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Small but strong: Socioeconomic and ecological resilience of a small European fishing community affected by a submarine volcanic eruption

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ABSTRACT

Small-scale coastal fishing communities are facing many new challenges, such as rapid ecological changes created by anthropogenic and natural events like earthquakes or volcanic eruptions. This paper explores how a coastal population has responded to such an event and highlights the diverse coping strategies used to tackle it. This research was conducted on the island of El Hierro (Spain), where a submarine volcanic eruption occurred in 2011, affecting a multiple-use Marine Protected Area (MPA) and the nearby fishing community of La Restinga. Our study illustrates how the local population coped with this situation by combining multiple monetary and non-monetary activities (e.g., informal exchanges) as well as the role of institutions in increasing local resilience by supporting fishers' demands and allowing their participation in the decision-making process in the immediate wake of a catastrophic event. Local families also exploited various natural resources in and near the MPA, thus ensuring access to crucial marine resources and continued recreational/cultural services. The results suggest that collective action played a key role in the recovery process after the eruption, creating some advantages for different local groups despite the hazardous nature of the event.

1. Introduction

Coasts are dynamic and sensitive systems (Haslett, 2009) and are home to more than 40% of the world's population (Haslett 2009; Maul, 2021). However, they are undergoing tremendous socio-economic and environmental changes (Neumann et al., 2015). They have also been intensively modified by anthropogenic and natural causes (Pascual--Fernández and Chuenpagdee, 2013) during the last century. At the same time, coastal areas are crucial for the livelihoods and growth of human populations worldwide, especially in island contexts (Bijlsma et al., 1995). In this arena, coastal communities face significant challenges regarding natural resource conservation and sustainable human development as global ecological and social changes accelerate (Pelling and Uitto, 2001). Coastal areas and their populations have also suffered short-term events, such as the impacts of tsunamis or other natural hazards (Adger et al., 2005; Haslett, 2009). In short, shocks, uncertainty, and local and global change are widely recognized as inherent in the dynamics of coastal socioecological systems (Schwarz et al., 2011) . Small islands can be particularly vulnerable due to the singular characteristics of their natural resources, economies, and (in many cases) cultures (Hess, 1990).

Although the definition of "small" may result "arbitrary" (Maul, 2021), many oceanic islands, such as the one in this study, have limited infrastructure, financial and natural resources, including land and drinking water (White and Falkland, 2009; Anthonj et al., 2020). The external dependence, for example, of the Canary Archipelago (2.172.944 inhabitants as of 2021) is extreme and well exemplified by fuel (all imported) or food provision. Despite being surrounded by the

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sea, seafood consumption in the Canary Islands is 91% dependent on imports of fishery and industrial fish farming products.[1] Furthermore, the Archipelago's economy depends on tourism and service activities, highly reliant on international markets and vulnerable to a diversity of hazards, as the COVID-19 pandemic has demonstrated. In addition, small islands face significant challenges regarding natural resource conservation and sustainable human development (Caujapé-Castells et al., 2010; Fernandes et al., 2015; Polido et al., 2014), as they are very susceptible to anthropogenic and natural hazards, which can affect their resilience to rapid socio-ecological change (Hein, 2010; Kuruppu and Willie, 2015; Sem, 2007). Also, following a natural hazard, tourists' perceptions and the damage to an island's reputation as an attractive destination for vacation and migration (Orlowski, 2021) may have even greater socioeconomic consequences.

In the case of volcanically active islands, such as El Hierro (Canary Islands, Spain), where this study was carried out, there are major socioeconomic issues related to recovery from the aftermath of an eruption (Maul, 2021). Indeed, previous volcanic events in the Canary Islands, like the one that occurred on Tenerife in 2004, had severe economic consequences (Carracedo et al., 2007; García et al., 2006; Martí et al., 2009), due to the island's high dependence on the tourism sector (Marrero et al., 2015). A recent eruption on another Canary Island (occurred in La Palma Island, 2021) has also dramatically evidenced the complexity caused by the collapse of infrastructures, such as roads or services (like water supply), or the control of fires or loss of electrical power.[2] In addition, examples of other ocean island volcanoes in the Macaronesia region, where the Canary Islands are located along with the Madeira and Azores archipelagos (Portugal), and Cape Verde, have highlighted vulnerability perceptions and hazard knowledge, which clearly affect the population (Rego et al., 2018). The four archipelagos are all volcanically active regions, and both Portugal and Spain, are included in the top 40 high risk volcanic countries (Pan et al., 2015). Cape Verde has registered almost three eruptions along the last 200 years according with the Global Volcanism Program, and Fogo Island has suffered 12 Holocene eruptive periods (Global Volcanism Program, 2013).

Regardless of the specific type of shock or hazard, it is becoming ever more obvious that stressors are multidimensional (Oliver-Smith, 2013). Similarly, there are multiple pathways of vulnerability (Adger, 2006), and different social and environmental factors (e.g., poverty, resource degradation) are fundamental in understanding its dimensions (Romero and Vidal, 2015). Accordingly, research into the vulnerabilities of coastal communities allow us to look closely at the social and ecological systems and their interactions, with a strong focus on social conditions and dynamics (Cutter et al., 2003). In this field, resilience can be understood as the local capacity to cope with any stressor, considering both internal and external factors and opportunities. Moreover, social and cultural capital, among other factors, are critical elements to alleviate the impact of endogenous and exogenous events. From a systems perspective (Adger, 2000; Berkes et al., 1998; Folke, 2006), 'resilience' thinking encompasses ecological and social components as intertwining processes (Lauer et al., 2013). The capacity of socio-ecology systems may be increased or decreased, with social capital being a determining factor (Romero and Vidal, 2015).

Social capital has multiple definitions and has been widely employed by philosophers, economists, sociologists, and political scientists during the last centuries. There are various conceptions of social capital that are based on different theoretical and methodological paradigms. For this paper, we consider social capital a community attribute, which encompasses 'aspects of social organization such as trust, norms, and networks, which can improve the efficiency of a society by facilitating coordinated action' (Putnam, 1993; Capdevielle, 2014: 6–7). Thus, social capital -like collective action-can play an essential role in coping with environmental stressors (Adger, 2003, 2006). Among other factors, the concept of social capital has a role in local mitigation policies, including traditional social support systems (Swift, 1989), gift relationships and exchanges (Sayer, 2015), and local forms of leadership and governance. Social capital can also be helpful when networks are dense, 'if there is frequent communication and reciprocal arrangements' (Pretty, 2003: 1914), especially in small groups, and if individualistic options are less successful or attractive. This is key to enhancing social resilience in the context of a disaster (Lucini, 2013).

Many challenges for commercial small-scale coastal fisheries have emerged in recent decades under different guises (e.g., recreational fisheries, coastal and marine tourism) (Lloret et al., 2018), but they do not always lead to a loss of resilience (Nicolosi et al., 2021). Moreover, examples of the importance of social and cultural capital in enhancing the resilience of coastal communities when they are confronted with natural disasters include cases in Chile (Marín et al., 2012, 2015), Japan (Koshimura and Shuto, 2015; Sun and Sun, 2019), and the Solomon Islands (Aswani and Lauer, 2014; Lauer et al., 2013), among others. More recently, in the COVID-19 pandemic context, food sharing examples (Bennett et al., 2020), investments in bringing local produce back to communities (Wood, 2020), and innovative market solutions (Villasante et al., 2021) have been identified in different coastal communities around the world. In the face of rapid changes and events, coastal communities and small-scale fishers are often immediately hard hit. But, being affected so fast, they may also rebound relatively quickly, demonstrating specific adaptive capacities, such as social networks (e.g., Chile), which may sustain the overall resilience of the system (Lauer et al., 2013; Marín et al., 2012).

Small-scale coastal fishing communities have many traditional and non-traditional tools at their disposal, such as occupational pluralism, multi-species fisheries, and access to a welfare system (i.e., social security, subsidies) to deal with protracted and rapid ecological changes (Adger, 2006; Neis et al., 2013). Indeed, fisheries support a set of activities that, to a greater or lesser degree, allow people to live and cope with uncertainty, considering both the formal and non-observed (parallel) economy (OECD, 2002), as the latter can also be important for communities' well-being (Miñarro et al., 2021). Indeed, the non-observed economy includes several components: the informal economy, self-consumption, and the economy unaccounted for by official statistics (Afonso et al., 2020; Eilat and Zinnes, 2002; OECD, 2002). Thus, fish and fishing must be considered within a broader livelihood framework (Eriksson et al., 2017), including women, men, and other family members as a way of generating subsistence and income in households (Frangoudes and Gerrard, 2019; Salmi and Sonck-Rautio, 2018). Additionally, small-scale fishing activity and fisher-folk populations may establish synergies with other economic activities (e.g., coastal, and marine tourism) (Pascual-Fernández et al., 2018; Nicolosi et al., 2021).

This study analyzes how coastal populations responded to an environmental disaster: a submarine volcanic eruption that occurred in El Hierro's coastal waters (Carracedo et al., 2012) (see Fig. 1). The eruption was located just off the coast of La Restinga village, where the main fishing community is located and affected a Marine Protected Area (MPA) classed within the IUCN category VI - *Protected area with sustainable use of natural resources* (Pascual-Fernández et al., 2018). The 'Punta de La Restinga-Mar de Las Calmas' (Sea of Calms hereafter) Marine Reserve is a multiple-use protected area, with special focus on sustainable, commercial small-scale fishing activity. However, there are other uses that are popular inside this MPA linked to marine tourism activities (e.g., scuba-diving, whale-watching, among others).

[1] Godenau, D., Cáceres Hernández, J. J., Martín Rodríguez, G., & González Gómez, J. I. (2019). El grado de autoabastecimiento alimentario de Canarias: propuesta de medición estadística. Canarias: Consejería de Agricultura, Ganadería, Pesca y Aguas, ULL. https://bit.ly/3pxEjKY Accessed: October 24, 2021.

[2] See for example: 'Canary Islands: Lava from erupting volcano destroys homes', BBC, September 20/2021. https://bbc.in/3m8y3aE (Accessed: October 25/2021). 'Photos of an Eruption: Canary Island Volcano Sends Thousands Fleeing' The New York Times, September 22/2021. https://nyti.ms/3b7r9fn (Accessed: October 25/2021).

