald test rho = 0: chi^2 (1) = 5,20, *p-value* = 0,026. Consistent *ivprobit* model.

[c] Instruments: *Services/remittances, Mining, Agriculture, 'Moto-taxis', recovery, OCMO, CSC1, CSC2, CSC3*. Wald test rho = 0: chi^2 (1) = 4,23, *p-value* = 0,04. Consistent *ivprobit* model.

[d] Instruments: *activity, recovery, OCMO, boat, leader CSC1, CSC2, CSC3*. Wald test rho = 0: chi^2 (1) = 6,29, *p-value* = 0,012. Consistent *ivprobit* model.

[e] Instruments: *activity, recovery, OCMO, CSC1, CSC2, CSC3*. Wald test rho = 0: chi^2 (1) = 4,98, *p-value* = 0,012. Consistent *ivprobit* model.

The coefficient that accompanies the *POV1* variable indicates that the probability of developing an alternative activity to fishing increases significantly as the household perceives itself to be more prosperous. Similarly, the poorer the family is perceived, the more likely it will continue to engage in fishing as its leading economic activity.

The coefficient that accompanies each of the alternative activities, both for the disaggregated variables and the variable *activity* that groups them, was not significant, indicating that the diversification of household livelihoods is not a determining factor in deciding to leave fishing. Although these results do not determine how alternative activities influence the decision to leave or continue fishing, it is possible to infer that these activities are not strategies that motivate households to leave fishing and use them as alternatives to obtain income. It is also necessary to mention that fishing is often an occupation to which fishers have a strong attachment (Pollnac and Poggie, 2008). Therefore, this occupation, which can be characterised as active and adventurous, usually satisfies the needs of the fishers who exercise it (Bavinck et al., 2012).

Finally, the coefficient that accompanies the *OCMO* variable is positive and significant in all the estimates. This allows us to analyse that when the occupational mobility of the household increases, the household will more likely decide to dispense with fishing as an economic activity principle. These results indicate that occupational mobility is an important strategy to reduce the vulnerability of fishing households, both to recover their lost benefits by abandoning fishing and find opportunities outside of it. The results are aligned with those recorded by researchers such as Agrawal and Perrin (2009), who argued that occupational mobility is necessary for adaptation to climate change and must be carefully analysed from recognising local realities.

In this sense, the poorer the home perceives itself, the more it resists leaving fishing. No alternative economic activity generates sufficient incentives to leave it and obtain adequate and sustainable livelihoods for the home. In turn, results reveal the poverty trap that is argued from the exogenous approach in fishing households. However, the self-perception of poverty of a household decreases when it has access to private capital and some social capital components. Although occupational mobility has been categorised as a fundamental strategy for the household to successfully adapt to climate change, as suggested by Agrawal and Perrin (2009), from a livelihood approach, the possibilities of diversification of the fisher's income are few. In that case, if these households manage to identify the likelihood of income diversification, they are limited by conditions that reduce their occupational mobility. All these indicate that Tumaco's fishing households face an eminent vulnerability as they

Table 10. Estimation of the second stage of the model: *willingness to change activity*.

Variable[a]	Ivprobit	Ivprobit (n.c.)[b]	Ivprobit (grouped activities)[d]	Ivprobit (grouped activities; n.c.)[c]
POV1	0.0617***	0.0574***	0.0563***	0.0545***
s.e.	(0.0102)	(0.0130)	(0.0110)	(0.0126)
Services/Remittances	-0.321	-0.354	-	-
s.e.	(0.390)	(0.389)	-	-
Mining	-0.716	-0.612	-	-
s.e.	(0.488)	(0.488)	-	-
Agriculture	0.409	0.404	-	-
s.e.	(0.330)	(0.338)	-	-
Moto-taxis	-0.355	-0.228	-	-
s.e.	(0.305)	(0.316)	-	-
Handicraft manufacturing	-0.00147	-0.0386	-	-
s.e.	(0.341)	(0.344)	-	-
activity	-	-	-0.0976	-0.0663
s.e.	-	-	(0.221)	(0.222)
recovery	-0.0393	-0.0390	-0.0855	-0.0921
s.e.	(0.167)	(0.177)	(0.161)	(0.166)
OCMO	0.00994***	0.0109***	0.00964***	0.0105***
s.e.	(0.00249)	(0.00269)	(0.00237)	(0.00249)
boat	-0.225	-	0.321	-
s.e.	(0.301)	-	(0.231)	-
leader	0.357	-	-0.129	-
s.e.	(0.233)	-	(0.285)	-
Constant	-2.759***	-2.615***	-2.596***	-2.505***
	(0.281)	(0.368)	(0.314)	(0.372)

[a] Dependent variable: decision to go out of fishing 'go out'. N = 130.
[b] [c] Estimated model with control variables per household.
Significance: *** 1%; ** 5%; * 10%.

depend considerably on fishing for food security and to obtain economic benefits and complement their consumption basket.

