A SPATIALLY EXPLICIT INTEGRATED ASSESSMENT OF A SOCIAL-ECOLOGICAL SYSTEM: THE GALAPAGOS SPINY LOBSTER FISHERY

by

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Los pilares sobre los que he construido mi vida personal y profesional están fundamentados en los principios y enseñanzas de mis padres.

A mi madre, que en paz descanse, le agradezco haberme alentado a no temer a perseguir mis sueños, inclusive si eso implicara alejarme de mi familia, mis amigos y mi país. A pesar del dolor que te causó mi partida, decidiste por tu gran amor y generosidad alentarme a seguir adelate para alcanzar mis sueños y metas de vida. Me mostraste así lo que significa el amor incondicional.

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ABSTRACT

There is a growing recognition that implementation of marine protected areas (MPAs) in combination with co-management regimes can be a solution to enhance the resilience of governing systems to respond to the social-ecological impacts produced by poor governance and external drivers of change, such as climate variability and market globalization. However, to date there are few empirical examples in Latin America and the Caribbean that demonstrate the challenges associated with the practical adoption of these alternative management approaches. In this dissertation, I used a social-ecological approach, in combination with GIS modelling techniques and boosted regression models, to conduct a long-term integrated assessment of the impact of Galapagos Marine Reserve (GMR)'s marine zoning and co-management regime on shellfish fisheries. My analysis focused on the impact of this alternative management approach, and other relevant human and climatic drivers, on the spatial distribution of fishing effort in the spiny lobster fishery. Based on this analysis, I identified: (1) the institutional factors that are preventing the effective transition from a resource-focused to social-ecological and ecosystem-based spatial management approaches; (2) the enabling conditions required to build institutional adaptability; and (3) fishers' adaptive responses to marine zoning implementation and other human and climatic drivers. My results suggest that substantial changes in fishing effort distribution occurred in the spiny lobster fishery due to economic perturbations produced by the boom-and-bust exploitation of the sea cucumber fishery and the global financial crisis 2007-2009, rather than no-take zone implementation. These drivers of change caused a severe reduction of fishing effort, which together with the combined effect of market forces and favorable environmental conditions contributed to recovery of spiny lobster stocks. Fishers´ adaptive responses varied according to the magnitude, extent, periodicity and intensity of the drivers of change analyzed, and the geographic and socioeconomic features of fishing communities in which fisher organizations are embedded. Therefore, a comprehensive understanding about how local fishing communities cope with the interactions of different human and climatic drivers is fundamental to reduce the risk of producing wrong conclusions about the role that no-take zones played on a fishery recovery, as it was revealed by this dissertation.

LIST OF ABBREVIATIONS USED

ASTM	Areas of Special Temporary Management
BA	Baquerizo Moreno
BRT	Boosted Regression Trees
CDF	Charles Darwin Foundation
CONACYT	Consejo Nacional de Ciencia y Tecnología
CPUE	Catch per Unit Effort
EAF	Ecosystem Approach to Fisheries
EBM	Ecosystem-Based Management
EBSM	Ecosystem-Based Marine Spatial Management
ENSO	El Niño Southern Oscillation
ESMP	Ecological Subtidal Monitoring Program
FEDECOOP	Federation of Cooperative Societies of the Fishing Industry of Baja California
FMP	Fishery Management Plan
GAM	General Additive Models
GBRMP	Great Barrier Reef Marine Park
GDP	Gross Domestic Product
GIS	Geographic Information System
GLM	General Linear Models
GMR	Galapagos Marine Reserve
GMRMP	Galapagos Marine Reserve Management Plan
GNPS	Galapagos National Park Service
GPS	Geographic Positioning System
GSL	Galapagos Special Law
IDB	Inter-American Development Bank
IMA	Interinstitutional Management Authority
INEC	Instituto Nacional de Estadística y Censos
INP	National Fisheries Institute of Ecuador
IOR	Index of Reuse
KBA	Key Biodiversity Areas
LAC	Latin America and the Caribbean
MAE	Mean Absolute Error
MEABR	Management Exploitation Areas for Benthic Resources
MPA	Marine Protected Area
MSC	Marine Stewardship Council
MSP	Marine Spatial Planning
NGO	Nongovernmental Organizations
NMAE	Normalized Mean Absolute Error
NOAA	National Oceanic and Atmospheric Administration
NRMSE	Normalized Root Mean Square Error

NSERC	Natural Sciences and Engineering Research Council of Canada
ONI	Oceanic Niño Index
PA	Puerto Ayora
PCUEM	Proceso de Conservación y Uso de Ecosistemas Marinos
PCZ	Provisional Coastal Zoning
PIMPP	Participatory Fisheries Monitoring and Research Program
PMB	Partcicipatory Management Board
PV	Puerto Villamil
RMSE	Root Mean Square Error
RN	Random Number
SDE	Standard Deviation Ellipses
SES	Social-Ecological System
SSF	Small Scale Fisheries
TAC	Total Allowable Catch
TURF	Territorial Use Rights for Fishing
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development
VI	Variable Importance
VMS	Vehicle Monitoring System

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CHAPTER 1. INTRODUCTION

1.1 Introduction

Small-scale fisheries (SSF) play a critical role in terms of food security and nutrition, poverty eradication, equitable development and sustainable resource utilization in Latin America and the Caribbean (LAC) (Begossi, 2010; FAO, 2014). Several million people are directly or indirectly engaged in (or benefited by) fisheries-associated livelihoods, including harvesting, processing, trading, ancillary services, etc. (Defeo and Castilla, 2005; Salas *et al.*, 2007). Nevertheless, despite the social, cultural, and economic importance of SSF for coastal and inland communities, most of them have been largely marginalized, ignored or dismissed in national and international policies (Berkes *et al.*, 2001; Pauly, 2006). Consequently, SSF governance has received inadequate financial, institutional, and scientific support, and an underrepresentation of the concerns and interests of fishing communities in policy discussions (Salas *et al.*, 2007; Chuenpagdee, 2012; FAO, 2014).

In this context, SSF sustainability has been difficult to achieve due to factors categorized as "wicked fishery problems"(*sensu* Jentoft and Chuenpagdee, 2009), known for undermining fisheries governance systems in the LAC region (Salas et al., 2011; Defeo and Castilla, 2012), which include: (1) there is a dominance of hierarchical (or top-down) governance systems, which tend to show poor centralized capacity to enforce regulations and to collect reliable biologic and socioeconomic fishery-related data; (2) conventional stock assessments are difficult or impossible to conduct because of lack of scientific data, precluding the management of SSF on the basis of catch quotas and effort control; and (3) as most SSF are developed along extensive coastlines under open access regimes, fishery agencies are unable to regulate access and avoid illegal fishing. Moreover, SSF are not only undermined by weak governance, but also by the negative impacts produced by large-scale anthropogenic and climatic drivers, such as the globalization of markets and extreme climatic events (e.g., El Niño, hurricanes, etc.) acting at multiple temporal and spatial scales (Badjeck *et al.*, 2010; Perry *et al.*, 2011; Defeo and Castilla, 2012; Defeo *et al.*, 2013). The negative impacts produced by all these drivers degrades the resilience of target and incidental species and their critical habitats, altering the structure and function of marine food webs (Perry *et al.*, 2010;

Hall, 2011). This causes cascading effects that disrupt ecosystem services, such as fisheries productivity, ultimately threatening food, nutrition and livelihoods security of fishing communities (Allison and Ellis, 2001; Smith *et al.*, 2010). As a result, several SSF in the LAC region are either overexploited or depleted (Salas *et al.*, 2007; Defeo and Castilla, 2012).

The evident failure in achieving sustainability in SSF, in the last two decades has encouraged a transition from a "resource-focused" to a "social-ecological systems" approach (Charles, 1995, 2001; Berkes *et al.*, 2001; McConney and Charles, 2010), as a potential solution to reverse the negative environmental and socioeconomic impacts produced by the global fishery crisis. The "resource-focused" approach is characterized by a strong bias to the biology and population dynamics of the resources, and in some cases the economic aspect of the fisheries. However, it ignores or under-values the environmental and the "human dimensions" of the fishery system (Berkes and Folke, 1998; Charles, 2001; Charles and Wilson, 2009). In contrast, the "social-ecological systems" approach recognizes that SSF are embedded in social-ecological systems, also known as "human-in-nature systems" or "human-environment systems" (Berkes *et al.*, 2001; Liu *et al.*, 2007; Ostrom, Janssen and Anderies, 2007). Thus, a social-ecological system (SES) is defined "as integrated complex systems that include social (human) and ecological (bio-physical) subsystems in a two-way feedback relationship" (Berkes, 2011). The SES approach explicitly recognizes that humans are part of, dependent on, and affect the ecosystem in which they live, work, and play (De Young, Charles and Hjort, 2008). In other words, it emphasizes that the delineation between social and ecological systems is artificial and arbitrary (Berkes and Folke, 1998).

Fisheries are typical examples of SESs, which can be broken down into three basic interacting subsystems (Charles, 1995, 2001; Defeo, McClanahan and Castilla, 2007): (1) resource (e.g., lobsters); (2) resource users (e.g., fishers) and (3) resource management (or governing system). These three interacting subsystems are linked to social, economic, and political settings and related ecosystems (Ostrom, 2009). All of them exhibit characteristics of complex adaptive systems, which are systems able to self-organize and build capacity for learning and adaptation (Folke, 2006; Mahon, McConney and Roy, 2008).

The assessment and effective governance of SSF as complex social-ecological systems requires a comprehensive knowledge about the dynamic interaction between biophysical and human subsystems (Berkes *et al.*, 2001; Folke, Colding and Berkes, 2003). This implies the need to recognize how different drivers of change (e.g., climate variability, markets globalization) affect the dynamics of resources, their marine environment and the people whose livelihoods depend on them, and how the feedback produced by each subsystem, in turn, alter the original dynamic of ecosystem services and human behaviors (Perry *et al.*, 2011; Defeo *et al.*, 2013). In practice, this means that one also needs to understand not only how the dynamics of fishery resources and their ecology is affected by human exploitation and climate, but the mechanisms through which fishing communities learn, self-organize and respond to the socioeconomic and ecological changes (Perry *et al.*, 2011). Such changes are often driven by: (1) the establishment of new institutions, policies and governance instruments, and (2) the crises produced by a wide variety of climatic and human events. The integration of this knowledge is fundamental to comprehend how stakeholders' behavior is affected by different management strategies, and the ecological and socioeconomic consequences of such changes (Salas and Gaertner, 2004; Branch *et al.*, 2006). Based on this information, policies aimed on building resilience in SSF can be designed to promote the capacity of fishing communities and institutions to cope with and adapt to change. Such policies would also take into account the particular ecological, socioeconomic and political setting of each case study under evaluation (Ommer *et al.*, 2011).

The SES approach is a key element of the ecosystem-based marine spatial management (EBSM) approach, also known as place-based management (Young *et al.*, 2007). This approach has emerged as a tangible way for translating the concepts regarding ecosystem-based management approach (EBM) into an operational management practice in coastal and marine environments (Ehler and Douvere, 2009). The EBSM approach emphasizes the idea that since marine ecosystems are places, and human activities affecting them (fisheries, tourism, marine transport, oil and gas exploitation, etc.) occur within those places, ecosystem-based management must be inherently place-based (Crowder and Norse, 2008). Hence, the main aim of EBSM is to provide a mechanism for a strategic and integrated plan-based approach to manage the full suite of human activities occurring in spatially demarcated areas, identified through a procedure that takes into account biophysical, socioeconomic, and jurisdictional considerations (Young *et al.*, 2007).

Marine spatial planning (MSP) represents a practical way to adopt an EBSM approach in the marine environment. It can be defined as "a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process" (Ehler and Douvere, 2009). This tool has proven to be useful for managing resource use conflicts, reducing the cumulative effects of human activities on marine ecosystems, optimizing sustainable socio-economic development and delivering protection to biologically and ecologically sensitive marine areas (Douvere, 2008).

A cornerstone for the application of an EBSM approach is the adoption of marine zoning, also known as ocean zoning. The latter is a spatially explicit tool that consists of regulatory measures to implement marine spatial plans (Agardy, 2010). It specifies allowable uses in all areas of the target ecosystem(s). Different zones accommodate different uses, or different levels of use. Recent studies suggest that the adoption of spatially explicit management measures such as Marine Protected Areas (MPAs), in combination with co-managed harvesting areas bearing exclusive spatial fishing rights to local communities, represents a more robust approach to address the roots of SSF management failures (Worm *et al.*, 2009; Gutiérrez, Hilborn and Defeo, 2011; McCay *et al.*, 2014; Defeo *et al.*, 2016).

1.2 Problem statement

There is a growing recognition that implementation of MPAs in combination with co-management regimes can be a solution to enhance the resilience of governing systems to respond to the social-ecological impacts produced by poor governance and external drivers of change, such as climate variability and market globalization (Badjeck *et al.*, 2010; Defeo and Castilla, 2012; Ortega *et al.*, 2012; Defeo *et al.*, 2013). Yet, to date there are few empirical examples in LAC that demonstrate:

1. The challenges and benefits associated with the adoption of these alternative management approaches on the ground (Gutiérrez, Hilborn and Defeo, 2011).
2. The institutional factors that preclude the transition from a resource-focused to a SES and EBSM approach.
3. How fishers' behavior is affected by MPAs and co-management regimes, particularly in those cases in which fishers must cope simultaneously with the interaction of different climatic and human drivers of change, and how their adaptive responses could influence the interpretation of no-take zones effectiveness assessments.

Despite the increasing number of MPAs implemented in LAC in combination with co-management regimes, very limited or no exertion of human and economic resources are usually allocated to monitor the performance of this alternative governance mode (Gutiérrez, Hilborn and Defeo, 2011). Given the lack of data, these systems are often plagued by the inability to evaluate the biological and socioeconomic outcomes of MPAs and co-management strategies implemented (Defeo *et al.*, 2016). For example, Gutiérrez et al. (2011) shows that only a small percentage of 130 co-managed fisheries, distributed in a wide range of countries with different degrees of development, included a long-term performance assessment framework. According to these authors, only 7% of 130 co-management systems evaluated showed a combination of interviews, fishery-dependent and independent data to evaluate their performance; meanwhile only 6% presented before-after, control-impact, or complete before-after-control-impact (BACI) approaches. On the other hand, even in those cases in which BACI approaches can be carried out, research is usually biased to the bio-ecological aspects of the coastal social-ecological systems (Salas *et al.*, 2007), leading to poor understanding about the human dimensions that influence the governance of MPAs.

Furthermore, spatial distribution of fishing effort and the socio-economic factors that influence the fishing behavior are often not well understood either (Wilen, 2004; Branch *et al.*, 2006; Horta e Costa *et al.*, 2013a). Consequently, lack of explicit consideration of space in stock assessment and fisheries management has usually led to spatial and temporal mismatches between the scale of biophysical systems and the scale of the rights, rules, and decision making procedures created to manage human interactions within these systems

(Hilborn, Orensanz and Parma, 2005; Young *et al.*, 2007; Prince, 2010). Such trends highlight the urgent need for spatially explicit integrated assessments to effectively evaluate the long-term performance of alternative management regimes, which produce well-grounded evidence about the factors that determine their success and failures in the LAC region.

The Galapagos Marine Reserve (GMR) represents a unique cases study in the LAC region to evaluate the challenges and results associated to the transition from a resource-focused to a SES and EBSM approach. In this multiple-use MPA, a marine zoning was implemented in combination with a co-management and common property regime. In addition to the implementation of this alternative management approach, fishing communities had to cope with the interaction of different climatic and human drivers of change. These include El Niño 1997/1998; the boom and bust exploitation of a very profitable fishery, the sea cucumber; and the globalization of markets, represented by the global financial crisis 2007-2009. In 2011, the spiny lobster fishery from the GMR showed a remarkable recovery after years of overexploitation. As the reasons behind such unexpected recovery are not fully known. It could be wrongly concluded that spiny lobster stocks recovery was the result of implementing no-take zones, leading to the adoption of misleading management actions. In consequence, a comprehensive understanding of how local fishing communities coped with the interactions of various human and climatic drivers, both temporally and spatially, is fundamental to understand how fishers' adaptive responses could influence the interpretation of no-take zones effectiveness assessments. This will contribute to reduce the risk of wrong conclusions about the relevance of no-take-zones on the recovery of the spiny lobster fishery from the GMR.

1.3 The Galapagos spiny lobster fishery as a case study

The Galapagos Archipelago is located in the Eastern Tropical Pacific about 960 km west of mainland Ecuador (González *et al.*, 2008). It is comprised of approximately 234 islands, islets and rocks with a total emerged land area and coastline of ca. 7 985 km^2 and 1667 km, respectively (DPNG, 2014). This volcanic archipelago is featured for being located at the convergence of three major seasonally varying warm and cool water current systems (Edgar *et al.*, 2004a): (1) the warm southwesterly flowing Panama current; (2) the cool northwesterly flowing Peru current; and (3) the cold eastward –flowing subsurface equatorial undercurrent. This produces strong differences in oceanographic conditions across the archipelago over short spatial-scales, which are reflected in broad-scale marine biogeographical patterns.

The archipelago is divided into five marine bioregions, referred to as far-Northern, Northern, South-Eastern, Western and Elizabeth – the latter being a bioregion located in the Western part of Isabela Island, whose proportion of endemic species is anomalously high (Edgar *et al.*, 2004a; Fig. 1.1). Each bioregion is featured for having distinctive reef fish and macro-invertebrate assemblages, most of which show a mix of species derived from Indo-Pacific, Panamic, Peruvian and endemic source areas. The abundance and distribution of all these marine species and their habitats are strongly affected by El Niño Southern Oscillation (ENSO), whose main influence area is the Equatorial Pacific Ocean. Hence, the particular location of Galapagos makes it a unique place to assess the potential impacts of climate variability on the demography and life history traits of marine species (Defeo *et al.*, 2013).

The particular geographic and oceanographic features of the Galapagos Islands influenced the origin of a high proportion of terrestrial and marine endemic species (ca. 18%), such as the marine iguana (*Amblyrhynchus cristatus*), flightless cormorant (*Phalacrocorax harrisi*), and the laminarian kelp (*Eisenia galapagensis*) (Edgar *et al.*, 2004a). This feature inspired the naturalist Charles Darwin to conceive his famed Theory of Evolution by Natural Selection, following his visit to the archipelago in 1835, and was responsible for the designation of the Galapagos Islands as World Heritage site by UNESCO in 1978.

A high diversity of marine species are commercially harvested, the most significant being the sea cucumber (*Isostichopus fuscus*) and spiny lobster (*Panulirus penicillatus* and *P. gracilis*). Both are caught in sub-tidal rocky habitats through hookah and free diving. In 2012, there were 1084 license holders and 416 vessels distributed across three main ports (Baquerizo Moreno, Puerto Ayora and Villamil; Fig. 1.1), although only 37% of them remained active in the spiny lobster fishery (Reyes and Ramírez, 2012) . Fishers are organized in four fishing cooperatives, located in Santa Cruz (1), Isabela (1) and San Cristobal Islands (2). The fishing industry employs approximately 3.6% of the active economic population (INEC, 2007) and its contribution to the Galapagos gross domestic product (GDP) is approximately 1.9% (USD 3.2 millions: Castrejón, 2011).

The overcapitalization of the small scale artisanal fishing fleet, driven by the boom and bust exploitation of the sea cucumber fishery, and the exponential growth of tourism activity in the archipelago, led to the participative elaboration and enacting of the Galapagos Special Law (GSL) in 1998 (González *et al.*, 2008; Castrejón, 2011). This implied the designation of the Galapagos archipelago and its surrounding open ocean as a multiple use MPA, known as the Galapagos Marine Reserve (GMR). The latter has 138,000 km^2 with an extension of its boundaries 40 miles offshore from the "baseline", i.e. an imaginary line joining the outer islands of the archipelago (Edgar *et al.*, 2004b).

Several management measures were implemented by the GSL to shift from an open-access to a common property regime in fishery resources between 1998 and 2002 (Heylings and Bravo, 2007; Castrejón, 2011). These included the prohibition of industrial fishing inside the reserve, the allocation of exclusive use rights to local fishers, in the form of licenses and fishing permits, and the adoption of an EBSM approach. The latter was implemented through the adoption of a marine zoning, a spatially explicit management tool that was designed, planned and implemented by a consensus-based participatory process between 1999 and 2006 (Calvopiña *et al.*, 2006; Heylings and Bravo, 2007). The GMR's marine zoning was brought forward, under a co-management regime, in order to (SPNG, 1998): (1) contribute to the sustainability of Galapagos fisheries by providing potential areas from which fishery stocks can recover and spillover into fishing grounds; (2) reduce conflicts among users as a result of incompatible demands for ocean space (e.g., tourism vs. fishing; small-scale vs. large-scale fishing); and (3) mitigate the impact of uses on sensitive ecological areas of the archipelago, which are critical to the functioning of marine ecosystems and the conservation of threatened species (Edgar *et al.*, 2008).

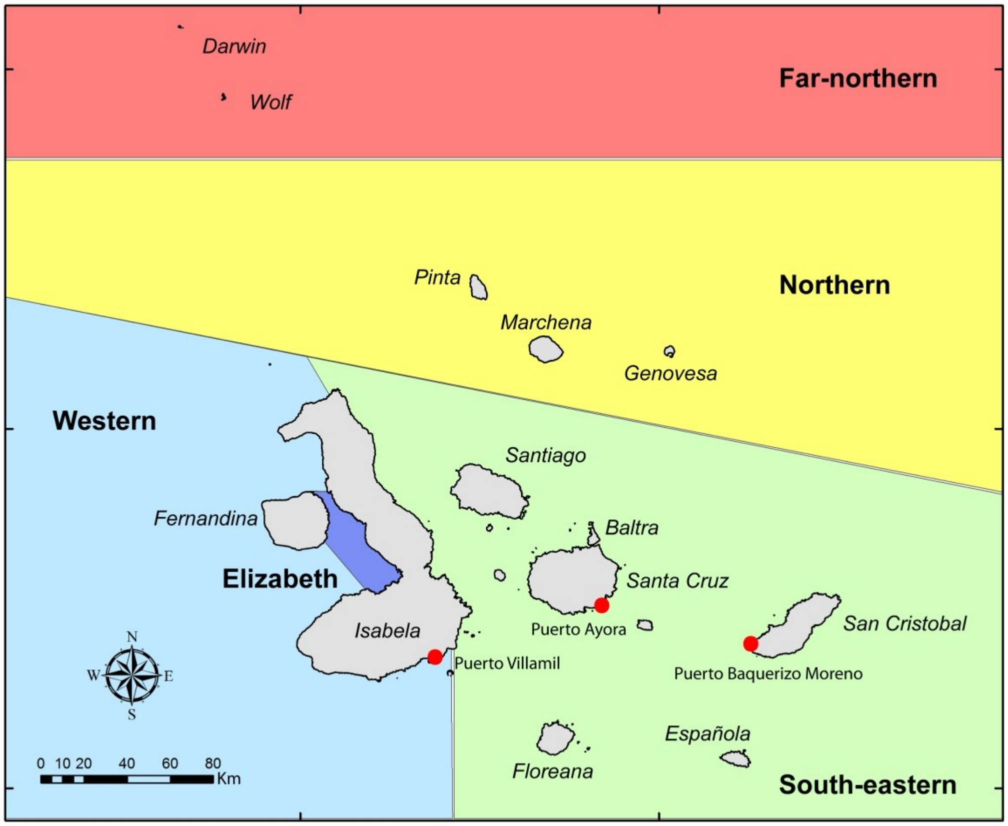

Figure 1.1 Bioregions, islands and ports of the Galapagos Islands, Ecuador.

The institutional shift from a top-down to co-management approach was achieved through the creation and institutionalization of two nested decision-making bodies (Heylings and Bravo, 2007; Castrejón, 2011): the Participatory Management Board (PMB) and the Institutional Management Authority (IMA). Both are forums, where local stakeholders (i.e., fishers, tourism operators, naturalist guides, scientist and conservationists) can participate in the decision-making process along with the GNP and the Environment Minister, the institutions in charge of the management of the GMR. Decisions are taken by consensus in the PMB and by majority of votes in the IMA. Such co-management scheme can be classified as in the category of "advised" (Defeo, Castilla and Castrejón, 2009).

Adoption of the alternative management approach triggered the transition from a resource-focused toward an SES approach. Nevertheless, this change has been precluded in part by the divergence between the innovations of the Galapagos legal framework and the real-world institutional constraints of local fishery agencies typically observed in developing countries (Mahon and McConney, 2004; Salas *et al.*, 2007; Andrew and Evans, 2011). The implementation of marine zoning, under a common property and co-management regime, represents an important step forward towards the adoption of an EBSM approach in the GMR. Nonetheless, it failed to prevent the collapse of the sea cucumber fishery in 2006 (Shepherd *et al.*, 2004; Castrejón, 2011), and was unable to ensure the sustainable exploitation of the spiny lobster fishery, which showed signs of overexploitation from the late 1990s to the middle 2000s (i.e., during and after co-management and marine zoning implementation) (Castrejón, 2011; Ramírez, Castrejón and Toral-Granda, 2012; Defeo *et al.*, 2016).

Several institutional, legal and socioeconomic factors have limited the successful implementation of marine zoning and co-management in the GMR (Castrejón, 2011; Defeo *et al.*, 2016), including: a) reactive governance due to lack of long term strategic planning and practical mechanisms for precautionary and adaptive management; b) poor implementation and enforcement of management practices, due to a weak monitoring, control and surveillance system; c) excessive fishing capacity due to the inappropriate allocation of user rights (licenses and fishing permits); and d) weak leadership, social cohesion and organization of local fishing cooperatives. However, a key factor that led to its failure was lack of attention to spatial-temporal dynamics of shellfish stocks and fleets during the design of marine zoning (Edgar *et al.*, 2004b). Thus, GMR's marine zoning was designed and implemented without considering the spatial-temporal distribution of fishing effort across the archipelago. It was not recognized that such knowledge is fundamental to design successful fisheries management systems to achieve the desired social, economic, and biological objectives (Branch *et al.*, 2006), including the minimization of conflicts between fleets or different economic sectors (small vs. large-scale fishing, or fishing vs. tourism). Furthermore, even though a large amount of spatially-explicit ecological and fishery related-data has been collected since 1997, a long-term spatially explicit integrated assessment about the impact of GMR's marine zoning on the spiny lobster fishery is still missing in the scientific literature.

1.4 Objectives and research questions

This doctoral thesis presents a long-term integrated assessment of the impact of GMR's marine zoning and co-management regime on the governance of shellfish fisheries, with emphasis on how this, along with other relevant human and climatic drivers, impacts the spatial distribution of fishing effort in the spiny lobster fishery. In four main chapters, this dissertation addresses the following specific objectives:

1. Understand the factors that have influenced the effectiveness of GMR's marine zoning and co-management regime on shellfish fisheries.

2. Determine the impact of no-take zones, and other relevant human and climatic drivers on the distribution of fishing effort in the spiny lobster fishery.

3. Evaluate how local institutions and fishing communities have responded to diverse climatic and human drivers, including implementation of marine zoning, and how these adaptive responses were shaped by the features of the coastal social-ecological system under assessment.

4. Provide recommendations to better realize the potential value of the EBSM approach to co-managing the shellfisheries of the GMR.

Based on these objectives, the following research questions will be examined:

1. What institutional factors are preventing the effective transition from a resource-focused to a SES and EBSM approaches in the GMR (Chapter 2 and 3).

2. Why has the adoption of a marine zoning scheme and a co-management system not been effective to better realize the potential value of the EBSM approach to co-managing the shellfisheries of the GMR (Chapter 3).

3. What are the enabling conditions required to build institutional adaptability in the GMR's co-management system (Chapter 3 and 4).

4. How was the spatiotemporal allocation of fishing effort in the spiny lobster fishery affected by the interactions of different human and climatic drivers, including marine zoning implementation, and how could fishers' adaptive responses influence the interpretation of no-take zone effectiveness assessments (Chapter 5).

5. What actions should be taken by local institutions to improve the management effectiveness of GMR's marine zoning on shellfish fisheries and the institutional adaptability of its co-management system? (Chapter 2-6).

1.5 Organization of the dissertation

This dissertation is organized in six chapters. Chapter 2 reviews the origin and advances of fishery science in the Galapagos Islands, before and after the creation of the GMR and its co-management system. It explains how these events triggered the transition from a resource focused to a SES approach. This review is focused on two local institutions, the Galapagos National Park Service (GNPS) and the Charles Darwin Foundation (CDF), which have played a key role in the development of fishery science in the archipelago. Based on this analysis, this chapter identifies the institutional factors that are preventing the effective transition from a resource-focused to a SES and EBSM approaches in the GMR, providing recommendations to complete such transition.

Chapter 3 explains the process followed in the GMR at the end of the 1990s to adopt an EBSM approach through the design and implementation of marine zoning, under a co-management regime. The aim of this chapter is to evaluate the shortcomings and lessons learned related to planning, implementation, monitoring, evaluation and adaptation of the GMR's marine zoning scheme. This chapter explores the extent to which GMR's marine zoning has achieved these five basic components since its inception. Based on this critical review, this chapter explains why the adoption of a marine zoning scheme and a co-management system not been effective to better realize the potential value of the EBSM approach to co-managing the shellfisheries of the GMR. Finally, it provides a set of insights to adapt and improve the GMR's marine zoning to address the roots of fisheries management failures that led to the overexploitation of the sea cucumber and spiny lobster fisheries.

Chapter 4 examines the GMR in a comparative context of other relevant fishery systems in Latin America, to evaluate how institutions learn, self-organize and respond to diverse climatic and human drivers. Comparing the GMR with six other examples of co-governance arrangements, this chapter identifies the enabling conditions required to build institutional adaptability in the GMR's co-management system.

Chapter 5 evaluates how the interaction of different large-scale human and climatic drivers have influenced the macro and micro-scale spatiotemporal dynamic of fishing patterns around no-take zones in the GMR. Using geographic information system (GIS) modelling techniques, in combination with boosted regression models, this chapter evaluates how the spatiotemporal allocation of fishing effort in the spiny lobster fishery was affected by the interactions of different human and climatic drivers, including marine zoning implementation. Based on this analysis, fishers' adaptive responses were identified, and their management implications analyzed, including their influence on the interpretation of no-take zone effectiveness assessments.

Finally, Chapter 6 presents a summary of each of the Chapter conclusions and discusses the academic and applied contributions of this work, including the actions that should be taken by local institutions to improve the management effectiveness of GMR's marine zoning on shellfish fisheries.

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CHAPTER 2. FISHERY SCIENCE IN GALAPAGOS: FROM A RESOURCE-FOCUSED TO A SOCIAL-ECOLOGICAL SYSTEMS APPROACH

2.1 Publication information

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2.2 Abstract

This chapter reviews the origin and advances of fishery science in the Galapagos Islands (Ecuador), before and after the creation of the Galapagos Marine Reserve and its co-management system. It explains how these events triggered the transition from a resource-focused to a social–ecological systems approach, which, however, remains incomplete due in part to a continuing dominance of the resource-focused approach within the structure and function of local institutions. It is argued that further progress toward a full social–ecological systems approach is needed to solve the increasingly complex socio-environmental problems faced by the archipelago. Transformation of the Charles Darwin Foundation into an inter-disciplinary research center is suggested as a key move toward this goal that would increase the adaptive capacity and resilience of local institutions to deal with potential impact of globalization and climate change on the archipelago.

2.3 Introduction

In Latin America, as in other parts of the world, the evident failure to achieve sustainability in small-scale fisheries (SSF) has intensified criticism of the assessment and management approaches commonly used in this type of fisheries. Here we refer to this common framework as "resource focused" to reflect a "conventional" combination of a narrow scope in terms of what is included in the approach (i.e., "single-species") and a "top-down" or "command-and-control" mechanism for decision-making.

Several scholars have advocated a fundamental change in this "resource- focused" or conventional fishery research and management paradigm, which is nevertheless still dominant in developing countries (Salas et al. 2007; Andrew and Evans 2011; Defeo and Castilla 2012). Most proposals involve adoption of a "fishery systems" (Charles 2001) or "social–ecological systems" (Berkes et al. 2001; McClanahan et al. 2009; Ommer et al. 2011) approach as a potential solution to reverse the negative environmental and socioeconomic impacts produced by the global fishery crisis.

The "resource-focused" approach, which is characterized by a strong bias to the biology and population dynamics of the resources and in some cases the economic aspect of the fisheries, ignores or undervalues the environmental and the "human dimensions" of the fishery system (Berkes and Folke 1998; Charles 2001). On the other hand, the "social–ecological systems" approach recognizes that SSF are embedded in social–ecological systems, also known as "human-in-nature systems" or "human-environment systems" (Berkes et al. 2001; Liu et al. 2007; Ostrom 2007). SES are composed of three basic interacting subsystems (Charles 2001; Defeo et al. 2007) (1) resource (e.g., lobsters), (2) resource users (e.g., fishers), and (3) resource management (or governance). All of these are linked to social, economic, and political settings and related ecosystems (Ostrom 2009) and exhibit characteristics of complex adaptive systems, which are able to self-organize and build capacity for learning and adaptation (Mahon et al. 2008).

The social–ecological systems (hereafter SES) approach integrates the biophysical and social sciences through an understanding of how human behaviors affect “press” and “pulse” dynamics and ecosystem processes and how the feedback produced, in turn, influences ecosystem services, thereby altering human behaviors and impacting the original dynamics and processes (Collins et al. 2011).

This approach has important implications for fishery research and management. It makes clear that assessment and management of SSF require an integrated knowledge about the biology and ecology of fish resources, as well as the socio- economic, resource user, and institutional factors that affect the behavior of fishers and policymakers (Seijo et al. 1998; McConney and Charles 2010). This knowledge is fundamental to understand how stakeholders’ behavior is affected by different management strategies and the ecological and socioeconomic consequences of such changes (Salas and Gaertner 2004). This highlights the need for interdisciplinary, integrated, and participatory research, involving biological, economic, social, and institutional analysis to describe and understand the dynamics within and beyond the fishery system (Charles 2001). This implies describing and understanding the social, economic, and political linkages of fishing with other elements of ecosystem and human systems (e.g., climate change, tourism) and extending fishery research from aquatic ecosystems and harvest sector to the processing, marketing, and distribution of aquatic resources (Garcia and Charles 2007). Therefore, the adoption of this alternative approach by national fishery agencies requires major transformations in their function and structure in order to produce expertise on interdisciplinary and participatory research, strategic planning, mediation, and facilitation. All of them have been identified as fundamental skills to change from a resource- focused to an SES approach, particularly in developing countries (Berkes et al. 2001; Mahon and McConney 2004).

In the Galapagos Islands (Ecuador), the assessment and management of SSF are gradually shifting from a resource-focused to an SES approach. A co-management and an ecosystem-based spatial management approach were legally implemented in Galapagos at the end of the 1990s to tackle the complex socio-environmental problems that are leading to the degradation of the natural and social capital of the archipelago, including shellfishery overexploitation

(Castrejón and Charles 2013). Adoption of these approaches, by the declaration of the Galapagos Special Law (GSL), triggered the transition toward an SES approach. Nevertheless, this change has been precluded in part by the divergence between the innovations of the Galapagos legal framework and the real-world institutional constraints of local fishery agencies typically observed in developing countries (Mahon and McConney 2004; Salas et al. 2007; Andrew and Evans 2011).

The objective of this chapter is to review the origin and advances of fishery science in the Galapagos Islands, before and after the creation of the Galapagos Marine Reserve and its co-management system. Particular emphasis is placed on the events that triggered the transition from a resource-focused to an SES approach and the institutional factors that are limiting this change. This review is focused on two local institutions, the Galapagos National Park Service and the Charles Darwin Foundation, which have played key roles in the development of fishery science in the archipelago. Recommendations are also provided to improve the means to deal with the complex socio-environmental problems faced by the archipelago, by transforming one of these institutions, the Charles Darwin Foundation, into a resilient interdisciplinary research institution that moves more fully into an SES approach to fishery research and management.

2.4 The origin and early development of fishery science in the Galapagos Islands (1788–1991)

Commercial exploitation of marine resources in the Galapagos Islands began at the end of the eighteenth century, approximately 253 years after its discovery by Fray Tomas de Berlanga in 1535 (Shuster 1983; Latorre 2011). Three species of marine mammals were heavily exploited, mainly by British and North American whalers and sealers, for almost 80 years (1788–1864; Latorre 2011): sperm whales (*Physeter macrocephalus*), fur seals (*Arctocephalus galapagoensis*), and Galapagos sea lions (*Zalophus wollebaeki*). The first studies of the magnitude and ecological impact of this industry were conducted by Townsend (1925, 1935), who evaluated the depletion of sperm whales and Galapagos giant tortoises, an endemic species, by whalers and sealers. His work could be considered the first fishery science in the archipelago. Similar studies were published in the 1980s and 1990s (Shuster 1983; Epler 1987; Whitehead et al. 1997). It took several decades after the studies of

Townsend (1925, 1935) to consolidate fishery science in the Galapagos Islands (see Table 2.1).

Table 2.1 Historical milestones in fisheries research and management in the Galapagos Islands from 1535 to 2012.