Considering key MPA features proposed by Edgar et al. (2014), this MPA has little conservation value: it is not a fully protected area or no-take zone nor is it in an isolated location -one of the most influential factors (Halpern, 2014), and, it is under 100 km^2. However, not only can MPAs produce positive outcomes for biodiversity, they can also increase local system governability (De la Cruz-Modino and Pascual-Fernández, 2013). For example, MPAs contribute to fishery compliance by local fishers (Read et al., 2011; Afflerbach et al., 2014), they can also promote community-based marine resource management practices (Johannes, 2002) and encourage adaptive co-management systems (Guidetti and Claudet, 2009). Moreover, MPAs can help consolidate local territorial boundaries (Cinner and Aswani, 2007), and foster the linkages between local fishing families and the services sector (Pascual-Fernández et al., 2018).

Thus, the main goal of this study is to evaluate the recovery of the La Restinga community, the most important fishing village on El Hierro, with a special focus on small-scale fishing activities along the affected coastlines. It also aims to examine the diversity of La Restinga villagers' livelihoods and coping strategies (Pomeroy et al., 2016) from a broader perspective during the economic lockdown of the entire island that took place the year following the eruption. Notably, it analyzes the role of the informal economy and traditional exchanges based on reciprocity among villagers in the coping process after the volcanic eruption. In addition, the study develops a focus on how MPAs can help coastal small-scale fishing communities by supporting key fish populations and/or traditional fishing practices (and thus local exchange). The ways in which collective action can facilitate a social and ecological recovery following a hazardous event are also analyzed.

This paper is organized in four sections. The first section contains a historical and ethnographic description of the La Restinga community, the MPA, and the volcanic eruption that took place in 2011. The fieldwork used a set of structured, semi-structured, in-depth, informal, and open-ended interviews. Data gathering for this phase took place during different stays in El Hierro from 2011 to 2015. However, it is worth mentioning that anthropological fieldwork in La Restinga community first commenced in the mid-1980s and has focused on a range of topics, including the establishment of a fishers' cooperative, fishers' identities and livelihoods, and local ecological knowledge (Galván Tudela, 1990, 1997). Thus, La Restinga's historical community characterization has been supported by this previous research—see Pascual-Fernández et al. (2018). Additional data were collected from official censuses and the fishing cooperative's landing records (Pascual-Fernández et al., 2015; Pascual Fernandez et al., 2011). The studies carried out by the marine biology research group of the University of La Laguna in La Restinga, for more than two decades, also provide one of the longest and most reliable sets of fishing statistics in the Canary Islands (Brito et al., 2013). The second section focuses on the level of recovery experienced by local families and small-scale commercial fishers based on new research activities carried out in 2018 and 2019. The third section presents the results obtained, considering the historical and cultural dynamics of the socio-ecological system affected by the volcanic eruption. Finally, this paper concludes with the lessons learned about the capacity of small-scale coastal communities to respond to environmental disturbances.

2. Study area

2.1. El Hierro and La Restinga fishing village

El Hierro shares with other insular regions the inherent problems of small islands (Pelling and Uitto, 2001), such as high transport costs, high costs in accessing external goods, small economies, small internal markets, high dependence on natural resources, and linked to its small size, small population, and remoteness. Notably, El Hierro did not undergo the economic growth experienced by the other Canary Islands during the past century through the development of sun, sand, and sea tourism (Peña-Alonso et al., 2018). The island's inhabitants have traditionally used various natural resources, including pastures and agricultural lands, drinking water, or coastal marine resources like fish and shellfish, under different communal or shared regimes (Galván Tudela, 1997). The population of El Hierro has historically remained below 10,000. In fact, the Island endured several waves of migration to South America, mainly to Venezuela, in the 1950s and 1960s after successive years of drought (Pascual-Fernández et al., 2018). However, many of these migrants and their relatives returned during the first decade of the new millennium. This return migration lasted until the underwater eruption occurred, which also coincided with one of the worst years of the Spanish economic crisis (2008–2014) (S1), derived from the 2008 global financial crisis.

La Restinga fishing village, 631 inhabitants (INE, 2020), was founded in the 1950s by some small-scale fishers from the island of La Gomera (Canary Islands). These early permanent settlers exchanged seafood for crop and livestock products with the inhabitants of the nearby farming village of El Pinar (1894 inhabitants including La Restinga, INE 2020) and, over time, established family ties (De la Cruz Modino and Pascual-Fernández, 2005; Pascual-Fernández et al., 2018). La Restinga's inhabitants have traditionally been involved in small-scale fishing and agricultural activities, but not exclusively. The diversification of small-scale fishing-household activities was 'a common strategy employed in the past, with fishing-related households employing a mix of livelihood strategies, taking part in coastal trade and agricultural activities in addition to their fishery activities' (Frangoudes and Pascual-Fernández, 2005: 18). Currently in La Restinga, there is a diversity of fresh seafood restaurants that depend on the catches of the local fleet. In this context, women play an important role in the fishing sector, as managers of these family enterprises, in different roles at seafood restaurants, and selling the fish. Women also manage the tourism accommodation supply, composed of approximately 800 beds mainly based on tourism apartments (De la Cruz-Modino and Pascual-Fernández, 2005; De la Cruz Modino and Hernández Barbuzano, 2007).

Small-scale fishing along the La Restinga coast has historically been characterized as artisanal and coastal (Bas et al., 1995; González et al., 2020). According to the EU definition, this can be termed as 'small-scale coastal fishing' carried out by fishing vessels with an overall length under 12 m and not using towed gear, even though many fishers switch their fishing gear from season to season depending on the available species (Pascual-Fernández et al., 2020). Fishers of La Restinga fish mainly within a mile offshore and combine demersal and pelagic fisheries with tuna fishing (Dorta and Martín-Sosa, 2022). Their main traditional fishing ground is the Sea of Calms, where the MPA is located. The vessels return to the same homeport daily, and smaller boats never leave the island, while a few larger boats occasionally fish for tuna on other islands. They employ very selective, low-power fishing gear (Pascual-Fernández et al., 2015), mainly hand-held techniques such as rods, hook & line, and harpoons. In 2008, before the volcanic eruption, the island's boats represented 4.97% of the total Canary Islands fleet. There were approximately 30 vessels and 23 small-scale fishing productive units[3] (Pascual Fernandez et al., 2011; Piñeiro- Corbeira et al., In Press). During the pelagic fishing season, called the '*zafra*', many fishers

[3] A small-scale fishing productive unit integrates a group of people involved in the economic activity of fishing (e.g., catching, processing, and distribution) and who can take different roles (Pascual Fernández, 1991). Furthermore, fishing productive units have the hardware required for their activity (boats, gears, technology, infrastructures, etc.) and, for example, a fishing productive units may have more than one boat (De la Cruz-Modino, 2012). Finally, productive units accumulate knowledge, know-how, and skills over generations, allowing them to position themselves in the marine environment, locate target species and catch them, optimizing the use of the workforce and the means of production (Andersen, 1972; Andersen and Wadel, 1972) -for further information see Piñeiro-Corbeira et al. (In press).

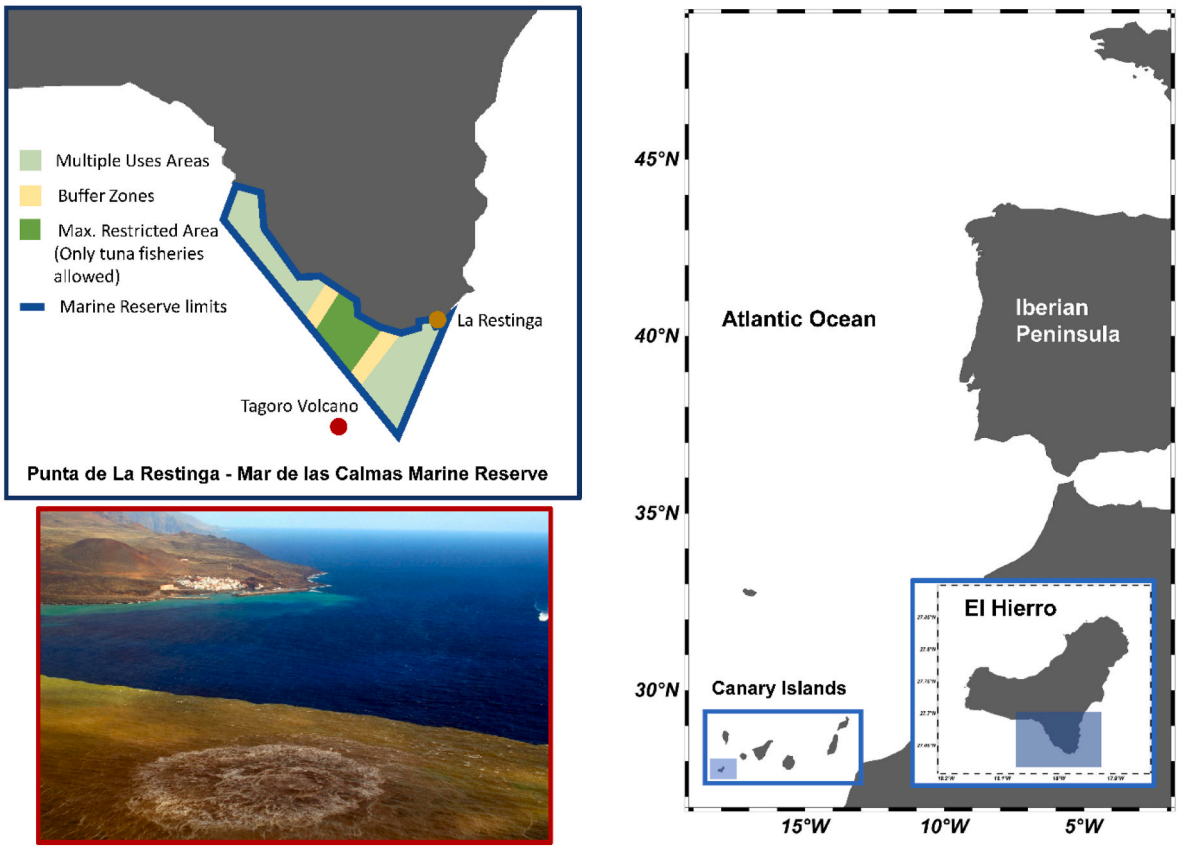

Fig. 1. El Hierro, La Restinga and the Marine Reserve and the coastal landscape with the submarine volcano eruption in the foreground during the submarine volcano eruption in 2011.

temporarily abandon demersal fisheries and concentrate on pelagic ones. Moreover, some fishers believe that the '*zafra*' protects demersal resources, 'when effort is shifted to tuna fishing' (Jentof et al., 2012: 189).