5. Conclusions and recommendations

The projections of the effects of climate change estimate a potential reduction in fisheries yields, effectiveness, and capture capacities for the tropics (Cheung et al., 2010) and for Colombia, specifically in the coastal municipality of Tumaco, artisanal fishing has traditionally been a primary and subsistence productive activity. Therefore, the identification of strategies to adapt the fishing activity for local communities is an imminent need.

This study contributes to the conceptualisation and estimation of social preparedness strategies in the face of possible adverse effects for Tumaco's fishing households and the region as a consequence of climate change. It contributes to identifying determinants of the adaptive capacity to climate change in the grounds of the fishing communities of the Pacific coast of Colombia. In the homes of artisanal fishers in Tumaco, two groups are recognised: one characterised by having infrastructure for fishing and education and another that has neither. For the former, faced with a decline or the impossibility of sustaining themselves with fishing, the diversification of livelihoods in certain economic activities that require knowledge is considered an adaptation strategy to maintain their well-being. However, for the second group, the diversification of poorly paid economic activities outside fishing fails to recover their well-being. In this context, the diversification of livelihoods is considered an effective adaptation strategy to achieve a balance of income between activities and seek or sustain the gain in household well-being in a scenario of decrease or impossibility of sustenance with the economic activity of fishing.

A fishing household in Tumaco and the Pacific subregion of Nariño can increase its adaptive capacity by generating sources of income other than fishing, allowing the conclusion that the diversification of livelihoods is a strategy that will create less dependence on the resource, greater capacity to anticipate the possible economic impacts of the effects of climate change and in particular will allow them access to markets in general. The results obtained in this research are consistent with previous findings in which it is argued that the high dependence of poor households on fishery resources increases their vulnerability and with those found by other authors who study the diversification of livelihoods in rural households as a fundamental strategy to alleviate the effects of climate change (Zanmassou et al., 2020; Chepkoech et al., 2020; Martins and Gasalla, 2020; Chepkoech et al., 2020; Yomo et al., 2020). In addition, low educational levels and the lack of adequate social policies and interventions increase the limitations and reduce the possibility of livelihood diversification, which imposes additional impediments to improve their income; when considering, for example, the possible case of occupational mobility between fishing and agriculture, where other social, cultural and economic dynamics converge, which in the historical context of Colombia represent additional challenges to face such as the possibility of access, and use of the land, violence and governability.

On average, the studied households manage to recover 29.57% of their benefits with the performance of alternative and complementary activities to fishing. However, the identified alternative activities are not sufficient to generate an advantage to overcome the opportunity cost caused by fishing, indicating an economic vulnerability in households that must obtain income from agriculture, informal services, manufacture and sale of handicrafts, and motorcycle taxis. Activities such as teaching and artistic work tend to generate more significant benefits than fishing. However, being qualified to conduct these activities usually requires additional base resources like educational and professional accreditation, which leads to a restriction of occupational mobility for fishing households if they cannot be employed in fishing in possible adverse situations due to the effects of climate change.

Households of artisanal fishers that do not diversify their livelihoods tend to be more vulnerable to adverse changes. The estimates made it possible to recognise some components of adaptive capacity as determinants to mitigate this vulnerability. Within the home adaptation strategies measured by each of the ACI components, it was evidenced that occupational diversity, occupational mobility, solidarity, cooperation, reciprocity, and less dependence on fishing resources make it possible to reduce the levels of economic vulnerability of the household, generating greater capacity to anticipate the possible economic impacts of the effects of climate change.

Of the fishers surveyed, 41.54% exhibited an intention to leave fishing and engage in other alternative activities. However, dispensing with fishing as a primary or even secondary economic activity is subject to a slightly more complex structural component, where the self-perception of poverty or household wealth converges.

This study could constitute an input for creating public policy that guides increased efforts in achieving strategies for the sustainability of fishing households that continue to choose fishing as their main economic activity and the generation of other livelihoods. This is framed in need to provide access to education, private capital, and market institutions that generate reciprocity, solidarity, and cooperation, in the face of local conditioning social dynamics.

It is recommended that future research considers other adaptation strategies and exposure scenarios to which the population is subjected, which allows generating a longitudinal study to identify how adaptation strategies evolve. The analyses also raise the possibility of continuing to study occupational mobility as a fundamental strategy to adapt and mitigate the effects of climate change in households. Studies could focus on developing methodologies that measure the occupational mobility of households in an inter and intragenerational manner to identify the impact of this strategy on reducing poverty and household vulnerability. Consequently, the influence of local and governmental institutions in mitigating the climatic effects faced by the most vulnerable households could be analysed. It is necessary to investigate the role of local and government institutions in the prevention and mitigation of climate effects faced by the most vulnerable households.

Declarations

Author contribution statement

John Josephraj Selvaraj: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Daniel Guerrero: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

María Alejandra Cifuentes-Ossa: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ángela Inés Guzmán Alvis: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

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