Year	Historical milestone
1535	Discovery of the archipelago by Fray Tomas de Berlanga
1788	Beginning of the whaling industry
1832	Integration of Galapagos to the Republic of Ecuador by General José Villamil
1835	Expedition of Charles Darwin across the archipelago aboard of H.M.S. Beagle
1864	Ending of the whaling industry
1925	First fishery study conducted by Towsend (1925); unsuccessful attempt to establish a fish canning industry by Norwegian settlers
1930	Commercial exploitation of tuna by foreign industrial fishing fleets; coastal fisheries by local settlers start as an occasional activity
1940	Expansion of the finfish fishery (locally known as "pesca blanca")
1959	Creation of the Charles Darwin Foundation (CDF) and Galapagos National Park (GNP)
1960	Establishment of the Charles Darwin Research Station in Puerto Ayora, Galapagos; Foundation of the National Fisheries Institute of Ecuador (INP); commercial exploitation of the spiny lobster fishery initiated
1964	Ecuadorian government and CDF signs collaboration agreement; first comprehensive description of Galapagos fisheries by Quiroga and Orbes (1964)
1968	Foundation of the Galapagos National Park Service
1970	An Ecuadorian industrial fishing fleet initiates commercial exploitation of tuna
1975	First study about the Galapagos marine coastal ecosystems by Wellington (1975)
1976	INP and CDF initiated a local-based marine research program and scientific unit
1983	First stock assessment of the spiny lobster and Galapagos grouper fisheries
1986	Establishment of the Galapagos Marine Resources Reserve
1989	Prohibition of capture and marketing of sharks: establishment of the first zoning scheme by ministerial decree
1992	Management plan for the Galapagos Marine Resources Reserve; illegal beginning of the sea cucumber fishery
1993	Inclusion of social sciences in the assessment of the small-scale fishing sector
1994	Sea cucumber experimental fishing season
1995	Precautionary closure of the sea cucumber fishery
1996	Participatory Fisheries Monitoring and Research Program (PIMPP)
1998	Galapagos Special Law; Galapagos Marine Reserve (GMR); adoption of a co-management and common property regime; exclusion of industrial fishing; first annual fishing calendar
1999	Management plan of the GMR; official opening of the sea cucumber fishery; annual fishing calendar
2000	Approval of marine zoning arrangement; creation of an ecological subtidal monitoring program; annual fishing calendar

Year	Historical milestone
2001	Annual fishing calendar
2002	Fishing calendar (2002-2006); moratorium on the allocation of new fishing licenses and permits
2003	Fishing regulations
2005	Official recognition of the failure of the co-management system by the Participatory Management Board and the Inter-institutional Management Authority; prohibition of long-line fishing; approval of recreational fishing; recognition of Galapagos as a social-ecological system in the GNP management plan
2006	First official closure of the sea cucumber fishery since official opening; physical implementation of the GMR's coastal marine zoning
2007	Closure of the fishery observers program; annual fishing calendar; opening of the sea cucumber fishery
2009	Approval of a new fisheries management plan (i.e., Capítulo Pesca); closure of the sea cucumber fishery
2010	Closure of the sea cucumber fishery
2012	Official beginning of the Galapagos marine and terrestrial management plans integration process; closure of the sea cucumber fishery

The development of biological sciences (including fishery science) is closely related to the establishment of the Charles Darwin Research Station (CDRS) at Santa Cruz Island, in 1960. The CDRS represented the first local-based biological research station in Galapagos, conceived to assist the Ecuadorian government in the task of conservation (Kasteleijn 1987). The CDRS acts as the operating arm of the Charles Darwin Foundation for the Galapagos Islands (CDF). The latter is an independent, international, and nongovernmental organization, established under Belgian law on 23 July 1959 (Smith 1990). In the same year, the Ecuadorian government created the Galapagos National Park, which provided legal protection to all uninhabited areas of the archipelago.

A collaboration agreement was signed between the Minister for External Affairs of Ecuador (Armando Pesantes García) and the first president of the CDF (Victor van Straelen) on 14 February 1964 to define the terms on which the CDF could own and operate the CDRS and promote conservation and scientific investigation in the Galapagos for 25 years (Smith 1990). This agreement has been renewed for successive 5-year periods since 1991. The current agreement is valid until 2016. Thus, CDF has played a leading role as scientific adviser of the Ecuadorian government in relation to Galapagos conservation since the 1960s.

For eight years (1960–1968), the Galapagos National Park existed solely as a legal framework. In practice, the Ecuadorian government lacked the necessary infrastructure, technical capacity, and funding to manage protected areas of the archipelago (Ospina 2006; Chap. 7). For this reason, it entrusts CDF with the execution of Galapagos biodiversity inventory and conservation activities. This situation changed through the creation of the Galapagos National Park Service (GNPS) in 1968, which received full responsibility to manage the park.

The GNPS and CDF collaborated in a sustained and prolific manner on five priority research and conservation issues since inception (Smith 1990) (1) providing logistic and technical support to visiting scientists, who have conducted most of the scientific research in Galapagos; (2) increasing knowledge about the taxonomy, distribution, and abundance of Galapagos flora and fauna, particularly terrestrial endemic species, such as giant tortoises; (3) developing a tortoise preservation program through the establishment of a rearing center in Santa Cruz Island; (4) eradicating introduced and invasive species and controlling their spread on pristine areas; and (5) developing an educational program to build technical and scientific capacity, as well as to create public environmental awareness about the importance of conserving the flora and fauna. In practice, most of these activities still remain as the main priorities of both institutions.

The development of fishery science was not considered an immediate priority for the GNPS and CDF, although some scientists envisioned the importance of marine research and conservation, such as David Snow, third director of the CDF (1963–1964), and Ian Grimwood, an expert on national park management. According to Smith (1990), there was a perception, at the beginning of the 1960s, that Galapagos marine ecosystems were relatively undisturbed and did not require as immediate conservation actions as their terrestrial counterparts, so little local research was done to explore the underwater resources of the archipelago. In fact, as the Galapagos National Park lacked a marine protected area at that time, the GNPS only had legal jurisdiction and management responsibility over the terrestrial protected area. Consequently, neither the GNPS nor the CDF had available funding for the development of a local-based marine research program.

Research and management priorities of both institutions changed as a result of the work of Gerard M. Wellington, a US Peace Corps volunteer who was assigned to the CDF and GNPS to develop a proposal for a marine reserve in the Galapagos National Park. His study of Galapagos marine coastal ecosystems showed that a large proportion of marine endemic species were distributed across different types of highly diverse and complex habitats (Wellington 1975). He also highlighted the complex and fragile relationship between marine and terrestrial ecosystems. His findings and recommendations were used as a basis for the creation of the Galapagos Marine Resources Reserve in 1986 (Kasteleijn 1987).

Fishery science began formally at the Galapagos Islands in the middle 1960s, with the work conducted by the National Fisheries Institute of Ecuador (INP, Spanish acronym). The first comprehensive description of the structure and functioning of the Galapagos fishing sector was done by Quiroga and Orbes (1964). They provided estimates of the number of fishers, vessels, and fishing gears per island, as well as total production per fishery (including the tuna fishery carried out by foreign vessels), unit price per product, and local consumption and export levels. Holthuis and Loesch (1967) provided complete taxonomic descriptions of the three lobster species exploited in Galapagos: red (*Panulirus penicillatus*), green (*P. gracilis*), and slipper (*Scyllarides astori*) lobsters, including information about their fishery. One of the most prolific periods of fishery science in the archipelago was the late 1970s and early 1980s: Thanks to the economic bonanza produced in Ecuador by high oil prices in the 1970s, the financial contribution of the Ecuadorian government to the INP and CDF increased. In 1976, the INP initiated a local-based marine research program and scientific unit in collaboration with CDF (Kasteleijn 1987). The University of Guayaquil joined in 1977. This was the first interinstitutional local fishery research group in Galapagos. The main objective of this program was to coordinate research efforts and funding to evaluate the distribution and abundance of Galapagos fishery resources, as well as the population dynamics of green sea turtle populations (Reck 1979). The CDF created its own Department of Marine Biology and Oceanography in 1979 (Kasteleijn 1987).

Several scientific papers, theses, and technical reports were produced, mainly on the spiny lobster (Barragán 1975; Reck 1983, 1984) and the Galapagos grouper (*Mycteroperca olfax*, locally known as “bacalao”) (Bostock and Mosquera 1984; Rodríguez 1984, 1987; Coello 1986; Granda 1990; Coello and Grimm 1993). These studies described a range of biological, technological, and/or economic aspects of Galapagos fisheries.

The most relevant study published in the 1980s was by Reck (1983). He conducted the first stock assessment of the spiny lobster and Galapagos grouper fisheries, including an evaluation of the spatial distribution of yields, catch composition, and fishing effort. He also performed a qualitative assessment of socioeconomic aspects that affected fishers’ behavior, providing valuable insights about the basic social and economic linkages of the local small-scale fishing sector with other elements of the human system, such as tourism. Therefore, it could be considered the first spatially explicit and integrated fishery assessment in the archipelago. Unfortunately, this advance was interrupted in the early 1980s as governmental funding began to gradually decline because of the international oil price drop. INP suspended the periodic collection of fishery-related data by fishery inspectors at the main ports of Galapagos, which produced a discontinuity in the baseline assessment and ongoing monitoring of the spiny lobster (1982–1993) and finfish fisheries (1991–1996) (see Castrejón 2011).

At the end of the 1980s, the expansion of the spiny lobster fishery and the growing Asian market for shark fins increased public pressure on the Ministry of Industries and Fisheries to adopt conservation and management measures. In the absence of a management plan, a ministerial agreement was published in 1989 (Decreto Ejecutivo 151, published in the Official Register No. 191) in order to (1) prohibit the capture and marketing of sharks; (2) prohibit nocturnal and spear fisheries; and (3) establish a zoning scheme, which limited industrial fishing to an area between 5 and 15 nm offshore from the “baseline” (i.e., an imaginary line joining the outer islands of the archipelago). In 1992, the management plan for the Galapagos Marine Resources Reserve was approved 6 years after its creation (Decreto Ejecutivo No. 3573, published in the Official Register No. 994). This plan established a new zoning scheme and governance framework, but neither of these was implemented.

2.5 Advances of fishery science in the Galapagos from 1992 to 2013

Fishery science in the archipelago increased in relevance at the end of the 1990s as a result of two events: the illegal extraction of sea cucumbers and the creation of the Galapagos Marine Reserve (see Table 2.1). Both events encouraged the CDF and the GNPS to expand their locally based marine research and management programs. This section explains how these, and other events have influenced the development of fishery science from 1992 to 2013 and describes the most relevant studies produced during this period.

2.5.1 The influence of the sea cucumber fishery (1992–1998)

The collapse of the sea cucumber fishery (*Isostichopus fuscus*) along the Ecuadorian continental coastline in 1991 produced a "roving bandits effect" (*sensu* Berkes et al. 2006)—sequential depletion of this species in the Galapagos Islands since 1992 by mobile agents, notably Asian middlemen together with fishers (and non-fishers) from coastal provinces of mainland Ecuador (Castrejón 2011; Castrejón and Charles 2013). This event attracted massive governmental, scientific, and public attention, particularly from nongovernmental organizations (NGOs) and international development agencies. These organizations tried to avoid the spread of invasive species (e.g., fruits, insects) to pristine areas of the archipelago by poachers, who usually established illegal fishing camps in the protected areas. Other important concerns were (1) the ecological extinction of *I. fuscus* due to the open access nature of the fishery and the high unit prices that stimulated overcapitalization of the small-scale fishing sector, (2) the ecological impact produced by industrial fishing, and (3) the exponential growth of tourism and immigration (Macfarland and Cifuentes 1996).

The increasing social conflicts and ecological degradation caused by the inter- action of socio-environmental problems led to the declaration of the Galapagos Special Law (GSL), which included the creation of the Galapagos Marine Reserve (GMR) in March 1998. Both measures represented an important step forward to tackle in an integrated way the complex socio-environmental problems faced by the archipelago (González et al. 2008; Castrejón and

Charles 2013) and were associated with increased external funding directed to conservation and sustainable development initiatives, which peaked in 2003 (Ospina 2006). These events influenced the development of fishery science in the archipelago between 1992 and 1998, as follows:

1. The boom-and-bust exploitation cycle of *I. fuscus* was the almost exclusive focus of local fishery management authorities and NGOs for 14 years, until the economic collapse of the sea cucumber fishery in 2006. Between 1992 and 1996, most research efforts focused on evaluating biological and ecological impacts produced by the illegal expansion of the sea cucumber fishery (Aguilar et al. 1993; Richmond and Martínez 1993; Bermeo 1995; De Paco et al. 1995), as well as its reproductive biology (Tora-Granda 1996).

   Based on the findings and recommendations produced by a fishery observer program created by the INP (1994–1998), precautionary management measures were implemented, including an experimental fishing season (October–December 1994) and a total fishery closure (1995–1999). The enforcement of both measures generated several conflicts between fishers, managers, and NGOs, which escalated severely at the middle of the 1990s through violent protest and strikes (Macfarland and Cifuentes 1996).

2. Social–environmental conflicts caused by the sea cucumber fishery encouraged the inclusion of social sciences, particularly in the assessment of the small-scale fishing sector (Ospina 2007). Sociological studies conducted between 1993 and 1997 focused on two main interrelated issues: (a) the conflicts and socioeconomic impacts produced by the sea cucumber fishery (Andrade 1995; Barona and Andrade 1996; Macfarland and Cifuentes 1996; De Miras et al. 1996) and (b) the relationship between the exponential and unregulated growth of fishing and tourism activity and the increasing number of immigrants from mainland Ecuador (Grenier 1996). The most influential social analyses of the 1990s were conducted by Grenier (1996) and Macdonald (1997), who provided useful insights about the impact of globalization on the

socioeconomic dynamic of Galapagos human populations and identified the conflicts associated with the top-down management and open access regime of Galapagos fisheries. In particular, Macdonald (1997) provided recommendations for the design and adoption of common-property and co-management regimes within the GMR. The latter was operationalized by two nested decision-making bodies: The Participatory Management Board (PMB) and the Interinstitutional Management Authority (IMA).

3. In 1996, the exponential growth of the fishing sector produced by the illegal expansion of the sea cucumber fishery encouraged CDF to create the Galapagos Fishery Monitoring Program, currently known as Participatory Fisheries Monitoring and Research Program (PIMPP, Spanish acronym) in close collaboration with the GNPS, the Undersecretary of Fishing of Ecuador, and the local fishing sector (Bustamante 1998). The PIMPP was initially sponsored by the David and Lucile Packard Foundation and later by the United States Agency for International Development (USAID). PIMPP represented the beginning of the systematic collection of fishery-dependent data on a daily basis in the three main Galapagos ports (Puerto Ayora, Baquerizo Moreno, and Villamil). This monitoring program, which included fishery observers (1999–2006), produced from 1997 to 2006 an extensive and spatially explicit database, particularly for the sea cucumber, spiny lobster, and finfish fisheries.

2.5.2 Co-management of the GMR (1998–2013)

After formal declaration of the GMR, the GNPS assumed full responsibility for the management of the marine protected area. Consequently, the Undersecretary of Fishing of Ecuador ceded its management responsibility, although it is still represented within the Interinstitutional Management Authority (IMA). This institutional change led the GNPS to create its own Marine Resources Department, currently known as "Proceso de Conservación y Uso de Ecosistemas Marinos" (PCUEM), and to strengthen its collaborative framework with the CDF, particularly through the enhancement of the PIMPP.

Between 1998 and 2006, the PCUEM focused its management efforts on (Jácome and Ospina 1999; Anónimo 2000, 2001, 2002) (1) participatory development of the GMR's legal framework, including the GMR management plan, fishing registry, fishing rules, coastal marine zoning, and fishing calendars; (2) management of the sea cucumber and spiny lobster fisheries; and (3) preventing illegal harvesting of tuna and sharks by national and foreign industrial fleets. The CDF assumed a leading role in coordinating and executing the PIMPP and, in the development of fishery science, strengthening its role as scientific and technical adviser of the GNPS and co-management bodies.

The information generated by the PIMPP led to the second prolific research period in the archipelago, which lasted from 1998 to 2007. In this period, substantial external funding was provided by bilateral and multilateral organizations, mainly by the Inter-American Development Bank (IDB), USAID, and the Spanish Agency for International Development Cooperation. Between 2002 and 2006, these organizations spent more than US$10.8 M to foster conservation and sustainable development initiatives in the GMR (González and Tapia 2005; BID 2006; Ospina 2006; WWF-USAID 2006). Most of this funding was directed to (1) support the PMB in facilitating local stakeholder's participation and capacity building, including the design of a monitoring system; (2) enhance the PIMPP and fishery management; (3) develop participatory planning and implementation of the GMR's coastal marine zoning and the development of a long-term ecological subtidal monitoring program; (4) strengthen GNPS's monitoring, control, and surveillance system; and (5) develop alternative livelihood activities for the local small-scale fishing sector in order to compensate them for the short-term impacts of marine zoning. Unfortunately, many of these initiatives failed once the external agencies and NGOs left these projects in the hands of local institutions and stakeholders, without effective exit strategies to sustain the necessary local capacity building, long-term governmental funding, institutional memory, and/or sustained interest of beneficiaries.

An additional key factor of failure was the political and management instability observed in Ecuador between 1996 and 2006, which was reflected in the absence of a provincial science and technology plan for the archipelago (a problem that persists). Consequently, Galapagos management and research priorities changed constantly according to personal interests of management authorities and external donors' agendas. Thus, allocation of the economic and human resources available for conservation and sustainable development initiatives was made, in many cases, in an uncoordinated way without clear guidelines on the "shared vision" (González 2007). As time went by, this problem created a disconnection between the priorities of the GNPS and external donors, such as bilateral and multilateral organizations and NGOs.

While CDF researchers participated in several of the activities described above, particularly on (1), (2), and (3), their research efforts were mostly focused on the biological baseline assessment and monitoring of fishery resources, particularly sea cucumber and spiny lobster from 1997 to 2006. During this period, several technical reports were published by CDF in collaboration with GNPS (e.g., Hearn and Toral 2006), including reports of a lobster tagging program (Hearn 2004) and participatory sea cucumber surveys (e.g., Castrejón et al. 2005; Toral-Granda 2005a). All these studies were used as the basis for decision-making.

An interinstitutional project led by CDF and GNPS to evaluate the ecological impact produced of long-line fishing (Murillo et al. 2004) deserves a special mention. The findings and recommendations of this and other similar studies (Garcia 2005; Tejada 2006) represented one of the most controversial management issues between 2002 and 2005. The conflicts associated with this fishing gear were finally resolved by IMA in 2005 through the prohibition of long-line fishing inside the GMR and the authorization of an alternative livelihood activity for the local fishing sector, named locally as "pesca artesanal vivencial" (known in English as "recreational fishing"; see Zapata 2006; Schuhbauer and Koch 2013).

The studies conducted by the CDF have been important to consolidate the development of fishery science in the archipelago. Nevertheless, the contribution of CDF to mainstream fishery science has been historically low, as a result of its applied focus as an NGO and biased to the evaluation of the reproductive biology and stock assessment of fishery resources. For example, just 5 % of the 130 peers- reviewed papers published by CDF-based scientists between 2005 and 2011 was fishery related (Table 2.2). Most fishery-related studies conducted by the CDF are part of the "grey literature," which still represents the most important source of knowledge about the origin and development of fishing in the Galapagos Islands.

Table 2.2 Scientific production of the Charles Darwin Foundation from 2005 to 2011. FR= Fishery-related. Note: only peer-reviewed papers, technical reports, theses, and other documents about the Galapagos Islands produced by CDF´s scientific staff (2005-2011) and adjuncts researchers (2007-2011) are included. Source: CDF annual reports (2005-2011).

Year	Peer review (ISI Journals)		Technical reports, thesis and others		Total
	Non-FR	FR	Non-FR	FR	
2005	11	1	15	6	33
2006	7	1	31	7	46
2007	12	3	62	8	85
2008	24	2	47	4	77
2009	35	0	71	6	112
2010	19	0	36	3	58
2011	15	0	19	0	34
Total	123	7	281	34	445

At the international level, the joint contribution of CDF and other local and international institutions (e.g., universities, research centers, NGOs, etc.) to main- stream fishery science is similarly quite limited. A total of 1,392 Galapagos-related peer-reviewed papers, indexed in the Journal of Citation Report (JCR), were published between 1535 and 2007 (Santander et al. 2009). Most of them are classified as part of "natural sciences" (92 %); only 3.8 % are classified as part of "social sciences" (53 papers), a category that includes "fisheries" as an area of knowledge. This category represents the higher percentage within social sciences (29.3 %), followed by "history" (22.4 %) and "tourism" (15.5 %). This implies that only 16 socioeconomic fishery-related peers-reviewed papers were published in a period of 472 years. Santander et al. (2009) did not include a category called "fisheries" within "natural sciences," so that natural science work in fisheries was classified as part of "taxonomy," "conservation biology," or "evolutionary ecology," which represent the areas of knowledge with more

Galapagos-related peer-reviewed publications. However, based on our experience, the number of peer- reviewed papers about the biology and population dynamics of the main Galapagos fishery resources (*I. fuscus*, *M. olfax*, *P. penicillatus*, and *P. gracilis*) is quite limited.

Most CDF fishery-related studies have evaluated the management and/or population dynamics of *I. fuscus* (Shepherd et al. 2004; Hearn et al. 2005; Toral-Granda 2005b; Toral-Granda and Martínez 2007; Wolff et al. 2012b), *P. penicillatus* (Hearn and Toral-Granda 2007; Hearn and Murillo 2008), and *S. astori* (Hearn 2006). Very few interdisciplinary studies were done between 1997 and 2007, none of them directly by CDF researchers. Two examples are the work of Taylor et al. (2007), who conducted a quantitative analysis about the economic links between tourism, fishing, and immigration, and the study of Conrad et al. (2006), who conducted a bioeconomic analysis to evaluate the trade-offs associated with alternative management approaches for the sea cucumber and lobster fisheries. Both studies are interdisciplinary fishery assessments whose findings and recommendations could be relevant to decision-making.

Since 2007, fishery research has focused on evaluating the GMR's governance subsystem (Baine et al. 2007; Heylings and Bravo 2007; Viteri and Chávez 2007; Hearn 2008; Defeo et al. 2009; Castrejón 2011; Jones 2013), the ecological impact of "El Niño" and climate change on fisheries and marine ecosystems (Larrea and Di Carlo 2009; Edgar et al. 2010; Wolff et al. 2012a; Defeo et al. 2013), and the spatial dynamics of fishery resources and the fishing fleet (Peñaherrera 2007; Castrejón 2011; Bucaram et al. 2013) in order to measure and model the applicability of spatially explicit management measures (e.g., territorial use rights for fishing, seasonal closures, spatial gear restrictions spatial gear restrictions, etc.), as recommended by Defeo et al. (2009), Castrejón (2011), Ramírez et al. (2012a) and Castrejón and Charles (2013).

Nevertheless, in the most recent years, the GNPS and NGOs have moved their funding and research efforts forward to (1) evaluate the management effectiveness of the GMR, including marine zoning (Hockings et al. 2012; Castrejón and Charles 2013); (2) improve the management and marketing system of the spiny lobster fishery (Ramírez et al. 2012a); (3) improve the assessment and management of Galapagos grouper and wahoo (*Acanthocybium solandri*), taking as basis the studies conducted by von Gagern (2009) and Jobstvogt (2010); and (4) adapt and integrate the GNPS' marine and terrestrial management plans, a work in progress.

2.5.3 Limitations to the progress of fishery science (1998–2013)

The development of fishery science was gradually limited by the inclusion of the CDF into the Participatory Management Board (PMB), as a representative of the Conservation, Science and Education Sector (1998–2008). The dual role played by the CDF as scientific advisor and conservation advocate (i.e., "judge and prosecutor") blurred the separation between science and management (Castrejón 2011; Orensanz et al. 2013). The conservation advocacy role played by the CDF had several implications (1) scientists were required to allocate less time for fishery research and more time to participate in highly politicized management meetings, (2) conflicts emerged in the PMB when some scientists "crossed the line" from science to advocacy, and (3) advice provided to the PMB gradually lost legitimacy and credibility because some recommendations provided by CDF scientists were seen as biased and not based on sound scientific knowledge (Ben-Yami 2001; Ramírez 2007; Castrejón 2011). Also, CDF's scientific role in objective data gathering during fishery monitoring was not clearly separated from GNPS's function to control minimum landing sizes (Reck, pers. obs.).

The situation described above affected negatively the relationship of the CDF with the fishing sector and especially with the GNPS. The relationships between both institutions worsened as some CDF scientists came to be seen as preoccupied with their institutional image, as well as in some cases showing condescension and even outright arrogance during PMB management meetings (Ramírez 2007; Gibbs 2008). In response, the GNPS—as it acquired more experience, infrastructure, and technical and scientific capacity—gradually has tried to become more independent of the advice provided by the CDF. A competitive environment for funding and leadership emerged between GNPS and CDF, which has fractured their relationship over time.

In 2007, the management attention (and funding) that fishing-related programs and projects had been receiving from management authorities and NGOs decreased abruptly for three main reasons:

1. The sea cucumber fishery was informally declared as a “lost cause” by some leading “conservationists” who considered its economic collapse as a necessary step to weaken the fishing sector’s political power and to eliminate ongoing conflicts over management of this fishery. Paradoxically, the economic collapse of *I. fuscus* in 2006 led to a severe reduction of research directed toward its recovery. An opposite trend has been observed in other Latin American countries, such as Chile and Uruguay, where a fishery collapse was seen as an opportunity to promote institutional and operational tools for stock rebuilding, such as the implementation of territorial use rights for fishing (TURFs) and co-management regimes (Defeo et al. 2009).

2. The CDF lacked external funding (and interest) to continue coordinating and executing the PIMPP, which resulted in the closure of the fishery observer program by the end of 2006. In 2007, the PCUEM took full responsibility of the PIMPP. This change produced a discontinuity in the ongoing fishery monitoring, the representativeness of the data collected, and the production of technical reports (Ramírez et al. 2012b).

3. Exponential and unregulated growth of tourism was recognized as the main socioeconomic driver affecting Galapagos conservation (Epler 2007; Watkins and Cruz 2007). Thus, CDF’s executives lost interest in strengthening the CDF’s fishery research and monitoring program and changed conservation efforts toward comparatively less conflictive issues (tourism management) and more “charismatic” species (shark conservation). This change improved CDF’s fund-raising efforts, whose total budget had declined since 2004 (CDF 2006a). Nevertheless, the number of CDF’s fishery scientists was reduced from six in 2007 to two in 2013. As a result, the scientific production in fishery science has been negatively affected (Table 2.2).

Only a few fishery research projects are currently conducted by the CDF, most of them biased toward the biology and ecology of the Galapagos grouper. In this scenario, other international NGOs (e.g., WWF and Conservation International) and the University of San Francisco de Quito have increased their participation in the development of fishery science in the archipelago, acquiring a growing importance as scientific advisors of the GNPS.

2.6 The transition from a resource-focused to a social–ecological systems approach: a work in progress

The transition from a resource-focused to an SES approach in the archipelago officially initiated in 1998 with the declaration of the Galapagos Special Law (GSL), which legitimized the adoption of a co-management regime in the GMR. Such an approach is seen as a key component within a social–ecological framework (Berkes 2011). The term "social–ecological systems" appeared first in the research literature in the late 1990s (Berkes and Folke 1998); at that time, the conceptual and methodological framework for an SES approach was naturally poorly known and still in development. It was likely for this reason that this innovative management approach was not adopted explicitly either in the GSL or in the management plan of the GMR. Nevertheless, establishment of a co-management regime helped "pave the way" for the gradual adoption of an SES approach.

The legitimation of local stakeholders as co-managers of the GMR created a process within which fishers could indicate their aspirations, needs, and concerns in the PMB and IMA and within which it became clear that attention to both the people and the natural system is important for the conservation of the archipelago. A better sense of the complexity of the socio-environmental problems facing the management of the main Galapagos shellfisheries arose from this.

Differing perspectives, particularly about the status and management of the sea cucumber fishery, created serious conflicts between fishers, managers, scientists, and conservationists from 1994 to 2005. Co-management of the sea cucumber fishery did not avert its economic collapse in 2006. However, the subsequent debate over the causes of this major failure, within and beyond the limits of the PMB and IMA, contributed to prioritizing adoption of an SES approach in the GMR, which thus emerged in a bottom-up way through a “learning by doing” process, as will be explained below.

The middle of the 2000s was a period characterized by a general questioning of the usefulness of the resource-oriented approach adopted by CDF’s conservation science, as a means to resolve the main socio-environmental problems of Galapagos Islands, including shellfishery overexploitation. This issue was one of the main topics discussed in the first international scientific colloquium of social science held at Quito and Santa Cruz Island in August 2006 (Ospina and Falconí 2007). Based on the results of this colloquium and taking into consideration the studies of Watkins and Cruz (2007), Gibbs (2008), González et al. (2008), Tapia et al. (2009), and Castrejón (2011), some key conclusions can be drawn (1) science in Galapagos is biased toward research and management of charismatic threatened and endangered species and aggressive invasive species but excludes issues concerning the governance of urban and rural areas; (2) research projects developed by NGOs are not responding to the management needs of the GNPS, but to the interests of external donors; (3) there are no truly interdisciplinary research teams in Galapagos, with biological and social scientists working separately; (4) an SES approach is necessary to achieve an integrated understanding of the economic, social, cultural, institutional, and ecological drivers of change that are affecting the complex dynamics of the Galapagos Islands, in particular of globalization and the exponential and unregulated growth of tourism. Such knowledge is fundamental to evaluate alternative management scenarios; (5) a new institutional approach is needed to build resilience and capacity building to cope with constant and unexpected changes; and (6) effective communication, coordination, and participatory methods must be adopted to redefine priority research areas and to develop a science and technology plan for Galapagos.

Public recognition of the six points described above has facilitated the transition from a resource-focused to an SES approach, not only in the assessment and management of Galapagos fisheries but for all the human activities in Galapagos as a whole. This process is still in progress, with important management actions having been taken to complete the change. In terrestrial areas, the transition was legitimized with the approval of the Galapagos

National Park management plan in May 2005. This plan adopted explicitly a conceptual and methodological SES framework to assess and manage the protected areas of the archipelago (González et al. 2008). This was the first time that the GNPS conceptualized the archipelago as an SES. At the time of writing, the GNPS is working on the adaption and integration of the Galapagos marine and terrestrial management plans. The main objective of this social–ecological management plan, known as "plan de manejo de las áreas protegidas de Galápagos para el buen vivir" (management plan of the Galapagos protected areas for the good living), is encompassing both the marine and terrestrial protected areas, as well as additional (inhabited) areas, in order to manage them as a complex adaptive system (José A. González, pers. comm.).

The transition from a resource-focused to an SES approach continued with the CDF's participatory internal process to redefine its institutional mission and vision through the creation of its strategic plan 2006–2016 (CDF 2006b). In the fishery area, the transition process acquired a new impetus in 2006 with the participatory development of a fishery management plan (see Castrejón 2011).

2.6.1 Participatory development of a new fishery management plan

The failure of the GMR's co-management system to assure the biological and economic sustainability of the main Galapagos shellfisheries was recognized by PMB and IMA members in 2005; these bodies requested an evaluation of the GMR's co-management scheme and the design and adoption of a new management approach. One year later, the first official closure of the sea cucumber fishery was implemented. A social–ecological systems approach was suggested by Defeo (2007), Defeo et al. (2009), and Castrejón (2011) to identify the biological, socio- economic, scientific, and legal problems associated with the poor performance of this co-management regime. Most recommendations produced by these studies were used by a PMB technical commission to develop a draft fishery management plan (FMP). After 3 years of participatory work, the PMB and IMA unanimously approved the FMP (locally called "Capítulo Pesca") in January 2009 (see http://galapagospark.org/documentos/capitulo_pesca_reserva_marina_galapagos.pdf).

The FMP (previously known as fishing calendar) was the first plan unanimously approved by all fishing sector representatives since 1999. The most important innovation of the FMP was the participatory definition of strategic planning, which defined an action plan to reach a "shared vision." The FMP strategic planning has been useful to communicate the GNPS's management and research priorities to NGOs, multilateral organizations, and potential donors. For example, the WWF-Galapagos Program used the FMP's strategic planning as an input to review and adapt its own sustainable fishery strategy for the 2005–2015 Galapagos Program. The FMP also included for the first-time specific management objectives for each fishery, as well as practical and straightforward mechanisms to review and adapt the FMP and to define research priorities in a participatory way. It also incorporated target and limit reference points using a precautionary "traffic light" approach (*sensu* Caddy 2002) for the sea cucumber fishery. The annual independent survey plan for this species was revised and redesigned to provide accurate estimates of stock size and the corresponding total allowable catch (Wolff et al. 2012b). The decision rule agreed upon for the sea cucumber fishery contributed to reducing the conflicts associated with its management (Orensanz et al. 2013). Application of this management approach has led to the fishery being closed four times (2009, 2010, 2012, and 2013) as required.

2.6.2 Transition challenges

Implementation of co-management and ecosystem-based spatial management approaches represents important steps forward to tackle the complex socio- environmental and institutional problems that led to overexploitation of the sea cucumber and spiny lobster fisheries (Castrejón and Charles 2013). Nevertheless, effectiveness of these approaches in assuring the sustainability of Galapagos SSF was limited by several socioeconomic and institutional factors, being one of the most important lack of long-term strategic planning and practical mechanisms for precautionary and adaptive management (see Defeo et al. 2009; Castrejón 2011). The FMP was created to resolve this problem and to facilitate the adoption of an SES approach. Nevertheless, its full implementation is being precluded by the continuing dominance of the resource-focused approach within the structure and function of PCUEM and CDF's fishery research and monitoring programs. This makes these programs inadequate to deal properly with the social-ecological assessment and co-management of SSF in the archipelago.

In 2012, the GNPS' internal administrative structure and organization was adapted by management authorities to increase its effectiveness. However, at time of writing this chapter, the PCUEM still lacks of the expertise and funding needed to conduct the interdisciplinary and participatory research required to manage SSF. It also lacks the skills and resources needed to promote the effective adoption of a co-management approach and the implementation of the FMP, such as mediation, facilitation, and strategic planning.

On the other hand, despite several attempts by CDF since 2007 to restructure its marine and terrestrial research programs, based on the priorities defined in its strategic plan 2006–2016, its fishery research program remains focused on bioecological aspects and conventional stock assessment. As a result, there is an inadequate, outdated, and in some cases nonexistent information based on the local socioeconomic, cultural, and institutional issues that affect SSF management in the Galapagos Islands (Castrejón and Charles 2013). There is also a poor understanding about the drivers of change, such as globalization and climate variability (e.g., El Niño), that are affecting the dynamics of fisheries. In the same way, few studies have been conducted to evaluate the socioeconomic linkages of fishing with other elements of the human system, such as tourism. Therefore, it can be said that the innovation that took place in fishery management since 1998 outpaced the innovation in fishery research.

2.6.3 Building institutional resilience

There is no doubt about the significant role that CDF has played in the development of science and capacity building in Galapagos for the last 53 years. However, despite CDF's valuable efforts to accomplish its mission, greater and more reliable funding and scientific capacity, as well as infrastructure and equipment, are required to meet the growing requirements of local authorities and stakeholders for social–ecological research in fishery, marine, and terrestrial sciences.

A new institutional approach is needed to evaluate and manage the Galapagos Islands as an SES. This is crucial to increase the resilience and adaptive capacity of institutions to deal with potential impacts of globalization and climate change (Watkins and Cruz 2007; Gonza´lez et al. 2008; Defeo et al. 2009, 2013). As the CDF has played a leading role in the development of fishery science, as well as marine and terrestrial sciences in general, it is important to evaluate how this institution can enhance its institutional resilience in order to promote the adoption of an SES approach in the archipelago. Such analysis is timely, considering that the collaboration agreement between the Ecuadorian government and the CDF will end in 2016, and it is uncertain if it will be renewed, modified, or cancelled. Therefore, this analysis can be used as input in the current debate about the causes of the institutional crisis faced by CDF and its future role as scientific advisor of the Ecuadorian government.

Three main problems have precluded the consolidation of the CDF as a research institution (1) the dual role played by the CDF as both scientific advisor and conservation advocate, (2) the lack of an adequate and steady income (Smith 1990), and (3) the instability and low resilience of its research programs (Gibbs 2008). The ambiguous role played by the CDF has affected its relationship with the GNPS (see previous sections); in combination with the global economic crisis, this has reduced the political and economic support provided by the Ecuadorian government and several multilateral organizations. As a result, the CDF's total income decreased 27 % from USD 4.24 M in 2007 to USD 3.06 M in 2011 (CDF 2008, 2012). Total investment on research, technical assistance, and information decreased 24 % from USD 3.01 M to USD 2.28 M between 2007 and 2010 (no official data for 2011 and 2012). Such a crisis has resulted in a large loss of institutional memory, reflected also in a massive resignation and dismissal of scientists. For example, the CDF's administrative and scientific staff decreased 19 % from 143 in 2005 to 115 in 2011 (CDF 2006a, 2012).

The challenging economic environment, noted above, and the high turnover rate in CDF's scientific staff (see Gibbs 2008) have negatively affected the stability and effectiveness of research programs. The leadership and decision-making of these programs lie in the hands of a small number of senior researchers, so that when, inevitably, some of these individuals leave the CDF (usually without a proper knowledge transfer process), such programs enter into a dysfunctional state. While CDF does then reassign project management responsibilities, this is often to newly hired researchers, which also limits the capability to meet project objectives (Gibbs 2008). This is a recurrent problem that not only impoverishes CDF's institutional memory but degrades the resilience of research programs.

The precarious economic and organizational situation faced by the CDF is threatening its very existence (CDF 2012). The CDF's mission— "to provide knowledge and assistance through scientific research and complementary action to ensure the conservation of the environment and biodiversity in the Galapagos" (CDF 2006b)—may now be unsustainable. As an example, the production of peer- reviewed papers, technical reports, and theses by CDF researchers have decreased since 2009, particularly in relation to fishery science (Table 8.2). In the latter, the scientific production was zero in 2011.