Catches are mainly marketed through a local cooperative called the 'Sociedad Cooperativa del Mar PescaRestinga' (hereafter PescaRestinga). Its foundation in the 1990s was motivated by a conflict between local fishers and a powerful middleman, who previously controlled the local seafood value chain, fixing prices and maximum catches per boat (Galván Tudela, 1990; Pascual-Fernández et al., 2018). Its implementation was based on a collaboration between small-scale fishers, organized through their *cofradía* (or fishers' organization, see Bavinck et al., 2015), and the island government (called the *Cabildo*). The latter supported technically and economically the birth of the cooperative. This is a good example of how collective action was triggered when the net collective benefit for a close-knit community was high, and support from the island authorities was secured (Wade, 1987, 1988). Marketing of the catches required some organization, as the catches had to be exported due to the small size of El Hierro's market. During the last decades, PescaRestinga has provided important stability to the sales and marketing of seafood in the community, particularly for tuna species (e.g., skipjack tuna *Katsuwonus pelamis* and yellowfin tuna *Thunnus albacares*) (De la Cruz Modino and Pascual-Fernández, 2013). Initially, a new working system was established whereby fishers organized themselves to fish collectively, sharing boats, gears, and crews through PescaRestinga (Galván Tudela 1990; De la Cruz Modino 2012) in a complex sharing system. Nowadays, PescaRestinga still manages the marketing of the catches, but they do not organize the activity at sea. However, some fishers from the smaller boats may join the crews of larger boats during tuna season, especially where family ties exist, even if they are not officially enrolled on them.

Since the 1990s, La Restinga and the MPA have been the most important tourist coastal destinations on the island, with significant development of scuba diving tourism (De la Cruz Modino et al., 2012; De la Cruz Modino et al., 2010). After the MPA's creation, scuba-diving businesses expanded from three to more than ten companies managed mainly by non-local families, rendering the community less dependent on fishing, but still maintaining the fishing culture and tradition (De la Cruz Modino, 2012; Pascual-Fernández et al., 2018). These include a long recreational fishing tradition on the coast of the island, i.e., mainly angling from the shore. Recreational fisheries on La Restinga's coasts and the Sea of Calms, mostly used by El Pinar and La Restinga inhabitants and domestic tourists, are highly seasonal (from June to September mainly). There are few studies that have evaluated in depth recreational fishing's impact on the MPA and the Sea of Calms.[4] However, angling from the shore can be a relevant motivation for travelling to El Hierro and La Restinga. In fact, *Sparisoma cretense* (hereafter parrotfish) is considered as the most important target species in terms of expectations and catches among anglers (Pascual-Fernández et al., 2007).

2.2. The marine reserve Punta de La Restinga-Mar de las Calmas

Just off the coast of this village, the 'Punta de La Restinga - Mar de las Calmas' Marine Reserve was proposed and discussed inside their *cofradía* in the early 1990s. It was finally declared an MPA in 1996 with

[4] See for example: 'El impacto de la pesca recreativa en las reservas marinas: La Reserva Marina de Punta de La Restinga – Mar de Las Calmas (El Hierro, Islas Canarias) como caso de estudio.' Poster. Spanish Institute of Oceanography (IEO). https://bit.ly/3EhuDsp (Accessed: October 25/2021).

the designation of 'marine reserve with fishing interest' (Jentoft et al., 2012) and covering an area of just 9.156 Km^2 .[5] Initially, a proposal from a scientist at the University of La Laguna (Tenerife, Canary Islands) was not well received in the community. Later, a process develops inside the *Cofradía* to explore alternatives for creating a marine reserve (Jentoft et al., 2012). In particular, fishers were concerned about creating a marine reserve that would fit their circumstances. Thus, the process took several years and multiple meetings were held inside the *cofradía* with scientists to discuss the potential limits of the reserve and the gears allowed (De la Cruz Modino 2004, 2012).[6] Finally, an agreement on the design of the marine reserve was reached by local small-scale fishers through their *cofradía*, and the scientist, national and regional governments, so that the marine reserve was implemented in 1996. Protecting demersal fisheries and defending local fishing territories against increased pressures (from recreational fishers, poachers, and commercial fleets from other islands) were arguments supported by small-scale fishers to promote the creation of the MPA. Moreover, the marine reserve also protected fishing bait locations, which are indispensable for tuna fisheries. Since then, representatives of the local *cofradía* have participated in the governing bodies of the marine reserve (Pascual--Fernández et al., 2018).

MPAs are known for the positive benefits they create within the reserve, such as increased biomass, density or species diversity (PISCO 2007), especially for demersal fishes with low mobility during their adult life (Claudet et al., 2006). However, in the case of La Restinga, the initiative for the creation of the marine reserve is also related to pelagic fisheries and the creation of PescaRestinga. Particularly as the marine reserve limits new fishing entrants and potential rivals as well as bait captures. Live bait is essential to the pelagic fisheries on the island, *Boops boops* and *Scomber japonicus* are most used for tuna fisheries, followed by the sardine *Sardina pilchardus* (Clupeidae) (Melnychuk et al., 2001). So, the marine reserve imposed a kind of spatial property rights-based fisheries *de facto*, improving both fishery profits and abundance.

The MPA includes a Maximum Restricted Area (1.877 km^2; GeoPortal MAPA/MITECO: https://sig.mapama.gob.es/geoportal/), where all human uses are excluded, except for scientific research and tuna fisheries (only when a tuna school enter the area while being fished -an extremely rare event-). This fact reveals the importance of the tuna fisheries in the areas affected by the MPA initiative in El Hierro and La Restinga coast. It also has two buffer zones (0.372 and 0.715 km^2; GeoPortal MAPA/MITECO: https://sig.mapama.gob.es/geoportal/) on either side of the restricted area, where some small-scale fishing and scuba diving are allowed with several restrictions. The MPA has two more areas (3.064 and 3.128 km^2; GeoPortal MAPA/MITECO: https://sig.mapama.gob.es/geoportal/) where, in addition, recreational angling is permitted (Fig. 1). This multiple-use MPA model is common in the rest of the Canary Archipelago, where the 'fishing interest' character prioritizes local fishing rights and traditional fisheries over the development of new entrants (e.g., commercial or recreational fishers) and/or new marine uses (e.g., marine tourism).

The main criticisms of the MPA focus on its small size, especially that of the Max. Restricted Area (e.g., Tuya et al., 2006), as well as the fact that it is sheltered from the winds, limiting larval dispersion. However, longitudinal studies performed using underwater visual censuses before and after the MPA's establishment in two locations (protected and unprotected), which also follow the short-term changes in fishery regime in La Restinga between 1997 and 2005, showed that the protection contributed to the increase and/or maintenance of species richness along El Hierro's coasts. There was greater abundance and biomass of parrotfish, mainly caught using hand-line gears (Falcón et al., 2007a, 2007b). The abundance of this highly valued fishery resource has been a good indicator of the state of the fish stocks and ecosystem services (Lazzari, 2015) provided by the marine reserve.

2.3. The submarine volcanic eruption

In 2011, the underwater eruption gave rise to a new shallow submarine volcano in the MPA and the Sea of Calms. It caused a green stain from the ejection of gases and magmatic materials and triggered the evacuation of 535 people from La Restinga (González Cárdenas et al., 2015; Moreno 2012). Large quantities of mantle-derived gases, solutes, and heat were released into the surrounding waters (Fraile-Nuez et al., 2012; Santana-Casiano et al., 2013). As a result, catastrophic mass mortality of species was recorded (Mendoza et al., 2020). All coastal economic activities in La Restinga ceased, including commercial fishing and coastal tourism, and many families lost their source of income temporarily. La Restinga villagers were also evacuated at least twice for two periods of an average of 30 or 35 days in total. Most were rehoused in second or family homes in El Pinar.

In the immediate wake of the volcanic eruption, all fisheries were banned in the Sea of Calms and La Restinga's coast. From October 2011 to June 2013, commercial fishers abandoned fishing on the entire island. However, recreational fishing remained active on different coasts of the island, though almost all scuba diving activities stopped for the next six months. The commercial small-scale fishing ban was initially decided by the local small-scale fishers of La Restinga, inside their own *cofradía*, through a voluntary fishing closure adopted with the support of the Canary Island Universities and the MPA management'. In addition, the national government declared a temporary fishery closure, supporting the commercial small-scale fishing ban for six months, and provided small-scale fishers with financial aid (Pascual-Fernández et al., 2015).

Following June 2013, commercial small-scale fishing activities were re-launched on the island and in the MPA. However, small-scale fishers voluntarily adopted some additional fishing management measures through their *cofradía*, so restrictions remained for 462 days. From June to March, fishers only caught pelagic fisheries, and exceptionally alfonsino (*Beryx decadactylus*) and wahoo (*Acanthocybium solandri*). Afterwards, they recovered demersal fisheries but established a maximum 'quota' for parrotfish catches by fisher: 10 Kg per fisher/day, inside the Sea of Calms, and 15 Kg per fisher/day, on the rest of the island. In addition, fishers agreed to increase the size classes for parrotfish (25 cm minimum) and eels *Gymnothorax unicolor* (55 cm min), and *Muraena augusti* (60 cm min). They also limited the use of pots and traps on the whole island temporarily. Research campaigns carried out from 2012 highlighted the recovery of fishing activity to previous levels before the eruption (Brito, 2012a, 2012b; Brito et al., 2013). Brito et al. (2013) and Tejera (2018) reported that all the representative demersal fisheries around El Hierro showed a good degree of recovery between 2013 and 2018. Parrotfish are caught with a specialized line called *'puyón'* (Pascual-Fernández et al., 2018); eels with cylindrical drum-traps; black comber (*Serranus atricauda*), triggerfishes (*Balistes capriscus, Canthidermis sufflamen*), alfonsinos and amberjacks (Seriola spp., four species) with handlines; and pandalid shrimps (Pandalidae) with shrimp-traps. These studies supported the idea that the ban and the additional measures adopted by the small-scale fishers improved the majority of El

[5] We have detected some differences with respect to the MPA's surface area, among official sources. The Order of January 24, 1996, establishing a marine reserve around 'Punta de la Restinga-Mar de las Calmas' (Island of El Hierro). Official State Gazette number 30, February 3, 1996. Ministry of Agriculture, Fisheries and Food, established an official surface area of 750 ha, and with a Max. Restricted area of 180 ha. But the official webpage of this Ministry indicates that it currently covers 1180 ha. In addition, some papers argue different sizes (e.g., Tuya et al., 2006). In this regard, in this study we finally consulted the official GeoPortal MAPA/MITECO: https://sig.mapama.gob.es/geoportal/from the Spanish government and we recalculated the size of the entire MPA and its different areas.