The decreasing trends in funding, institutional memory (i.e., number of expert scientists), and scientific production may signal a loss of CDF's institutional resilience—the capacity to manage continuity and change in order to adapt an institutional system while not changing it so often that stakeholders lose their trust in the institutional setup (Herrfahrdt-Pa¨hle and Pahl-Wostl 2012). At some point, the three indicators mentioned above may decline below critical threshold values, leading potentially to institutional collapse. Precautionary management measures are needed to avoid such an undesirable pathway.

The CDF has confronted several economic and institutional crises since its inception in 1959 (see Smith 1990). However, the history of the CDF itself suggests that the crisis that it is currently facing would not be resolved in the long term simply by creating a new strategic plan, acquiring external funding, and hiring more senior scientists. All these strategies have been attempted several times in the past, and they have not been effective in building institutional resilience. Therefore, instead of preserving the status quo, the CDF crisis should be used as an opportunity for learning, adapting, and entering onto more sustainable pathways (Herrfahrdt- Pa¨hle and Pahl-Wostl 2012). To this end, it is advisable to envision multiple alternative scenarios and actions that might attain or avoid particular outcomes; thus, it will be possible to identify and choose resilience-building policies before a threshold is exceeded (Folke et al. 2002).

A scenario to consider is the transformation of the CDF into an interdisciplinary research center. This would address the fundamental point, as evidenced throughout this chapter, that most of CDF's institutional weaknesses are related to its structure and functioning as an international NGO. This has had profound implications about how science is being conducted, advice provided, and funding obtained.

The transformation of the CDF would need to be accompanied by a broadening of support, within and beyond the limits of the CDF. In particular, significant additional resources from the national government and bilateral and multilateral organizations are required. The Ecuadorian government, as any other state in the world, must assume responsibility and leadership in the development of its science and technology. Fortunately, this has been recognized as a strategic goal within Ecuador's national development plan 2013–2017 (SENPLADES 2013). This represents a window of opportunity that can be drawn upon to transform the CDF into an interdisciplinary research center, which should have at least the next fundamental features:

1. The center must be governmental in order to receive an adequate and steady income from the Ecuadorian government. This will require major changes in the legal structure, organization, and administration of the CDF, as well as reforms in the Galapagos Special Law.

2. The center must be financially and administratively autonomous from governament management institutions, particularly from the GNPS, in order to separate management from science. Otherwise, scientific work could be controlled by political or personal agendas, which could limit or censor science, outreach, and critical thinking, as sometimes has happened in Galapagos (Castrejón and Reck, pers. obs.). As an example, the Canadian government has been recently accused of muzzling and censoring its scientists to the point that research cannot be published, even when there

is collaboration with international researchers, unless it matches government policy (Lavoie 2013).

3. The structure and function of the Stockholm Resilience Centre in Sweden (SRC 2009) and the research centers of the Mexican National Council for Science and Technology (CONACYT, Spanish acronym) could be good examples to follow.

4. Research priorities must be defined according to a Galapagos-specific science and technology plan that integrates the FMP into it and is not reliant on external agendas, as suggested by Tapia et al. (2009).

5. An integrated conceptual framework for long-term social–ecological research should be adopted. For example, the "press-pulse dynamics" (PPD) framework developed by Collins et al. (2011) could lead to a more thorough understanding of Galapagos as an SES.

6. The center must create strong bridges with stakeholders and local institutions, particularly with GNPS, municipalities, universities, and NGOs. Research efforts must be coordinated to create synergies and complementarity, while negative competition among institutions must be avoided.

7. Scientists within the center must focus on doing science and providing objective feedback to local institutions and stakeholders while avoiding conservation advocacy. In this sense, "science advice must meet idealistic standards for objectivity, impartiality, and lack of bias. Acknowledging that science advisors are imperfect at meeting those standards, they nonetheless need to strive to produce sound, non-partisan advice, because of the privileged accountability given to science advice in decision-making. When science advisors cease to strive for those ideals and promote advocacy science, such advice loses the right to that privileged position" (Rice 2011, p. 2007).

8. A solid interdisciplinary research group at a high academic level mostly from Ecuador must form the center (to the extent that the scientific capacity exists in the country). Furthermore, to ensure continuity in information and expertise and avoid loss of institutional memory (Herrfahrdt-Pa¨hle and Pahl-Wostl 2012), at least some CDF staff should remain. The center also must include a high-quality research school for postgraduate capacity building.

9. Finally, a strategic and long-term plan-based approach must be adopted to mitigate the high turnover rate persistently observed in the Galapagos' scientific community. This is a key factor to increase the resilience of research programs.

Other scenarios can be envisioned, such as the creation of a new interdisciplinary public research institution, with the CDF remaining as an international NGO. Nevertheless, whichever the scenario selected, the goal recommended is accomplishing six crucial objectives (1) enhance the quality, relevance, and applicability of science conducted in the archipelago; (2) encourage the leadership of Ecuador in the development of its own science and technology; (3) define research priorities, funding, and scientific capacity required, based on a Galapagos-specific science and technology plan; (4) maintain the separation between management and science; (5) avoid the total loss of institutional memory and expertise developed by the CDF; and (6) adopt a new institutional approach to enhance the resilience of research programs and meet, in a cost-effective way, the growing requirements of social–ecological research in fishery, marine, and terrestrial sciences in the Galapagos Islands.

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CHAPTER 3. IMPROVING FISHERIES CO-MANAGEMENT THROUGH ECOSYSTEM-BASED SPATIAL MANAGEMENT: THE GALAPAGOS MARINE RESERVE

3.1 Publication information

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3.2 Abstract

Ecosystem-based spatial management (EBSM) can provide a mechanism for a strategic and integrated plan-based approach to managing human activities in the marine environment. An EBSM approach was adopted in the Galapagos Marine Reserve (GMR) at the end of the 1990s with the adoption of marine zoning. The latter was created under a co-management regime to reduce conflicts among users arising over incompatible demands for ocean space, to mitigate the impact of human activities on sensitive ecological areas, and to contribute to the sustainability of Galapagos fisheries. Unfortunately, the promise of an EBSM approach in the GMR has not been matched by effectiveness in practice, in achieving the established management objectives. The aim of this paper is to evaluate the shortcomings and lessons learned related to planning, implementation, monitoring, evaluation and adaptation of the GMR's marine zoning scheme, and to provide recommendations to better realize the potential value of the EBSM approach to co-managing the shellfisheries of the GMR.

3.3 Introduction

A key problem with conventional approaches to fisheries management has been its focus on production from a single target species. That single-species preoccupation has made this management approach inadequate because it did not consider the impact of fishing on non-target species and marine habitats, and neglected the human factors (social, economic, cultural and institutional) that affect fisheries management (Charles, 2001; Garcia and Charles, 2007; FAO, 2009). Recognition of the significant direct and collateral impacts that fishing imposes on marine ecosystems has encouraged adoption of ecosystem-based management (EBM, also referred to as the ecosystem approach to fisheries, EAF). This integrated approach considers the entire ecosystem, including humans, and has as a main goal maintaining an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need (McLeod *et al.*, 2005; De Young, Charles and Hjort, 2008).

Even though EBM has been recognized as a potentially powerful approach for rebuilding depleted marine fish populations and for restoring the ecosystems of which they are part (Worm *et al.*, 2009), several challenges to its wide implementation must be addressed. One of the most important is a lack of clear, concrete and comprehensive guidelines that outline in a practical manner how EBM can be implemented in marine areas (Ehler, 2008).
The EBM approach interacts closely with that of integrated management, which focuses on managing the multiple human uses of spatially-designated areas, and which is typically viewed as incorporating EBM as a fundamental component (Charles, 2011). The idea is that since marine ecosystems are places, and human activities affecting them (fisheries, tourism, marine transport, oil and gas exploitation, etc.) occur within those places, ecosystem-based management must be inherently place-based (Crowder and Norse, 2008). Hence, combining ideas of ecosystem-based management and spatial management, the integrated approach of ecosystem-based spatial management, EBSM, has emerged over the last decade as a way to apply EBM in coastal and marine environments (Douvere and Ehler, 2009).

The main aim of EBSM (which in the marine context of this paper includes marine spatial planning, MSP) is to provide a mechanism for a strategic and integrated plan-based approach to manage current and potentially conflicting uses, to reduce the cumulative effects of human activities, to optimize sustainable socio-economic development and to deliver protection to biologically and ecologically sensitive marine areas (Douvere and Ehler, 2009). This management approach has been successfully used in several marine areas of the world, with Australia's Great Barrier Reef Marine Park (GBRMP) considered a particularly successful example of its implementation (Day, 2008; Douvere, 2008).

An EBSM approach was adopted in the Galapagos Marine Reserve (GMR; Fig. 3.1) at the end of the 1990s. This occurred in order to deal with several ecological, socioeconomic and political challenges strongly related to the rapid growth of fishing and tourism activity in the archipelago (González *et al.*, 2008; Castrejón, 2011). The cornerstone for the application of an EBSM approach in the GMR was the adoption of marine zoning, a spatially explicit management tool that was designed, planned and implemented by a consensus-based participatory process between 1997 and 2006 (Heylings, Bensted-Smith and Altamirano, 2002; Calvopiña *et al.*, 2006).

The GMR's marine zoning was brought forward, under a co-management regime, in order to (SPNG, 1998): (1) contribute to the sustainability of Galapagos fisheries by providing potential areas from which fishery stocks can recover and spillover into fishing grounds; (2) reduce conflicts among users as a result of incompatible demands for ocean space (e.g., tourism vs. fishing; small-scale vs. large-scale fishing); and (3) mitigate the impact of uses on sensitive ecological areas of the archipelago, which are critical to the functioning of marine ecosystems and the conservation of threatened species (Edgar *et al.*, 2008).

This paper examines the effectiveness of GMR's marine zoning approach, as an illustration of EBSM, based on a set of evaluation criteria widely seen as essential to successful marine management, including EBSM: effective planning, monitoring, implementation, evaluation and adaptation (Day, 2008; Douvere, 2008). The paper explores the extent to which GMR's marine zoning has achieved these five basic components since its inception, and on the other hand, highlights shortcomings in implementation of EBSM that limit its potential to improve GMR's shellfisheries co-management.

Further, the paper provides a set of insights to improve the GMR's marine zoning. Such an analysis is timely to inform the first comprehensive and integrated management effectiveness evaluation of the GMR's marine zoning, which is being undertaken by the Galapagos National Park (GNP), the institution in charge of the management of the GMR, with the support of several local and international non-governmental organizations (NGOs).

The organization of this article is as follows. Section 2 provides a background on the history of the current marine zoning scheme in the GMR, and its impact on the co-management of shellfisheries. Section 3 examines the shortcomings and lessons learned related to the GMR's marine zoning, while Section 4 provides recommendations to improve its performance. Section 5 presents the main conclusions.

3.4 History of marine zoning in the Galapagos Marine Reserve

3.4.1 Creating a legal framework

The Galapagos Archipelago is recognized worldwide by its particular oceanographic and geological features, which influenced the origin of unique terrestrial and marine ecosystems that include a high biological endemism. The unique biodiversity of this place inspired the naturalist Charles Darwin to conceive his famed Theory of Evolution by Natural Selection following his visit to the archipelago in 1835, and was responsible for the designation of the Galapagos Islands as a World Heritage site by UNESCO in 1978.

Management of coastal and marine resources of this unique place faced several socioeconomic and political challenges in the mid-1990s (González *et al.*, 2008). The most significant of these were overcapitalization of the small scale artisanal fishing fleet driven by the rapid development and expansion of the sea cucumber fishery, and exponential growth of tourism activity in the archipelago (Castrejón, 2011). Both stimulated new sources of economic development which attracted an increasing number of immigrants from mainland Ecuador. As a result, the total human population of Galapagos increased dramatically, rising from 1346 to 18,640 individuals between 1950 and 2001 (Larrea, 2007). The above factors increased pressure on access and use of the Galapagos marine resources, and on demand for coastal space, as well as increasing the demand for raw material imported from the mainland, thereby increasing the risk of arrival of invasive species to the most pristine areas of Galapagos (Watkins and Cruz, 2007).

Increasing social conflicts and ecological degradation led to adoption of the Galapagos Special Law (GSL) and the Galapagos Marine Reserve Management Plan (GMRMP) in March 1998 and April 1999, respectively (Heylings and Bravo, 2007). According to the GMRMP, the main management objective is "*protect and conserve the coastal and marine ecosystems of the archipelago and its biological diversity for the benefit of humanity, the local population, science and education*" (SPNG, 1998).

The Galapagos archipelago and its surrounding open ocean were designated as a multiple use marine reserve of nearly 138,000 km^2 (Fig. 3.1) with an extension of its boundaries 40 miles offshore from the "baseline" (i.e., an imaginary line joining the outer islands of the archipelago). However, the most important measure was an institutional shift from a centralized top-down to a co-management approach, coupled with the prohibition of industrial fishing inside the GMR, allocation of exclusive use rights to local fishers, in the form of licenses and fishing permits, and adoption of a spatial EBM-oriented approach (Castrejón, 2011). [The term EBSM is not used or explicitly defined in the GSL and GMRMP, but the general and specific management objectives and principles established for management of the GMR (SPNG, 1998) are compatible with the definitions provided by McLeod et al. (McLeod *et al.*, 2005) and Douvere & Ehler (Douvere and Ehler, 2009).

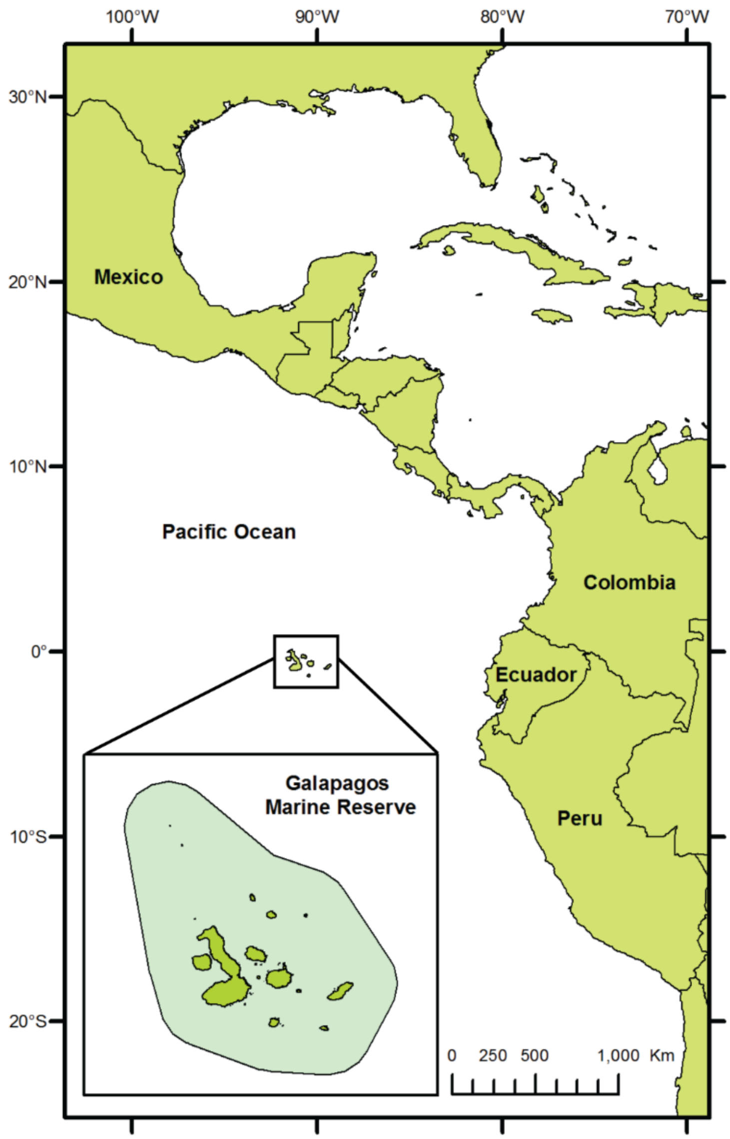

Figure 3.1 Location of the Galapagos Marine Reserve.

In addition, the GSL and the GMRMP provided the legal framework for the institutionalization of two nested decision-making bodies: the Participatory Management Board (PMB) and the Institutional Management Authority (IMA). Both decision-making bodies were used by local stakeholders and GNP's authorities to initiate and institutionalize a consensus-based participatory process to zoning the GMR (Heylings and Bravo, 2007). This spatially-explicit management tool facilitated the adoption in practice, for the first time, of an EBSM approach.

3.4.2 Planning phase

The GMR's marine zoning planning phase was undertaken between June 1997 and April 2000. The specific aims were to reduce conflicting uses generated by human activities (e.g., tourism vs. fishing) that coexisted in the same geographical zones; to conserve and protect biodiversity; to ensure the sustainability of economic activities in the RMG; and to enforce the management principles and objectives set up in GSL and GMRMP (SPNG, 1998). The process involved can be subdivided in two main stages, based on the descriptions provided jointly by SPNG (SPNG, 1998), Heylings et al. (Heylings, Bensted-Smith and Altamirano, 2002), and Edgar et al. (G J Edgar, R H Bustamente, *et al.*, 2004).

The first stage involved institutionalization of a general zoning provision agreement (June 1997- April 1999). The objectives, zone categories and regulations of the GMR's zoning were generated and agreed upon by a "core group", composed of local stakeholders and GNP representatives, during the planning phase of the GMRMP. As a key element of this, the GMR was divided in three main zones: 1) multiple use zone, 2) limited use zone, and 3) port zone. The multiple use zone includes deep waters (> 300m) located inside and outside the GMR's boundaries; all human activities permitted by the GNP can be undertaken (fishing, tourism, scientific research, navigation and surveillance manoeuvres). The limited use zone embraces the coastal waters (< 300 m) that surround each island, islet or protruding rock. This zone was divided in four subzones:

- Comparison and protection (Conservation subzone).
- Conservation and non-extractive use (Tourism subzone).
- Conservation, extractive and non-extractive (Fishing subzone).
- Areas of special temporary management (ASTM).

The first three of these, the Conservation, Tourism and Fishing subzones, have regulations associated with them as follows:

- Scientific research is permitted in all subzones (Tourism, Fishing, and Conservation).

- Diving, cruise ships, sailing, kayaking, snorkelling, surfing, and swimming are only permitted in the Tourism subzone.
- The various fishing activities – handline, pole and line, mesh netting, hooka diving, and trolling – are only permitted in the Fishing subzone.

The fourth subzone, the ASTM, can be implemented within any of the other subzones and includes special areas conceived to implement experimental management schemes in the future (e.g., seasonal closures), or to allow the recovering of species and marine habitats that have been severely affected by human activities (overexploitation, oil spill, etc.) or by extreme environmental conditions (e.g., El Niño).

However, the “core group” did not reach a consensus about the boundaries and distribution of the limited use subzones (i.e., Conservation, Tourism and Fishing subzones). The resolution of the no-consensus points was postponed and, instead, a process to create a “provisional coastal zoning (PCZ)” was agreed upon (Heylings, Bensted-Smith and Altamirano, 2002). As a result, the GMRMP was approved in April 1999 without including a complete and integrated zoning scheme.

The second stage of the process involved development and consensus on the above “provisional coastal zoning” (April 1999 - April 2000). A “zoning group” was formed of representatives of the national park, local small-scale fishers, tourism operators and NGOs, and developed a proposal, which was reviewed and approved by PMB in April 2000. Each stakeholder group negotiated based on their particular interest, with the goal being to minimize the short term impact of zoning over their own economic activities. Specifically, with regard to the key issue of establishing no-take zones, each resource harvesting group sought to avoid placing these in areas with high densities of the most valuable species for their corresponding sector. According to Edgar et al. (G J Edgar, R H Bustamente, *et al.*, 2004), sea cucumber fishers argued for having no-take zones only in those areas with low densities of sea cucumbers. On the other hand, tourism operators promoted no-take areas specifically for those areas with high concentrations of large pelagic species, such as hammer-head and white-tip sharks, which are valuable species for scuba diving tourism.

Finally, NGOs did not line up with any of these human use sectors, instead arguing for the protection of a range of sites of different sizes and at various distances apart, representative of different habitats in each of the five bioregions recognized by Harris (Harris, 1969). Overall, this mix of objectives led to a negotiated geographic distribution of no-take zones within the GMR (G J Edgar, R H Bustamente, *et al.*, 2004).

The final stages in reaching consensus on the zoning utilized "*an innovative method for conflict management, which was strongly based on incentive and pressure strategies*" ((Heylings, Bensted-Smith and Altamirano, 2002), p. 16), which were aiming to link directly the final PCZ proposal to the management of the GMR's fisheries (Heylings, Bensted-Smith and Altamirano, 2002). In other words, decisions on all measures to regulate the area's fisheries in 2000 were conditioned on the achievement of a zoning agreement. Even more important as an incentive for adoption of the zoning was the agreement to develop an "action plan" to provide alternative livelihoods to the fishing sector in order to "compensate" them for the short-term impacts of the zoning (Heylings, Bensted-Smith and Altamirano, 2002). These included the promise to allocate commercial diving and sport fishing licenses to those fishers that wanted to leave commercial fishing and become tourist operators.

The zoning arrangement was finally approved by "consensus" in 2000. It includes 130 management zones, comprising 14 separate conservation zones, 62 tourism zones, 45 fishing zones and 9 mixed management zones ((G J Edgar, R H Bustamente, *et al.*, 2004); see Fig. 3.2). Conservation and tourism zones (i.e., no-take zones) encompass 18% of the Galapagos coastline (Heylings, Bensted-Smith and Altamirano, 2002). Each individual zone ranges in size from small offshore islets to a 70 km span of coast (G J Edgar, R H Bustamente, *et al.*, 2004). However, no offshore boundaries were established. As a result, the total marine area per zone was not legally agreed on.

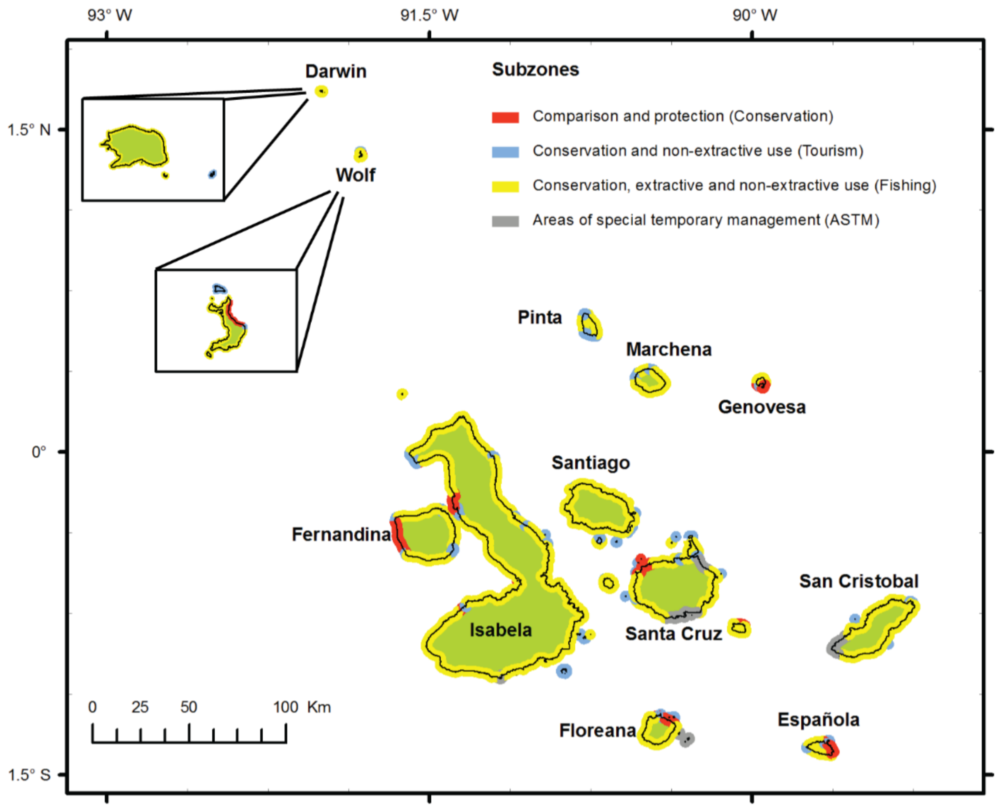

Figure 3.2 Marine zoning of the Galapagos Marine Reserve (limited use zone).

3.4.3 Implementation phase

The co-management system faced several conflicts after the zoning was approved, most related to management of the sea cucumber fishery and to development of the legal framework necessary to implement the principles and rules established in the GSL and GMRMP (Castrejón, 2011). As a consequence, the physical demarcation of the zoning was delayed by six years. During that period, enforcement was weak as the GNP lacked adequate control and surveillance infrastructures, and some fishers were unaware of the zoning boundaries (Altamirano and Aguiñaga, 2002). As a result, the GNP decided to focus on preventing illegal harvesting of tuna and sharks by large-scale fleets from mainland Ecuador, and to combat local illegal fishing during sea cucumber and spiny lobster fishing seasons (Reyes and Murillo, 2007). Despite those efforts, several infractions occurred, most related to illegal fishing of sea cucumber in no-take zones (Altamirano and Aguiñaga, 2002).

The zoning system was physically demarcated in September 2006, but despite this, illegal fishing in no-take zones continues to occur (Murillo and Reyes, 2008). Nevertheless, the adoption of a vessel monitoring system (VMS), jointly with the improvement of surveillance and sanction capacity, has contributed successfully to reduce illegal harvesting by large-scale fleets, which frequently attempt to harvest tuna and shark species inside the boundaries of the GMR (M. Villalta, Galapagos National Park, Ecuador; personal communication).

3.4.4 Monitoring phase

Before the physical demarcation of the GMR's marine zoning, the Charles Darwin Foundation (CDF), a locally-based international NGO that provides scientific advice to the GNP and PMB, conducted a broad-scale subtidal independent survey in 2000-2001 (G J Edgar, R H Bustamente, *et al.*, 2004). Its main aims were to define the ecological baseline of each management zone before the physical demarcation of the GMR's zoning, and to clarify broad-scale marine biogeographical patterns across Galapagos (G J Edgar, S Banks, *et al.*, 2004).

Three main results were obtained by Edgar et al. (G J Edgar, R H Bustamente, *et al.*, 2004): (1) the mean sea cucumber density in the Western sector of Galapagos, the most productive sector of this species, was three times higher in zones open to fishing (42.2 ± 10.9 ind 100m-2) in comparison with conservation zones (14 ± 4.2 ind $100m^{-2}$); (2) the mean density of spiny lobster and Galapagos grouper was not different between management zones; (3) the mean shark density was five times higher in tourism zones in comparison with conservation and fishing zones. These results reflected the bias associated with the selection and distribution of no-take zones within GMR (G J Edgar, R H Bustamente, *et al.*, 2004); i.e., that the compromises inherent in their selection led to their having low intrinsic densities of sea cucumbers and high densities of large pelagics.

These human dimensions were dominant in the actual selection of no-take zones, rather than more ecologically-oriented aspects. For example, Edgar et al. (G J Edgar, S Banks, *et al.*, 2004) showed that Galapagos coastal waters were best divided into five marine bioregions referred to as far-Northern, Northern, South-Eastern, Western and Elizabeth – the latter being a bioregion located in the Western part of Isabela Island, whose proportion of endemic species is anomalously high. As a result, these authors argue for a higher level of protection of the far-Northern and Elizabeth bioregions, which are not properly represented and conserved by the current GMR's zoning design.

While such aspects were not built into the current marine zoning design (and would need to be better incorporated in any future adaptation of the design), the results obtained by Edgar et al. (G J Edgar, S Banks, *et al.*, 2004) were used by the zoning commission, jointly with the GMR's approved zoning design and the advice of external consultants, to develop a long term ecological subtidal monitoring program (ESMP). This program was designed to evaluate spatial and temporal patterns of change in coastal marine ecosystems across the different bio-geographic regions in the GMR, before and after zoning implementation, and in relation to oceanographic, climate and human impacts (Banks, 2007b).

In October 2004, the PMB reviewed and approved the ESMP proposal. The responsibility to manage the ESMP was given to the CDF. Since then, CDF scientists have compiled a unique 12-year bio-physical dataset to support an assessment of the management effectiveness of the zoning. The ESMP is mostly funded by international aid agencies and NGOs.

In addition to the ESMP, the CDF and the GNP have managed the Participatory Program of Fisheries Monitoring and Research (PIMPP) since 1997. The latter marked the beginning of the systematic collection of fishery-related data in Galapagos (Castrejón, 2011). The PIMPP was the most important monitoring program between 1997 and 2006, particularly during the expansive phase of the sea cucumber fishery (1999-2002). However, over the past 50 years, the CDF has also compiled large amounts of other oceanographic, ecological and biological data about Galapagos marine habitats and native and endemic species. In recent years, most monitoring efforts have focused on the project-basis collection of socioeconomic and governance data, in particular to evaluate performance of the co-management system (Heylings and Bravo, 2007), the socioeconomic impact of tourism (Epler, 2007), and the potential impact of climate change on Galapagos (Larrea and Di Carlo, 2009).

3.4.5 Evaluation and adaptation phase

According to the GMRMP, the zoning system was to be adapted and made "permanent" two years after its declaration, based on the results of an assessment of management effectiveness (SPNG, 1998). The latter had to include an evaluation of the initial ecological and socio-economic effects of the zoning. However, there is not yet a comprehensive, integrated, peer-reviewed quantitative analysis of marine zoning effectiveness nor of application of the EBSM principles in the GMR. Consequently, the marine zoning scheme has not been formally adapted. Furthermore, decision-makers have not received regular and conclusive feedback about the ecological and socioeconomic impacts of the EBSM over Galapagos marine ecosystems and over the range of activities affecting it.

Despite this lack of comprehensive assessment, there is some evidence, both positive and negative, concerning the performance of marine zoning in the Galapagos. First, for the particular case of shellfish fisheries, recent studies suggest that marine zoning, in conjunction with the establishment of a co-management system, have not been effective in preventing overexploitation of the sea cucumber and the spiny lobster fisheries (Defeo, Castilla and Castrejón, 2009; Castrejón, 2011). Both management measures have not been enough to eliminate the fishers' incentive to compete with each other for a bigger proportion of the total allowable catch (TAC) each fishing season. Such behavior, known worldwide as a 'race for the fish', has encouraged over-capitalization as fisherman seek to increase their competitiveness through investment in more substantial and faster vessels, and high technology fishing equipment. The resulting intense search for short-term profit, combined with a lack of social and institutional mechanisms for resource stewardship, has compromised the long-term recovery of fishery stocks. This is indeed a situation in which the "tragedy of the commons" (Hardin, 1968) seems to apply.

As sea cucumber and spiny lobster stocks have declined over the last decade, the race for fish has intensified resulting in more illegal fishing and more restrictive management measures, such as the reduction of TAC and fishing season length. This has led fishers to work within an increasingly competitive environment, encouraging risk seeking behaviors, and creating dangerous work conditions. For example, the decline in spiny lobster abundance in the shallow waters around Galapagos has encouraged fishers to dive at night, deeper and for longer periods in order to sustain or increase their catch rates. As a result, the number of fishers with decompression sickness has increased during the last decade (Castrejón, 2011). In contrast to the above negative outcomes, a preliminary study suggests partial benefits associated with marine zoning in the Galapagos. According to (Banks, 2007a), the proportion of larger individuals of groupers (*Mycteroperca olfax*), endemic sea basses (*Paralabrax albomaculatus*) and Galapagos grunts (*Orthoprostis forbesi*) is significantly higher in no-take zones in comparison with fishing zones. This trend has been observed in particular areas where the level of protection from fishing is higher, whether due to high levels of tourism and/or such areas being near to the enforcement authority's outposts (Banks, 2007a).

3.5 Concerns arising with marine zoning in the Galapagos

The marine zoning scheme represents undoubtedly the best effort undertaken to date to manage the GMR through an EBSM approach. However, application of EBSM in the GMR, through marine zoning, has been severely limited by lack of effective enforcement and a high rate of non-compliance by fishers, who consider fisheries management measures, including no-take zones, as illegitimate (Viteri and Chávez, 2007). As noted above, the most important shellfisheries of the GMR, the sea cucumber fishery (*Isostichopus fuscus*) and the spiny lobster fisheries (*Panulirus penicillatus* and *P. gracilis*), show signs of overexploitation (Defeo, Castilla and Castrejón, 2009). The steady expansion of tourism activity in the archipelago, jointly with the carrying out of illegal sport-fishing operations, are generating new conflicts between local tourism and fishing sectors (E. Naula & M. Casafont, Galapagos National Park, Galapagos, Ecuador; personal communication). Furthermore, a recent study shows that the current GMR's marine zoning design is not providing enough protection to several threatened species and key biodiversity areas (Edgar *et al.*, 2008).

These problems with EBSM have contributed to a lack of credibility and legitimacy concerning what could be potentially a valuable tool to co-manage the GMR's fisheries. In this section, such problems are examined from the perspective of the five basic components essential to successful marine management, including EBSM, as outlined earlier in the paper:

effective planning, monitoring, implementation, evaluation and adaptation.

3.5.1 Planning issues

3.5.1.1 Short-term approach

The GMR's marine zoning system was created without a strategic and integrated long-term plan-based approach. It is clear that the consensus-based approach used during the planning phase focused mainly on determining no-take zones without considering the "bigger picture" needed to adopt an EBSM in a marine protected area (MPA: Charles *et al.*, 2009). As a consequence, the zoning only impacted the places where fishing (and tourism) can take place, not the inappropriate incentives and the institutional failures that lead to fisheries overexploitation. The latter problem areas include reactive governance with a short term vision, inappropriate allocation of use rights (licenses and fishing permits), excessive fishing capacity, limitations in monitoring, control and surveillance, and weaknesses in the organization and social cohesion of the local fishers' organizations (Defeo, Castilla and Castrejón, 2009; Castrejón, 2011).

3.5.1.2 Excessive focus on no-take zones

The zoning system has been considered in Galapagos as synonymous with no-take zones. This represents a serious misconception about EBSM, also present in other parts of the world (Murawski, 2007). It is necessary to highlight that no-take zones represent only one type of MPA, and only one of many management tools available for the successful implementation of EBSM in the marine environment, such as territorial user rights for fisheries (TURFs), seasonal closures, spatial gear restrictions, etc. (Worm *et al.*, 2009). Thus no-take zones need to be evaluated and compared to viable alternative management tools, and used, where appropriate, as one element in a broader package of measures (Hilborn *et al.*, 2004).

3.5.1.3 Unexpected incentives

The "innovative" incentive-pressure strategy described and used by Heylings et al. (Heylings, Bensted-Smith and Altamirano, 2002) to encourage consensus on zoning, contributed in reality to the generation of perverse incentives and to the loss of credibility and legitimacy for zoning, especially among grassroots fishers. As described in section 3.4.2, this strategy produced a final zoning consensus when the PMB declared that all management measures required to regulate the GMR's fisheries during 2000 would be implemented only if there was a zoning consensus (the 'pressure' component of the strategy). Furthermore, the PMB agreed to develop an "action plan" to provide alternative livelihoods to the fishing sector in order to "compensate" them for the short-term impacts of the zoning (the 'incentive' component).

The fishing sector's representatives signed the agreement for implementation of zoning expecting that the Ecuadorian Government (represented by the GNP) and NGOs would produce alternative livelihoods for the entire fishing sector, which in 2000 included a total of 1229 fishers as registered by GNP (Castrejón, 2011). The zoning agreement could be considered a win-win situation for fishers for two reasons: (1) most no-take zones were declared outside the main sea cucumber fishing grounds (G J Edgar, R H Bustamente, *et al.*, 2004), the most valuable and abundant fishery resource of the GMR at that time, so it is quite probable that the short-term economic impact of the zoning on the fishing sector was low, particularly given that enforcement was weak (Altamirano and Aguiñaga, 2002); and (2) the GNP and NGOs agreed to make a "compensation payment" to fishers, in the form of new "alternatives", for 18% of "their" fishing grounds becoming no-take zones. However, an unexpected result happened, in that the incentive-pressure strategy encouraged non-fishery individuals, mainly from mainland Ecuador, to obtain fishing licenses, in order to get access to the sea cucumber fishery (legally opened in 1999), as well as the alternative livelihoods that were promised. This contributed to the exponential growth of the fishing sector, which increased between 1999 and 2000 from 795 to a historic maximum of 1229 fishers (Castrejón, 2011). This trend intensified the 'race for the fish', which eliminated any incentive to conserve sea cucumber and spiny lobster fisheries. In other words, fishers were not encouraged to conserve fishery resources in the long term because, in the end, all fishing license holders, including those not dependent on fishing for their livelihoods, were to be compensated with "alternatives".

A few years after approval of the zoning system, conflicts abounded in the management of sea cucumber, as most fishers felt “cheated” in that expected “alternatives” were not implemented as quickly as they expected. As a result, the credibility and legitimacy of the zoning (and the GNP and NGOs themselves) declined severely between 1999 and 2001 (Barber and Ospina, 2007). Currently, such lack of legitimacy has a strong impact on fishers' decision to comply with the regulations, particularly with no-take zones (C Viteri and Chávez, 2007).

3.5.1.4 Lack of attention to threatened species

The design of the zoning system is not offering enough protection to all threatened species of Galapagos. Edgar et al. (Edgar *et al.*, 2008) point out that of the 38 inshore key biodiversity areas (KBA) recently identified in Galapagos, 27 currently possess protection from fishing. Such areas occupy 8.5% of the coastline (142 km). The remaining 11 KBAs are located inside fishing zones (7) and multi-use zones (4). These authors argue for the implementation of no-take zones in certain zones, located in Isabela and San Cristobal Islands, which possess threatened species of macroalgaes and gastropods not found in any other site of the archipelago. According to Edgar et al. (Edgar *et al.*, 2008), all KBA's could be protected by converting only 1.9% of the current total fishing area in no-take zones.