[6] This process was not an exceptional event, small-scale fishers from La Restinga had traditionally played an important role in fishery governance in their traditional fishing grounds in the Sea of Calms, through their *cofradía*. Before the MPA proposal, they voluntarily banned fish traps and bottom-longlines (De la Cruz Modino and Pascual-Fernández, 2013).

Hierro's commercial demersal fisheries. The sizes of all fish species landed were larger than before the volcanic eruption, except for alfonsino (Brito et al., 2013: 47). Also, Lazzari, after different campaigns carried out in 2012 and 2014 inside of the marine reserve, highlighted that "fish communities are recovering, as the abundances of high trophic level species have increased over time as occurs in a natural process of ecological succession" (2015: 23).

After the submarine volcanic eruption, data on tourist and visitor arrivals to La Restinga and El Hierro reflected a significant drop during the last quarter of 2011. Indeed, tourist arrivals and total passengers registered on the island declined from 2008 onwards, but 2012 and 2013 were the worst years (S2) (Martín Suárez, 2015). Marine tourism entrepreneurs operating in the Sea of Calms reported losses of almost two million euros (González Cruz, 2021). All scuba diving companies moved from La Restinga during the last quarter of 2011 and early 2012. Some of these continued working in other localities of the island, but others left the island, at least temporarily. Restaurants and bars remained closed for almost three months. Employment experienced a similar disruption, with an unemployment rate of 29.42% in the fourth quarter of 2011 that reached 34.34% in the same quarter of 2012 (ISTAC, 2021) (S3). A tourism reactivation plan was implemented during 2013 with economic support from the Canary Island Government, and since that time different marketing campaigns have focused on a renewed destination image (González Cruz, 2021). In 2015, once the Spanish economic crisis was over, the municipality of El Pinar of El Hierro, which includes La Restinga village, was ranked among the eighteen poorest municipalities out of the fifty-four that make up the province of 'Santa Cruz de Tenerife'[7] (INE, 2021a). And this was despite a full recovery in marine tourism activity in the area. In 2014, we estimated that 2621 diving tourists arrived in La Restinga, spending a total of 609,384 euros in scuba-diving alone during that year (Ordoñez, 2014).

By contrast, after the volcano and the fishing closure, PescaRestinga expanded its commercial network, reaching almost every restaurant and supermarket on the island. Subsequently, sales staff increased, and in 2015 PescaRestinga reached an agreement with a Fishing Producer Organization in Tenerife, ISLATUNA, to improve tuna marketing. This change made it possible to increase catches of some tuna species (i.e., *Tunnus obesus, Tunnus alalunga*), which, although common in the waters off the island of El Hierro, were not previously fished intensively. This kind of agreement is quite common in the Canary Islands, where Fishing Cooperatives or Fishing Producer Organizations have historically played a vital role in managing tuna marketing (Pascual-Fernández et al., 2019) due to the limits of the local market. The Cooperative PescaRestinga, signed a multi-year agreement to market their catches using the infrastructures of ISLATUNA in return for a percentage of the final sale. PescaRestinga can only market an average of 10% of fresh tuna catches in El Hierro. After the volcanic eruption, when small-scale fishers from La Restinga started fishing again but only focused on tuna species, this cooperation between PescaRestinga and ISLATUNA intensified.

Another important issue arising from this natural disturbance was the proposal of the creation of a Marine National Park in the Sea of Calms along the affected coasts, led by the Spanish government in 2014. Commercial fishers supported the proposal through their *cofradía*. However, recreational fishers opposed it because they felt that a National Park would restrict recreational fishing. Conflict between recreational fishers and commercial fishers was born linked to the temporary fishery closure, after the volcano eruption. But, since then, conflicts have become more acrimonious (Pascual-Fernández et al., 2015).

3. Material and methods

Research activities focused on the socio-economic recovery in La Restinga after the underwater eruption occurred and were carried out during 2018 and 2019. Such research combined different sampling methods, and quantitative and qualitative research tools, thanks to the collaboration of different stakeholder groups (e.g., commercial small-scale fishers, marine tourism workers, MPA managers'). During the summer of 2018, fieldwork was mainly oriented towards exploring the characteristics of La Restinga's households' and obtaining different insights into topics related to the signs of socio-economic recovery of families after the eruption. A set of in-person interviews were performed using a first questionnaire (Q1). They were conducted by a team composed of sociologists and anthropologists and took place among family households of La Restinga. Q1 was divided into four sections. The first one contained different closed questions focused on the household's main characteristics (e.g., type of property, maintenance costs) and family characteristics (e.g., number of members, age, and educational level, related jobs). The second section focused on the household's current economic situation, with a set of binomial questions (Yes/No) based on the main AROPE (At Risk of Poverty and/or Exclusion) indicator.[8] The third section contained open and binomial (Yes/No) questions to evaluate overall household incomes, as well as their stability. This section asked specifically about all sources of income of all household members, and if they arose from fishing activity, tourism, or both. Finally, questionnaire Q1 also included binomial (Yes/No) and qualitative inquiries related to the volcano's impact on the family's day-to-day and activities (e.g., studies, family relations), subsidies requested, and their sense of self-economic rebound.

Systematic sampling was planned, and houses were chosen randomly, but this was not possible due to the small size of La Restinga and some difficulties in delimiting the population effectively living in the village during 2011 and 2012, as many families left the island in 2012 (S1). Finally, participating households were selected by opportunistic sampling to maximize the number of responses. The total sample obtained was 50 households, with a total of 146 people being interviewed from a total of 539 people (Statistical Database of the Municipal Register as of 1-1-2018, ISTAC). The total sample was 146 individuals, which is a significant number given the limitations described above. Univariate statistics were used in the household analysis of local family recovery ($n = 50$) including both households and their members ($n = 146$) and was made with the help of the package IBM SPSS Statistics 22. Both databases are open access (De la Cruz-Modino et al., 2021).

In addition to the above, a set of in-depth interviews were carried out to explore consequences on women related to tourism and fishing activities. Seven interviews, which were carried out *in-person*, were performed employing open-ended questions (questions that don't lead to a "yes" or "no" answer) to encourage respondents to expand their stories and points of view and were recorded. Sampling was distributed considering women workers and businesswomen in the services and tourism sectors (active and retired), women linked to fishing activities (i.e., fish sellers and fishermen's wives), and local policymakers (i.e., town council workers). Our objective was to analyze in depth their main strategies and support during the volcanic eruption process and the following economic lockdown because they were not included in the financial compensations for the temporary fishery closure, and no direct or financial aids were provided to tourism workers. Apart from the above, we also performed face-to-face interviews between 2018 and 2019 with other key agents: political decision-makers, civil servants (e.

[7] The archipelago of the Canary Islands is administratively divided into two main provinces: Santa Cruz de Tenerife and Las Palmas. The island of El Hierro is located in the province of Santa Cruz de Tenerife together with the islands of La Gomera, La Palma and Tenerife. This region has the highest rates of unemployment (21.9%), youth unemployment (40.9%), long-term unemployment (38.1%), and relative poverty (35%), as well as the highest rate of the population at risk of social exclusion in the entire country, with an AROPE (At Risk of Poverty and Exclusion) index of 44.6% in 2016 (Betancort et al., 2018).

[8] See: Eurostat: Statistics Explained: Glossary: At risk of poverty or social exclusion (AROPE). https://bit.ly/3Beqcg2.

g., social workers, development agents, police, etc.), scientists from different institutions involved in volcanic risk management tasks (e.g., Centre of Scientific Research –CSIC, in Spanish-, Volcanology Institute of the Canary Islands -INVOLCAN, in Spanish), and local tourism entrepreneurs and leaders (e.g. El Hierro Centre for Tourist Initiative representatives). All these interviews were carried out to gain in-depth accounts of institutional responses to the crisis ($n = 29$). All these open interviews were analyzed from an interpretative and qualitative perspective to contextualize the *emic* view (Bernard and Gravlee, 2015) of the process.

During the summer of 2018, a second questionnaire (Q2) was employed to analyze the recovery of small-scale fishing activity in the area affected by the volcanic eruption. Interviews using Q2 were carried out with boat captains/owners to identify those regularly involved in commercial small-scale fishing activities to understand fishers' perceptions of the role of the MPA and the effectiveness of the temporary fishing ban after the eruption. A total of 12 interviews ($n = 12$) were carried out from a population of 37 small-scale fishers (owners and sailors included) who work actively and are organized around 25 small-scale fishing productive units on 33 fishing boats authorized to fish inside the MPA. Following the fieldwork phase, an Excel database was created with binomial answers (0/1) and the package IBM SPSS Statistics 22 was used to analyze the interviews. We also constructed a time series of the fleet allowed to fish inside the MPA using historical data and the official census of the marine reserve (S4). Q2 databases are open access (De la Cruz-Modino et al., 2021).

Q2 was carried out jointly with a participative map in which fishers drew their main fishing grounds in the MPA and the Sea of Calms ($n = 12$). In addition, we also explored the main fishing areas through interviews and participatory mapping with other key informants, chosen for their relationship to the fishing area and the MPA (Piñeiro-Corbeira et al., In press). Semi-structured face-to-face interviews were held in different localities of the island (not only La Restinga) with retired small-scale fishers, recreational fishers, and some employees of the MPA involved in surveillance tasks ($n = 6$). During these interviews, interviewers drew maps with the support of a bathymetric map and a 1:42000 scale nautical chart of the study area. These maps were digitized and georeferenced into a GIS with the help of QGIS 3.16-Hannover. Key informants and stakeholders reviewed the final maps to ensure that all information was correctly digitized.

A second round of fieldwork was performed during the summer of 2019, when a third questionnaire (Q3) was carried out to analyze seafood consumption patterns and informal food supply exchange networks. The previous year, we had been unable to find substantial economic and welfare losses among households interviewed, despite all economic activity having stopped for almost a year. Public and private aid, such as tax breaks and fishing subsidies, were provided in 2012, but we wanted to explore how households were able to ensure their food needs. In this regard, Q3 investigated households' food provision including the role of family and relatives in providing food, as well as self-provision. Firstly, we listed different food groups (e.g., fruits, vegetables, and protein foods), condiments (e.g., salt, pepper) and cooking herbs (e.g., cilantro, oregano), as well as olive oil for cooking, and beverage groups (e.g., water, wine). After that, Q3 was divided into four sections. The first section described what, when and where interviewed families usually ate, considering five possible meals per day, which are common in the Spanish context. Secondly, we asked, specifically, which foods and beverages were consumed at home but not purchased, and how they obtained them. If self-production activities were identified, complementary questions about the existence of fishing boats, crops, or farms were applied. Finally, Q3 contained a set of questions related to food exchanges (i.e., if families received or took food to friends or relatives) considering the type of foods, the exchange regularity and how they viewed them. Again, participating households were selected by opportunistic sampling to maximize the number of responses. We built an Excel database with binomial answers (0/1) and used the package IBM SPSS Statistics 22 to analyze food provision among families ($n = 26$) using univariate statistics. Q3 databases are open access (De la Cruz-Modino et al., 2021).