3.5.1.5 Lack of attention to spatial structure

The spatial structure of sea cucumber and spiny lobster stocks in the archipelago was not considered in GMR's zoning design. Several studies have shown, in a descriptive manner, that the distribution of sea cucumber and spiny lobster in the GMR is spatially heterogeneous, as is the allocation of fishing effort (Hearn *et al.*, 2006; Toral *et al.*, 2006). Nevertheless, no study has attempted to measure and model the spatial dynamics of shellfish stocks and of the fishing fleet. As a consequence, such spatial patterns have been ignored during the design of management strategies. Such information is fundamental to understanding the population dynamics and distribution patterns of these species (which do not fit the classic models developed for conventional stock assessments) and to evaluating the applicability of spatially explicit management measures (TURFs, seasonal closures, spatial gear restrictions, etc.) in order to reduce overexploitation risks.

3.5.2 Implementation issues

In addition to previously-noted issues over enforcement of regulations, there are also very specific operational concerns. For example, physical boundaries in the zoning scheme are inadequate to demarcate the offshore boundaries of each subzone – especially at night when most fishing activity takes place. There is a need for a new system of boundary demarcation based on coordinates of latitude and longitude, to simplify boundary description, as has been implemented in the Great Barrier Reef Marine Park (GBRMP) of Australia (Day, 2008). The latter interfaces zoning boundaries with modern navigating devices, such as Global Positioning Systems (GPS), and contributes to improve public understanding, enforcement and compliance in the GBRMP.

Concerns have also arisen with the original names assigned to each subzone, which proved complicated, confusing and difficult to remember. In fact, the names have been already changed by stakeholders. For example, fishers refer to the conservation, extractive and non-extractive use subzone as the “Fishing zone”, while tourism operators refer to the conservation and non-extractive use subzone as the “Tourism zone”.

3.5.3 Monitoring and evaluation issues

A large amount of spatially-explicit ecological and fishery related-data has been collected over the last 13 years, but such information has never been integrated and analyzed in a comprehensive way. Indeed, integrated and interdisciplinary studies have been relatively rare in Galapagos, representing only 8% of scientific references published between 1535 and 2007 (Santander *et al.*, 2009). Accordingly, there is a need for comprehensive evaluation, integration and coordination to produce suitable spatial planning information.

Furthermore, most research has focused on the baseline assessment and ongoing monitoring of biological and oceanographic aspects of the zoning with little attention to the “people side”. For example, in contrast to the large amounts of temporal and spatial information on the abundance and distribution of target and non-target species that has been collected on a regular basis during the last decade, little information has been collected on such topics as local fishery knowledge, perceptions about management regulations, market and non-market values of ecosystem services, and historical and current resource use patterns. It is important to recognize that not only fishery management but also the planning, implementing and managing of MPAs require taking into consideration the human dimensions (social, economic and institutional) that affect the outcomes of implementation (Charles and Wilson, 2009).

3.5.4 Adaptation issues

Adaptive management has been institutionalized as a management principle in the Galapagos legal framework (i.e., GSL and GMRMP), but it has not been properly implemented. For example, the GMRMP indicates that the zoning system would be adapted and made "permanent" after a 2-year period time after declaration, based on the results of an assessment of management effectiveness (SPNG, 1998). However, it did not provide clear guidelines about how to take into account new information or shifting conditions, so adaptation (amendment) of the system (and indeed the GMRMP) has never occurred since inception. Indeed, the terms "provisional" and "permanent" used in the GMRMP are in opposition to the adaptive management concept. In particular, use of the term "permanent" has created a serious misinterpretation about the foundations of adaptive management, which could result in future resistance by stakeholders (or decision-makers) to adaptation of the zoning design.

3.6 Toward effective zoning in the Galapagos Marine Reserve

The lessons learned through the identification and analyses of issues in the previous section are fundamental to adapt and improve the zoning system in the GMR. This section provides some paths to the future, drawing on lessons learned from the GBRMP (Fernandez *et al.*, 2005; Day, 2008), as well as from the recommendations and guidelines provided by Hilborn et al. (Hilborn *et al.*, 2004); Wilen (Wilen, 2004); Gilliand & Laffoley (Gilliand and Laffoley, 2008); Charles & Wilson (Charles and Wilson, 2009); and Douvere & Ehler (Douvere and Ehler, 2009).

3.6.1 Effective planning

The most important step to improve the GMR's zoning is adopting a strategic and integrated long-term plan-based approach, which considers the "bigger picture" needed to adopt an EBSM for GMR's fisheries management. The process followed in Australia's GBRMP to establish a large, comprehensive, and representative network of no-take areas within a broader spatial management framework, represents a successful example of the practical adoption of an EBSM to manage a multiple-use marine reserve. According to Fernandes et al. (Fernandez *et al.*, 2005), the key success factors that were central to review and adapt the GBRMP zoning were: focusing initial communication on the problems to be addressed; applying the precautionary principle; using independent experts; facilitating input to decision making; conducting extensive and participatory consultation; having an existing marine park that encompassed much of the ecosystem; having legislative power under federal law; developing high-level support; ensuring agency priority and ownership; and being able to address the issue of displaced fishers. These factors of success should be carefully evaluated in the context of Galapagos and used, if appropriate, to evaluate and to adapt the GMR's zoning.

3.6.2 Appropriate no-take zones

The reality that no-take zones represent only one of multiple management tools available for the successful implementation of EBSM must be emphasized. A portfolio approach, based on a judicious combination of management tools, provides a more robust approach to resource governance (Charles, 2009). Indeed, a recent integrated assessment of the status, trends, and solutions in marine fisheries worldwide found that a combination of traditional approaches (catch quotas, community-based management) coupled with strategically placed fishing closures, more selective fishing gear, ocean zoning, and economic incentives is the best potential solution to restore marine fisheries and ecosystems (Worm *et al.*, 2009).

Furthermore, having seen in Galapagos that zoning is a useless management tool if it is not appropriately enforced, it is worthwhile to adopt the insight of Hilborn et al. (Hilborn *et al.*, 2004) that no-take zones (or marine reserves) must be evaluated previous to their implementation in the context of: 1) clear management objectives, 2) the social and institutional ability to maintain and enforce the closures, 3) existing management actions that no-take areas could complement under certain conditions; and 4) the capacity to monitor and evaluate success.

3.6.3 Suitable incentives

The incentive-pressure strategy (*sensu* Heylings et al., (Heylings, Bensted-Smith and Altamirano, 2002)) to encourage consensus on zoning should not be used again during the adaptation phase of the GMR's zoning. It is clear that such a strategy generated perverse incentives that led to the loss of credibility and legitimacy in the zoning. Instead, it is necessary to establish new mechanisms to realign economic incentives with resource conservation. This critical component of successful rebuilding efforts for fisheries (Worm *et al.*, 2009) focuses on what is referred to variously as fishing rights, tenure, or dedicated access privileges (Charles, 2002, 2009; Hilborn, Parrish and Litle, 2005). Which form of fishing rights fits which type of fishery is a complex matter (Charles, 2009), depending on the frequent pre-existence of fishing rights, on the species involved, on the history of the fishery, and many other factors. However, when chosen well, these have effectively eliminated the race for the fish in many fisheries around the world – whether through TURFs, individual quotas (catch shares), rotation of fishing grounds or other means (Costello, Steven and Lynham, 2008; Defeo, Castilla and Castrejón, 2009; Gutiérrez, Hilborn and Defeo, 2011).

For example, the exclusive allocation of TURFs to small-scale fisher communities in Chile has generated a sense of exclusive use and ownership among fishers. This has resulted in (Castilla and Defeo, 2001; Defeo, Castilla and Castrejón, 2009): (1) a co-management success with long-term effects in the economic welfare of fishers; (2) the strengthening of fishers' organizations, which led to the implementation, by fishers themselves, of effective monitoring, control and surveillance procedures, and (3) the accomplishment of objectives for management and conservation. In addition, TURFs have proved to be useful as experimentation tools to refine stock assessment and management procedures. Furthermore, recent studies have shown that, under certain conditions, strategically sited MPAs can be an effective complement to TURFs, increasing abundance and fishery profits (Costello and Kaffine, 2009).

3.6.4 The "people" side of EBM and MPAs

Attention must be paid in equal terms to the biological, oceanographic and human dimensions related to the planning, monitoring, implementing and managing of the GMR's zoning. The importance of people-oriented aspects has been highlighted with regard to ecosystem-based management, notably in regard to fisheries (De Young, Charles and Hjort, 2008) and to MPA creation and implementation (or adaptation), to improve acceptance and ultimate performance of MPAs (Charles and Wilson, 2009). The latter authors suggest ten key 'human dimensions' considerations for MPAs: objectives and attitudes, "entry points" for introducing MPAs, attachment to place, meaningful participation, effective governance, the "people side" of knowledge, the role of rights, concerns about displacement, MPA costs and benefits, and the bigger picture around MPAs. Such people-oriented factors should be evaluated in the Galapagos context and taken into account during the evaluation and adaptation phase of the GMR's zoning.

3.6.6 Spatial dynamics

The spatial dynamics of fishery resources (notably the key sea cucumber and spiny lobster stocks) and of the fishing fleet must be measured and modeled to assess the applicability of spatially-explicit management measures (TURFs, seasonal closures, spatial gear restrictions, etc.) in order to reduce overexploitation risks. Consider, for example, the case of broadcast spawners, such as sea cucumbers, which – as for many sedentary species – require high density concentrations in order to reproduce successfully. Such high-density patches are the first to be targeted by fishers in a fishery regulated by catch or effort limits (Hilborn *et al.*, 2004), making management measures such as total allowable catch (TAC) inappropriate in the fisheries for these species. In this case, a spatially explicit management tool, such as seasonal closures, could be more effective than a TAC (e.g., to protect sea cucumber juveniles). On the other hand, caution is needed with spatial measures such as no-take zones since changes in the distribution of fishing effort could lead to overfishing of the stocks located outside the zone (Charles, 2010; Hilborn *et al.*, 2004) – it is thus necessary to evaluate the impact of zoning on fleet distribution.

3.6.7 Better monitoring

Current monitoring programs must be evaluated, adapted, and coordinated with the goal of producing needed spatial planning information, integrating the collection of socioeconomic data on a regular and strategic basis. According to Day (Day, 2008), the establishment of a robust monitoring system to evaluate the effectiveness of marine spatial management plans requires a major institutional reorientation at the policy level. In the case of Galapagos, it will require a major adaptation of the GMRMP, including as a priority the allocation of suitably long-term governmental funding to ensure the continuity and efficiency of the monitoring programs.

Also important are efforts to better utilize existing data (biophysical, socioeconomic and fishery data) in order to extract the maximum value from them (Gilliand and Laffoley, 2008). Furthermore, the above-noted monitoring capability of VMS together with the recent implementation of an Automatic Identification System (AIS) for the entire local fishing fleet, provides an unique opportunity to better understand the spatial behaviour of fishers, and thereby to predict how this behaviour interacts with spatial population processes to determine the character of exploited meta-populations; and to understand the implications of policy options ranging from no-take zones to TURFs (Wilen, 2004).

3.6.8 Evaluation of management effectiveness

Such an evaluation of the GMR will facilitate adaptation of the marine zoning scheme, taking into consideration the scientific information available, the local fishery knowledge and the lessons learned as outlined above. Recent guidelines have been published in relation to evaluation of management effectiveness of MPAs (Day, 2008; Gilliand and Laffoley, 2008), to the practical adoption and application of the ecosystem approach to fisheries (EAF) taking into account its human dimensions (FAO, 2009), and to undertaking marine spatial planning (MSP) on a step-by-step basis (Ehler and Douvere, 2009). The latter guidelines, which are largely based on analysis of MSP initiatives around the world, including the GBRMP, lead to a comprehensive spatial management plan for a marine area or ecosystem. This plan is implemented through a zoning map and/or a permit system, the latter based on the zoning maps and the comprehensive spatial plan (Ehler and Douvere, 2009). One important aspect of this guideline is an explicit recognition that other management measures besides zoning (e.g., seasonal closures, TURFs, limitation of fishing effort, etc.) are needed to manage the diversity of human activities that take place on MPAs.

3.7 Discussion

Implementation of marine zoning in the GMR represents an important step forward, but to date it has not adequately provided the mechanisms to address the roots of fisheries management failures that led to the overexploitation of the main shellfisheries of the GMR. Several institutional and socioeconomic challenges must be overcome in order to successfully adopt the recommendations described in the previous section.

3.7.1 Credibility and legitimacy

One of the most important challenges to meet is to re-establish the credibility and legitimacy of the GMR´s marine zoning. To accomplish this objective, it will be fundamental to engage stakeholders in the re-zoning process, through extensive and participatory consultation. The latter was identified by Fernandes et al. (Fernandez *et al.*, 2005) as a key factor for the successful review of Australia's GBRMP zoning.

As a first step, participants in the decision-making bodies formed earlier – PMB and IMA– need to agree upon and support the process that is being implemented by GNP´s authorities to evaluate for the first time the management effectiveness of the GMR, as well as the adaptation process that will be followed to fine-tune the GMR´s zoning design. This will contribute to a more efficient use of the economic and human resources locally available. However, an even more important step will be to engage GMR´s grassroots fishers, a difficult task due to a lack of social cohesion, leadership and representativeness of fishers' organizations (i.e., co-ops). This problems are illustrated by Avendaño's (Avendaño, 2007) results showing that 51.4% of the 262 members of COPROPAG (one of the major co-ops of the GMR) believes the main problem facing their cooperative is a lack of unity, followed by bad leadership (14.6%), lack of economic capital (12.9%), and lack of organization (5.8%). Consequently, most grassroots fishers do not trust their leaders, most not being considered legitimate representatives of fishers' interests (Heylings and Bravo, 2007). For this reason, many decisions taken by the PMB and IMA are not considered legitimate by grassroots fishers. To overcome this problem, extensive and participatory consultation is needed beyond the boundaries of the PMB. Such a process could be adapted from that described by Fernandes et al. (Fernandez *et al.*, 2005), and include not only those in the small-scale fisheries sector but also tour operators, naturalist guides, conservationist, researchers, representatives of local governments and the general public. This will contribute credibility and legitimacy to the evaluation and adaptation processes of the GMR´s zoning and, at the same time, will provide voice to several members of local communities whose interests are not currently represented in the PMB, but who have influence or are influenced by the decisions taken concerning management of the GMR.

3.7.2 The co-management system

Another institutional challenge to face is the uncertainty about the future role of the Galapagos' co-management system, caused by recent changes in Ecuador's legal framework, which could discourage and delegitimize the participation of stakeholders in the re-zoning process. Ecuador approved a new constitution by referendum in September 2008, which resulted in fundamental changes to the Galapagos' government structure.

According to article 258 of the new constitution, the province of Galapagos will be managed by a Government Council, to replace IMA as the main manager of the Galapagos province. However, the functions and the relationship of the Government Council to the GNP (the main manager of the GMR) and the PMB have not been approved and specified yet in the corresponding legal framework (i.e., Galapagos Special Law). Thus, the future role of the Galapagos co-management system is uncertain and will be known only at the end of the reform process of the Galapagos Special Law, which began in 2009 and is expected to conclude at the end of 2012.

Unfortunately, the failure of the GMR's marine zoning and its co-management system has disappointed many fishers and decision-makers, as well as those scientists and conservationists who strongly promoted co-management in Galapagos to this point. As a result, the Ecuadorian government is proposing changing the GMR's co-management system from an advisory type to a consultative type *(sensu* Sen & Nielsen, (Sen and Nielsen, 1996)). Considering this scenario, members of the PMB and the IMA should seek agreement on the consultation and decision-making process to adopt for evaluating and adapting the GMR's marine zoning. This should be done before the end of the reform process for the Galapagos Special Law, making clear how stakeholder inputs will be used to develop the new zoning plan, as well as the procedure that will be implemented to take the final decision on how to re-zone the GMR. This will be fundamental to legitimize the decision-making process, thereby contributing to encouragement of stakeholder participation and avoidance of potential conflicts between the Ecuadorian government (i.e., Government Council) and GMR stakeholders.

3.7.3 Right-based management

However, the most important institutional and socioeconomic challenge facing Galapagos fisheries relates to a lack of clearly defined and limited fishing rights. This problem, which lies at the roots of fisheries management failures, is reflected in the misalignment of economic incentives with respect to resource conservation. To address this, and thereby improve the GMR´s zoning, it will be necessary to implement a new rights-based management system, through amendments to the Galapagos' legal framework as well as a practical mechanism approved by the PMB and IMA (or Government Council).
This task will require selecting, in a participatory way, a new portfolio of use rights (Charles, 2002, 2009) taking five key factors into consideration:

(1) There is likely a need to re-allocate fishing licenses, in a manner that privileges the historical activity in the fishery and the performance of active fishers, as well as the distribution of the fishing effort according to the productive capacity of fishery resources, and the particular labour needs of each fishery. To do so, there will need to be changes to the legal framework to provide mechanisms to re-allocate fishing licences, based on the number of active (full time and part time) fishers, and to make it legally possible to exclude those inactive license holders listed in the GNP's fishing registry. For example, in 2008, only 33% and 37% of the total 1101 license holders registered by the GNP participated actively in the sea cucumber and spiny lobster fisheries, respectively

(Castrejón, 2011). The remainder are "inactive fishers", and these license holders are typically recognized, by fishers themselves, as opportunistic individuals that only keep their fishing license to gain access to economic "alternatives" created by NGOs and the GNP.

(2) The institutionalization of co-management in the Galapagos Special Law has not been sufficient to ensure its success (Defeo, Castilla and Castrejón, 2009), but strong support to the PMB from the Ecuadorian government can assist this local decision making-body in facilitating participation, capacity building and secure access and management rights for fishers. Otherwise, the outcomes expected will continue to be similar to those obtained commonly by a top-down management approach.

(3) There is no "magical recipe" or one-size-fits-all solution to eliminate the race for fish (Charles, 2001, 2009; Defeo, Castilla and Castrejón, 2009).Consequently, each use rights option (e.g., TURFs, individual quotas, no-take zones, seasonal closures, etc.) must be evaluated and adapted, considering the particular socio-ecological conditions of Galapagos, so that together they provide the necessary incentives, and increase the probabilities of success in management. This implies conducting interdisciplinary and integrated (systems-oriented) research to understand and describe the dynamics of the main interacting subsystems in the fishery system: resource (e.g., sea cucumber), resource users and resource management (Charles, 1995, 2001).

(4) The new rights-based management system must guarantee the fundamental rights of fishers, such as food, livelihood, and participation in decision-making. Following the recommendation of Kearney (Kearney, 2007), fishery managers should ensure their focus goes beyond narrow economic efficiency measures to include economic and social objectives relating to local communities (such as employment, feasible access of community members to the fishery, and avoidance of excessive concentration of ownership).

(5) To increase the chances of success for the new rights-based co-management system needed in the GMR, the Ecuadorian government needs to adopt a strategic and integrated long-term plan-based approach that contributes to improving the leadership, social cohesion and organization of fishers. The latter factors have been identified as fundamental to the successful implementation of co-management regimes (Defeo, Castilla and Castrejón, 2009; Gutiérrez, Hilborn and Defeo, 2011).

3.7.4 Lesson for beyond the Galapagos

Drawing on the specific lessons learned in this case study of the shortcomings of the Galapagos fisheries management system, there emerges five more general insights potentially relevant as well within other contexts of ecosystem-based spatial management (EBSM), marine zoning and related management approaches worldwide:

(1) The probability of success of EBSM is strongly reduced if it is adopted without a strategic and long term plan-based approach and adequate funding.

(2) The institutionalization of marine zoning under a co-management regime is not enough to ensure its success if major shortcomings exist within its five basic components (planning, monitoring, implementation, evaluation and adaptation).

(3) Lack of enforcement, inappropriate allocation of fishing rights and the presence of perverse incentives all contribute to a loss of credibility and legitimacy, as well as disincentives to conserve fishery resources.

(4) No-take zones are not useful, and may be counter-productive, if inadequately enforced, and if designed without taking into consideration the spatial dynamics of the resources and fleet, as well as the spatial distribution of key biodiversity areas.

(5) Adaptive management requires that clear and straightforward guidelines be specified in the corresponding legal framework to be applied in practice.

A serious and collaborative analysis, by Galapagos' management authorities and local stakeholders, of shortcomings experienced in GMR's marine zoning and lessons learned as a result (as described throughout this paper) will contribute to improving the effectiveness of what could be one of the most important fisheries management measures of the GMR. The resulting insights, such as those described in this section, may well be useful further afield, as aspects of ecosystem-based spatial management are explored and implemented in fisheries around the world.

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3.10 Glossary

- **Automatic Identification System (AIS):** a very high frequency (VHF) radio broadcasting system that transfers packets of data over the VHF data link (VDL). The latter enables AIS equipped vessels and shore-based stations to send and receive identification information that can be displayed on an electronic chart, computer display or compatible radar using global positioning systems (GPS). AIS is used by vessel traffic services (VTS) stations to monitor vessel location and movement primarily for traffic management, collision avoidance, and other safety and fisheries management applications (e.g. enforcement of no-take zones). Available from < http://www.amsa.gov.au/publications/ais_brochure.pdf > [accessed May 2012].

- **Co-management:** "*a partnership arrangement in which the community of local resource users (fishers), government, other stakeholders (boat owners, fish traders, boat builders, business people, etc.) and external agents (non-governmental organizations [NGOs], academic and research institutions) share the responsibility and authority for the management of the fishery*" (Pomeroy and Riviera-Guieb, 2006)

- **No-take zone:** a type of MPA where all extractive activities are prohibited permanently or temporally. Available from < http://www.mpa.gov/glossary.html > [accessed May 2012]. Also referred as "marine reserve" or "no-take reserve" (Al-Abdulrazzak and Trombulak, 2012)

- **Marine protected area (MPA):** "*any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment*" (Resolution 17.38 of the 17th General Assembly of the IUCN, 1988).

- **Marine zoning:** a spatially explicit tool that consists of regulatory measures to implement marine spatial plans. It specifies allowable uses in all areas of the target ecosystem(s). Different zones accommodate different uses, or different levels of use (Agardy, 2010).

- **Rights-based management:** a fisheries management regime in which access to the fishery is controlled by fishing rights which may include not only the right to fish, but also specify any or all of: how the fishing may be conducted (e.g. the vessel and gear); where they may fish; when they may fish; and how much fish they may catch (Charles, 2002).

CHAPTER 4. CO-GOVERNANCE OF SMALL-SCALE SHELLFISHERIES IN LATIN AMERICA: INSTITUTIONAL ADAPTABILITY TO EXTERNAL DRIVERS OF CHANGE

4.1 Publication Information

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4.2 Abstract

The resilience of small-scale shellfisheries in Latin America is increasingly threatened by climatic and human drivers acting simultaneously at multiple temporal and spatial scales. Co-governance is emerging as a potential solution to enhance the capability of governing systems to respond to the social-ecological impacts of external drivers of change. Although there is an increasing understanding of the factors that determine the success and failures of diverse co-governance arrangements in Latin America, there is still a poor understanding about how this mode of governance responds to different crises, and how these responses are shaped by past experiences and by the features of the governing system and the system-to-be governed. In this chapter, we evaluate how institutions learn, self-organize and respond to diverse climatic and human drivers in seven co-governance arrangements, and identify the factors that enable or inhibit building institutional adaptability. Our analysis shows that the combined impact of different drivers produced social-ecological impacts on local fishing communities' wellbeing. In this context, institutions and actors displayed coping and adaptive responses to prevent or mitigate the damage on fishery resources and fishers' livelihoods. These varied according to

the magnitude, extent, periodicity and intensity of press and pulse perturbations, and were shaped by past crises, social-ecological memory and the particular social features of fishing communities in which institutions are embedded. In most cases, after severe crises, small-scale fishers took collaborative actions for re-organizing their cooperatives and their harvesting and trading strategies in order to prevent future crises and enter into more sustainable pathways. In conclusion, the same factors that promote (or preclude) high governability are also those that enable (or inhibit) building institutional adaptability and resilience.

4.3 Introduction

Small-scale shellfisheries in Latin America and around the world are increasingly threatened by climatic and human drivers acting simultaneously at multiple temporal and spatial scales (Perry *et al.*, 2010; Hall, 2011; Defeo *et al.*, 2013). Climatic drivers, such as El Niño Southern Oscillation (ENSO), affect habitats and ecological patterns and processes of target and non-target species, causing changes in habitat suitability, biogeography and demography, as well as modifications to dispersal, feeding, growth and behavioral patterns (Badjeck *et al.*, 2009; Ortega *et al.*, 2012). The negative changes induced by climatic drivers (e.g., mass mortalities) are exacerbated by human drivers (i.e., market globalization and weak governance), leading to loss of resilience in small-scale shellfisheries (Defeo and Castilla, 2012). In this context, resilience refers to the capability of fishing communities and institutions (e.g. cooperatives, fishery agencies) to cope with, adapt to, and shape change to sustain a fishery system within a desirable state (Berkes and Folke, 1998; Folke, Colding and Berkes, 2003).

Co-management is emerging in Latin America as a potential solution to enhance the capability of the governing system to respond to the social-ecological impacts of external drivers of change (see e.g., Micheli et al. 2012 and McCay et al. 2014). Co-management is defined as "*a partnership arrangement in which government, the community of local resource users (fishers), external agents (non-governmental organizations, academic and research institutions), and other fisheries and coastal resource stakeholders (boat owners, fish traders, money lenders, tourism establishments, etc.) share the responsibility and authority for* *decision-making in the management of a fishery*" (Berkes et al. 2001, p. 255). Within the interactive governance perspective, co-management is conceptualized as a form of "co-governance" where fishers, managers, scientists and other stakeholders collaborate and cooperate to improve the governability of small-scale fisheries (Kooiman and Bavinck, 2013).

Although there is an increasing understanding of the factors that determine the success and failure of co-governance arrangements in Latin America (Castilla and Defeo 2001; Sosa-Cordero et al. 2008; Defeo et al. 2014; Gelcich et al. 2010; Gutiérrez et al. 2011; McCay et al. 2014), there is still a poor understanding about how this governance mode responds to different types of crises, and how these responses are shaped by past experiences and by the particular features of the governing system and the system-to-be governed. Such knowledge is important to understand how co-governance institutions and actors learn, self-organize and respond to diverse climatic and human drivers, as well as to design policies aimed at maintaining or increasing resilience in small-scale fisheries (Adger *et al.*, 2005; Badjeck *et al.*, 2009).

Coping responses occur on short time scales and allow a system to survive a crisis without being altered, while an adaptive response occurs on longer time scales when permanent changes in the system are required to survive a crisis (Perry et al. 2011). Coping and adaptive capacity are a related-resilience aspect that reflects the adaptability of a system, i.e., the ability of institutions (or individuals) to learn and store knowledge and experiences to address new challenges, as well as the flexibility to experiment and adopt novel solutions (Walker *et al.*, 2002). According to the interactive governance approach, adaptability is a key characteristic of the governing system and system-to-be governed that contributes to their governability. The system-to-be governed can be seen as a social-ecological system comprised of two subsystems (human-social and biophysical) that operate through interdependent feedback relationships (Ostrom, 2009; Perry *et al.*, 2010). The governing system represents the institutions and organizations that have a steering role in fisheries governance (Ostrom, 2009; Kooiman and Bavinck, 2013), which in turn are embedded within the social component of the system-to-be governed. In the context of Latin America, two key questions are: (1) how co-governance arrangements in small-scale shellfisheries respond to different climatic and human drivers; and (2) what factors enable or inhibit building institutional adaptability. To address these issues, we characterized and compared seven co-governance arrangements in order to evaluate how they responded to different types of external drivers, and to identify the factors that enabled or inhibited building institutional adaptability.

4.4 Methods

4.4.1 Case studies

We examined seven small-scale shellfisheries involving three different groups of benthic resources: crustaceans (lobsters), mollusks (bivalves and gastropods), and echinoderms (sea cucumbers). The case studies selected (Table 4.1) are from Mexico (spiny lobsters *Panulirus interruptus;* abalone *Haliotis corrugate* and *H. fulgens*), Ecuador (spiny lobsters *Panulirus penicillatus* and *P. gracilis;* sea cucumber *Isostichopus fuscus*), Uruguay (yellow clam *Mesodesma mactroides)* and Chile (surf clam *Mesodesma donacium*). The case studies were selected based on the availability of peer-reviewed and grey literature, as well as considering our first-hand experience.

We also considered the following selection criteria: (1) target species are coastal shellfishes, whose extraction is restricted to intertidal and shallow subtidal habitats; (2) resources are harvested through artisanal fishing methods, including hand-gathering, dredging, diving, and trap deploying; (3) fishers have some kind of informal or formal organization, including cooperatives, associations, syndicates, and/or federations; (4) there is a co-governance arrangement implemented and recognized by local institutions or acknowledged in national legislation; and (5) there is evidence that fisheries have been impacted by one, or more, external climatic and human drivers. Most co-governance arrangements were formally implemented in the 1990s, usually as a response to an environmental, political or socioeconomic crisis (Table 4.1). The only exception is the spiny lobster fishery from Punta Allen (Quintana Roo, Mexico), where co-governance emerged in a bottom-up way (i.e., *de facto*) during 1968 as a result of the geographical isolation and strong organization of the

“Vigía Chico” cooperative, whose members allocated territorial user rights for fisheries (TURFs) among themselves in specific fishing lots, locally known as “campos” (Seijo 1993).

Co-governance arrangements differ in the way governments and actors interact in the decision-making process (Table 4.1), and can be classified as two types (Sen and Nielsen, 1996; Gutiérrez, Hilborn and Defeo, 2011): (1) consultative, where consultation mechanisms between the government and actors are minimal, and final decisions are taken exclusively by the government; and (2) cooperative, where fishers are legally recognized as equal partners in decision-making, and final decisions are taken in cooperation. Fishers’ organizations are embedded in communities with strong social cohesion, leadership, and organization (Castilla and Defeo, 2001; McCay *et al.*, 2014) with the exception of Galapagos where fishing cooperatives lack those social attributes (Castrejón and Charles, 2013). In all cases, exclusive access rights have been implemented (e.g., TURFS, fishing licenses and permits), together with spatio-temporal closures and/or marine protected areas (Table 4.1). Other governance instruments include total and individual quotas and minimum landing sizes.

4.4.2 Framework for characterizing adaptive capacity of co-governance arrangements

To identify the factors that enable or inhibit institutional adaptation processes in the seven case studies selected, we identified the most relevant external drivers that affected each small-scale shellfishery. In most cases, the perturbations produced by the human and climatic driver selected occurred exclusively after a co-governance arrangement was implemented. Just in two cases – the sea cucumber and surf clam fishery – the perturbations were initiated before co-governance implementation and still continue (see Tables 4.1 and 4.2).

We considered two external driver categories (Hall, 2011): “Climatic and environment” and “International trade and globalization of markets”. Such drivers were subdivided in “pulse” and “press” perturbations. According to Collins et al. (2011), pulse perturbations are relatively discrete and rapidly alter species abundances and ecosystem functioning (e.g., a hurricane), while press perturbations are sustained and chronic (e.g., sea level rise). Both have the capacity to change the quantity and quality of ecosystem services (e.g., seafood). We define pulse perturbations as extreme climatic or socioeconomic events that in a short time period modify the structure and function of the system-to-be governed, and whose impacts persist temporally or permanently after the event has ended. In contrast, press perturbations exert a long-term pressure over the system-to-be governed, whose intensity increases gradually through time.

We selected *a priori* two large-scale pulse perturbations: El Niño 1997-1998 (hereafter EN97-98) and the global financial crisis 2007-2009. The first was an extreme climatic event that strongly impacted the Pacific coast of Latin America for 14 months, while the second was an economic perturbation produced by the collapse of financial markets and lending institutions that abruptly impacted the global economy for at least 18 months (Table 4.2). Both drivers affected most of our case studies, allowing us to assess how different co-governance arrangements responded to similar external drivers that occurred at the same time. We also identified *a posteriori* other drivers, based on a literature review (Table 4.2), to assess how different case studies responded to specific pulse and press perturbations.

To characterize the adaptability of co-governance arrangements, we identified the social-ecological impacts produced by each driver in the system-to-be governed (Table 4.3). Then, we identified the coping and adaptive responses produced by the governing system (i.e., fishery agencies, co-governance bodies and fishing cooperatives) and the social component of the system-to-be governed (i.e., individual fishers and local communities). We also investigated if the responses were adopted in a preventive (before the event occurred) or reactive (during or after the event occurred) way. Finally, we identified the factors that enabled coping and adaptive responses by the governing system and the system-to-be governed, concluding with some generalizations based on the comparative analysis of case studies.

Table 4.1 General descriptions and acronyms of the seven small-scale shellfisheries analyzed in this study with emphasis on co-governance and operational arrangements in place. Governance instruments: (1) territorial user rights for fisheries (TURFs); (2) fishing licenses and permits; (3) spatio-temporal closures; (4) marine protected areas; (5) total allowable catch; (6) individual quotas; (7) minimum legal size; (8) protection for berried females; (9) effort limit (traps); (10) escape windows in traps; (11) prohibition of SCUBA and hooka diving, gillnets and hooks.

Target species	Country	Location	Acronym	Habitat	Fishing method	Co-governance type	Year of implementation	Motivation for co-governance	Governance instruments
Spiny lobster *Panulirus argus*	Mexico	Punta Allen (Ascension Bay, Quintana Roo)	SLQR	Subtidal, sandy and rocky	Skin-diving and artificial shelters	Consultative	1968	Agreed upon by fishers themselves	1, 3, 7, 8, 11
Yellow clam *Mesodesma mactroides*	Uruguay	Rocha (Barra del Chuy)	YCUY	Intertidal, sandy beach	Hand-gathering	Consultative	1990	Resource depletion	3, 6, 7
Abalone *Haliotis corrugata* *H. fulgens*	Mexico	Peninsula of Baja California (central zone)	ABBC	Subtidal, rocky	Hookah and SCUBA diving	Cooperative	1992	Abalone overexploitation and negative impact of 1982-1983 El Niño event	1,3,4,5,7
Spiny lobster *Panulirus interruptus*			SLBC		Traps				1, 3, 4, 7, 8, 9, 10
Spiny lobster *Panulirus penicillatus, P. gracilis*	Ecuador	Galapagos Islands	SLGPS	Subtidal, rocky	Hookah and skin diving	Cooperative	1998	Illegal and unregulated expansion of the sea cucumber fishery promoted by roving bandits since 1992	2, 3, 4, 5, 7, 8

Target species	Country	Location	Acronym	Habitat	Fishing method	Co-governance type	Year of implementation	Motivation for co-governance	Governance instruments
Sea cucumber *Isostichopus fuscus*			SCGPS						2, 3, 4, 5, 7
Surf clam *Mesodesma donacium*	Chile	Tongoy Bay (northern-central zone)	CLCHL	Intertidal and shallow subtidal, sandy beach	Hand-gathering and hooka diving	Cooperative	1998	Ensure a sustainable exploitation of *M. donacium* by the TURF system created as a response to the "Loco" (*Concholepas concholepas*) fishery collapse (1991)	1, 3, 5, 7

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Table 4.2 External drivers analyzed in this study. ABBC: abalone Baja California; CLCHL: surf clam Chile; SCGPS: sea cucumber Galápagos; SLBC: spiny lobster Baja California; SLGPS: spiny lobster Galapagos; SLQR= spiny lobster Quintana Roo; YCUY: yellow clam Uruguay.

Category	External driver	Type of perturbation	Temporal scale	Spatial scale	Fisheries affected
Climate and environment	Hurricane Gilbert	Pulse	September 14, 1988 (~12 hours)	Regional	SLQR
	El Niño 1997/1998	Pulse	April 1997-June 1998 (~14 months)	Regional	SLBC, ABBC, SLGPS, SCGPS, CLCHL
	Oceanographic regime shift	Press	1994-onwards (decades)	Regional	YCUY
	Oceanographic regime shift	Press	1977-onwards (decades)	Regional	CLCHL
International trade and globalization of markets	Roving bandits	Press	1992-onwards (decades)	Local	SCGPS
	Massive seafood importation	Press	2008-onwards (> 2 years)	National	YCUY
	Global financial crisis	Pulse	December 2007-June 2009 (~18 months)	Global	SLBC, ABBC, SLGPS, SCGPS

4.5 Coping and adaptive responses

4.5.1 How co-governance arrangements respond to different climatic and human drivers?

4.5.1.1 Hurricane Gilbert

In Punta Allen (Mexico), Hurricane Gilbert damaged extensive areas of coral reefs and shallow seagrass beds (*Thalassia testudinum*), the main nursery and foraging habitats of

Panulirus argus. The loss of shelters increased the vulnerability of spiny lobsters to predators, reducing temporally their abundance (Fonseca-Larios and Briones-Fourzán, 1998).

The hurricane also destroyed thousands of lobster shelters, collapsing the lobster production and preventing the completion of a new seafood processing plant (Leslie, 2000). As catch and catch per unit effort (CPUE) declined markedly after the hurricane (Sosa-Cordero, Liceaga-Correa and Seijo, 2008), fishers were unable to pay their debts. Consequently, the processing plant was seized by a bank, and the cooperative's risk of default increased. In the short-term, dozens of fishers coped with this economic crisis by waiving their memberships, transferring their exclusive access rights (i.e., fishing lots) to other members to pay their debts, and emigrating to nearby urban areas (Leslie, 2000). Thus, cooperative membership declined from 100 to 71 at the end of the 1980s, while the local population contracted from 500 to 400 residents (Carr, 2007).