Finally, data on the trajectory of fish catches before and after the eruption, a time series of monthly landings (in kg) and market value at the point of the first sale (in €) of target species were collected from the official website of the regional fisheries department of the Canary Island Government for 2007–2019 (Department of Agriculture, Livestock and Fisheries of the Government of the Canary Islands, 2021).[9] Monthly values were used to estimate total annual landings (kg/year) for the main target species —i.e., shellfish, demersal fish, and wahoo. The monthly time series of target species landings were split into a combined trend-cycle component and a seasonal component (as a Seasonal Index). The combined trend-cycle component was estimated by smoothing the time series data using a simple moving average with a span equal to the length of seasonality (Calsals et al., 2002; Lan et al., 2013). The seasonal component was estimated by removing the trend-cycle from the data and then averaging all observations within a month to remove the irregular component. The resulting estimate was expressed as a percentage, such that an average season would have an index equal to 100. Finally, the original time series were seasonally adjusted by removing the seasonal effects, leaving both the trend-cycle and irregular components. Seasonal decomposition was performed with the help of STATGRAPHICS Centurion XVI Version 16.1.11.

4. Results

4.1. Impact on households of volcanic eruption

Most of the fifty households interviewed were families composed of an average of 2.9 individuals. The average total household income amounted to 1510.4 € per month (sum of the incomes of all individuals, regardless of the number of household members) in 2018. Regardless of their economic activity (n = 50), many interviewees believed that the village of La Restinga had fully recovered. The profiles of family members interviewed and household per capita income in 2018 are described in Table 1. Among those, there were families involved in small-scale fisheries, tourism activities, and other households without any relation to these activities.

Regarding the AROPE indicators, it is important to highlight that there were no material, energetic or nutritional deficiencies. Although the village of La Restinga was evacuated twice, and the neighbors remained more than a month away from their homes, most of the families stayed on the island and were re-housed by their own means. As a social worker acknowledged, '(we) *are very fortunate that the inhabitants of La Restinga have a second home or their relatives here*.' Only 98 people had to be accommodated in a student residence, located in Valverde (the capital), including tourists and residents without family ties on the island. Nevertheless, some families had to ask for money to cope with the losses (12% of interviewees) derived from the cessation of economic activity. Right after the volcanic eruption, some of them had to ask for help from public entities (18%) to obtain food, clothes, or other basic goods: mainly food (12%), but also housing. In addition, during the volcanic crises or just after, some families received compensation related to the impacts suffered (22%). A total of nine families interviewed received money due to the temporary fishery closure, and two families were supported with other aid for companies.

There was some consensus among the interviewees that the impacts had been uneven in the village, among different groups (44%). Many

[9] Landings and price-market fishery data employed in this study are public, and they are available on the Canary Island Government official website: Department of Agriculture, Livestock and Fisheries of the Government of the Canary Islands. See more information at: https://www.gobiernodecanarias.org/agp/sgt/temas/estadistica/pesca/index.html.

Table 1
General profile, and effects on employment and incomes.

Employment	Working actively (employed and/or self-employed)	38.6%
	Unemployed	11.7%
	Retired (pensioner and/or with a permanent disability)	14.4%
	Homemaker	6.2%
	Other (i.e., irregular jobs)	1.4%
Average incomes per person and household (n = 50 household)		597.5 €/month
Average incomes per person who have incomes (n = 103)		870.2€/month men 556.7 €/month women
Affected by the volcanic eruption because their income was reduced or disappeared during or immediately after the eruption (e.g., they were laid off or work decreased)		33.3%
Economic compensation for the fishing closure received		18%
Request assistance from public administrations for food or rent		18%
Request assistance from financial companies (i.e., banks)		4%

Source: Fieldwork

considered that tourism workers were most affected by the volcano, as well as the economic lockdown experienced during the months following the eruption. Data from households that identified themselves as fishers revealed some differences from those with members related to tourism activities. Most homes with household members involved in fishing ($n = 12$) were engaged in fishing all year round (83.3%). Among the families primarily related to tourism activities ($n = 11$), most were involved in tourism activities all year round (81.8%). Some interviewees talked about informal jobs in the tourist sector, usually part-time, considering it as a "supplement" to their official job or unemployment benefits. Those exclusively dedicated to tourism were slightly more affected by the volcano's eruption than the families whose members were solely devoted to fishing. Some of them had to modify (22.2%) or cease their activity (11.1%) after the eruption. Yet, they were able to maintain their income stream thanks to low-interest loans from banks. Six years later, families exclusively dedicated to tourism still considered it difficult to make ends meet (66%). However, only a small portion (20%) of the families with members solely dedicated to fishing declared "difficulties" to make ends meet. Only a few fishing (10%) and tourism (10%) families had to ask for help from family or friends for food, clothing, or other essential goods in the last year. Likewise, only 10% of tourism families had to ask for help from some public or private entity, showing their resilience. Most families with members in tourism or fishing activities declared no relevant changes after the volcano's economic crisis (50 and 60%, respectively). Indeed, 25% (tourism) and 30% (fishing) of them declared that their situation was better than before the crisis, and only 10% (both tourism and fisheries) said it is worse. Interestingly, 58% ($n = 29$) of the non-fishing/tourism families reported being economically affected by the volcanic eruption.

Most of the interviewees agreed that they began to perceive a recovery at the end of 2013 and that, in economic terms, they reached pre-eruption levels in 2014. Qualitative data pointed out that in 2013 the 'Bajada de la Virgen de Los Reyes' took place, a religious event that takes place every four years in July and comprises numerous celebrations in which many islanders take part, even if they have to return from another Canary Island or Venezuela temporarily. Many interviewees believed that the commemoration helped the local economy to recover. Except for retired women and public workers, all women interviewed were temporarily affected by job and income loss. No specific assistance was provided for these, and many felt that the media exaggerated the crisis (especially the press and television), which could damage the tourist destination's 'image'. During the interviews with tourism entrepreneurs (e.g., diving entrepreneurs, restaurateurs, active tourism companies), many local or Spanish, a certain lack of collective organization and 'sense of the group' was apparent. Their lack of organization could have been detrimental to them when applying for compensatory aid from the public administration. Indeed, they did not receive direct financial assistance, as in the case of commercial fishers. Notably, the Center for Tourist Initiatives (CIT) was created for the first time on the island in response to the crisis. In the words of its director: '*That is how the CIT came about (…) we started to make proposals. We quickly created a small platform and began to bring small groups* (of tourists) *to the island of El Hierro*'.

4.2. Recovery of fish landings and small-scale fishing activity

Fishing activities around the MPA and the Sea of Calms did not change after the volcanic eruption regarding fishing gear and main fishing grounds. Fishing activity, commercial and recreational, are again concentrated around the MPA and the Sea of Calms. The MPA and the coast of La Restinga are the areas in which both types of fishing are most intensively carried out (Fig. 2) and focus on demersal species throughout the year. The total number of commercial small-scale fishing boats registered in the MPA fishing census was also the same in 2018 as in 2010 (S4). Small-scale fishers' questionnaire results reveal how younger fishers concentrated their fishing activity on the MPA as did those productive units with boats from 6 to 8 m in length, which are the majority (S5, S6). Most fishers considered that fish stocks had entirely recovered in the area affected by the submarine volcanic eruption. Many noticed that they fished "*more*" and "*there were more fish*'' in their usual fishing grounds when commercial fishing was relaunched in 2013. They considered that the fishing ban was relevant to the recovery and believed that the MPA also had an influence thanks to its restricted area. Some of them affirmed that '*the fishing closure helped a lot*'. But also, that '*the Marine Reserve offers a place for fish (…). That's where the parrotfish come from*', based on fishers' comprehension of the positive MPA effects on the parrotfish population.

Overall, our results show a rapid recovery in landings soon after the volcanic event for most species previously captured (Figs. 3, 4, and S8). Examples of recovery include several species whose trend-cycle components were highly correlated, indicating that their landings followed broadly similar trajectories over the investigated years, e.g., parrotfish, black limpet (*Patella candei*), alfonsino and, to a lesser extent, yellowmouth barracuda (*Sphyraena viridensis*) and wahoo (*Acanthocybium solandri*) (Fig. 3). Landings of these species after the volcanic event equaled or even exceeded those recorded before (Fig. 3). Moreover, a slight upward trend can even be discerned at the end of the time series for parrotfish, black limpet, and alfonsino. The recent upward trend also applies to dusky and island groupers (*Epinephelus marginatus* and *Mycteroperca fusca*, respectively). Interestingly, the seasonally adjusted data for black limpet show that this fishery follows a regular pattern since the eruption, alternating fishing and non-fishing periods within each year. Similarly, the seasonally adjusted data show that wahoo landings follow a regular pattern with alternating peaks and troughs every 2–3 months from 2015 onwards. The pattern before the eruption was more erratic. Furthermore, landings have been consistently higher after the eruption for the migratory skipjack tuna (*Katsuwonus pelamis*) and the non-migratory blacktail comber (*Serranus atricauda*). Despite their parallelism, it is noteworthy that the blacktail comber was regularly caught in smaller quantities before the eruption, while skipjack tuna landings were virtually non-existent before the event. Finally, only the landings of white limpet (*Patella aspera*) have dropped since the eruption. This mollusk showed strong interannual fluctuations before the eruption, but landings gradually decreased afterwards to become practically non-existent at the end of the time series.