In the long term, the devastation caused by Hurricane Gilbert made remaining small-scale fishers aware of their vulnerability to climatic variability, which encouraged them to take preventive actions to strengthen fishery governability and the financial administration of their cooperative (Carr, 2007; UNDP, 2012). Thus, Vigía Chico's fishers adapted collectively their harvesting strategies by fine-tuning their fishing effort according to spiny lobster abundance, and applying rigorous penalties (e.g., expulsion from the cooperative and confiscation of fishing lots and fishing equipment) to those members who infringed upon federal and internal management regulations. Eight years later, catch and CPUE showed signs of recovery (Sosa-Cordero, Liceaga-Correa and Seijo, 2008). Other adaptive responses were applied, including (Carr, 2007; Sosa-Cordero, Liceaga-Correa and Seijo, 2008; Ley and Quintanar, 2010; UNDP, 2012): (1) stabilization of fishers population by limiting the allocation of new memberships only to children of cooperative members and restraining, by preference, their own fertility rate, which has been one of the lowest in Mexico since the mid-1990s. The logic behind this trend is that keeping a low number of fishers and children ensures the prosperity of the entire community, particularly in times of resource scarcity; (2) enhancement and proper management of the cooperative's financial affairs by hiring a private accounting firm; (3) diversification of livelihoods by creating tourism cooperatives since 1994; (4)

diversification of products by catching and trading of live lobsters since 1995; (5) enhancement of the spiny lobster value chain since 2004 by establishing a partnership between Vigía Chico and five cooperatives from Sian Ka'an and Chinchorro biosphere reserves (Mexico). These cooperatives formed a collective enterprise called "Integradora de Pescadores de Quintana Roo" to sell their product directly to retailers from hospitality and ecotourism industries, using their own brand ("Chakay"). This arrangement added value to the product, increased compliance with regulations and mitigated the influence of middlemen, resulting in higher profits for fishers; and (6) establishment of a rotating fund, which acts as a financial buffer in times of financial difficulty, resource scarcity, and natural disasters. All these adaptive responses were adopted thanks to the strong social cohesion, organization and leadership of fishing communities in which cooperatives are embedded (Sosa-Cordero, Liceaga-Correa and Seijo, 2008), as well as to the economic support and capacity building provided by diverse governmental institutions and non-governmental organizations (Ley and Quintanar, 2010). Consequently, the Vigía Chico cooperative increased its adaptability and resilience, as it was demonstrated when Hurricane Wilma, one of the most intense tropical cyclone ever recorded in the Atlantic basin, hit the Yucatan Peninsula in 2005 (UNDP, 2012).

4.5.1.2 El Niño 1997/1998

Negative and positive social-ecological impacts were caused by EN97-98 (Table 4.3). In Baja California, this event reduced the recruitment, abundance, and physiologic condition of abalone stocks, which could be associated with the temporal disappearance of *Macrocystis pyrifera* algal beds (Guzmán, Pérez and Laguna, 2003), a source of food and shelter for abalones. These negative impacts exacerbated fishery overexploitation. Fortunately, years before EN97-98 occurred, the Federation of Cooperative Societies of the Fishing Industry of Baja California (FEDECOOP), in collaboration with government agencies and research institutions, designed a stock rebuilding strategy that included: (1) consideration of the effects of climatic variability on abalone abundance in stock assessment methods; (2) establishment of a decision rule to set a total allowable catch (TAC) per cooperative; (3) government support to conduct research on abalone aquaculture and transfer knowledge to cooperatives; and (4) active participation of cooperative fishers in monitoring, surveillance and restocking activities. Since then, cooperatives have diversified their fishing effort to other fisheries to cope with abalone scarcity (McCay *et al.*, 2014). These adaptive responses helped mitigate the impact of EN97-98, allowing the gradual recovery of the fishery since 2001 (Searcy-Bernal, Ramade-Villanueva and Altamira, 2010). Furthermore, one cooperative implemented two experimental marine reserves within its territorial use rights in fisheries (TURF) to increase the resilience of abalone stocks to overfishing and climatic variability (Micheli *et al.*, 2012).

In contrast, the abundance of spiny lobsters (*P. interruptus*, *P. penicillatus* and *P. gracilis*) and sea cucumbers (*I. fuscus*) from Baja California and Galapagos increased markedly after EN97-98, probably as a result of strong recruitment pulses (Guzmán, Pérez and Laguna, 2003; Hearn *et al.*, 2005; Vega *et al.*, 2010). In Baja California, government agencies, again with full support from FEDECOOP, adjusted temporal closures before EN97-98 occurred to ensure the reproductive success of lobster spawning stocks. This decision was taken based on scientific evidence produced after EN82-83, which demonstrated that increasing sea surface temperatures accelerate the breeding time of *P. interruptus*, leading to spawning events earlier than normal (Vega, 2003). This preventive response, together with the effective enforcement of other regulations (e.g., escape windows in traps) and the reduction of illegal fishing – through self-enforcement mechanisms – contributed to protect recruitment and reach maximum historic landings in the central zone of Baja California during 2000 and 2002; i.e., two and four years after EN97-98. Since then, landings have remained remarkably high.

An opposite trend was observed in Galapagos, where fishers individually reacted by intensifying their fishing effort in the spiny lobster fishery. Such a coping response was shaped in turn by a previous response to another external driver: the boom and boost exploitation of sea cucumbers promoted by roving bandits (see following sections). Consequently, maximum historic landings were registered in the spiny lobster and sea cucumber fisheries, two and five years after EN97-98, respectively (Defeo *et al.*, 2013). However, few years later both fisheries showed signs of overexploitation (Ramírez, Castrejón and Toral-Granda, 2012).

Table 4.3 Social-ecological impacts of different climatic and human drivers over the system-to-be-governed of seven co-governance arrangements in Latin American small-scale shellfisheries. ABBC: abalone Baja California; CLCHL: surf clam Chile; SCGPS: sea cucumber Galápagos; SLBC: spiny lobster Baja California; SLGPS: spiny lobster Galapagos; SLQR= spiny lobster Quintana Roo; YCUY: yellow clam Uruguay. D1: Gilbert hurricane; D2: El Niño 1997/1998; D3: regime shift; D4: roving bandits; D5: global financial crisis; D6: massive seafood importation. Impact on stocks: green (increase); red (decrease), blank cell (no impact reported).

	SLQR		SLBC		ABBC		SLGPS		SCGPS			YCUY		CLCHL
Ecological impacts	**D1**	**D5**	**D2**	**D5**	**D2**	**D5**	**D2**	**D5**	**D2**	**D4**	**D5**	**D3**	**D6**	**D3**
Condition of nursery and foraging habitats	red				red									
Survivorship	red				red							red		red
Abundance	red		green		red		green		green	red		red		red
Recruitment	red		green		red		green		green	red		red		red
Physiologic condition					red									
Spawning stock biomass	red				red					red		red		red
Spawning time variation			green											
Conservation status of protected areas										red				
Social impacts														
Condition of fishing gear (e.g., lobster shelters)	red													
Socio-economic well-being (temporal or permanent)	red	red	green	green	red		green	red	green	red		red	red	red
Landings	red	red	green		red		green	red	green	red		red		red
CPUE	red		green		red		green	green	green	red		red		red
Unit price		red		green		red		red		green				
Export		red				red		red		green				
Population growth	red									green				
Diversity and complexity of social structure	red									green				
Interest in the co-governance arrangement										red				red
Consumption of domestic seafood products													red	

4.5.1.3 Regime shift

The populations of the yellow clam (*M. mactroides)* and surf clam (*M. donacium*) from Uruguay and Chile, respectively, were decimated by periodic mass mortalities associated with large-scale regime shifts from cold to warm waters (Ortega *et al.*, 2012). In the Pacific Ocean, the regime shift occurred in 1977 (Fiedler, 2002), while in the Atlantic Ocean the regime shift took place in 1994 (Goldenberg *et al.*, 2001) – four years after a successful co-governance arrangement was implemented in Barra del Chuy, Uruguay (Castilla and Defeo 2001; Table 4.1). Since then, the systematic increase of sea surface temperature has been inversely correlated with declining trends in the abundance of both species (Defeo *et al.*, 2013).

Before 1994, fishery agencies were unaware of the occurrence and impacts of mass mortalities in Uruguay. Therefore, no contingency plans were in place and managers were not prepared to cope with the unusual changes that occurred in the system-to-be-governed when mass mortalities began. They just reacted by implementing a fishery closure in 1994. However, as no options were provided to fishers to mitigate the economic impact on their livelihoods, this measure caused loss of incomes and unemployment. Small-scale fishers immediately responded by diversifying their livelihoods in other sectors of the economy (e.g., construction, agriculture). The co-governance arrangement was re-organized 14 years later, through the participatory development of new policies, institutions and governance instruments, once yellow clam stocks showed signs of recovery (2007-2008). Managers and fishers agreed that this mode of governance was suitable to promote fishery recovery and to enhance fishing communities' well-being. This decision was based on the successful co-governance arrangement implemented before mass mortalities occurred. Since then, fishery governability has improved (Defeo 2014).

In Chile, a TURFs system called Management Exploitation Areas for Benthic Resources (MEABR) was implemented at the national level in 1991 to solve the fishery crisis faced by the gastropod *Concholepas concholepas* (Castilla and Defeo, 2001). The success of this co-governance system (Gelcich *et al.*, 2010) led to its widespread application across different shellfish resources, including the surf clam *Mesodesma donacium* (known as "*macha*"). This species consists of a metapopulation with a highly dispersive planktonic larval phase that imposes uncertainty in the replenishment of local beds. Despite this fact, a MEABR system was implemented at Tongoy Bay in 1998. However, the fishery collapsed after three years of sporadic success because of lack of recruitment and high natural mortality levels mainly attributed to mass mortality events that occurred in Northern Chile and Peru (Riascos *et al.*, 2009; Ortega *et al.*, 2012; Aburto and Stotz, 2013). In response, fishers switched to other economic activities or alternative fisheries. The fishery showed a moderate recovery between 2009 and 2010. However, as landings were much lower than those registered under the MEABR system, the local community lost interest in maintaining the co-governance arrangement (Aburto and Stotz, 2013).

4.5.1.4 Roving bandits

The boom-and-bust exploitation cycle of sea cucumbers by roving bandits – in this case symbolized by Asian middlemen – was initiated in the Galapagos Islands in 1992, one year after this fishery collapsed in the Ecuadorian continental coastline (Jenkins and Mulliken 1999; Shepherd et al. 2004). Dozens of fishers from mainland Ecuador immigrated to Galapagos sponsored by roving bandits themselves. The exploitation of *Isostichopus fuscus* rapidly attracted the interest of local small-scale fishers (residents), who received training and loans from Asian middlemen to participate in the fishery (De Miras, Marco and Carranza, 1996). Thus, a resource that had not been traditionally exploited by the local population became unexpectedly the most lucrative fishery of the Galapagos and, most importantly, a pervasive partnership was created between roving bandits and fishers (migrants and residents).

Clandestine processing camps were set up on protected land areas to cook and dry sea cucumbers, thus increasing the risk of accidental fires and the introduction of invasive species (e.g., fruits, insects). These concerns, together with the potential ecological extinction of *I. fuscus* due to the open access nature of the fishery, attracted large international attention, particularly from conservation organizations (Castrejón *et al.*, 2014). The strong international pressure encouraged the Ecuadorian government to implement precautionary management measures, including a total fishery closure (1995-1999). Fishers responded with violent protests and strikes, behavior that was influenced by their precarious economic situation. As the fishery was abruptly closed, most of them were unable to pay their debts to Asian middlemen, local retailers and banks (De Miras, Marco and Carranza, 1996). Therefore, the increasing indebtedness of fishers, together with the uncertainty about the future access to the fishery, intensified illegal fishing and strengthened a "black market", whose main objective was to satisfy the payment of debts (Castrejón, 2011).

The conflicts caused by the sea cucumber fishery led to an institutional shift from a hierarchical to a co-governance mode in 1998, which included the establishment of the Galapagos Marine Reserve (Castrejón and Charles, 2013). Furthermore, several governance instruments were implemented to shift from an open access to a common property regime, including migratory rules, a ban on industrial fishing, the establishment of a moratorium on the entry of new fishers, the creation of a limited-entry program and marine zoning, the inclusion of *I. fuscus* in Appendix III of CITES, and even an unsuccessful attempt to implement an individual quota system in 2001 (Toral-Granda, 2008; Castrejón, 2011). Despite these adaptive responses, co-governance bodies were unable to "break down" the partnership created between roving bandits and local fishers.

Management measures were undermined by poor enforcement capacity coupled with an anthropogenic Allee effect (*sensu* Defeo and Castilla 2012). In other words, as sea cucumber abundance decreased due to overexploitation, the willingness of Asian markets to pay higher prices increased exponentially (Defeo et al. 2014). Thus, the expectancy of fishers to obtain higher profits motivated them to accelerate their exploitation rates, even under diminishing abundance levels. In this context, the roving bandits, with the additional participation of local middlemen, encouraged local fishers to catch sea cucumbers either below legal landing sizes or during seasonal closure periods. Illegal fishing intensified as resource abundance became scarcer and its exploitation and trading were restricted. This vicious cycle of globalized exploitation led to the collapse and closure of the fishery in 2006. Once the fishery was not profitable, the roving bandits moved to Nicaragua to continue the sequential exploitation of other sea cucumber species. However, they usually return to Galapagos every time the fishery is re-opened.

4.5.1.5 Massive seafood importation

Seafood importation affects fishing communities' livelihoods through the displacement of domestic products from national markets. In Uruguay, favorable market conditions led to an exponential increase in the importation of frozen bivalves, mainly from Chile, particularly since 2008. Demand of yellow clams – a domestic product – dropped as retailers and consumers opted for cheaper imported seafood products. Thus, yellow clams were partially displaced from international resorts, such as Punta del Este. Fishing communities from Barra del Chuy responded collectively by diversifying their products and markets, sponsored technically and economically by the government. Instead of selling 80% of yellow clams for bait and 20% for human consumption – as was traditionally done since the 1980s – fishers decided to add value to their production to increase its freshness and quality. The adaptation of products to the changing market conditions and consumer expectations allowed fishers to sell 95% of their landings since 2010 for human consumption, particularly in seaside resorts. This adaptive response of the community, under a co-governance arrangement, partially mitigated the negative effects caused by the massive importation of seafood. Nevertheless, this driver still represents an external threat to local fishing communities' livelihoods.

4.5.1.6 Global financial crisis

The global financial crisis contracted the consumption of lobsters and abalones in the United States and European Union– the main foreign markets of most Latin American countries (Cook and Gordon, 2010; Monnereau and Helmsing, 2011). In Galapagos, the sharp worldwide decline in lobster demand produced a price drop of 32% between 2008 and 2009 (Ramírez, Castrejón and Toral-Granda, 2012). As middlemen refused to buy landings at higher prices, fishers reacted individually in three ways: (1) abandoning the fishery; (2) diversifying their product by trading whole fresh lobsters instead of lobster tails, as had been done historically since the 1960s; and (3) diversifying their market by selling their product directly to the local hospitality sector and general public. Consequently, total fishing effort, catch, and exports to mainland Ecuador declined 20%, 23% and 45%, respectively (Defeo et al. 2014). While the economic crisis was detrimental for Galapagos fishers, it was beneficial for spiny lobster stocks. Two years after the official end of the recession, lobster CPUE and catch increased 91% and 102%, respectively, whereas fishing effort only increased 6% between 2009 and 2011. Since then, these indicators have remained remarkably high. Price also increased, although it remains 24% below the value registered before 2007.

In Punta Allen, fishers were in a better position to face the global financial crisis because of the adaptive responses adopted after Hurricane Gilbert (see previous sections). Nevertheless, two factors made them vulnerable to this driver: (1) the poor diversification of their market – most landings were destined to the Mexican hospitality industry of Cancun and the Riviera Maya (ITAM-CEC 2007); and (2) the outbreak of "swine flu" in April 2009. When the US market entered into recession and the "swine flu" outbreak occurred, middlemen stopped buying lobsters and the number of foreign tourists declined; thus, the domestic market collapsed, and prices dropped 50% between 2008 and 2009 (Noticaribe, 2010). In response, Vigía Chico's members stopped fishing for three months (July-September 2009) until market conditions improved. Since then, they have intensified their efforts in collaboration with other cooperatives, government and NGO's to acquire the infrastructure, technology and expertise needed to export live lobsters to Asia and Europe in order to sell their product at better prices.

By contrast, the spiny lobster fishery from the Central part of Baja California was relatively "immune" to the global financial crisis, thanks to the harvesting and trading strategies adopted by the ten cooperatives that form the FEDECOOP before the crisis occurred. Unlike Quintana Roo's cooperatives, FEDECOOP exports about 90% of its production to Asia, France and USA (ITAM-CEC 2007), using their own brand ("Rey del Mar"). Most of the production is sold live; however frozen and cooked lobsters (whole and tails) are also traded to spread the risk of market contraction. FEDECOOP cooperatives trade their landings in coordination, so that unit price and harvesting levels are agreed before the beginning of each fishing season, based on global market conditions, the production of the last five seasons, and the recommendations made by fishery agencies (SCS, 2011). Once the initial price is internally agreed, it is negotiated with foreign middlemen and local retailers. Market prices are monitored daily along the fishing season to regulate fishing effort based on a cost-effectiveness analysis. If market conditions are unfavorable, an early closure is agreed and implemented in a coordinated way, as happened during 2009 when the fishing season was closed ten days earlier than planned (SCS, 2011). Thanks to these harvesting and trading strategies, promoted by the strong organization, social cohesion, and leadership of FEDECOOP, the live lobster price increased 39% between 2008 and 2009, reaching maximum historic prices in 2011. The same harvesting and trading strategies were adopted by FEDECOOP in the abalone fishery to cope with the global financial crisis (Searcy-Bernal, Ramade-Villanueva and Altamira, 2010).

4.6 What factors enable or inhibit building institutional adaptability?

Our results show that climatic drivers affected the demography and life traits of target species, either directly or indirectly, by damaging the quality and availability of critical habitats (i.e., the ecological component of the system-to-be-governed). The combined impact of climatic and human drivers produced social-ecological impacts that affected local fishing communities' wellbeing (i.e., the social component of the system-to-be-governed) and the governing system. In this context, coping and adaptive responses were adopted by institutions (i.e., cooperatives, fishery agencies, or co-governance bodies) or actors (i.e., fishers) to prevent or mitigate the negative effects of these drivers on fishery resources and communities' livelihoods. Coping and adaptive responses varied according to the magnitude, extent, periodicity and intensity of press and pulse perturbations, and were shaped by past crises, social-ecological memory (*sensu* Folke et al. 2003) and the particular social features of fishing communities in which institutions are embedded.

In Punta Allen and Baja California, adaptive responses were triggered in the spiny lobster and abalone fisheries when fishers acquired a "collective awareness" about their vulnerability to climatic and human drivers. After extreme crises (i.e., pulse perturbations), fishers re-organized their cooperatives, harvesting and trading strategies in a collaborative way. They were successful in these enterprises thanks to the strong social cohesion, leadership, and organization of the fishing communities in which these cooperatives are embedded (Sosa-Cordero, Liceaga-Correa and Seijo, 2008; McCay *et al.*, 2014), as well as to their institutional capacity to take actions based on lessons learnt from previous crises (e.g., Hurricane Gilbert and El Niño events) and their own social-ecological memory. Effective adaptive responses were also enabled thanks to prolific partnerships created between cooperatives and fishery agencies, research centers and NGOs. The support provided by these institutions to small-scale fishers, in terms of scientific knowledge and capacity building, has been fundamental to prevent and mitigate the social-ecological impacts produced by diverse climatic and human drivers. Such results suggest that co-governance arrangements were successful in building institutional adaptability in Punta Allen and Baja California. This is reflected in the implementation of innovative solutions that enhanced governance quality (i.e., its governability; Kooiman and Bavinck 2013). These include: (1) the adoption of exclusive access rights (e.g., TURFs) and self-enforcement mechanisms to prevent over-exploitive fishing practices; (2) the flexibility of institutions to adapt management measures to prevent the impact of climatic drivers, based on the availability of sound scientific knowledge; (3) the development of participatory rebuilding strategies, including the implementation of decision rules to restrict harvest; and (4) the entrepreneurial capacity of cooperatives to adapt their trading strategies to the changing global financial trends, thus preventing the impact of unfavorable market conditions and mitigating the bargaining power of middlemen within fisheries' value chains. The implementation of these solutions have produced several benefits, including (Castilla and Defeo 2001; Sosa-Cordero et al. 2008; Defeo et al. 2014; McCay et al. 2014): (1) improved sense of ownership and stewardship, which in turn promote legitimacy, acceptability and compliance of regulations; (2) optimization of data collection methods, minimization of conflict and strengthening of long term strategic planning processes; (3) the creation of multilevel social networks, i.e., legal, political, and financial frameworks that enhance sources of social and ecological resilience (Adger *et al.*, 2005); and (4) enhancement and stabilization of bioeconomic indicators such as population abundance, CPUE and economic revenues. These successful results were recognized by the Marine Stewardship Council (MSC), which certified the spiny lobster fisheries from the central zone of Baja California and the Sian Ka'an and Banco Chinchorro Biosphere Reserves in 2004 and 2012, respectively. In Baja California, the MSC certification produced non-economic benefits to FEDECOOP, including empowerment, community strengthening, and greater prestige at national and international level (Pérez-Ramírez, Ponce-Díaz and Lluch-Cota, 2012). In the long term, the legitimacy and the political and bargaining power of FEDECOOP have increased, allowing it to ensure its exclusive access rights (i.e., TURFs), to obtain government's economic support for community development and to negotiate better prices for its seafood products in the international markets. Such benefits have reinforced the willingness and interest of fishers to comply with MSC required standards and to expand their involvement in co-governance arrangements, thus promoting optimum conditions to continue building institutional adaptability and resilience within the governing system and the system-to-be-governed.

In Uruguay, the co-governance arrangement of the yellow clam fishery was effective in enhancing governability (Defeo, Castilla and Castrejón, 2009). However, this governance mode was not resilient to the detrimental impacts caused by mass mortalities. Despite this unexpected failure, fishers and managers decided to work collaboratively to re-organize their governing system in order to promote the recovery and sustainable management of the fishery. The critical factors that enabled this adaptive response were: (1) recognition about the key role that the previous co-governance experience played in promoting good governance and sustainable fishing practices (i.e., existence of social-ecological memory); (2) recognition by all actors that stocks were depleted (i.e., shared images); and (3) participatory development of a rebuilding strategy, based on sound scientific knowledge about the ecology and resilience of targeted species and their roles in ecosystem dynamics (i.e., collaborative governance). Although yellow clams have not fully recovered yet, the collective response of fishers to mitigate the detrimental impact of seafood importation suggests that this co-governance arrangement is being consolidated by building adaptability and collaboratively rebuilding plans, leading to higher governability of the fishery. By contrast, the Tongoy Bay *macha* fishery became less governable, regardless of the co-governance arrangement developed around it, when the *macha* population crashed and small-scale fishers perceived that their conservation efforts would not produce the economic benefits that they expected (Aburto and Stotz, 2013).

Most case studies described above reinforce the notion that crises represent opportunities for learning, adapting, and entering onto more sustainable pathways (Folke, Colding and Berkes, 2003). In Galapagos, ecological and social crises also triggered adaptive responses. However, such responses were not effective in building institutional adaptability and resilience. Several factors explain why cooperatives and fishery agencies have a poor capacity to learn, self-reorganize and respond proactively to the problems at hand. In Galapagos, unlike Mexico and Uruguay, cooperatives are embedded in fishing communities that are socially fragmented (Castrejón, 2011; Castrejón and Charles, 2013). This is reflected in the incapacity of small-scale fishers to take collaborative actions to reorganize their cooperatives, adapt their harvesting and trading strategies, and implement self-regulatory mechanisms in order to exclude outsiders, avoid illegal fishing and mitigate the impact of roving bandits.

The adoption of collective adaptive responses was also inhibited in Galapagos by the existence of contrasting images about the status of the sea cucumber fishery. This avoided the creation of prolific partnerships among fishers, managers, scientists, and conservationists for at least 15 years (1992-2006). In this context, stakeholders perceived each other as "enemies", instead of potential partners whose particular capacities, knowledge, skills and resources could contribute to cope with external drivers of change. Consequently, management measures were implemented under pressure, usually without the consensus of fishers' representatives. Thus, decisions taken by Galapagos co-governance bodies were perceived as illegitimate by grassroots fishers, having a negative impact on fishers compliance with regulations (César Viteri and Chávez, 2007). Furthermore, some management measures were not based on sound scientific knowledge (e.g., total allowable catch), leading to the loss of credibility in fishery agencies, NGOs, and finally in the entire co-governance arrangement (Castrejón and Charles, 2013). This case study illustrates how the establishment of a cooperative co-governance mode, through the institutionalized inclusion of fishers as equal partners in the governance process, is not always effective in generating high governability, particularly when: (1) local fishing communities lack a sense of stewardship and critical social attributes (leadership, social cohesion, organization and social-ecological memory); (2) exclusive access rights implemented, in this case licenses and fishing permits, are deficient at mitigating over-exploitive fishing practices, (3) strong pervasive partnerships exist between fishers and middlemen; and (4) fishery agencies lack long-term economic and human resources to enforce regulations and to conduct the research needed to formulate solid governance instruments.

Based on the comparative analysis of our seven case studies, it can be concluded that the governability of a fishery is not dependent on the co-governance mode established (e.g., consultative or cooperative), but mainly on the social attributes of fishers' organizations, the quality of the interactions between government and other actors, and the institutional adaptability to external drivers of change. Institutions with strong social cohesion, organization and leadership, and willingness to change and work in a collective and collaborative way, displayed a higher institutional capacity for adaptation and innovation. The latter was reflected in the capacity of institutions to take actions, based on past experiences and social-ecological memory, to re-organize themselves, create prolific partnerships, change harvesting and trading strategies, and implement self-regulatory mechanisms to prevent over-exploitive fishing practices. According to our results, co-management arrangements that show these features, such as those located in Baja California, Punta Allen and Uruguay, also displayed a higher institutional adaptability to different climatic and human drivers, resulting in better governability. In contrast, poor governability was observed in those cases where such characteristics were lacking, as in Galapagos, or where fishers perceived that their conservation efforts would not produce the expected economic benefits as in the Tongoy Bay *macha* fishery. In conclusion, the same factors that promote (or preclude) high governability are also those that enable (or inhibit) building institutional adaptability and resilience within the governing system and the system-to-be-governed.

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CHAPTER 5. IMPACT OF HUMAN AND CLIMATIC DRIVERS OVER FISHING PATTERNS DYNAMICS IN A MARINE PROTECTED AREA: THE GALAPAGOS MARINE RESERVE

5.1 Publication information

This chapter will be submitted to the journal PLOS ONE, and will be co-authored by Mauricio Castrejón and Anthony Charles.

5.2 Abstract

No-take zones effectiveness assessments usually assume that fishing patterns change exclusively because of no-take zones implementation. Few studies have examined how fishers respond to those situations in which, besides the implementation of no-take zones, they have to cope with the interaction of different climatic and human drivers of change, and how their adaptive responses could influence the interpretation of no-take zones effectiveness assessments. This type of study is usually unfeasible in Latin America and the Caribbean due to the dominance of data-poor fisheries, which precludes employing before-after approaches to assess the biological and socioeconomic outcomes of Marine Protected Areas (MPAs). We evaluated how the spatiotemporal allocation of fishing effort of three fishing communities in the Galapagos Marine Reserve (Ecuador) was affected by the interactions of different human and climatic drivers, before and after the implementation of no-take zones. Fishery related data were collected on a daily-basis by interviewers (1997-2011) and fishery observers on-board (2000-2006) at the three main ports of Galapagos Islands. Geographic information system (GIS) modelling techniques were used in combination with boosted regression models to identify how different human and environmental factors influenced fishers' behavior, evaluating the management implications of fishing pattern identified. Our results show how the interaction of different large-scale human and climatic drivers have influenced the macro and micro-scale spatiotemporal dynamic of fishing patterns around no-take zones in the Galapagos Marine Reserve.

5.3 Introduction

Ecosystem-based management approach (EBM) has become well established in terrestrial environments and is now embraced widely in marine fora (FAO 2009). It is gradually being implemented within operational management practice in coastal and marine environments (Ehler and Douvere, 2009), in a range of manners, notably in the context of explicit spatial management and integrated management. Its main aim is to provide a mechanism for a strategic and integrated plan-based approach to manage the full suite of human activities occurring in spatially demarcated areas, identified through a procedure that takes into account biophysical, socioeconomic, and jurisdictional considerations (Young et al., 2007).

Often seen as related to EBM is the use of Marine Protected Areas (MPAs), which can be classified in two main types (Agardy *et al.*, 2003; Agardy, 2010; Long, Charles and Stephenson, 2015): (1) no-take zones, or marine reserves, where all extractive activities are prohibited, and (2) multiple-use MPAs that allow regulated use, generally under marine zoning schemes, which may include no-take zones. MPAs, in the right circumstances, can be effective governance instruments to build resilience in SSF and conserve biodiversity (Gutiérrez, Hilborn and Defeo, 2011; Micheli *et al.*, 2012; McCay *et al.*, 2014). However, MPAs can also do harm, if not understood properly – including biological, oceanographic and human (social, economic, cultural and institutional) dimensions – and implemented fairly and effectively, through suitable practical and policy measures. In particular, human dimensions of MPAs have been often neglected (Charles and Wilson, 2009; Charles 2014), especially in many developing countries, in which the dominance of data-poor fisheries usually precludes proper assessment of the biological and socioeconomic outcomes of MPAs.

Most research efforts in regard to the impacts of MPAs on fisheries have focused on how fishers deal with the displacement from their traditional fishing grounds and the factors, as a result of MPAs, and management implications associated with the adaptation of their fishing patterns, i.e., variations in the selection of fishing grounds, fishing methods, target species, organizational and marketing process (Salas and Gaertner, 2004; Stelzenmüller *et al.*, 2008; Horta e Costa *et al.*, 2013a). There are also analyses of how, in many cases, fishing effort tends to aggregate around MPA boundaries, an effect known as “fishing the line”, indicating that MPAs location is of interest for fishers either because they have traditionally fished around those areas or because a spillover effect has occurred (Kellner et al. 2007).

However, while the need to understand the implications of MPAs, notably on fisheries, is clear (Charles et al., 2016; Westlund et al., 2017), it is important to recognize that other factors affect fishing patterns in addition to MPAs. Recent studies suggest that spatiotemporal allocation of fishing effort is not only influenced by the location of MPAs, but also by factors such as distance of fishing grounds to the nearest port, weather and oceanographic conditions, habitat features, fishing method employed, travel costs, product price and expected revenues (Horta e Costa *et al.*, 2013a; Soykan *et al.*, 2014). To our knowledge, no study has examined yet how fishers respond to those situations in which, besides the implementation of an MPA, they have to cope with the interaction of different external drivers, such as extreme climatic events (e.g., hurricanes, El Niño, etc.), markets, globalizations and, most frequently, the development and/or collapse of alternative fisheries. Additionally, little is known about how fishers' adaptive responses could influence the interpretation of the effectiveness of MPAs.

Each driver of change can produce "cascade effects" on the socioeconomic dynamics of fishing communities, whether through changes in the availability and accessibility of target species or variations in environmental and market conditions. This leads fishers to adapt their fishing patterns to prevent or mitigate the damage on their livelihoods (Salas & Gaertner 2004). If the main reasons behind these adaptations are not well understood, a potential bias in the interpretation of the observed patterns could be produced, potentially misleading the management recommendations adopted. This is relevant for fisheries management, particularly in those cases in which the main assumption of a MPA effectiveness assessment is that any adaptation in fishing patterns was caused exclusively by MPA implementation, rather than by the combined impact of different human and climatic drivers of change.

In this study, we assess how the spatiotemporal allocation of fishing effort of three fishing communities in the Galapagos Marine Reserve (GMR) was affected by the interactions of different human and climatic drivers, before and after the implementation of no-take zones. To evaluate the management implications of fishing patterns, we used geographic information system (GIS) modelling techniques with boosted regression models to identify how the interaction of different large-scale human and climatic drivers have influenced the micro-scale spatiotemporal dynamic of fishing patterns around no-take zones in the GMR. The integration of this knowledge is fundamental to design policies aimed on building resilience in SSF. In other words, promote the capacity of fishing communities and institutions to cope and adapt to change (Ommer *et al.*, 2011), taking into account the particular ecological, socioeconomic and institutional setting of this cases study.

5.4 Method

5.4.1 Study area

The Galapagos Islands is comprised of approximately 234 islands, islets and rocks with a total land area and coastline of ca. 7 985 km^2 and 1667 km, respectively (DPNG, 2014). This volcanic archipelago is divided into five marine biogeographical regions (G J Edgar, S Banks, *et al.*, 2004), named as far-Northern, Northern, South-Eastern, Western and Elizabeth (Fig. 5.1). Each one shows particular assemblages of fish and macro-invertebrate species, whose abundance and distribution are strongly affected by El Niño Southern Oscillation (ENSO) (Wolff, Ruiz and Taylor, 2012; Defeo *et al.*, 2013).

Only 4% of the total land area is inhabited by ca. 25 144 residents (Table 5.1) distributed in five islands (Santa Cruz, Baltra, San Cristobal, Isabela, and Floreana). The remaining land area is natural protected area. There are three main fishing ports (Baquerizo Moreno, Puerto Ayora and Villamil; Fig. 5.1) that display particular geographic and socioeconomic features, particularly in terms of population density, number of fishers, composition of the fishing fleet, and available land-based tourism infrastructure (Table 5.1). Fishers are organized into four fishing cooperatives, most with low levels of organization, social cohesion and leadership (Avendaño, 2007; Castrejón and Charles, 2013). There are 1084 license holders and 416 vessels registered in Galapagos, although only 37% of them remain active in the spiny lobster fishery (Table 5.1). Each fishing license provides to its owner the right to fish any type of shellfish and finfish species commercially permitted. Approximately 97% of active vessels are smaller than 9.6 m long (fiber glass or wooden made) and equipped with outboard engines (15–200 HP). Only 13% consist of wooden large boats (8 to 18 m long) equipped with inboards engines (30-210 HP). These “mother boats” are used as storage, resting and towing units for up to four small vessels (Bustamante et al. 2000). Most harvesting activities usually last one or two days, although mother boats are able to operate for a maximum of 12 days.

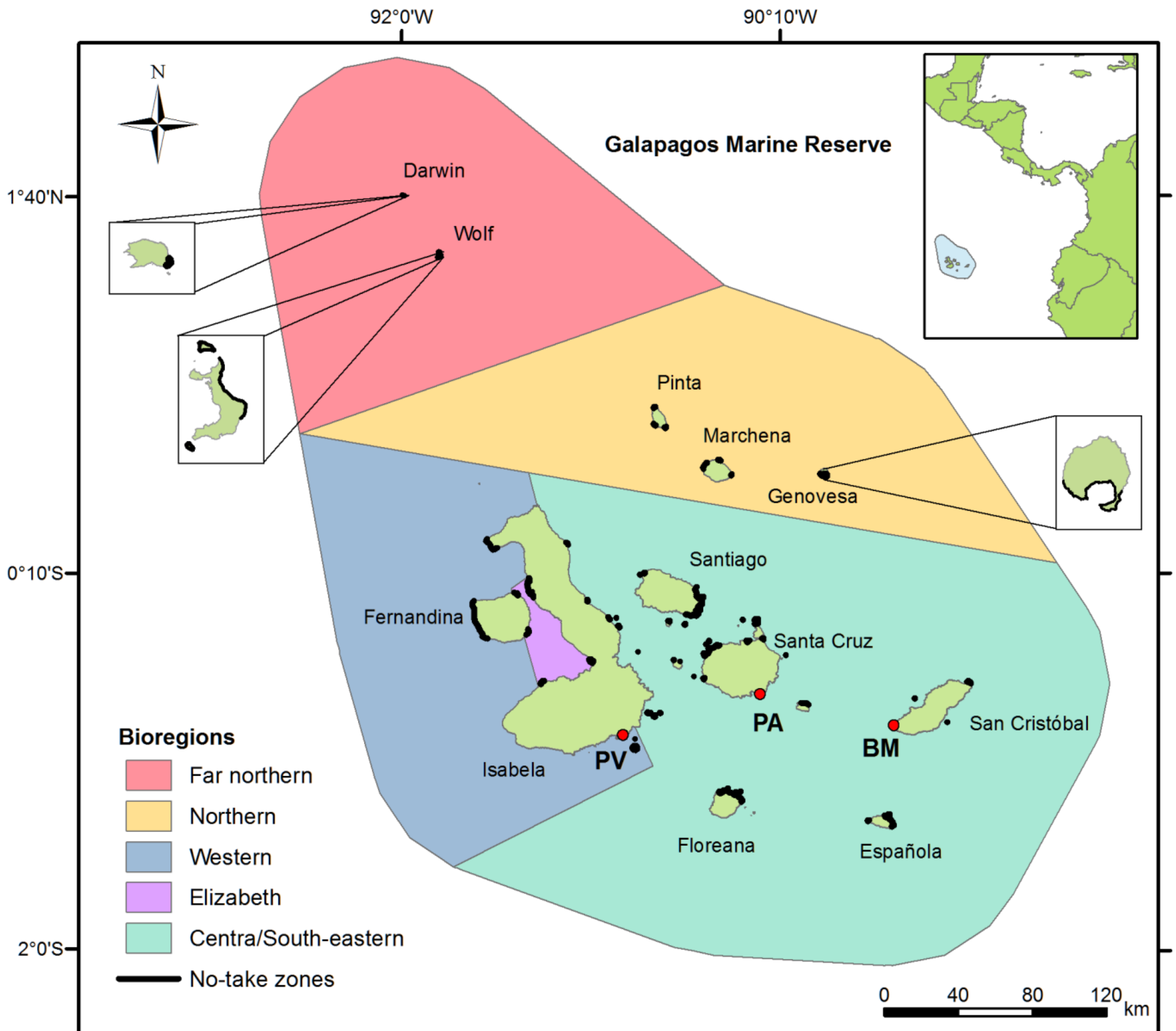

Figure 5.1 Marine biogeographical regions of the Galapagos Islands, according to Edgar et al. (2004). Red circles indicate the location of the three main fishing ports: Puerto Villamil (PV), Puerto Ayora (PA) and Baquerizo Moreno (BM). Black areas indicate the location of no-take zones.