The seasonal index shows how the catches of some fisheries complement each other throughout the year. Landings follow a distinct seasonal cycle with winter lows and spring-summer peaks in many target species. The skipjack tuna is an extreme example, with landings swinging from a minimum of 2% of the annual average in January to a 281% peak in August. Similar but less marked patterns occur in

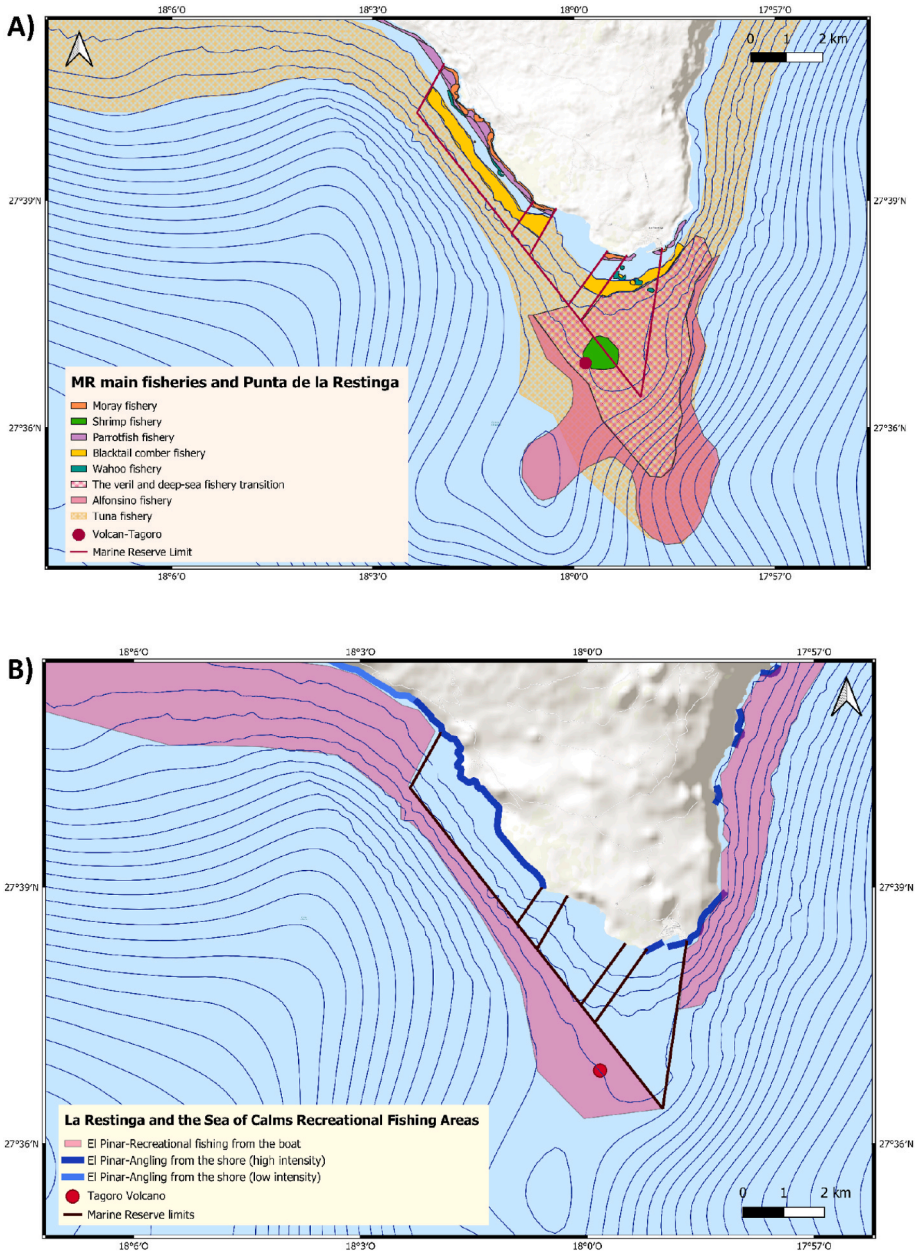

Fig. 2. Main fisheries and fishing areas in La Restinga and the Sea of Calms.

parrotfish (61% of the annual average in February, 149% in August), black limpet (25–48% in winter, 140–210% in spring-summer), or island grouper (from 40 to 49% in winter to a 177% peak in June). On the other hand, landings from other fisheries remain largely stable year-round, with no decline in winter (e.g., wahoo, alfonsino, splendid alfonsino, blacktail comber). The lowest seasonal catches in these fisheries usually occur in summer rather than in winter. Nonetheless, the summer decline is usually modest (60% of the annual average) except for wahoo, a regionally relevant fishery whose summer landings fall to a meagre 23% of the annual average in July.

Total fishing landings grew considerably after the volcanic event, jumping from 75,078–91,277 kg/yr before the eruption to 113,398–210,450 kg/yr afterwards (Fig. S9). The increase was partly due to the more significant landings of skipjack and yellowfin tuna recorded after the eruption (15,396–124,780 kg/yr than 4718–22,300 kg/yr before) thanks to an agreement between PescaRestinga and other Canary Island small-scale fishing organizations. Indeed, with tuna excluded from the records, the difference between the mean annual landings before (56,546 kg/yr) and after (66,697 kg/yr) the eruption become marginally non-significant (*t*-test *p*-value = 0.052). Understandably, the total annual value of landings has also risen since the eruption, moving from a 341,975–445,192 €/yr range before the volcanic event to 504,372–867,321 € afterwards. This means that annual fishery revenues are, on average, 52% higher after the eruption than before (95% confidence interval for the increase after the eruption: 23–88%). Again, the difference between the mean annual revenues registered pre- (365,286 €/yr) and post-eruption (482,730 €/yr) become non-significant (*t*-test *p*-value = 0.08) if tuna species are removed from the records, underscoring the economic importance of this fishery in the post-eruption period. Nonetheless, the most significant contribution to total fisheries revenues still comes from other demersal species traditionally fished in the Restinga, such as the demersal parrotfish (24–45%) of total fisheries revenues) and splendid alfonsino (4–13%). Unlike tuna, the annual revenue from these fisheries have changed little in the post-eruption period.

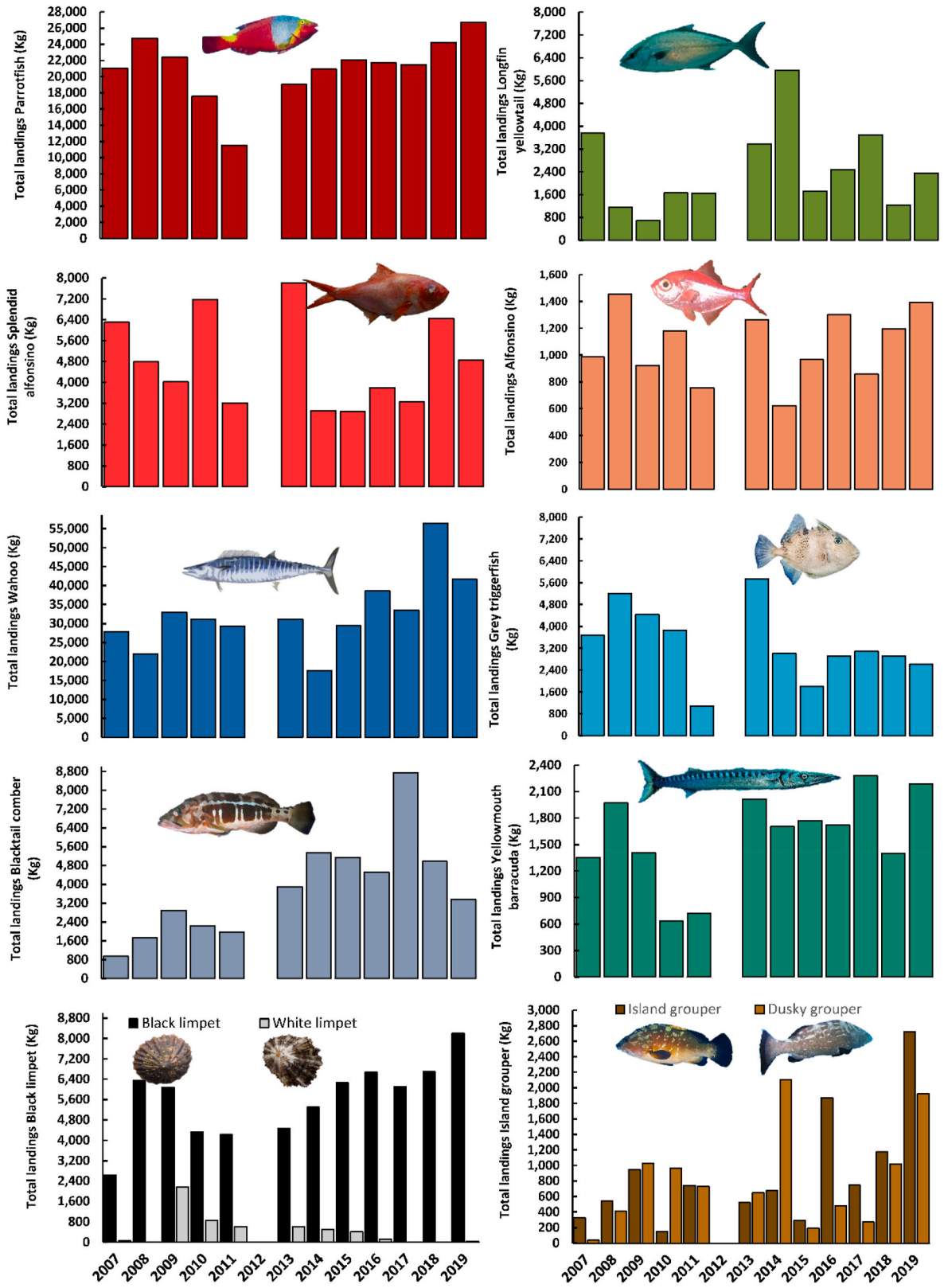

Fig. 3. Total landings (kg) for main target species before and after the eruption.