The most valuable shellfish species in Galapagos are the red and green spiny lobsters (*Panulirus penicillatus* and *P. gracilis*), and the sea cucumber *Isostichopus fuscus*, harvested exclusively by artisanal hookah and skin divers mostly in sub-tidal rocky habitats. The fishing season for sea cucumbers usually lasts from June to August (two months) and for spiny lobsters from September to December (four months) since 1999, although slight variations have occurred through the years. Only in 2004 both fisheries overlapped for 40 days. Traditionally, the most important lobster fishing grounds have been located in the southern and south-western coast of Isabela Island, and around Santa Cruz, Santiago and Floreana islands (Reck, 1983). The number of landing sites along the coast is quite limited (Table 5.1), facilitating the systematic and reliable collection of fishery-related data at each port since 1997.

In March 1998, the Galapagos archipelago and its surrounding open ocean were enclosed in a multiple-use marine reserve of nearly 138,000 km^2, the Galapagos Marine Reserve (GMR), through the enacting of the Galapagos Special Law (Heylings and Bravo, 2007; Castrejón and Charles, 2013). This law further decreed the implementation of several governance instruments to promote an institutional shift from a hierarchical (top-down) to a co-governance mode, and from an open access to a common property regime. These included: (1) institutionalization of two nested decision-making co-management bodies: the Participatory Management Board (PMB) and the Institutional Management Authority (IMA); (2) establishment of migratory rules; (3) prohibition of large-scale fishing; (4) establishment of a moratorium on the entry of new fishers; and (5) allocation of licenses and fishing permits exclusively to local artisanal fishers by the creation of limited-entry program (locally known as fishing registry). The establishment of these new policies, institutions, and governance instruments coincided with the 1997/98 El Niño, the most intense climatic event recorded in Galapagos during the last three decades. Several governance instruments were developed during a four-year transition period (1998-2002) to regulate access to fishery resources, including the first GMR management plan, the fishing registry, and fishing regulations. In 1999, the sea cucumber fishery was re-opened, after a five-year precautionary closure, becoming the most lucrative fishery of Galapagos. The boom-and-bust exploitation of this fishery lasted until 2006, when a total closure was implemented.

In April 2000, a marine zoning scheme was brought forward to provide potential areas from which fishery stocks can recover and spillover to fishing grounds (Castrejón and Charles, 2013). This spatially-explicit management tool is comprised of 130 management zones with different levels of protection, embracing the coastal waters (< 300 m) that surround each island, islet or protruding rock. Heylings et al. (2002) indicate that a two nautical miles' offshore boundary applies to all management zones. However, this limit is not specified in the GMR's legal framework. In consequence, the total area per management zone was not legally established (Castrejón & Charles 2013).

There are 76 no-take zones distributed across the archipelago, covering 17% of the coastline (Fig. 5.1). Their dimensions range from small offshore islets to 22.8 km of coastline. Fishing and touristic activities are prohibited inside 14 no-take zones, known as "conservation zones". In the remaining 62 no-take zones, known as "tourism zones", only touristic activities are permitted. No buffer zones were established. Therefore, in some regions, conservation and tourism zones are contiguous, so that they constitute "no-take networks" (i.e., interconnected groups of individual no-take zones). The largest ones are distributed in Fernandina, Santiago, Santa Cruz and Floreana islands (Fig. 5.1).

The spiny lobster fishery showed signs of overexploitation from 2000 to 2005 denoted by decreasing trends in CPUE and catch (Defeo *et al.*, 2016). In addition to overexploitation of the sea cucumber and spiny lobster fisheries, small-scale fishing communities had to cope with the economic perturbation produced by the collapse of financial markets and lending institutions that abruptly impacted the global economy from December 2007 to June 2009 (Castrejón and Defeo, 2015). The global financial crisis caused a sharp contraction in the consumption of lobsters in the United States, the main foreign market for Galapagos lobsters, causing a price drop of 32% between 2008 and 2009 (Ramírez, Castrejón and Toral-Granda, 2012). Nevertheless, an unexpected and remarkable recovery of the spiny lobster fishery occurred in 2011 (Defeo *et al.*, 2016; Szuwalski *et al.*, 2016).

Table 5.1 General features of the three main fishing ports of the Galapagos Islands, including a summary of the fishery information analyzed in this study with emphasis on the data collection method used.

	San Cristobal	Santa Cruz	Isabela	Total
Fishing port	Baquerizo Moreno	Ayora	Villamil	3
Main landing sites	1	2	1	4
Population[1]	7495	15393	2256	25144
Coastline (km)[2]	~ 156	~ 170	~ 617	~ 944
Hotel capacity (beds)[3]	449	990	193	1632
Restaurants and bars[3]	35	61	18	114
License holders (active/registered)[4]	174/552	136/293	100/239	410/1084
Small vessels (active/registered)[4]	59/163	44/87	48/107	151/357
Mother boats (active/registered)[4]	2/32	1/19	1/8	4/59
Cooperatives	2	1	1	4
Interview based data[5] (1997-2011)	4387	4246	6727	15360
Fishery observer based data[5] (2000-2006)	1058	719	586	2363

[1] Galapagos census 2010 conducted by INEC.
[2] PNG (2005).
[3] Epler (2007).
[4] Reyes and Ramírez (2012).
[5] Participatory Programme of Fisheries Monitoring and Research; no data were collected in 2007.

5.4.2 Data

Fishing effort data for the period 1997-2011 were gathered from the Participatory Programme of Fisheries Monitoring and Research (PIMPP, in Spanish). Before this period, there are no spatially explicit fishing effort data available for analysis. Only annual aggregated fishing effort data (in fishing days) per island for the period 1974-1979, published by Reck (1983), remain for comparative purposes.

Fishery related data were collected from 17,764 fishing trips, equivalent to 20,203 fishing effort data per fishing ground, either by interviewers (1997-2011) or observers onboard (2000-2006), at the three main ports of Galapagos (Puerto Ayora, Baquerizo Moreno, and Villamil) on a daily-basis over each fishing season (Table 5.1 and 5.2). Geographical positioning systems (GPS) were usually used by observers to collect spatially-explicit data onboard fishing vessels, including position of fishing grounds, fishing method, effective fishing hours, number of divers, vessel type and name, departure and landing port, departure and arrival date, and catch per spiny lobster species.

The same types of data were collected by interviewers using semi-structured questionnaires. However, in this case, fishing grounds' names visited per fishing trip were obtained instead of the exact geographical location where fishing activity took place. To make this subset of data spatially explicit, we added the geographic coordinates published by Chasiluisa and Banks (2004), who defined reference positions (latitude and longitude) for 320 fishing grounds identified and distributed across the archipelago.

The PIMPP dataset was extensively reviewed, standardized and cleaned up before being filtered. Data collected by interviewers and observers onboard were included in this study. However, analyses were restricted to those spiny lobster fishing trips conducted in small vessels (fiber glass and wooden made) by one or two hooka divers, where the number of effective fishing days, at a single fishing ground, ranged from one to seven. The final dataset accounts for 17 723 fishing effort data units (Table 5.1), representing 88% of the original dataset. Approximately 78% of these data are georeferenced, i.e., they include the exact, or reference, position of each fishing ground visited per fishing trip. The remaining 22% of the data simply specify the islands in which fishing activity took place.

Table 5.2 Summary of the total fishery information gathered about the lobster fishery at the main ports of the Galapagos Islands, before and after marine zoning implementation. NA= Not available. Source: Participatory Programme of Fisheries Monitoring and Research (PIMPP, in Spanish), Moreno et al. (2007); Reyes and Ramírez (2012).

Fishing season	Small vessels			Catch (tail t)	CPUE (tail kg diver^{-1} hour^{-1})	Effort (diver hours)		
	Active	Sampled by interviews (% of total)	Sampled by observers (% of total)			Total	Sampled by interviews (% of total)	Sampled by observers (% of total)
1997	147	83 (56)	0	65.2	1.7	38349	4064 (11)	0
1998	147[1]	78 (53)	0	30.8	1.3	24150	3833 (16)	0
1999	194	140 (72)	0	52.8	1.8	29589	7963 (27)	0
2000	286	244 (85)	18 (6)	82.8	2.1	38952	16587 (43)	1283 (3)
2001	287	236 (82)	53 (18)	64.5	1.7	38156	14721 (39)	2352 (6)
2002	276	196 (71)	49 (18)	50.1	1.3	38454	10521 (27)	2483 (6)
2003	228	184 (81)	32 (14)	45.9	1.2	37680	10156 (27)	1398 (4)
2004	280	81 (29)	36 (13)	25.7	1.1	22533	2141 (10)	1260 (6)
2005	245	30 (12)	63 (26)	34.3	1.2	28105	283 (1)	1892 (7)
2006	177	45 (25)	62 (35)	29.6	1.4	21833	2801 (13)	2221 (10)
2007	NA	0	0	30.2	NA	NA	0	0
2008	150	102 (68)	0	29.8	1.8	16463	2417 (15)	216 (1)
2009	126	126 (100)	0	20.4	1.5	13486	12659 (94)	0
2010	128	128 (100)	0	21.7	1.5	14706	14083 (96)	0
2011	167	167 (100)	0	41.7	2.8	15041	14474 (96)	0

[1] Because lack of data, it is assumed that the number of active vessels in 1998 is equal to 1997.

To evaluate the amount, type and representativeness of data selected, we estimated the number of active small vessels and the total fishing effort per year, measured in diver hours, registered between 1997 and 2011 (Table 5.2). In 2007, there was a discontinuity in the ongoing fishery monitoring (Castrejón *et al.*, 2014). However, sampling effort by interviews increased significantly since 2009 (Table 5.2), although the observers onboard program has remained closed since then. Total fishing effort was calculated by dividing the annual total catch (in tail kg) by the annual average catch per unit effort (CPUE), with the latter expressed in tail kg diver^{-1} hour $^{-1}$. Then, we estimated the number and percentage of active small-vessels and effective fishing effort sampled through interviews and observers onboard per fishing season (Table 5.1). Our results show that sampling effort of active small vessels by interviews ranges from 12 to 100% (average 67%). A similar trend applies to total fishing effort, with the exception of 2005 (average 37%). In contrast, sampling effort of active small vessels by observers onboard range from 6 to 35% (average 19%), while for fishing effort this ranges from 1 to 10% (average 5%). These results suggest that interview-based data are more representative of the spatiotemporal dynamics of the fishing fleet than data from observers onboard. However, they could also be less reliable, if fishers provided inaccurate information about the locations of their fishing grounds. To account for this type of uncertainty, both data sources were analyzed separately to compare the fishing patterns identified.

5.4.3 Data analysis

5.4.3.1 Climatic and human drivers

The most relevant climatic and human drivers that occurred between 1997 and 2011, as they pertain to the Galapagos fisheries, are indicated in Table 5.3, which shows the category of the driver, the specific form of the change, and the corresponding time scale.

Table 5.3 Main climatic and human drivers that affected the spiny lobster fishery from the Galapagos Islands between 1997 and 2011. Categories defined according to Hall (2011).

Category	**Drivers of change**	**Temporal scale**
Climate and environment	El Niño 1997/1998	April 1997-June 1998 (~14 months)
Governance	Co-governance and common property period	March 1998-onwards
International trade and globalization of markets	Boom and bust exploitation of the sea cucumber fishery by roving bandits	April 1999- (decades)
Governance	Marine zoning	April 2000-onwards (decades)
International trade and globalization of markets	Global financial crisis	December 2007- June 2009 (~18 months)

The goal of this analysis was to group the fishing effort data into a suitable number of time periods to evaluate how the spatio-temporal dynamics of fishing patterns in the spiny lobster fishery were affected by the drivers. However, as the temporal scale of each driver is different, and most of them occurred simultaneously, it was not feasible to divide the data available evenly between periods. Accordingly, we defined the time periods based on the following logic:

- We subdivided the boom and bust exploitation period of the sea cucumber fishery into four phases (re-opening, expansion, overexploitation and collapse) to evaluate their specific impact on the spatial allocation of fishing effort in the spiny lobster fishery. The sea cucumber overexploitation phase and the marine zoning implementation were grouped together because both occurred simultaneously. In this case, we assumed that the Galapagos' marine zoning was implemented after a transition period of three years (2000-2003), once the moratorium on the entry of new fishers was put in place, fishing regulations were decreed, enforcement capacity increased, and fishers were aware of zoning boundaries and legal framework.

- We grouped the sea cucumber collapse phase and the global financial crisis together because both drivers affected the profitability of fishing activity in Galapagos, allowing us to evaluate their combined impact on fisher's behaviour. Data from 2009 and 2010 were excluded from this period because lack of georeferenced data.

- The unexpected and remarkable recovery of the spiny lobster fishery was considered an additional period. Such an event does not represent a driver itself, at least not in the short term, but a social-ecological impact potentially caused by different climatic and human drivers occurred in earlier periods.

Combining the drivers in Table 5.3 with this analysis produced six periods defined in Table 5.4.

Table 5.4 Periods defined to evaluate the spatio-temporal dynamic of fishing patterns in the spiny lobster fishery, based on the most relevant climatic and human drivers occurred between 1997 and 2011.

Period	Acronym	Temporal scale
1. Co-governance and El Niño	CoM-EN	June 1997-December 1998
2. Sea cucumber re-opening phase	RovBan1	September 1999- December 2000
3. Sea cucumber expansion phase	RovBan2	September 2001- December-2002
4. Sea cucumber overexploitation phase and marine zoning	MarZon	September 2003-December 2005
5. Sea cucumber collapse phase and global financial crisis	Crisis	September-December 2006 and September-December 2008
6. Spiny lobster recovery	Recovery	September-December 2011

5.4.3.2 Interaction between sea cucumber and spiny lobster fisheries

We performed a correlation analysis to evaluate how the fishing effort capacity in the spiny lobster fishery was affected by the different phases (re-opening, expansion, overexploitation and collapse) of the boom-and-bust exploitation of the sea cucumber fishery, using as variables the number of active fishers, small-vessels and mother boats in both fisheries between 1997 and 2011. The information was obtained from PIMPP, GNP fishing registry, Moreno et al. (2007) and Reyes and Ramírez (2012).

5.4.3.3 Spatiotemporal analysis of fishing patterns: 1. allocation of fishing effort

The spatiotemporal allocation of fishing effort across the entire archipelago was evaluated employing geographic information system (GIS) modelling techniques with ArcGIS 10.2.2 (ESRI) software. We calculated standard deviation ellipses (SDE) polygons by point pattern statistics (Fortin and Dale, 2005) to determine the core areas and distribution ranges of the fishing fleets based in the three ports (Baquerizo Moreno, Puerto Ayora and Villamil) during the six periods defined.

In this study, SDE represent graphical summaries of the central tendency, dispersion and directional trends of fishing fleets. Core areas and distribution ranges refer to those areas covering 68% (1 SDE) and 95% (2 SDE) of the full spatial extent of fishing fleets distribution, respectively. Furthermore, to determine if the same areas have been reused by fishers from different ports at different periods, we estimate an index of reuse (IOR), following the procedure described by Morrisey and Gruber (1993) and Horta e Costa et al. (2013b). Small vessels' core areas and distribution ranges were used to estimate IOR, by the following formula (Morrisey and Gruber, 1993):

$$IOR = \frac{OV(A_1 + A_2)}{A_1 + A_2}$$

where [OV (A_1+A_2)] refers to the overlapping area between two core areas (or distribution ranges), and (A_1+A_2) to the total area of both core areas (or distribution ranges). IOR values range from 0 (both areas do not overlap) to 1 (both areas overlap completely). One and two-way ANOVAs were employed to test the null hypothesis of absence of differences in core areas, distribution range and IOR between different periods, and between ports and sampling methods (interviews vs fishery observers). A Bartlett's test was performed prior to all analyses to test the assumption of homogeneity of variances among treatments. When data were heteroscedastic, or did not fulfill normality assumption, transformations were conducted.

5.4.3.4 Spatiotemporal analysis of fishing patterns: 2. hotspot analysis

We also performed a hotspot analysis using area pattern statistics (Fortin and Dale, 2005) to evaluate if the areas where most fishing effort concentrates (i.e., hotspots) have varied across each period and to determine if the fishing patterns identified vary according to the sampling method employed. Based on this analysis, we determined the spatial distribution of hotspots before and after marine zoning implementation, allowing us to evaluate if fishers were displaced from their traditional fishing grounds and if fishing effort concentrates around no-take zones, producing a "fishing the line" effect. We aggregated fishing effort data per period and sampling method, and performed a single hotspot analysis for each possible combination (nine in total). The following procedure was applied to each combination: (1) a grid with a 2.25 km^2 cell size was superimposed over the entire archipelago. Such resolution was selected considering the size of the study area, as well as the precision and resolution required to evaluate the fine scale distribution of fishing fleets; (2) a buffer of 2.5 km was delimited around the coastline of each island, islet and rock, defined based on the dispersion of data and a maximum bathymetry of 40 m, so as to contain the area where the spiny lobster fishery takes place. Grid cells located outside this buffer, including the land area, were removed; then, we proceeded to eliminate those resulting grid cells smaller than 3% of the original grid cell size; (3) total fishing effort (diver-hours) per grid cell was summarized and a measure of effort density (diver-hours km^{-2}) was calculated by dividing the total sum of fishing effort per cell by the original grid cell size (2.25 km^2); (4) a spatial weights matrix was generated using the k-nearest neighbors ($k= 8$) as the conceptualization of the spatial relationship among data (i.e., small-vessels). The latter method was selected considering the extensive and uneven spatial distribution of our data across the study area and the skewed distribution of fishing effort values; (5) finally a hotspot analysis was performed, using effort density as input field. Such analysis identified statistically significant spatial clusters of high effort density values (hot spots) and low effort density values (cold spots) across the archipelago, based on the Getis/Ord Gi* statistic (Ord and Getis, 1995). It produces a Z-score and p-values as measures of statistical significance.

The null hypothesis in this case is that the spatial allocation of fishing effort is the result of random spatial processes, which is rejected if Z-score ≥ |1.96| and $p < 0.05$ with a 95% confidence level. A high Z-score and small p-value indicates a hotspot, while a low negative z-score and small p-value indicates a cold spot. The higher (or lower) the Z-score, the more intense the clustering, while a Z-score near zero indicates no apparent spatial clustering (Ord and Getis, 2001).

5.4.3.5 Climatic and human drivers affecting spatial fishing effort allocation

Explanatory variables

We defined for each fishing georeferenced data a diverse suit of explanatory variables potentially having an influence on the spatial allocation of fishing effort, measured in diver hours. Geographic, oceanographic and socioeconomic variables were selected based on the human and climatic drivers identified as relevant for this study. Each was categorized as either temporally static or temporally dynamic, based on whether they change over time (Soykan *et al.*, 2014).

The first category includes latitude, longitude, bioregion, homeport, distance to home port (DistHP), and distance to the nearest no-take zone (NearNTZ). Here, we defined homeport as the port from which a vessel primarily operates, regardless of its registry. To calculate the shortest effective distance between each fishing record and the corresponding vessel's home port, we conducted a cost-distance analysis using the spatial analyst extension in ArcGIS 10.2.2. The same analysis was used to calculate the shortest effective distance between each fishing record and the nearest no-take zone.

The second category includes historic period (Period), month, average ex-vessel price per year (ExVesPrice), lobster catch obtained in previous fishing trips (PrevCatch), average sea cucumber revenues obtained the fishing season before the beginning of lobster season (SeaCucRev), vessel type, and the Oceanic Niño Index (ONI). The ONI represents the month moving average of ERSST.v3b SST anomalies in the Niño 3.4 region (i.e., west of the GMR 5ºN – 5ºS, 120º-170ºW), based on centered 30-year base periods updated every 5 years. ONI is the main indicator used by NOAA for monitoring El Niño and La Niña, which are opposite phases of the climate pattern called the El Niño-Southern Oscillation (ENSO). Data were obtained from the NOAA Climate Prediction Centre at www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/detrend.nino34.ascii.txt

Boosted regression trees

Analysis of fishing effort hotspots and fishing fleets' distribution ranges and core areas were used to evaluate how spatiotemporal distribution changes in relation to the external drivers analyzed in this study. Then, boosted regression trees (BRTs) were used to identify the factors that explain such spatiotemporal patterns. The goal was to predict fishing effort, measured in diver-hours per port and period, as a function of geographic, oceanographic and socioeconomic variables described above.

BRT models can be defined as flexible additive regression models in which individual terms are simple trees, created by recursive binary splits constructed from predictor variables and combined to optimize predictive performance, which are fitted in a forward, stagewise fashion (Hastie et al. 2001, Elith et al. 2008). Unlike more traditional regression methods, such as General Linear Models (GLMs) and General Additive Models (GAMs), BRT models accommodate missing values in continuous or categorical predictors, being able to handle outliers, collinear variables, interactions between variables, and nonlinear relationships between predictor and response variables, showing additionally similar, or even stronger, predictive performance (Elith et al. 2008, Martínez-Rincón et al. 2012, Soykan et al. 2014). Despite these advantages, few studies have used BRT models to predict the spatiotemporal distribution of fishing effort as a function of geographic, oceanographic and socioeconomic variables (Soykan et al. 2014).

BRT model fitting requires the definition of three parameters: (1) *learning rate* (lr), also known as the shrinking parameter, which determines the contribution of each tree to the growing model (i.e., it controls the rate at which the model converges on a solution); (2) *tree* *complexity* (tc), which refers to the number of nodes (or splits) in a tree (i.e., the ability of model interactions); and (3) the two previous parameters are used to estimate the *optimal number of trees* (nt) required to increase performance prediction. In addition, to improve accuracy and reduce overfitting, we introduced stochasticity to the BRT model through a "bag fraction", which specifies the proportion of data to be selected at each step (Elith et al. 2008).

The BRT model was fit to allow interactions using a tree complexity of 2 and a learning rate of 0.005 and a bag fraction of 0.6. Ten-fold, cross-validation of training data was used to determine the optimal number of trees necessary to minimize deviance and maximize predictive performance to independent test data. Model performance was assessed based on predictions made using the independent testing set that was withheld during cross-validation. The following measures were used to evaluate the performance of each model: deviance explained, mean correlation (r), false positive and false negative error rates. Furthermore, variable importance (VI) was estimated by averaging the number of times a variable is selected for splitting and the squared improvement resulting from these splits (Friedman, 2001; Friedman and Meulman, 2003). VI scores provide a measure of the relative influence of predictor variables used to build the model (Soykan *et al.*, 2014). Values are scaled so that the sum adds to 100, with higher numbers indicating a stronger influence on the response variable. Following Soykan et al. (2014), a random number (RN) between 1 and 100 was added to identify useful variables for modeling a response. Useful variables in predicting fishing effort were those that had higher VI scores than RN. Finally, for interpreting BRT models results, we generated a partial dependence plot for each predictor variable. Such graphs show the effect of a variable on the response after accounting for the average effects of all other variables in the model, including the RN (Soykan *et al.*, 2014). BRT model fitting was conducted in the R statistical programming language, version 3.1.2 (R Development Core Team 2014) using the "gbm" and "dismo" libraries complemented with the brt.functions code developed by Elith et al. (2008).

5.5 Results

5.5.1 Interaction between sea cucumber and spiny lobster fisheries

The analysis of active fishing capacity from 1999 to 2011 suggests that the boom-and-bust exploitation of the sea cucumber fishery produced a large-scale impact over the fishing effort dynamics in the spiny lobster fishery. The active number of fishers and vessels in the sea cucumber fishery reached maximum values between 2002 and 2004, i.e., during the expansion and overexploitation phases of this fishery (Fig. 5.2a,b,c). As fishing licenses are not resource-specific, new fishers and vessels also obtained access to the spiny lobster fishery, whose fishing season (September-December) occurred after sea cucumber fishing season (usually July-August). Therefore, as fishing capacity increased in the sea cucumber fishery, it also increased in the spiny lobster fishery, leading a few years later to the overexploitation of both fisheries (Defeo et al. 2016). During this period the active number of fishers and vessels in both fisheries showed a strong positive linear trend in Puerto Ayora, Baquerizo Moreno and Puerto Villamil (Fig. 5.2a, b, c).

Fishing capacity in both fisheries decreased as the sea cucumber and spiny lobster stocks showed signs of overexploitation. Between 2004 and 2010, fishing capacity in the sea cucumber fishery decreased linearly in Puerto Ayora, Baquerizo Moreno and Puerto Villamil, notably after the first total closure of this fishery occurred in 2006 (Fig. 5.2d, e, f). The spiny lobster fishery showed a similar trend. Our results suggest that the number of active vessels and fishers in this fishery decreased remarkably between 2004 and 2010 due to the overexploitation of spiny lobster stocks, the total closure of the sea cucumber fishery and the global financial crisis (Fig. 5.2a, b, c). These factors influenced a significant number of fishers and vessels from Puerto Ayora, Baquerizo Moreno and Puerto Villamil to abandon not only the sea cucumber fishery, but also the spiny lobster fishery. The total number of fishers and small vessels increased slightly between 2011 and 2012, probably due to the temporal opening and recovery of the sea cucumber and spiny lobster fisheries, respectively (Fig. 5.2a, b). In contrast, the number of mother boats have remained in low numbers (Fig. 5.2c). These macro-scale changes influenced the micro-scale spatiotemporal dynamic of fishing patterns in the Galapagos Marine Reserve, as described in the next sections.

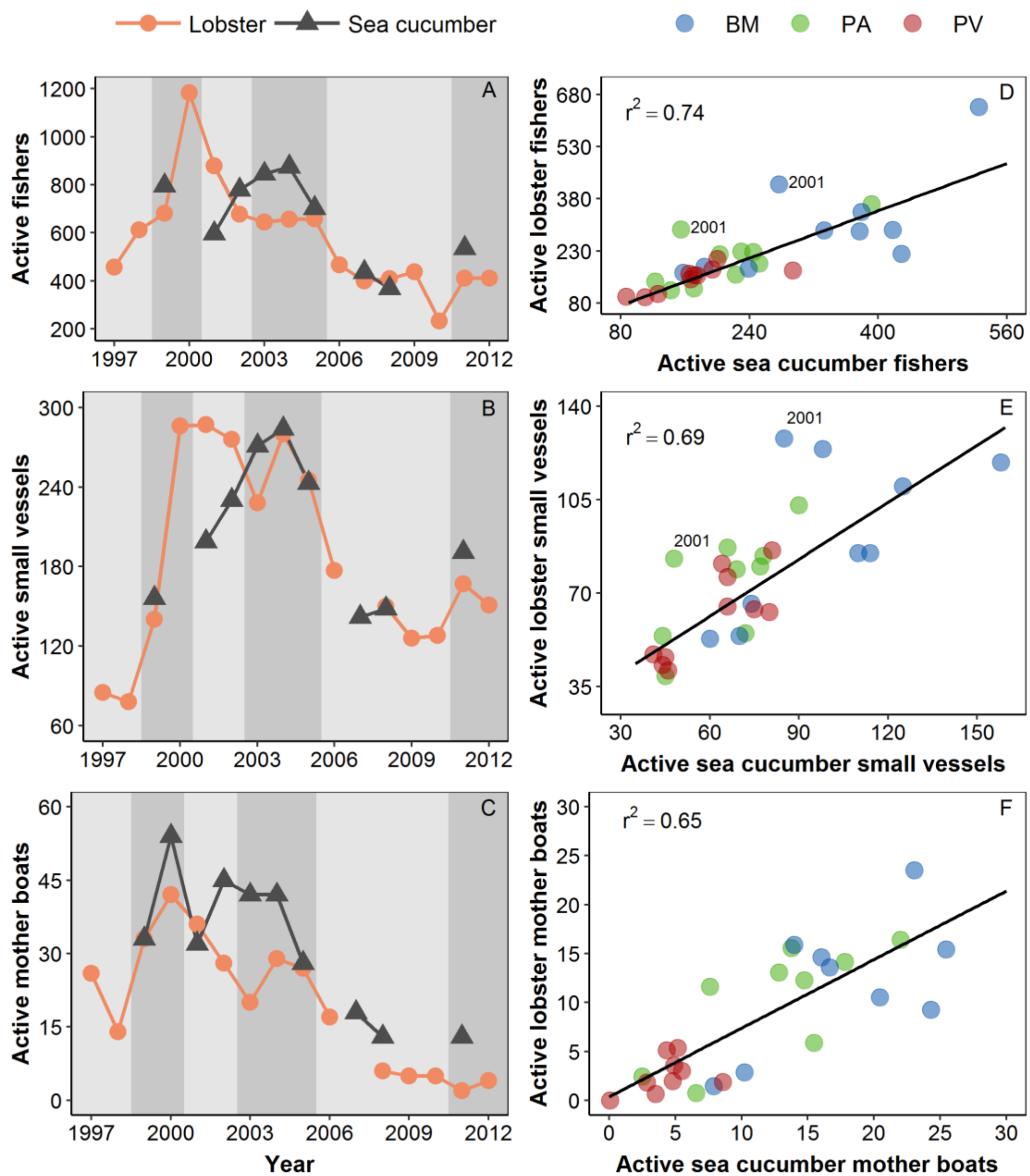

Figure 5.2 Long-term variations in fishing capacity in the spiny lobster and sea cucumber fishery from the Galapagos Marine Reserve: a) active fishers per year; b) active small-scale vessels per year; c) active mother boats per year; d) relation between active lobster and sea cucumber fishers per port; e) relation between active lobster and sea cucumber small-vessels per port; and f) relation between active lobster and sea cucumber mother boats per port. BM: Baquerizo Moreno; PA: Puerto Ayora; PV: Puerto Villamil. The sea cucumber fishery was closed five times during the period analyzed (2006, 2009, 2010, and 2012). In 2001, there was an unsuccessful attempt to implement an individual quota system in the sea cucumber fishery, which led to a temporal reduction in fishing effort (Toral-Granda, 2008; Castrejón, 2011).

5.5.2 Spatiotemporal analysis of fishing patterns: 1. allocation of fishing effort

The spatiotemporal allocation of fishing effort showed different patterns between ports and periods, which did not vary, in most analyses, according to the sampling method used (Fig. 5.3 and 5.4). According to port interview data, Puerto Ayora and Baquerizo Moreno's fishing fleets showed larger core areas (CA) and distribution ranges (DR) than Puerto Villamil (Table 5.5; Fig. 5.3). However, such differences were not significant between ports (CA: H= 2.667; d.f.= 2; p= 0.264; DR: H= 1.906; d.f.= 2; p= 0.385). Similar results were obtained using the observer onboard data analysis (CA: H= 5.955; d.f.= 2; p= 0.051; DR: H= 5.067; d.f.= 2; p= 0.079, although in this case Baquerizo Moreno's fishing fleet showed larger core areas and distribution ranges than Puerto Ayora (Table 5.6; Fig. 5.4).

Table 5.5 Estimated mean core areas (in km^2), according to port interview data collected at the three main ports of Galapagos from 1997 to 2011. SD: Standard deviation.

Port	Core Area		Distribution range	
	Mean	SD	Mean	SD
Puerto Ayora	5221.2	± 5529.9	24581.3	± 25564.6
Puerto Villamil	904.2	± 499.5	6577.2	± 4098.1
Baquerizo Moreno	4143.1	± 4347.4	17844.0	± 17360.9

Table 5.6 Estimated mean core areas (in km^2), according to observer onboard data collected at the three main ports of Galapagos from 1997 to 2011. SD: Standard deviation.

Port	Core Area		Distribution range	
	Mean	SD	Mean	SD
Puerto Ayora	8751.6	± 7851.4	38911.5	± 36070.3
Puerto Villamil	1706.5	± 209.0	9163.2	± 2314.9
Baquerizo Moreno	17724.2	± 4899.9	72419.5	± 20181.1

According to the data collected by port interviews, and using site fidelity (IOR_{95}) of fishing fleets, the similarity of core areas and distribution ranges was higher between Puerto Ayora and Baquerizo Moreno compared to Puerto Ayora and Puerto Villamil, and to Baquerizo Moreno and Puerto Villamil, between 1997 and 2011 (Table 5.7). In other words, a larger number of fishing grounds is shared between Puerto Ayora and Baquerizo Moreno's fishing fleets in comparison with any other combination of ports. Baquerizo Moreno and Puerto Villamil's fishing fleets show the lowest degree of overlapping of their fishing activity spaces (Fig. 5.3). Similar patterns were identified by observer onboard data analysis (Table 5.8; Fig. 5.4). Overall, these results suggest that Galapagos fishing fleets have shown, on average, low degrees of overlap in their fishing activity spaces since 1997, particularly in relation to their core areas.

Table 5.7 Estimated site fidelity (IOR95) of fishing fleets to similar core areas and distribution ranges, according to port interview data collected at the three-main port of Galapagos from 1997 to 2011. SD: Standard deviation.

Port	Core Area		Distribution range	
	IOR95	SD	IOR95	SD
Puerto Ayora-Baquerizo Moreno	0.013	± 0.021	0.090	± 0.084
Puerto Ayora-Puerto Villamil	0.002	± 0.004	0.050	± 0.039
Puerto Villamil-Baquerizo Moreno	0.000	± 0.000	0.013	± 0.020

Table 5.8 Estimated site fidelity (IOR95) of fishing fleets to similar core areas and distribution ranges, according to observer onboard data collected at the three-main port of Galapagos from 1997 to 2011. SD: Standard deviation.

Port	Core Area		Distribution range	
	IOR95	SD	IOR95	SD
Puerto Ayora-Baquerizo Moreno	0.137	± 0.083	0.250	± 0.090
Puerto Ayora-Puerto Villamil	0.003	± 0.006	0.043	± 0.025
Puerto Villamil-Baquerizo Moreno	0.000	± 0.000	0.040	± 0.036

However, the central tendency, dispersion and directional trends of Baquerizo Moreno, Puerto Ayora and Puerto Villamil fishing fleets' core areas and distribution ranges showed variations among periods, changing from no overlap to large overlap. According to the data collected by port interviews, the Baquerizo Moreno fishing fleet's core area and distribution range was located exclusively around San Cristobal Island both before and after marine zoning implementation, i.e. between 1997 and 2005 (Fig. 5.3), showing no overlap with the Puerto Ayora and Puerto Villamil fishing fleets ($IOR_{CA,\ DR}$ = 0.00). However, Baquerizo Moreno's fishing fleet core area expanded towards Santa Fe, western and southern parts of

Santa Cruz and Santiago Islands, respectively, since the closure of the sea cucumber fishery (Fig. 5.3). Fishing grounds located in these zones are shared between Baquerizo Moreno and Puerto Ayora's fishing fleets, whose IOR_{CA} values ranged between 0.00 to 0.05 between 1999 and 2011. Baquerizo Moreno's fishing fleet distribution range showed a similar but larger expansion pattern. In this case, Baquerizo Moreno's fishing fleet moved toward Española, and the eastern part of Isabela Island during the closure of the sea cucumber fishery, reaching the western part of Floreana during the recovery of the spiny lobster fishery (Fig. 5.3). IOR_{DR} values estimated for Baquerizo Moreno in relation to Puerto Ayora are also quite low (0.00-0.22), but higher than those estimated in relation to Puerto Villamil (0.00-0.04). Based on these results, a key pattern is elucidated: spiny lobster fishing grounds located along San Cristobal Island are used exclusively by fishers from Baquerizo Moreno, although Puerto Ayora's fishing fleet expanded temporally part of its distribution range toward San Cristobal during the re-opening and expansion phases of the sea cucumber fishery.

The same dataset showed that the Puerto Ayora fishing fleet registered a large variation in its spatiotemporal distribution between 1997 and 2011 (Fig. 5.3). The core area and distribution range of this fishing fleet covered exclusively Santa Cruz and Santa Fe Islands between 1997 and 1998, showing no overlapping positions with Puerto Villamil and Baquerizo Moreno ($IOR_{CA, DR}$=0.00). However, Puerto Ayora's core area expanded to Santiago and the west and eastern parts of Isabela Island, while the distribution range extended practically to the entire archipelago during the re-opening and expansion phases of the sea cucumber fishery, with the exception of the far-northern islands of Darwin and Wolf. In contrast, the core area and distribution range contracted remarkably during marine zoning implementation, reaching similar dimensions to those observed between 1997 and 1998; i.e., during the Co-governance and El Niño period. However, during the recovery of the spiny lobster fishery, core area and distribution range re-expanded again until reaching dimensions similar to those observed during the marine zoning implementation.

Unlike Puerto Ayora and Baquerizo Moreno, Puerto Villamil´s fishing fleet showed minimum variations of its core area and distribution range through the years, denoting a remarkable fidelity of Puerto Villamil's fishers to their traditional fishing grounds. In this case, the fishing fleet's core area was located exclusively in the southern part of Isabela Island, although it expanded temporally to the Bolivar Channel, located between the eastern and western parts of Fernandina and Isabela Islands, respectively, during the sea cucumber collapse phase and global financial crisis period (Fig. 5.3). Puerto Villamil fishing fleet's distribution range showed a consecutive expansion and contraction pattern similar to that described for Puerto Ayora during the same periods. However, unlike Puerto Ayora's fishers, who expanded their distribution range beyond Santa Cruz Island, Puerto Villamil's fishers remained fishing exclusively along the coastline of their home island, Isabela. Indeed, the Puerto Villamil fishing fleet's core area did not overlap with those of Puerto Ayora and Baquerizo Moreno between 1997 and 2011 (IOR_{CA}= 0.00). This result elucidates another key pattern: spiny lobster fishing grounds located in the southern and western part of Isabela Island tend to be used exclusively by fishers from Puerto Villamil. The only exception occurred during the reopening phase of the sea cucumber fishery, when Puerto Villamil and Puerto Ayora fishing fleets' core area slightly overlapped, showing an IOR_{CA} value of 0.01.