4.3. Local seafood consumption and exchange-networks

Q3 results revealed a wide range of self-sufficiency activities among La Restinga's inhabitants. Most families interviewed had their own garden (38%), or accessed a family one (46%), generally located in El Pinar village. Family vegetable gardens in El Pinar usually include small plots of crops and fruit trees, occasionally raising small farm animals, mainly chickens, and rabbits. There were 20% of the families interviewed who owned animals (23%) or had access to them thanks to their relatives or friends (27%). Except for 'charcuterie', interviewees

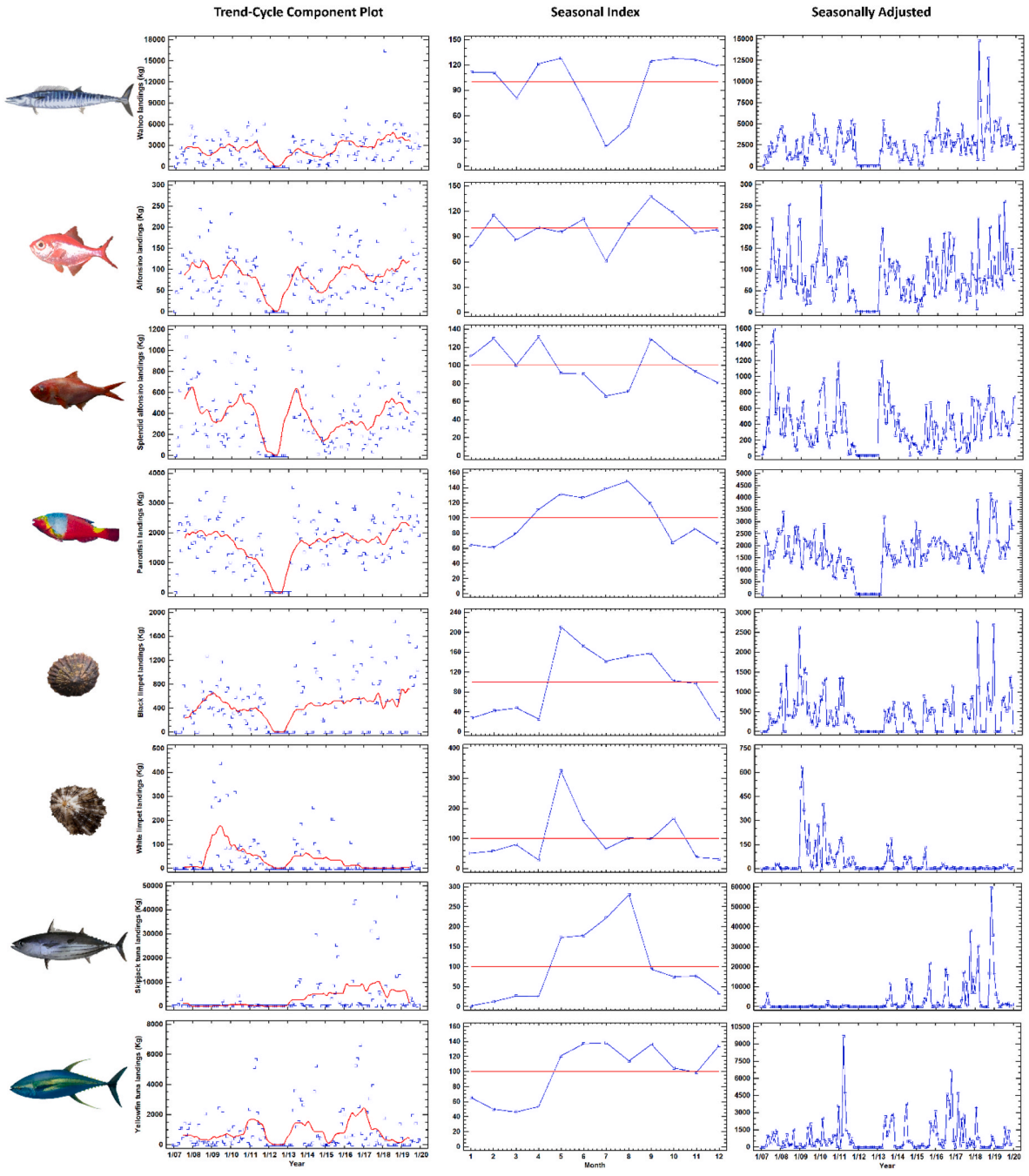

Fig. 4. Seasonal decomposition of landings of the most important fisheries associated with the MPA and the Sea of Calms. (a) Trend-cycle component (red line) and (b) seasonal index. Seasonally adjusted data in (c) show the combined effect of the trend-cycle and irregular components after removing the seasonality effect.

obtained bread, cereals and derivatives, cheese, eggs, fresh vegetables, seafood, chicken, other lean meat (e.g., pork, rabbit, goat), legumes, fruit, infusions, dairy products and related products, condiments and salt, wine and vinegar, olive oil and water, and a traditional dessert called 'quesadilla' without purchasing them. This was because these foods and drinks are self-produced or picked, or because the interviewees received them from family, friends or relatives to a lesser or greater degree. From these foods and drinks, fish turned out to be the most popular food given as gifts, as many families interviewed admitted.

Results obtained from the 'dietary questionnaire' show that, on average, 68% (0.68 ± 0.095) of the interviewees got fish without buying it, considering households with commercial small-scale fisher or with recreational fisher members. Most of these people got fish because someone from the family unit had caught them (0.44 ± 0.101), or because someone gave it to them as a gift (0.36 ± 0.098), followed by those who caught the fish themselves because they have a boat (0.20 ± 0.082) or because they fished them from land (0.12 ± 0.066). Only an average of 0.08 ± 0.055 obtained fish because they work on a small-scale fishing boat. The results also show that more than half of the interviewees gave fish to other people (0.64 ± 0.098), mainly to friends and family (0.60 ± 0.100 and 0.68 ± 0.095, respectively) and, to a lesser extent, to neighbors (0.44 ± 0.101). Indeed, giving away fish is a common practice (an average of 0.28 ± 0.092). Interestingly, most of those who obtained fish through the family unit also gave fish to other people (0.73 ± 0.141), but even those who received fish through gifts gave them to other people (0.8 ± 0.2). Finally, results show that most people who obtained fish for free considered them a gift (0.24 ± 0.087), and a few felt it was an exchange (0.04 ± 0.04).

Additionally, the qualitative analysis of questionnaire responses revealed that family members angling from shore typically fished in the multiple-use section of the MPA and the nearby pier. Also, the places where salt is usually collected are generally located in the multiple-use area of the MPA. Informants reported that food obtained from local harvesting and collection (both terrestrial and marine) was never sold (Fig. 5). However, apart from goods circulating through social networks and kinship relationships, some income-generating activities were identified linked to marine and agricultural resources collection (e.g., figs and pine needles to prepare fig-drying for their subsequent sale) mostly carried out by women.

We should highlight the widespread distribution of fruit and vegetables among the extended family. The kinship group usually collaborates in farm and livestock work, cultivating and caring for the animals together. Thereby, they all see themselves as users of these goods and resources, to the extent that '*everything belongs to everyone*.' Those who do not have such properties or access to them through kinship networks could obtain crop and animal food through gifts. Sometimes, processed products such as cheese and 'quesadillas' are often prepared with family or friends, allowing them to keep some food. Restaurant workers usually distributed leftover food, as many of them are family restaurants.

5. Discussion

By 2018, most families from La Restinga, related or not to fishing, indicated that they had fully recovered their financial level prior to the 2011 eruption. The local community had coped with the hazardous event by combining multiple monetary and non-monetary activities (e.g., informal exchanges), employing different natural resources, and involving the nearby farming village of El Pinar, as they have historically done. Indeed, fishing populations commonly exhibited multi-activity patterns until the twentieth century in the Canary Islands (Pascual Fernández, 1991; Pascual-Fernández et al., 2005). Of course, some conflicts arose between recreational anglers and commercial small-scale fishers, but they seem to be more related to the lack of anglers' participation in the management of the recovery process and leadership (i.e., interviews with non-professional fishers revealed their opposition to the fishing closure), not to the competition for resources, itself (Pascual-Fernández et al., 2015).

Overall, our research shows that the primary economic activities (i.e., fishing, agriculture, and livestock) responded better than the tertiary sectors (tourism and services related) right after the volcanic eruption. The submarine eruption affected both fishing and tourism activity, and the destination's 'credibility and 'image' (Veasna et al., 2013), which is harder to monetarize (García-Negro et al., 2007). Fortunately, tourist destinations have shown a relatively rapid recovery capacity after environmental hazards and disasters, thanks to the effectiveness of response strategies (Ghaderi et al., 2012), and media coverage strategies (Henderson, 2007). Faulkner and Vikulov (2001) have also highlighted the importance of renovation of general and tourism-specific infrastructures, as a support for local industries while fostering tourism sector cohesion. On El Hierro, similar efforts were carried out, and in 2014, the tourism industry was recovering, in fact, the general perception of the interviewees was that the main affected group corresponded to tourism workers, most likely, due to the lack of direct financial aid and participation in the recovery plans. El Hierro's tourism entrepreneurs already constituted a poorly organised sector before the submarine volcanic eruption. This fact may have reduced their response capacity in the immediate aftermath of the eruption. Instead, the fishers' experience in collective action and their historical and active

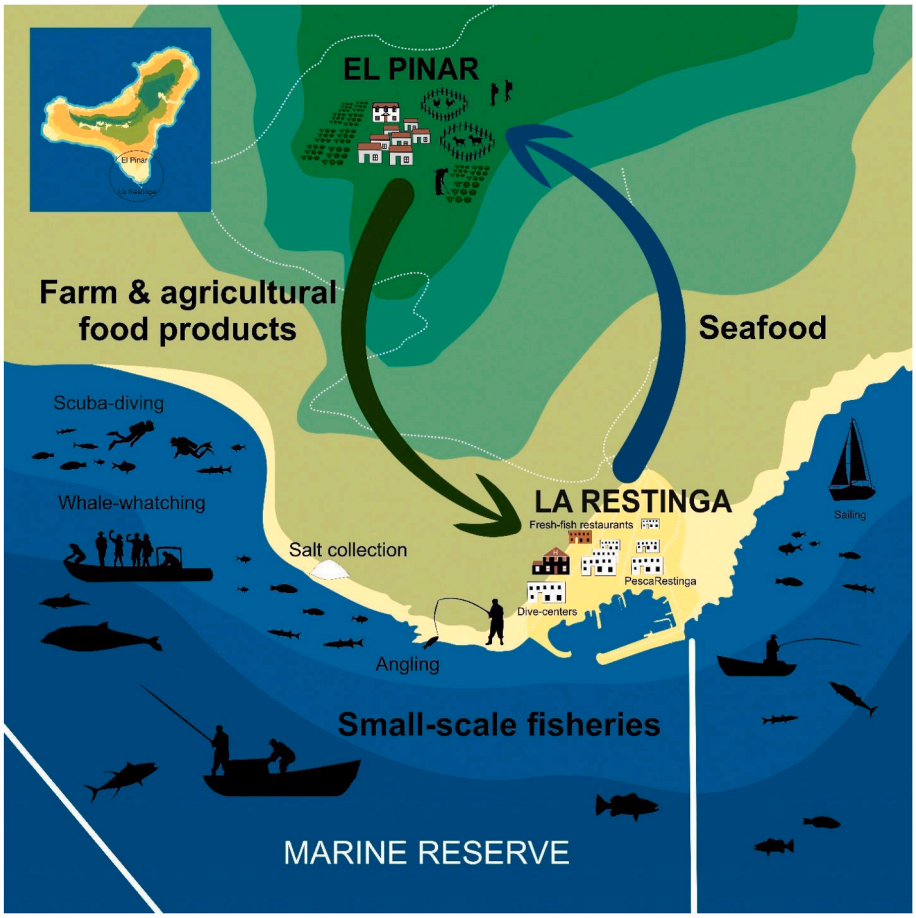

Fig. 5. Food and products flow between La Restinga and El Pinar villages.

participation in fisheries management through their *cofradía* was relevant in the post-eruption recovery period to negotiate and lead the fishing ban and to take advantage of fishing subsidies, as well as the subsequent, successful return to the fishing activity. Post-disaster responses in different communities have shown that those with robust social networks are better able to coordinate recovery (Aldrich, 2012). In fact, when comparing commercial fishers to marine tourism workers, we found that better organized groups obtained better benefit distribution, as also pointed out by (LeBlanc, 2015). In this regard, resilience reflects the degree to which the fishers' group was capable of self-organization and adaptation (Adger et al., 2005).

Clearly, the diversity of social networks and collective action provides resilience in socio-ecological systems in the face of rapid changes and challenges derived from such changes (Marín et al., 2020). Local collective action, in the recent history of this community, has promoted resource protection through the establishment of an MPA and other fishing management strategies that were implemented, temporarily or permanently, and officially or unofficially. Collective action was also essential to protect the market and fish trade throughout the cooperative. This demonstrates resilience not only through the ecosystem (Adger et al., 2005), but also encourages further collective action, robust governance systems, as well as diversity of livelihood choices. Consequently, the resilience of social-ecological systems is clearly influenced by social factors such as fishers' adaptive capacity, their experience of collective action and management capacity, as mentioned above, as well as the community's local ecological knowledge (Ruiz-Mallén and Corbera, 2013). The ecological adaptiveness of their social practices, including professional (i.e., commercial small-scale fisheries) and non-professional ones (food production) are also important.

Despite the high mortality rates of marketable fish in 2011 (Hernández and Clemente, 2012), the various measures adopted during 2012 and 2013 facilitated the recovery of small-scale fishing activity. Following the lockdown year, most studied demersal species reached similar catch levels to those recorded before the eruption (Brito et al., 2013). The catch was particularly important for parrotfish, as detected by other authors (Mendoza et al., 2020). Contrary to what might be expected from a severe environmental disturbance, our data show no evidence of a drop in fish catches after the closure period. Moreover, total landings and their revenues exceeded the values usually recorded before the eruption, partly thanks to improved tuna fish marketing through the Cooperativa PescaRestinga. In this regard, the role played by PescaRestinga in improving marketing and maintaining the distribution of marketable fishery products should be highlighted. At the same time, the MPA also contributed to the resilience of demersal fisheries that we can consider 'essential' due to their stability and profitable maintenance (Dorta and Martín-Sosa, 2022). However, landings of white limpets decreased after the eruption. The reasons for this decline are unclear, and further work is necessary to understand the evolution of white limpet populations.

Our results show that coastal communities have multiple resources and provisioning strategies that ensure steady year-round food supplies. There is a key food exchange network for both fresh and processed foods, using various kinds of resources and products (e.g., fresh fish, fruits, vegetables, dairy products, etc.), reaching a large part of the population of La Restinga and their relatives in El Pinar. Food exchange networks ensure basic food security (Rocker et al., 2022), and kinship relationships and family resources, such as accommodation with relatives, were vital in the most critical stage of the volcanic eruption. In this regard, we consider that social networks and relationships have helped the socio-ecological recovery and were essential to respond to the hazard. Indeed, we agree with the statement that resilience 'requires that the qualitative relationships between the various parts of the network are maintained' (Sage et al., 2015: 409).

Although, overall, local families may be characterized as low-income households. Official discourses about poverty usually do not reflect the combination of official and 'informal' economic activities found in many coastal communities (Jentoft and Eide, 2011). This lack of recognition may result from the way in which coastal fishing populations used to be seen and conceived. For example, this situation has typically been described to explain overlooking women's contributions to small-scale fisheries (Harper et al., 2013), who are often ignored, as many of them have unpaid, informal, or part-time jobs, or simple tasks considered to be part of women's domestic responsibilities (Thomas et al., 2021). In this regard, it is crucial to understand that the term 'poverty' is often mistakenly identified with situations of lack or scarcity of material and monetary resources, forgetting that deprivation is also related to the availability of means of subsistence. Countries often have their own ways of categorizing poverty in small-scale fisheries (Jentoft and Eide, 2011). Official figures do not always reflect how coastal populations make their livelihoods involving a set of processes, activities, behaviors, etc., oriented to the satisfaction of needs (primary or not) for a group, community, or society (Atkinson, 2019; Jentoft et al., 2018). If we fail to notice how local strategies carried out by all community members, such as those specifically performed by women, provide well-being at the local level, we may make local groups more vulnerable (Adger, 2006) in the context of environmental risk and/or rapid ecological change management and recovery plans, by excluding them from such plans.

Our study demonstrates that the vulnerability level in La Restinga community was not only due to the magnitude of the event, as Pan et al. (2015) defended reviewing global volcanic fatality risk. It also depends on several social factors, and encompasses human decisions, values, governance, attitudes, and behavior (Kelman et al., 2015). Apparently, this community, relatively isolated, historically linked to fishing activity and embedded in a tourism-dependent context, could have been heavily impacted by the submarine volcanic eruption. However, the characteristics and circumstances of the community, considering the entire socio-ecological system in which it is rooted, made it less susceptible to the damaging effects of the eruption. Indeed, ongoing debates are questioning different 'islandness' aspects of vulnerability (Kelman 2020). As an example of coastal and islander populations, La Restinga's resources and opportunities are not bounded by the shoreline. On the contrary, community boundaries include the maritime area surrounding the entire Sea of Calms and its MPA, on a continuum between sea and land. On the other hand, smallness became a positive factor considering the importance of collective action and local participation in the management and recovery plans after the eruption. This case also shows the relevance of the small size of the groups affected and their capacity for managing local fishing catches. As well as the importance of fishing subsidies, as this money helped during the crisis (economic standstill) in the local community.

We consider that these elements facilitated fishery management (Guidetti and Claudet, 2009) and socio-ecosystem governance despite the conflicts that may arise after a hazardous event. The reduced population size, which has been relatively stable for a long time in the case of the small-scale fishing population, the community's location at the southwestern point of the Canary Islands (far away from other fleets and the mass-tourism development), and the historical fish resource use and dependence have been essential for the local population to experiment, learn and adapt to the local environment (Pascual-Fernández et al., 2005; Pinkerton, 1994). Other small and isolated communities dealing with natural hazards in the Solomon Islands and Indonesia have also provided examples of self organization (Gaillard, 2010; Schwarz et al., 2011). Finally, thanks to the cooperative PescaRestinga, the fishing community improved trade, even after the eruption and in the wake of the worst economic crisis suffered at national level. These facts make us confident of the strength of this small community, made resilient over the years and from its smallness and isolation spurring local action (Kelman, 2020). At the same time, we must pay attention to the cultural dimension as well as the complex economic and socio-political factors in our strategies for volcanic disaster risk reduction (Oppenheimer, 2015). In addition, there is the importance of engaging with communities to foster their participation in volcanic risk reduction policies (Cadag et al.,

2017) and recovery processes (Marín et al., 2020).

6. Conclusions

Human activity and its concomitant local impacts can often lead to the collapse of marine ecosystems (Halpern et al., 2019; Jackson et al., 2001) with catastrophic consequences for coastal communities and local groups highly dependent on natural resources (e.g., small-scale fishers). However, institutional arrangements developed by human populations can, on the contrary, create resilient socio-ecological systems, as exemplified in the case of the entire socio-ecological system involving La Restinga and El Pinar, the Sea of Calms and the MPA on the island of El Hierro.

Two relevant conclusions can be drawn from the El Hierro volcanic eruption and the La Restinga case study. First, protectionist measures (e.g., MPAs, fishing bans) should not be evaluated solely in the light of their ecological contributions, since when viewed as local institutions, these measures may support fundamental dynamics and local livelihoods, contributing decisively to community and ecosystem resilience over time. Second, fishing and fishery diversity have economically sustained the coastal population, but they have also been sustained thanks to social capital and social relations. So, we agreed with Rocker et al. (2022) affirming that formal and informal networks have played a critical role for the functioning and development of communities and their economies.

The results show that no abrupt changes occurred in La Restinga despite the exceptional nature of the event and its impact on the marine environment and the small coastal fishing community. We suggest that there have been no abrupt changes in local livelihoods because the community was highly resilient thanks to its endogenous resource use and access dynamics. The implications of these results are essential to understand better the response of small-scale coastal communities to environmental disturbances, whether protracted or sudden, and the locally coupled environmental and social characteristics that can make communities more or less resilient. Networks and institutions have played an important role, comprising diverse relationship types ranging from family to friendships or to commercial exchanges (Rocker et al., 2022). These have been crucial not just in the medium term after a major event, but also as a buffer against future risks (Adger et al., 2005). Livelihood systems that are self-sufficient and dynamic through local exchanges and guaranteed access to natural resources, in tandem with a flexible governance system and a healthy local environment are the first, key steps towards resilience in a rapidly changing world.

This study contributes to the understanding of the relationship between governance and the resilience of small-scale coastal populations (Jentoft et al., 2018; Pascual-Fernández et al., 2018), and the fisheries linked to them in developed countries by looking at their dynamics in the wake of a natural hazard. Although many global effects are experienced locally, similar problems may occur in different regions worldwide. Thus, solutions and adaptation strategies can be learned and shared across widely separated areas (Hobday et al., 2016), providing governance tools to deal with new uncertainties. The case study presented here exemplifies the relevance of collective action, which contributed to developing solid institutions like the *cofradía* or the MPA, itself. The accumulated experience of collective action has also contributed towards community and environmental resilience. In summary, this study shows how populations can successfully build different practices for dealing with the changeable dynamics of social and ecological systems (Berkes et al., 1998), even though they are small, they are strong and have increased their resilience in a global and uncertain world.

Authors' statement

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Data availability statement

Ethnographic data contains personal information, and its publication compromises anthropological ethical standards and Spanish legal requirements. The collected data (questionnaires and video records) will remain confidential, they will be used only for research purposes, and are not available to third parties. They are under custody of the University of La Laguna. See more information at https://www.ull.es/servicios/dpd/. On the other hand, fisheries data employed in this study are public and they are available at Canarian Government official website: Department of Agriculture, Livestock and Fisheries of the Government of the Canary Islands. See more information at: https://www.gobiernodecanarias.org/agp/sgt/temas/estadistica/pesca/index.html.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Raquel de la Cruz-Modino reports financial support was provided by CajaCanarias Foundation.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2022.106124.

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