In summary, our results suggest that boom and bust exploitation of the sea cucumber fishery and the global financial crisis period affected the central tendency, dispersion and directional trends of core areas and distribution ranges of the Baquerizo Moreno, Puerto Ayora and Puerto Villamil fishing fleets. Even though fishers showed fidelity to fishing grounds located near their homeport, fishing fleets' core areas and distribution ranges changed from no overlap to large overlap. This was reflected in the expansion of fishing effort beyond the home ports of the fishing fleets.

5.5.3 Spatiotemporal analysis of fishing patterns: 2. hotspot analysis

Hotspot analysis revealed the existence of significant fishing clusters across the archipelago and throughout the six periods analyzed (Fig. 5.5 and 5.6). According to the data collected by port interviews (Fig 5.5), fishing effort showed high densities exclusively in the southern part of Isabela and San Cristobal Islands, near of Baquerizo Moreno and Puerto Ayora, during the Co-governance and El Niño period (CoM-En). During the re-opening and expansion phase of the sea cucumber fishery, new hotspots appeared along western and eastern parts of Santa Cruz Island, western and southwestern parts of Isabela Island, eastern part of San Cristobal Island and southeastern part of Genovesa Island. Hotspot location patterns have shown few variations since the reopening phase of the sea cucumber fishery (RvBn1). Some hotspots disappeared sporadically during and after the sea cucumber overexploitation and marine zoning implementation phase (MarZon), particularly those located in the western and southwestern part of Isabela Island. However, most hotspots have remained in the same locations through the years, particularly those located near fishing ports. Only during the spiny lobster recovery period (Recovery), a single hotspot appeared in the southwestern part of Isabela Island, which had not been registered in previous periods, suggesting that fishing effort aggregated in new fishing grounds in 2011.

Similar fishing patterns were identified by analysis of onboard observer data (Fig. 5.6), although some slight variations were detected. According to this source of data, during the expansion phase of the sea cucumber fishery (RvBn2), there were a group of hotspots in the northwestern part of Marchena and Pinta Islands, as well as in the western and eastern part of Floreana Island, which were not detected by port interview data analysis. During this period, sampling effort of active small vessels by interviews was on average 32.5% between 2001 and 2002, while for observers onboard, the average was 6% during the same period (Table 5.2).

As a result, different results obtained by the two data sources could be explained by two reasons: (1) fisher provided inaccurate information about the location of their fishing grounds during the expansion of the sea cucumber fishery; or (2) observer onboard-based data are less representative of the spatiotemporal dynamics of the fishing fleet than interview-based data. In any case, despite the minor differences described, the general fishing patterns identified by both data sources were quite similar (Fig. 5.5 and 5.6).

In summary, our results suggest that the spatial distribution of fishing effort hotspots was not largely affected by the human and climatic drivers analyzed in this study. However, even though fishing effort concentrates in fishing grounds located near homeports, fishing fleets' core areas and distribution ranges showed large variations due to economic perturbations caused by the boom and bust exploitation of the sea cucumber fishery and the global financial crisis.

These fishing patterns could be explained by the existence of two types of fishers in the archipelago: specialist and generalist fishers. Specialist fishers concentrate in one area, on one species, or one fishing method, while generalist fishers switch areas, target species, fishing gears, or even engage in activities unrelated to fishing (Salas and Gaertner, 2004). Our results, and previous studies (Castrejón, 2011), suggest that both types of fishers operate in each homeport of the GMR. Most fishers in Puerto Villamil can be classified as specialists. This is reflected in their preference to allocate their fishing effort near their homeport, as shown by the position of hotspots and the fishing fleet's core area in the southern part of Isabela Island. However, expansion of the fishing fleet's distribution range suggests that there is also a group of generalists operating in the same homeport. This type of fishers expanded their distribution range to fishing grounds located farther away from their homeports, probably as a strategy to absorb the economic perturbation caused by the total closure of the sea cucumber fishery and the global financial crisis. The same fishing behavior was observed in Puerto Ayora and Baquerizo Moreno. However, our results suggest that most fishers in these two homeports are generalists due to the larger expansion of their core areas and distribution ranges during the boom and bust exploitation of the sea cucumber fishery. A further key result, important from a management perspective, is that while hotspot analysis revealed significant fishing clusters throughout the six periods analyzed, their location did not show large variations after marine zoning implementation. This suggests that fishers were not displaced from their traditional fishing grounds nor were they attracted to the boundaries of no-take zones by a "fishing the line" effect.

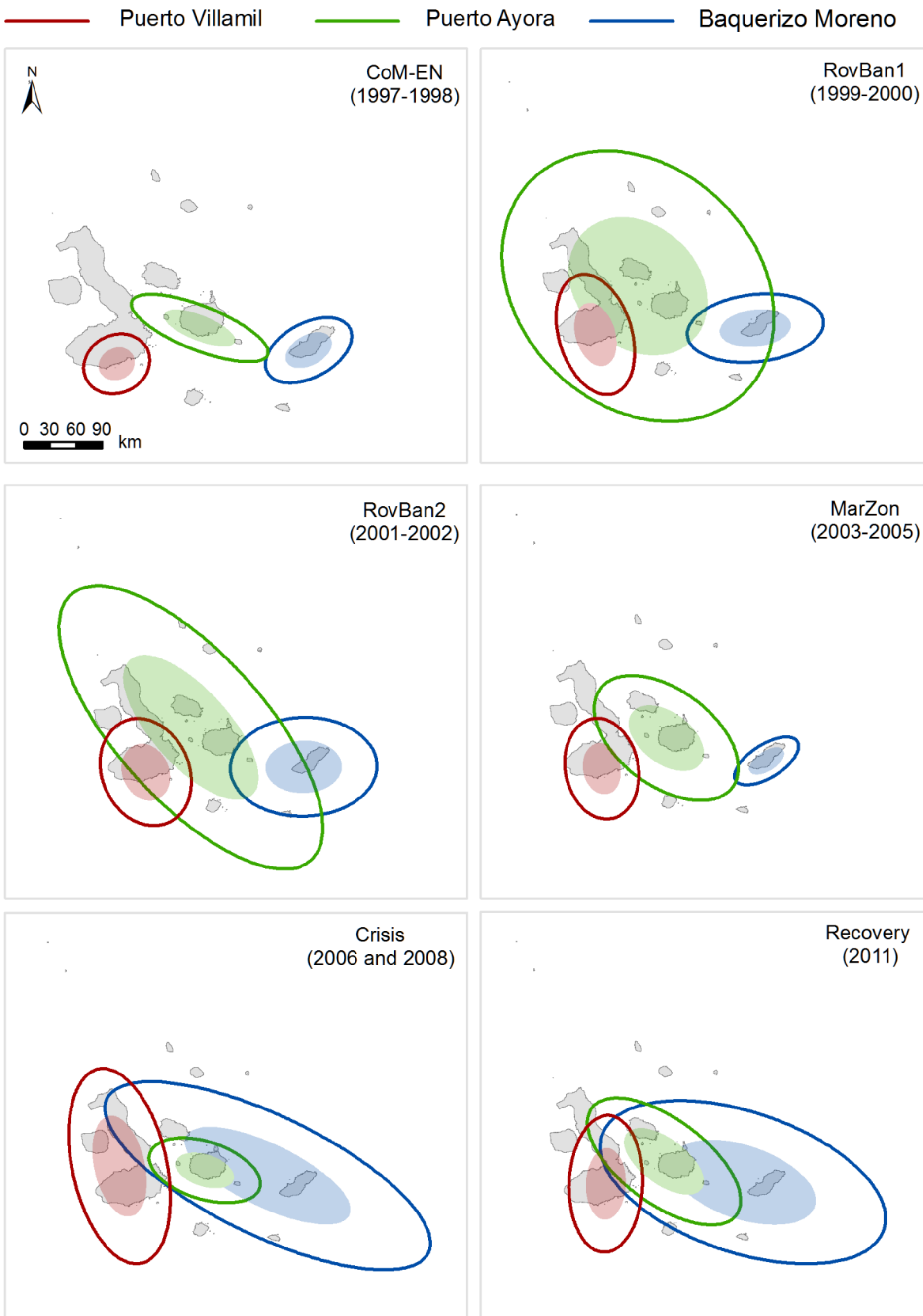

Figure 5.3 Core areas (filled ellipses) and distribution ranges (unfilled ellipses) of the fishing fleets from Puerto Ayora, Baquerizo Moreno and Puerto Villamil in the Galapagos Marine Reserve between 1997 and 2011, based on port interview data, for each of the 6 time periods: Co-governance and El Niño (CoM-EN); Sea cucumber re-opening phase (RovBan1); Sea cucumber expansion phase (RovBan2); Sea cucumber overexploitation phase and marine zoning (MarZon); Sea cucumber collapse phase and global financial crisis (Crisis); and Spiny lobster recovery (Recovery).

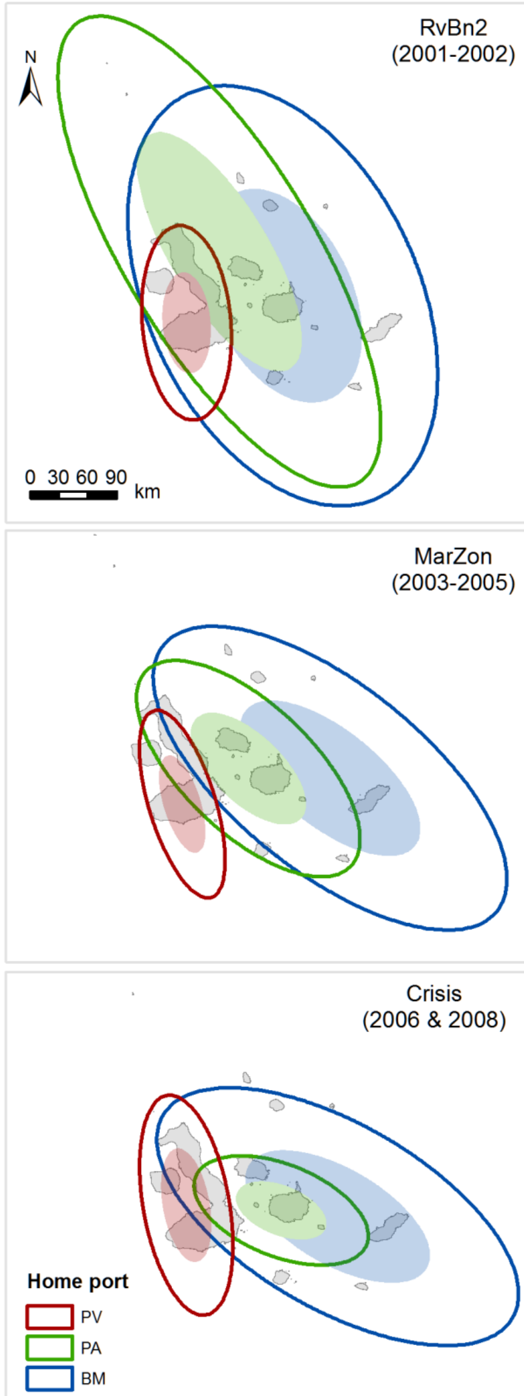

Figure 5.4 Core areas (filled ellipses) and distribution ranges (unfilled ellipses) of the fishing fleets from Puerto Ayora, Baquerizo Moreno and Puerto Villamil in the Galapagos Marine Reserve between 2001 and 2008, based on observer onboard data. Results are shown for three-time periods: Sea cucumber expansion phase (RovBan2); Sea cucumber overexploitation phase and marine zoning (MarZon); Sea cucumber collapse phase and global financial crisis (Crisis).

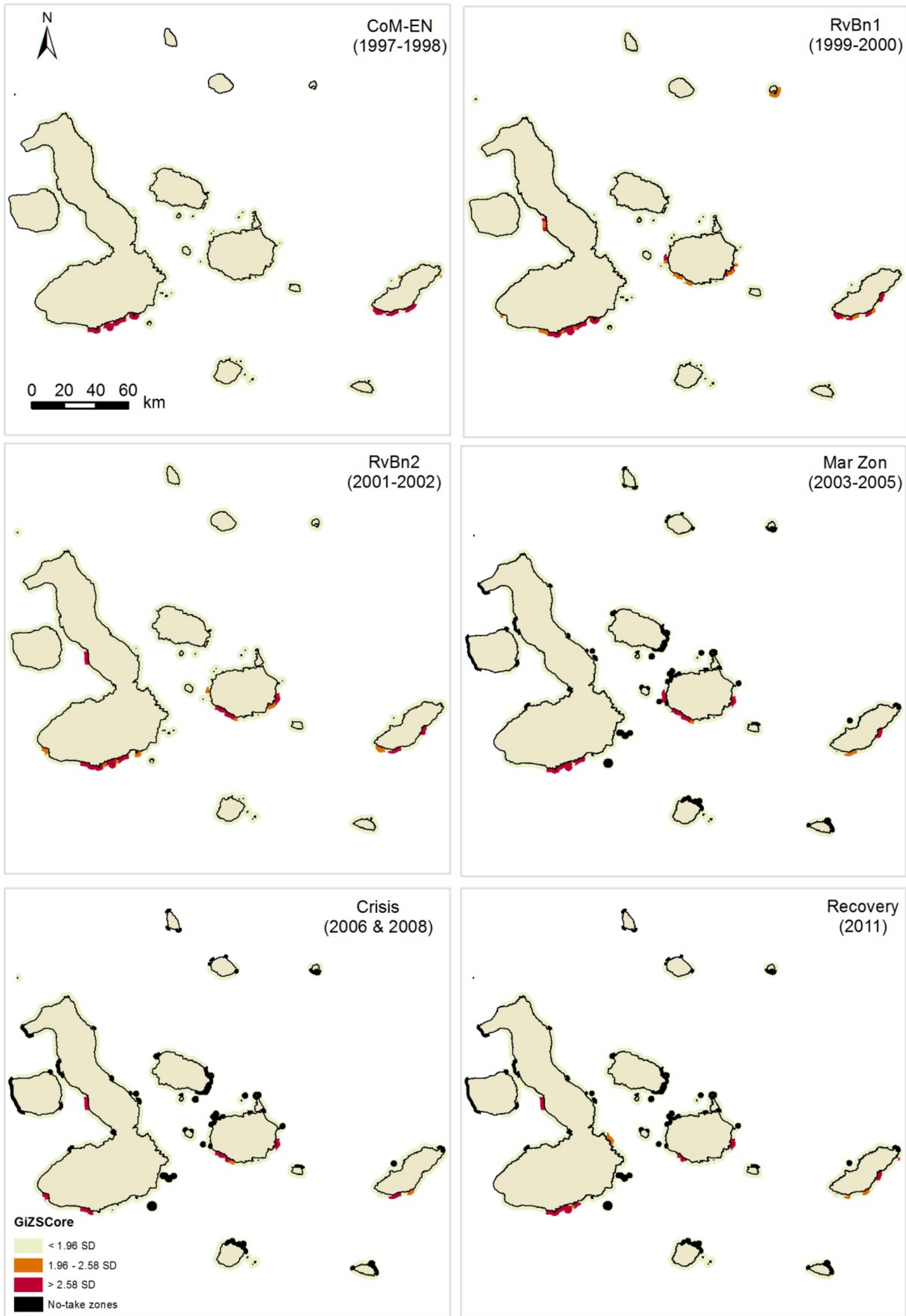

Figure 5.5 Fishing effort hotspots in the Galapagos Marine Reserve for the spiny lobster fishery between 1997 and 2011, based on port interview data. Six-time periods are shown: Co-governance and El Niño (CoM-EN); Sea cucumber re-opening phase (RovBan1); Sea cucumber expansion phase (RovBan2); Sea cucumber overexploitation phase and marine zoning (MarZon); Sea cucumber collapse phase and global financial crisis (Crisis); and Spiny lobster recovery (Recovery).

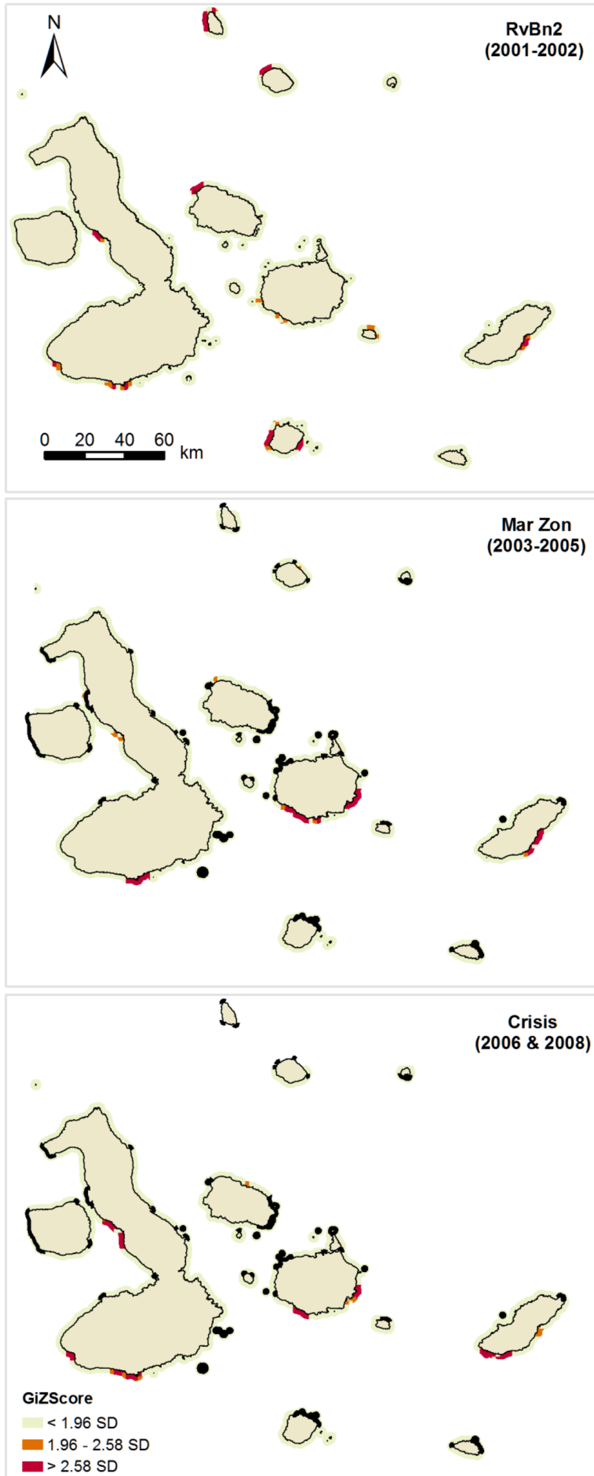

Figure 5.6 Fishing effort hotspots in the Galapagos Marine Reserve for the spiny lobster fishery between 2001 and 2008, based on observer onboard data. Three-time periods are shown: Sea cucumber expansion phase (RovBan2); Sea cucumber overexploitation phase and marine zoning (MarZon); Sea cucumber collapse phase and global financial crisis (Crisis).

5.5.4 Climatic and human drivers affecting spatial fishing effort allocation

Performance statistics for the BRT models suggests that all models showed a good predictive performance to independent test data, meaning that they effectively predicted fishing effort for the spiny lobster fishery in terms of the climatic and human drivers (Table 5.9). The regional BRT model explained 29.47% of the deviance in the data. Its Pearson correlation coefficient was 0.55, and the average difference between the predicted and observed fishing effort was MAE= 3.15 diver hours and RMSE= 5.43 diver hours (Table 5.9). BRT models per port showed, in most statistics, better predictive performance than the regional BRT model (Table 5.9). Specifically, the BRT models for Puerto Villamil, Puerto Ayora and Baquerizo Moreno explained 35.73, 32.66 and 15.74% of deviance in the data, respectively, while their Pearson correlation coefficients were 0.59, 0.54 and 0.44, respectively, and the average difference between the predicted and observed fishing effort were MAE= 3.11, 3.46, and 2.76 diver hours and RMSE= 5.97, 5.71, and 3.96 diver hours, respectively.

Regional analysis. Based on these significant results, it was seen that the three most important fishing effort predictors contributing to the regional BRT model were (1) distance to homeport, (2) previous spiny lobster catch and (3) time period (CoM-EN, RovBan1, RovBan2, MarZon, Crisis and Recovery), followed by (4) latitude, (5) longitude, (6) sea cucumber revenues and (7) Oceanic Niño Index (ONI; Table 5.9). These seven predictors explained 76.9% of the variance in the fishing effort data. The remaining predictors (nearest distance to no-take zones, spiny lobster ex-vessel price, homeport, bioregions, month and type of vessel) were not useful in predicting fishing effort (as they performed worse than random numbers (RN)). Based on the sum of the VI scores, static variables contributed very slightly more to the regional BRT model than dynamic predictor variables (Table 5.9, static: 50.0% dynamic: 45.3%).

Partial dependence plots for the regional BRT model showed the following effects on fishing effort (Fig. 5.7):

1. Fishing effort increased with distance to homeport, showing two peaks at 100 and 150 km, a decreasing trend between 160 and 220 km, followed by two additional peaks at 230 and 350 km.

2. Fishing effort increased with the previous spiny lobster catch up to a value of 60 kg tail/fishing trip, then decreased until previous spiny lobster catch was approximately 105 kg tail/fishing trip, and after this point, fishing effort showed a second peak at 110 kg tail/fishing trip, leveling off subsequently.

3. Effort increased dramatically due to the reopening of the sea cucumber fishery (RovBN1), then declined gradually until reaching a minimum value during the sea cucumber collapse phase and global financial crisis. However, it displayed a maximum peak during the recovery phase of the spiny lobster fishery.

4. Spatially, fishing effort increased from 1.0° S to 1.5° N, reaching maximum values between 1.0° N and 1.5° N; i.e., around Darwin and Wolf islands (in the northernmost part of the Galapagos). As Darwin and Wolf are located more than 300 km away from main fishing ports (Fig. 5.7), our results suggest that fishers spent more diving hours fishing around these two islands probably due to the time and cost required to travel to them. In relation to longitude, fishing effort showed a decreasing trend from 91.3° W to 90.2° W; i.e., from the Eastern part of Fernandina toward Santiago Island; this was then followed by a steep increase from 90.0° W to 89.5° W; i.e., from the Western part of Santa Cruz Island toward Española and the Southwestern part of San Cristobal. This suggests that fishing effort is largely influenced by the location of fishing ports, which are located in the southern part of Isabela, Santa Cruz and San Cristobal. In consequence, fishing effort is higher in those fishing grounds located near Puerto Villamil, Puerto Ayora and Baquerizo Moreno. This statement is supported by the strong performance of the DistHP variable as a fishing effort predictor (Table 5.9) and by the location of hotspots and fishing fleets' core areas (Fig. 5.3-5.6).

5. Regarding sea cucumber revenues obtained the fishing season before the beginning of lobster season (SeaCucRev), fishing effort increased when sea cucumber revenues ranged between USD2000 and USD5000/fishing season, showing a decreasing trend afterwards, including a steep decrease when revenues were higher than USD 11000/fishing season.

6. Finally, fishing effort increased when ONI ranged between -1.0 and 2.0. ONI values equal to or higher than +0.5 indicate El Niño conditions, meaning that the East-central tropical Pacific is significantly warmer than usual. In contrast, ONI values equal to or lower than -0.5 indicate La Niña conditions, meaning that the region is cooler than usual. Therefore, our results suggest that fishing effort increased during El Niño conditions.

Port-by-Port Analysis. Homeport BRT models showed, in most cases, similar patterns to the regional BRT model (Table 5.9). However, predictor variable contributions varied among homeports, particularly in Baquerizo Moreno (Table 5.9). As in the regional BRT model, the importance of static variables was higher than dynamic variables both for Puerto Villamil and Puerto Ayora BRT models (Table 5.9, PV: static (49.8%), dynamic (46.2%); PA: static (59.8%), dynamic (34.5%)). In contrast, dynamic predictor variables contributed more than static predictor variables in the BRT model for Baquerizo Moreno (Table 5.9, static: 37.0%; dynamic: 56.0%).

This difference could be attributed to the socioeconomic features of each homeport, which shows differences regarding number of fishers and composition of the fishing fleet (Table 5.1). Specifically, Baquerizo Moreno has historically had the largest concentration of fishers and mother boat vessels (Table 5.1; Castrejón, 2011). Such features probably have forced fishers to fish farther away from their homeport to reduce competition with their peers; thus, reducing the influence of static variables on fishing effort distribution. In contrast, the reduced number of mother boats in Puerto Ayora and Villamil increased the influence of static variables, which have probably forced fishers to catch spiny lobsters near homeports.

According to the BRT model for Puerto Villamil (Table 5.9), fishing effort was mostly influenced by eight variables (distance to homeport, previous spiny lobster catch, latitude, sea cucumber revenues, longitude, period, nearest distance to no-take zones, and ONI), all of which performed better than RN.

The most important predictors contributing to the BRT model for Puerto Ayora were quite similar to Puerto Villamil, although their ranking was different (Table 5.9). In both cases, the most important predictor was the distance to homeport. However, unlike Puerto Villamil, spiny lobster ex-vessel price performed better than RN in the BRT model for Puerto Ayora, while nearest distance to no-take zones and sea cucumber revenues performed worse.

Unlike Puerto Villamil and Puerto Ayora, the three most important predictors contributing to the BRT model for Baquerizo Moreno were longitude, ONI, and sea cucumber revenues, followed by previous spiny lobster catch, period, latitude, and distance to homeport (Table 5.9). The remaining predictors performed worse than RN.

Partial dependence plots for the most influential variables identified by BRT models showed, in most cases, different patterns among homeports (Fig. 5.8-5.10). In Puerto Villamil, fishing effort increased gradually between 30 and 70 km from the homeport, leveling off subsequently (Fig. 5.8). In contrast, fishing effort increased gradually between 20 and 150km from Puerto Ayora, then levelled off until 320 km, reaching maximum values after this distance (Fig. 5.9). In other words, fishers from Puerto Ayora tend to fish farther away from their homeport in comparison with their peers from Puerto Villamil. In Baquerizo Moreno, this explanatory variable performed better than RN. However, its importance as fishing effort predictor (7.4) was much lower in comparison with Puerto Ayora (17.5) and Puerto Villamil (22.2) due to the socioeconomic features explained above (Table 5.9; Fig. 5.10). In Puerto Villamil and Baquerizo Moreno, fishing effort increased with the previous spiny lobster catch, to a value of 30 and 55 kg tail/fishing trip, respectively, decreasing afterwards (Fig. 5.8 and 5.10). In both cases, fishing effort increased again up to a previous spiny lobster catch at 105 and 60 kg tail/fishing trip, respectively, and leveled off subsequently. In contrast, fishing effort in Puerto Ayora increased abruptly up to a previous spiny lobster catch between 40 and

60 kg tail/fishing trip, decreasing afterwards (Fig. 5.9).

Table 5.9 For each variable, the variable importance (VI) score (summing to 100) and the ranking is shown, for regional results and for each port. Green: predictor performed better than random numbers (RN); Red: predictor performed worse than RN. Shown at the bottom of the table are summary values for regional and homeport boosted regression tree (BRT) models, i.e. the sums of static and dynamic VI scores, the deviance explained, Pearson's correlation coefficient; the root mean square error (RMSE), the normalized root mean square error (NRMSE), the mean absolute error (MAE), and the normalized mean absolute error (NMAE). DistHP: distance to homeport; NearNTZ: distance to the nearest no-take zone; ExVesPrice: average ex-vessel price per year; PrevCatch: lobster catch obtained in previous fishing trip; SeaCucRev: average sea cucumber revenues obtained before the beginning of lobster fishing season season; ONI: Oceanic Niño Index; NA: No Applicable.

Variable	Regional	Ranking	Puerto Villamil	Ranking	Puerto Ayora	Ranking	Baquerizo Moreno	Ranking
DistHP	22.4	1	22.2	1	17.5	1	7.4	7
Latitude	9.0	4	10.5	3	15.7	3	8.4	6
Longitude	7.2	5	8.2	5	16.4	2	17.1	1
Bioregion	2.6	12	2.4	10	5.5	9	0.1	13
NearNTZ	4.7	9	6.5	7	4.7	10	4.0	10
Period	11.1	3	7.5	6	7.3	5	9.8	5
Month	1.9	13	1.3	12	2.1	11	5.7	9
ExVesPrice	4.1	10	2.0	11	6.2	7	2.3	11
Vessel	1.0	14	0.8	13	1.7	12	0.6	12
ONI	5.9	7	6.0	8	6.3	6	13.6	2
SeaCucRev	6.1	6	10.3	4	1.3	13	12.3	3
PrevCatch	15.2	2	18.3	2	9.6	4	11.7	4
HomePort	4.1	11	NA	NA	NA	NA	NA	NA
RN	4.8	8	4.0	9	5.8	8	7.0	8
Sum of static variables importance	50.0		49.8		59.8		37.0	
Sum of dynamic variables importance	45.3		46.2		34.5		56.0	
Deviance explained (%)	29.47		35.73		32.66		15.74	
Pearson's correlation coefficient (r)	0.55		0.59		0.54		0.44	
RMSE	5.43		5.97		5.71		3.96	
NRMSE	0.07		0.07		0.09		0.09	
MAE	3.15		3.11		3.46		2.76	
NMAE	0.04		0.04		0.05		0.06	

In Puerto Villamil, fishing effort in the spiny lobster fishery increased with sea cucumber revenues up to the latter value of USD2500/fishing season, showing a second and highest peak when revenues were higher than USD6400/fishing season (Fig. 5.8). In Baquerizo Moreno, fishing effort showed a positive relationship with sea cucumber revenues only when they reached values between USD4000 and USD5000/fishing season (Fig. 5.10). Before this threshold no relationship was found. In Puerto Ayora, this explanatory variable was not relevant (Fig. 5.9). These results suggest that sea cucumber revenues tend to subsidize fishing effort in the spiny lobster fishery, at least in Puerto Villamil and Baquerizo Moreno.

Spatially, fishing effort showed different distribution patterns across the archipelago, according to each fishing fleets' homeport. For Puerto Villamil, fishing effort showed two peaks at latitudes 1.1 S and 0.5 S, while longitude showed an increasing trend in fishing effort from 90.8° W to 91.2° W (Fig. 5.8). These results suggest that fishing effort increased from Puerto Villamil toward the Southwestern part of Isabela Island, reaching a peak probably in the hotspot located in the South part of this island (Fig. 5.5 and 5.6). Then fishing effort increased toward the North, reaching a peak probably in the hotspot located in the Western side of Isabela Island (Fig. 5.5 and 5.6). For Puerto Ayora, fishing effort increased gradually from 1.0° S toward 1.5° N, probably around Darwin and Wolf Islands (Fig. 5.9). Regarding longitude, fishing effort showed a decreasing trend from 90.0° W to 92.0° W; i.e., from the Western of Santa Fe Island toward Santa Cruz, Isabela and Fernandina Islands. Finally, fishing effort for Baquerizo Moreno showed a peak at -1.5°S, probably around Española Island, then increasing very slightly from South to North (Fig. 5.10). Regarding longitude, fishing effort showed an increasing trend from 89.5° W to 90.8° W (Fig. 5.10); i.e., from the Western part of San Cristobal Island toward Santiago Island. This trend is also shown by the direction of Baquerizo Moreno's fishing fleet core areas and distribution ranges (Fig. 5.3 and 5.4). These results demonstrate that BRT models reasonably predict fishing effort, as indicated by the similarity of predictions with those fishing patterns identified by GIS modelling techniques.

Only in Puerto Villamil, NearNTZ was identified by BRT models as relevant explanatory variable (Table 5.9). In this case, fishing effort increased with increasing distance from

NearNTZ, showing the highest values between 38 and 45 km (Fig. 5.8). This result suggests no 'fishing the line' effect around the nearest no take zones.

Fishing effort showed similar patterns in Puerto Villamil, Puerto Ayora and Baquerizo Moreno regarding the Oceanic Niño Index (ONI; Fig. 5.8-5.10). Fishing effort reached maximum values when ONI ranged between 1.2 and 2.0. In Puerto Villamil and Puerto Ayora, fishing effort showed an increasing trend from -1.0 to 1.5 (Fig. 5.8 and 5.9). Finally, fishing effort in Baquerizo Moreno increased gradually after 0, showing a peak around 2.0 (Fig. 5.10). Since ONI values equal or higher than +0.5 indicate El Niño conditions, meaning that East-central tropical Pacific is significantly warmer than usual (versus ONI values equal or lower than -0.5, indicating La Niña conditions, with the region cooler than usual), our results suggest that fishing effort increased during El Niño conditions.

This pattern could be caused by the redistribution of spiny lobster stocks from inshore to deeper waters, making them inaccessible to fishing by hooka diving. In this sense, there is scientific evidence that female spiny lobsters (*Panulirus argus*) migrate towards deeper waters to reproduce, returning to inshore waters once the season is over (Bertelsen *et al.*, 2009). Such reproductive migrations are influenced by temperature. According to Vega (2003), warmer temperatures during El Niño periods accelerate the time of breeding of *Panulirus interruptus* significantly, while the contrary occurred under colder temperatures caused by La Niña. Based on these studies, fishing effort probably was higher in the Galapagos spiny lobster fishery during El Niño events because of inaccessibility of these species to fishing. Reproductive migration of spiny lobsters to deeper waters probably resulted in increased search times, forcing fishers to increase their diving hours per fishing trip. However, additional studies about the impact of temperature on the ecology of *P. penicillatus* and *P. gracilis* stocks are required to test this hypothesis.

Finally, fishing effort showed different patterns according to the time period. In Puerto Villamil, fishing effort decreased gradually after the reopening of the sea cucumber fishery period (RovBn1) until reaching a minimum value during MarZon period, increasing afterwards until reaching a maximum peak during the spiny lobster recovery period (Fig.

5.8). In Puerto Ayora, fishing effort showed a maximum peak during the reopening of the sea cucumber fishery (RovBN1), declining gradually until reaching a minimum value during the spiny lobster recovery (Fig. 5.9). In Baquerizo Moreno, fishing effort showed maximum values between CoM-EN and RovBN2 periods. Then, it decreased until reaching a minimum value during the sea cucumber collapse phase and global financial crisis. Afterwards, fishing effort increased slightly (Fig. 5.10). These results, in combination with the results obtained by the analysis of active fishing capacity from 1999 to 2011 and the spatiotemporal analysis of fishing fleets' core areas and distribution ranges, suggest that fishing effort dynamics in the spiny lobster fishery were largely influenced by the economic perturbation created by the boom and bust exploitation of the sea cucumber fishery and the global financial crisis, rather than the marine zoning implementation. This statement is supported by the poor performance of the NearNTZ variable as a fishing effort predictor, which was reflected on the water in the lack of a 'fishing the line' effect around no take zones.

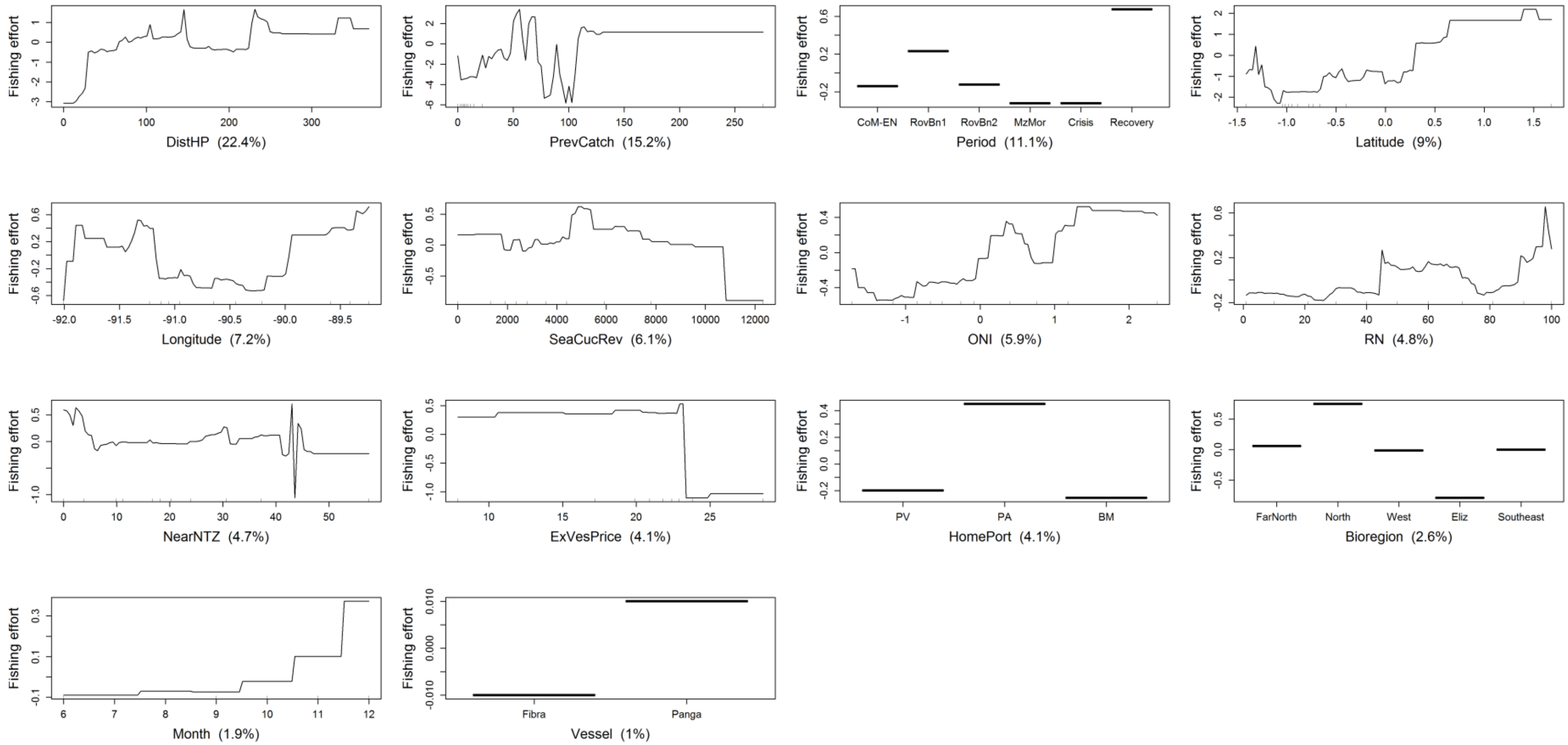

Figure 5.7 Variation of fishing effort (in diver hours) in relation to predictor variables for the spiny lobster fishery from the Galapagos Marine Reserve, according to the **regional** BRT model. The response variable (diver-hours) has been centered by subtracting its mean. Variable importance (VI) scores are shown in parentheses. Rug plots indicate the distribution of observations in relation to the predictor variable. Acronyms for the Period variable are described in Table 5.4.

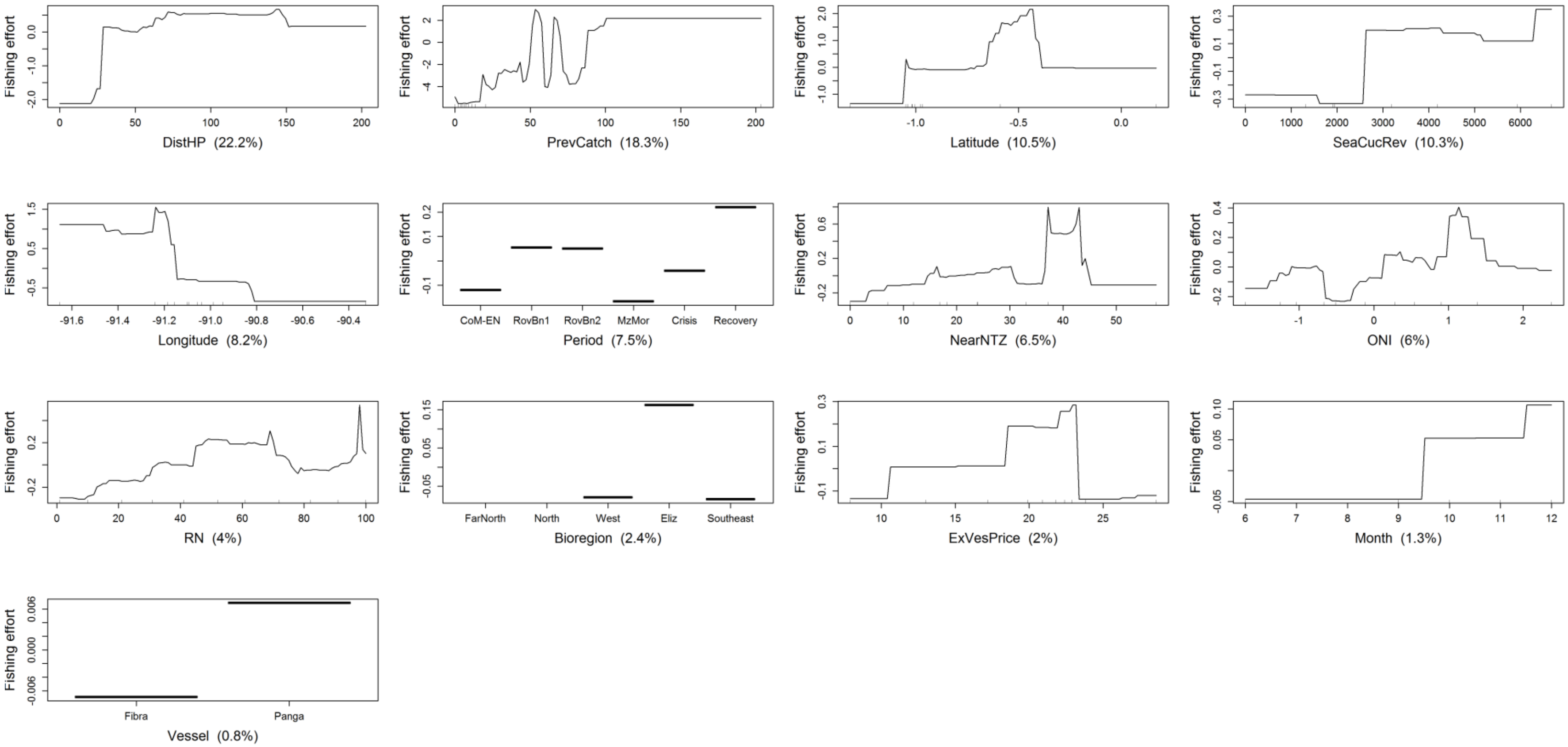

Figure 5.8 Variation of fishing effort (in diver hours) in relation to predictor variables for the spiny lobster fishery of the Galapagos Marine Reserve, according to the BRT model for **Puerto Villamil**. The response variable (diver-hours) has been centered by subtracting its mean. Variable importance (VI) scores are shown in parentheses. Rug plots indicate the distribution of observations in relation to the predictor variable. Acronyms for the Period variable are described in Table 5.4.

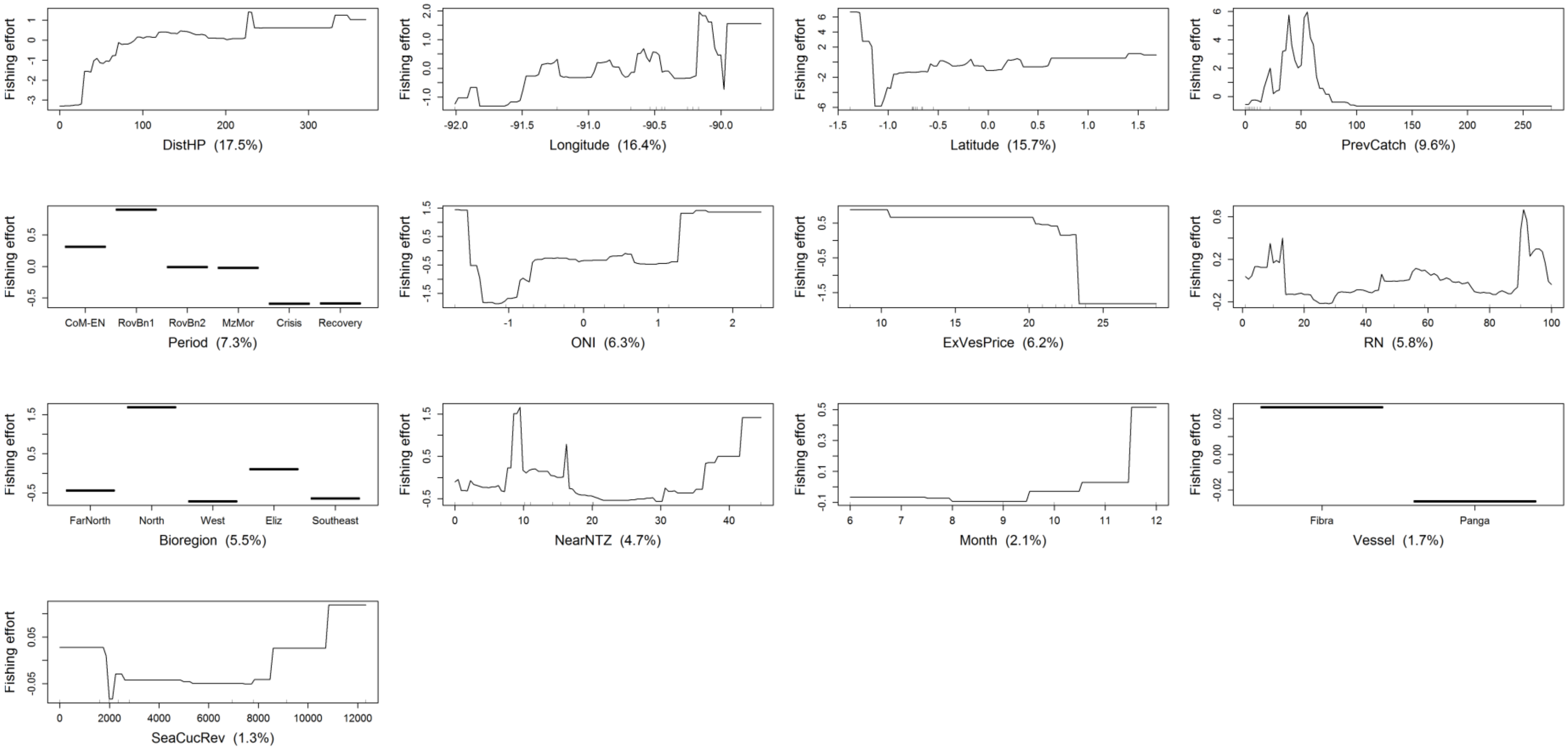

Figure 5.9 Variation of fishing effort (in diver hours) in relation to predictor variables for the spiny lobster fishery from the Galapagos Marine Reserve, according to the BRT model for **Puerto Ayora**. The response variable (diver-hours) has been centered by subtracting its mean. Variable importance (VI) scores are shown in parentheses. Rug plots indicate the distribution of observations in relation to the predictor variable. Acronyms for the Period variable are described in Table 5.4.

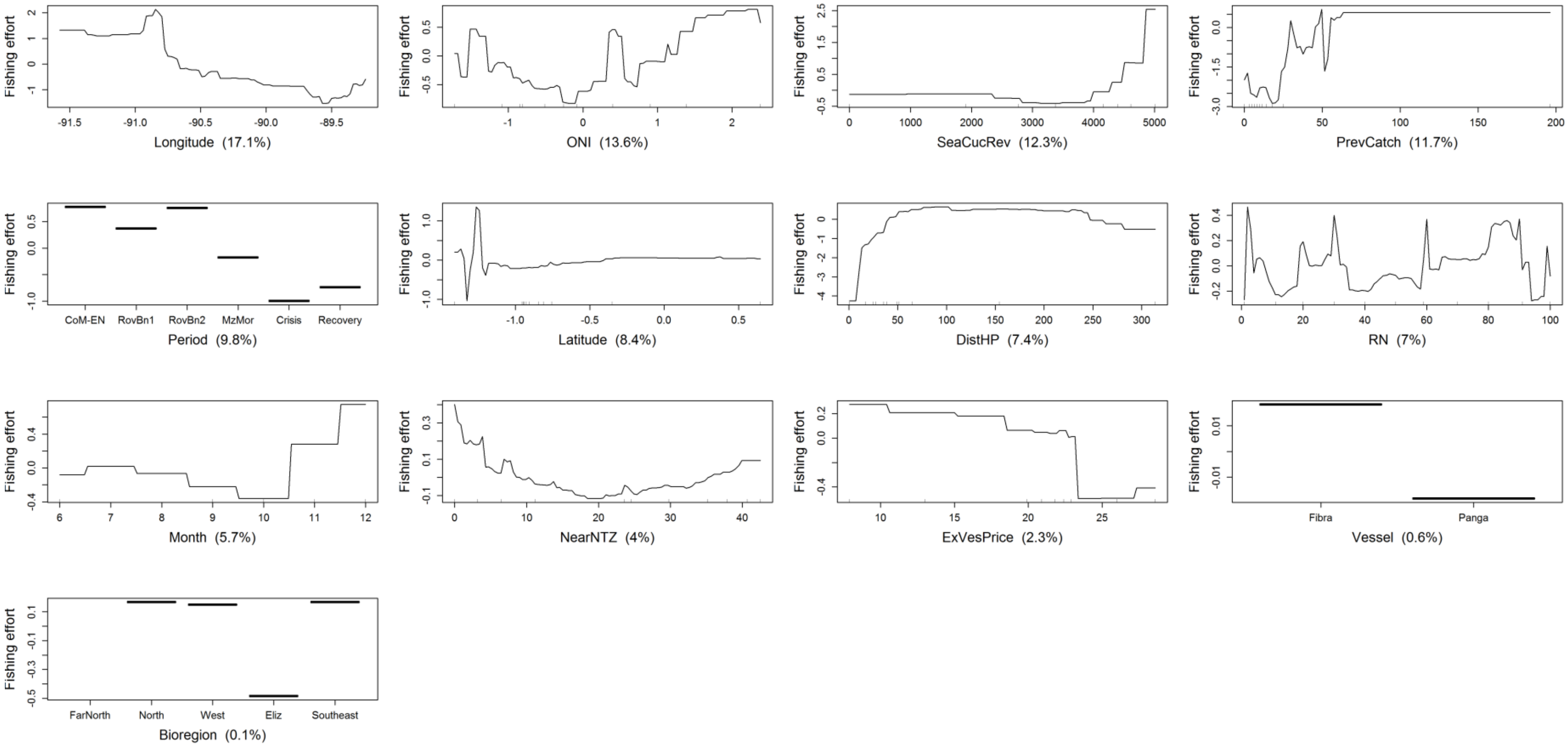

Figure 5.10 Variation of fishing effort (in diver hours) in relation to predictor variables for the spiny lobster fishery from the Galapagos Marine Reserve, according to the BRT model for **Baquerizo Moreno**. The response variable (diver-hours) has been centered by subtracting its mean. Variable importance (VI) scores are shown in parentheses. Rug plots indicate the distribution of observations in relation to the predictor variable. Acronyms for the Period variable are described in Table 5.4.

5.6 Discussion

This is the first study to evaluate the response of fishing effort distribution to human and climatic drivers, inside a multi-use MPA, using a combination of GIS techniques and boosted regression models. This type of study is usually unfeasible in developing countries due to the dominance of data-poor fisheries (Horta e Costa et al., 2013a; Soykan et al., 2014). However, availability of long-term fishery related data for the Galapagos spiny lobster fishery allowed us to examine how fishers´ adaptive responses differed according to the magnitude and intensity of diverse human and climatic drivers. Our results suggest that these responses were shaped by the nature of the spiny lobster fishery, and the geographic and socioeconomic features of fishing communities in which fisher organizations are embedded. Such knowledge provides insights about how fishers' adaptive responses could influence the interpretation of no-take zone effectiveness and the management implications of fishing patterns identified.

Our results showed that substantial changes in the core areas and distribution ranges of fishing fleets occurred in the spiny lobster fishery due to the interaction of different climatic and human drivers (and explanatory variables) acting at multiple temporal and spatial scales. The boom-and-bust exploitation of the sea cucumber fishery and the global financial crisis, rather than no-take zone implementation, were the most important drivers. Both drivers triggered substantial macro-scale changes in fishing effort dynamics within the Galapagos Marine Reserve, which in turn altered the micro-scale dynamics of fishing patterns in the small-scale fishing fleet. Macro-scale changes were represented by the reduction of fishing effort (number of fishers and vessels), while micro-scale changes were represented by spatiotemporal variations in the fishing fleets' core areas and distribution ranges.

One of the the most relevant patterns identified was that aggregation of fishing effort was not detected around no-take zone boundaries. Hotspots of fishing effort did not show large variations since 1997, suggesting that fishers were not displaced from their traditional fishing grounds nor attracted to no-take zone boundaries by a "fishing the line" effect. This result is supported by the poor performance of the 'nearest distance to no-take zones' variable (NearNTZ) in predicting fishing effort. NearNTZ was a relevant explanatory variable only to predict fishing effort in Puerto Villamil, although partial dependence plots showed that fishing effort increased with increasing distance from NearNTZ both in Puerto Villamil, Puerto Ayora and Baquerizo Moreno.

Lack of a "fishing the line" effect could be the result of the biased location of no-take zones across the Galapagos Marine Reserve. According to Edgar et al. (2004), the selection of no-take zones was not random, but rather fishers sought to minimize perceived impacts on their livelihood by locating no-take zones in areas with low densities of the most valuable commercial species, while tourism operators and sport divers promoted the protection of areas containing high densities of species important for tourism (e.g., sharks). Thus, sea cucumber and spiny lobster baseline densities were 3 and 2.7 times higher in fishing zones compared to no-take zones, respectively, although differences between both zone types was not significant for spiny lobsters (Edgar et al., 2004). Thus, the location of no-take zones in areas with low abundance of the most lucrative species explains why fishers have shown historically a lack of interest in these areas, as reflected in a lack of 'fishing the line' effect around no-take zone boundaries.

Even though fishing effort hotspots have not shown large variations since 1997, remarkable spatiotemporal variations in the core areas and distribution ranges of fishing fleets were detected. In 1999, the sea cucumber fishery was re-opened after a five-year precautionary closure without a complete and solid legal and institutional framework (Castrejón *et al.*, 2014). The growing social pressure to expand the exploitation of this resource delayed the application of the moratorium on new entrants decreed by the Galapagos Special Law for four years, resulting in the exponential growth of fishing capacity between 1999 and 2002.

The overcapitalization of the small-scale fishing sector caused by the rapid expansion of the sea cucumber fishery led to its overexploitation, resulting in the implementation of total closures beginning in 2006. As fishing licenses are not resource-specific (i.e., only one fishing license is needed to access all Galapagos fisheries), sea cucumber fishers, most of whom immigrated to Galapagos from mainland Ecuador in the 1990s (Castrejón, 2011), also acquired access to the spiny lobster fishery. As a consequence, fishing capacity increased in both fisheries as the sea cucumber fishery expanded across the archipelago. The core areas and distribution ranges of the Puerto Ayora and Baquerizo Moreno fishing fleets expanded during the re-opening and expansion phases of the sea cucumber fishery. A similar pattern was shown by Puerto Villamil´s fishing fleet during the same periods. However, unlike Puerto Ayora and Baquerizo Moreno, Puerto Villamil's fishers remained fishing exclusively along Isabela's coastline.

In contrast, all fishing fleets' core areas and distribution ranges showed a remarkable contraction during marine zoning implementation, re-expanding again during the crisis period caused by the total closure of the sea cucumber fishery and the global financial crisis. Only Puerto Ayora´s fishing fleet showed a further contraction of its core area and distribution range during the latter period. Similar fishing patterns were observed during the recovery period of the spiny lobster fishery, although Puerto Ayora´s fishing fleet re-expanded its core area and distribution range toward Santiago and the eastern part of Isabela Island.

According to BRT models, these adaptive responses were shaped by six predictor variables (distance to homeport, latitude, longitude, period, ONI, and previous spiny lobster catch), which performed better than RN. Sea cucumber revenues also showed a good predictive performance, although its usefulness for Puerto Ayora was irrelevant. The coastally oriented nature of the spiny lobster fishery, and the geographic and socioeconomic features of each homeport, help to explain why the six explanatory variables identified by BRT models are the most relevant as fishing effort predictors. Each port shows differences regarding number of fishers, composition of the fishing fleet, and available land-based tourism infrastructure (Table 5.1). Consequently, each fishing fleet showed different adaptive responses on the water to them, as explained below.

A special feature of Galapagos is the limited number of landing sites, which are located exclusively in the southern zone of each homeport. These geographic features, together with the limited autonomy of the Galapagos small-fishing fleet and the close proximity of homeports to the most productive fishing grounds (located in the southern part of Isabela Island, the western part of Santa Cruz and Santiago Islands, and southwestern part of San

Cristobal Island) explain why static rather than dynamic explanatory variables were more relevant as fishing effort predictors. Thus, distance to homeport, latitude and longitude are the most important variables explaining why fishers from the same homeport tend to use similar fishing grounds, creating exclusive core areas, which usually do not show overlapping positions.

In contrast, dynamic variables explain why fishing patterns changed during certain periods of time. In this sense, our results suggest that two variables – the revenues produced by the sea cucumber fishery and the previous lobster catch – are responsible for the alternate expansion and contraction of fishing fleets' core areas and distribution ranges during the boom-and-bust exploitation of the sea cucumber fishery, marine zoning implementation and the global financial crisis. Since 1999, the spiny lobster fishing season usually was initiated a couple of months after the conclusion of the sea cucumber fishing season. Higher revenues produced by the sea cucumber fishery and higher previous lobster catches were associated with increasing trends in fishing effort in the spiny lobster fishery. According to our results, this trend was reflected on the water in the expansion of fishing fleets' core areas and distribution ranges during the reopening and expansion period of the sea cucumber fishery. Higher revenues produced by this fishery during such periods probably acted as subsidies that allowed spiny lobster fishers to extend their fishing trips for longer times and farther away from their homeports.

This trend changed remarkably during marine zoning implementation. The contraction of distribution ranges and core areas that occurred during that period could be due to a severe reduction in fishing capacity produced by the overexploitation of the sea cucumber fishery. Our results showed that a significant number of fishers and vessels abandoned not only the sea cucumber fishery, but also the spiny lobster fishery between 2000 and 2006. This trend intensified after 2006 due to the total closure of the sea cucumber fishery and the climax of the global financial crisis that contracted the consumption of lobsters in the United States and European Union (Castrejón and Defeo, 2015). According to Defeo et al. (2016), this trend led to a 56% reduction in fishing effort in the spiny lobster fishery between 2005 and 2008.

During the financial crisis, middlemen refused to buy landings at higher prices. In response, some fishers decided to abandon the spiny lobster fishery. This resulted in declines of total fishing effort, catch, and exports to mainland Ecuador by 20%, 23% and 45%, respectively (Castrejón and Defeo, 2015; Defeo *et al.*, 2016). Our results suggest that those fishers who decided to remain in the spiny lobster fishery after 2006, responded on the water to the crisis by re-expanding their distribution ranges and core areas, probably as a strategy to increase their catch rates and reduce competition with their peers. This pattern was particularly notable in Baquerizo Moreno, probably because this homeport has historically comprised the largest proportion of fishers and mother boats (Castrejón, 2011).

Only Puerto Ayora's fishing fleet showed a contraction of its distribution range and core area during the crisis, probably caused by a remarkable diversification of markets and products. In Puerto Ayora, a small group of fishers reacted to the global financial crisis in two ways (Castrejón and Defeo, 2015): 1) diversifying their product by trading whole fresh lobsters instead of lobster tails, as had been done since the 1960s; and 2) diversifying their market by selling their product directly to the local hospitality sector and general public instead of middlemen. The restructuring of the value chain has improved fishers' revenues by increasing local consumption of whole lobsters and ex-vessel prices (Viteri and Moreno, 2014). Thus, instead of expanding its distribution range and core area to other islands, Puerto Ayora's fishers probably faced the crisis by adding value to their catches and, based on our results, by distributing their fishing effort toward fishing grounds located near their homeport. The latter probably increased their profits by reducing their variable costs (e.g., diesel fuel). Diversification of products and markets were adaptive responses, enabled by the fact that tourist and land-based infrastructure (hotels and restaurants) is higher in Puerto than in Baquerizo Moreno and Puerto Villamil.

While the economic crisis was detrimental for Galapagos fishers, it was beneficial for spiny lobster stocks. Two years after the official end of the recession, lobster CPUE (catch per unit effort) and catch increased 91% and 102%, respectively, whereas fishing effort only increased 6% between 2009 and 2011 (Defeo *et al.*, 2016). According to Defeo et al. (2013), spiny lobster recovery could be attributed to the substantial reduction in fishing effort, together with the combined effect of market forces and favorable environmental conditions. Nevertheless, although total fishing effort decreased due to the reduction in the number of active fishers and vessels, partial dependence plots suggest that Puerto Villamil and Baquerizo Moreno's fishers, who kept participating actively in the spiny lobster fishery, increased their fishing effort during the recovery period. In contrast, Puerto Ayora's fishers reduced their fishing effort during the same period. The total closure of the sea cucumber fishery, in combination with a lack of alternative livelihoods, probably has forced Puerto Villamil and Baquerizo Moreno's fishers to catch spiny lobsters more intensively. In contrast, as explained previously, Puerto Ayora's fishers have diversified their products and markets thanks to its higher number of tourist, hotels and restaurants, making fishers there less vulnerable to the economic impact caused by total closure of the sea cucumber fishery and the global financial crisis. For this reason, probably, sea cucumber revenues were irrelevant as a fishing effort predictor exclusively for Puerto Ayora's fishing fleet.

In summary, fishers showed different adaptive responses on land and water, according to the geographic and socioeconomic features of each homeport. Such adaptive responses allowed them to cope with the socioecological impact caused by the interaction of the human and climatic drivers analyzed in this study.

5.6.1 Lesson learned and management implications

A comprehensive understanding of how local fishing communities cope with the interactions of various human and climatic drivers, both temporally and spatially, is fundamental to reduce the risk of marine and fishery management decisions. In particular, in this case, a key risk lay in biased assessments of marine zoning effectiveness, which could lead to the adoption of misleading management actions in the Galapagos Marine Reserve. Without a full analysis, it might have been wrongly concluded that the spiny lobster stocks recovery was the result of implementing no-take zones whereas such a conclusion is not supported by our results, nor those of other studies (Castrejón and Charles, 2013; Defeo *et al.*, 2016).

Indeed, as the adoption of marine zoning, as a management strategy, is not contributing currently to the sustainability of Galapagos shellfish fisheries, a shift in fisheries policy direction in the Galapagos Marine Reserve is recommended, toward a broad-based and integrated social-ecological approach, which takes into consideration the spatial-temporal dynamics of fishery resources, fishing fleets and fisher response to regulations, as well as the spatial distribution of key biodiversity areas (Charles, 2001, 2012, Castrejón and Charles, 2013, 2014; Castrejón *et al.*, 2014).

As part of this shift, the spatial dynamics of fishing fleets and spiny lobster stocks – as well as other relevant fishery resources, such as sea cucumbers, Galapagos groupers (*Mycteroperca olfax*) and yellowfin tuna (*Thunnus albacares*) – should be evaluated in an integrated way to improve the design and management effectiveness of the current marine zoning scheme. In this sense, we suggest re-evaluating the distribution of no-take zones across the Galapagos Marine Reserve to promote the sustainability of the spiny lobster fishery. Following Castrejón and Charles (2013), we emphasize that no-take zones represent only one of multiple management tools available for the successful implementation of spatial EBM in the Galapagos Marine Reserve. A more effective approach could be a combination of a coastal network of no-take zones with co-managed harvested areas that allocate exclusive spatial fishing rights to local communities. This management approach has been suggested by recent studies as a more robust approach to address the roots of fisheries management failures that led to overexploitation of fisheries in the Galapagos Marine Reserve and elsewhere in the world (Salas *et al.*, 2011; Charles et al., 2016; Defeo et al., 2016; Westlund et al., 2017).

The active involvement of local communities in the co-management of strategically placed Territorial Use Rights for Fishing (TURF) could contribute, under certain enabling conditions, to generate a sense of exclusive use and ownership among fishers (Charles, 2009; White and Costello, 2011; Aburto and Stotz, 2013). This management approach could promote the implementation, by fishers themselves, of effective monitoring, control and surveillance procedures, and the accomplishment of objectives for management and conservation (Charles, 2012), as has been observed in spiny lobster fisheries from Baja California, México and Chile (Gelcich *et al.*, 2010; McCay *et al.*, 2014; Castrejón and Defeo, 2015), all currently certified by the Marine Stewardship Council (MSC) as sustainable (Pérez-Ramírez *et al.*, 2015).

Based on the distribution of core areas and fishing effort hotspots across the archipelago, for the Puerto Villamil, Puerto Ayora and Baquerizo Moreno fishing fleets, the most strategic places for the experimental implementation of TURFs in the Galapagos Marine Reserve are those located in the southern part of Isabela Island, the western part of Santa Cruz Island and the southeastern part of San Cristobal Island. These places are strategic because each is used exclusively by one fishing fleet, which reduces the likelihood of potential conflicts among different fishing fleets arising over competition for the same ocean space, and because each is located near the corresponding homeport and over most of those fishing grounds with the highest yields, which facilitates surveillance, control and monitoring activities and creates an economic incentive for TURF co-management.

No-take zones should be also strategically re-distributed across the archipelago to ensure the sustainability of the spiny lobster fishery. The biased location of no-take zones in areas of low abundance of the most lucrative species, in combination with a lack of effective enforcement and a high rate of non-compliance by fishers (César Viteri and Chávez, 2007), have severely limited the usefulness of a spatial ecosystem-based management (EBM) approach, through marine zoning, to promote the sustainability of Galapagos shellfish fisheries (Castrejón and Charles, 2013). Lack of the 'fishing the line' effect around no-take zones, found in this study, suggests that this spatially-explicit management tool has not contributed to rebuild spiny lobster stocks in the Galapagos Marine Reserve, either by a spillover or recruitment effect.

However, this hypothesis must be tested by a complementary study of the long-term impact of no-take zones on spiny lobsters across the archipelago. Such study should evaluate the mean effects of no-take zones and the influence of distance from no-take zones boundaries on the abundance, population structure and catch rates of spiny lobsters. This type of study was conducted by Kay et al. (2012) to evaluate the effect of a reserve network at the Santa Barbara Channel Islands (SBCI), California, USA over California spiny lobsters (*Panulirus interruptus*). These authors found that, after six years of reserve protection, there was a four-to eightfold increase in trap yields, a 5-10% increase in the mean size of legal sized lobsters, and larger size structure of lobster trapped inside vs outside of three replicate reserves. However, they did not find any signs of a fishing the line immediately outside reserve boundaries, probably due to moderate total mortality (Z=0.59) of legal sized lobsters outside reserves. According to this, and other studies (Guenther et al. 2015), spillover at the SBCI may be occurring, but probably the difference in CPUE and abundance between reserve boundaries and open fishing grounds is not sufficiently significant to encourage a redistribution of fishing effort outside reserve boundaries.

Spillover theory derived from MPA models and adjacent fisheries suggests that displaced fishermen concentrate effort along MPA borders (Guenther et al. 2015). However, the example provided above suggest that fishing the line does not always occur, even when there is evidence of spillover along MPA boundaries. This suggest that a fishing the line effect could not necessarily observed outside no-take zones in the GMR, even though there was an indication of lobsters' spillover. If future studies demonstrate that this is the case, then additional research efforts should focus on determining the specific ecological and socioeconomic variables that precludes the concentration of fishing effort around no-take zones in the GMR.

Further complicating the picture, no-take zones, to be effective, should be implemented in areas that ensure the protection of a proportion of the breeding stock and critical recruitment and nursery habitats, but the geographic location of these critical areas across the Galapagos archipelago is still uncertain. Fishing effort hotspots probably overlap with the location of spawning and nursery areas, another hypothesis that should be evaluated by future studies, but declaring fishing effort hotspots as no-take zones represents a huge challenge, considering the lack of evidence of the ecological and economic benefits provided by no-take zones and the high cost associated to their enforcement. That reality has contributed to reduce the acceptability and legitimacy of what could be potentially a valuable tool to co-manage Galapagos shellfisheries (Castrejón and Charles, 2013). In consequence, additional research and management effort are required to create the enabling conditions for the effective planning, implementation, monitoring and enforcement of the GMR marine zoning.

A key move in this direction would be through a governance system that allows a high degree of involvement and participation of local stakeholders, together with effective management and conservation frameworks and maintenance of decent fisheries livelihoods (Charles *et al.* 2016; Westlund *et al.* 2017). Based on our results, and to meet the need to create the enabling conditions required to reconcile fisheries and conservation objectives, we recommend two key steps the support the above governance system. First, the geographic definition of new management areas is needed, based on fishing fleets' core area and distribution ranges. Second, introducing an area-based co-management approach could enhance the acceptability and legitimacy of GMR's marine zoning, and specifically help to mitigate the potential conflict associated with the redistribution of no-take zones.

Within the area-based co-management system, we suggest creating specific co-management councils for each management area to promote the involvement and participation of local stakeholders in their planning, implementation, monitoring and enforcement. Each co-management council should be made up exclusively of those fishers, and other relevant stakeholders, who would be most affected by implementation of no-take zones, and/or the experimental allocation of TURFs, inside their fishing fleets' core area and distribution ranges. For example, decision-making regarding implementation of no-take zones in the south and western part of Isabela should involve exclusively fishers from Puerto Villamil because they are the ones who will be impacted directly by such management measures. In contrast, fishers' representatives from Puerto Ayora and Baquerizo Moreno should participate in the decision-making regarding no-take zones in Santiago, where fishing grounds are shared by both fishing fleets. Thus, area-based co-management could be useful to ensure a strategic distribution of no-take zones across the archipelago, to minimize the impact of zoning on fishing communities' livelihoods. This is turn could help to improve the acceptance, legitimacy and compliance of the new marine zoning scheme, as long as decision-making on implementation of spatially-explicit management tools is participatory, inclusive and transparent.

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CHAPTER 6. GENERAL DISCUSSION AND CONCLUSIONS

In this dissertation, I used a social-ecological approach, in combination with GIS modelling techniques and boosted regression models, to conduct a long-term integrated assessment about the impact of GMR's marine zoning and co-management regime on shellfish fisheries. My analysis focused on the impact of this alternative management approach, and other relevant human and climatic drivers, on the spatial distribution of fishing effort in the spiny lobster fishery. Based on this analysis, fishers' adaptive responses were identified, and their management implications analyzed, including their influence on the interpretation of no-take zone effectiveness assessments.

6.1 Main findings, recommendations and applied contributions

The following subsections present a general description about the social-ecological systems (SES) approach used in this dissertation to evaluate the Galapagos spiny lobster fishery. They also provide a summary of each of the Chapter conclusions, including a discussion about the academic and applied contributions of this work, and the actions that should be taken by local institutions to improve the management effectiveness of GMR's marine zoning and co-management regime on shellfish fisheries.

6.1.1 The Galapagos spiny lobster fishery as a social-ecological system

This dissertation explicity recognizes the spiny lobster fishery from the Galapagos Marine Reserve as a complex social-ecological system. In other words, it recognizes that the spiny lobster fishery is composed of three basic interacting subsystems: (1) the resource, represented by the spiny lobster stocks distributed inside the Galapagos Marine Reserve; (2) the resource users; represented by fishing communities from Puerto Ayora, Baquerizo Moreno, and Puerto Villamil, and (3) the resource management (or governing system), represented by the institutions and organizations that have a key role in the governance of Galapagos small-scale fisheries, such as the Galapagos National Park and the Charles Darwin Foundation.

By adopting a SES approach, my dissertation also recognizes that the dynamic of the three interacting subsystems described above was influenced by diverse human and climatic drivers between 1997 and 2011 (Fig 6.1). These drivers of change are represented in this dissertation by: (1) the establishment of institutions, policies and governance instruments, including the implementation of a co-management and common-property regime in combination with a marine zoning; (2) an extreme climatic event, represented by El Niño 1997/1998; (3) the expansion and overexploitation of a complementary fishery, represented by the boom-and-bust exploitation of sea cucumber fishery by roving bandits; and (4) the globalization of markets, represented by the global financial crisis 2007-2009.

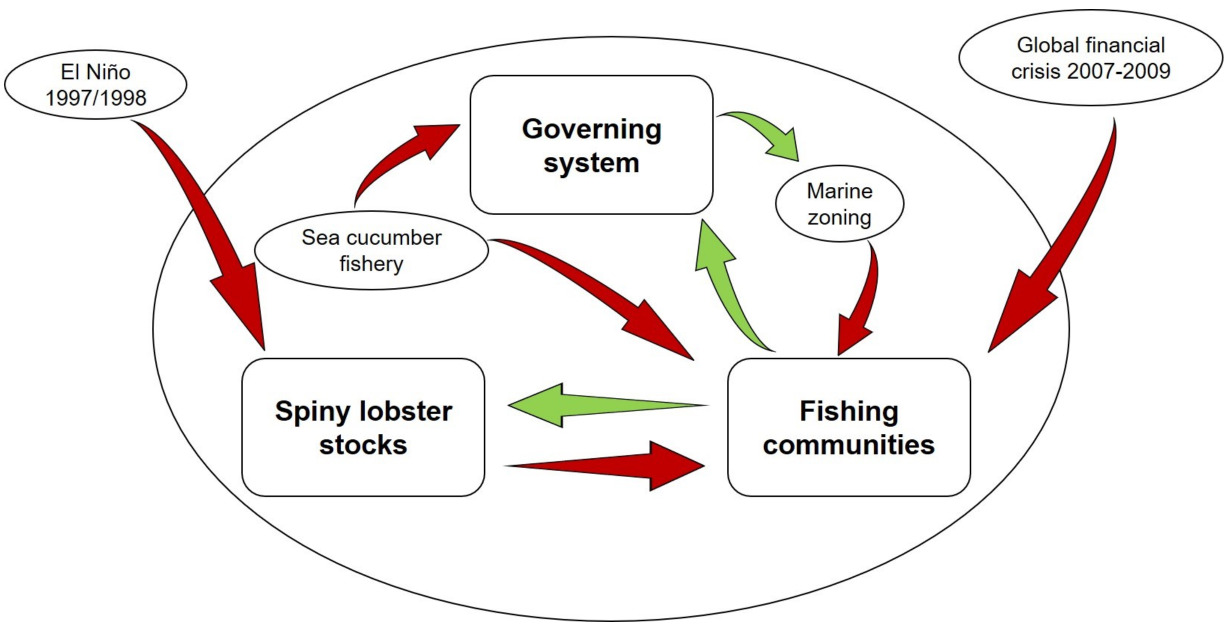

Figure 6.1 Visual representation of the spiny lobster fishery from the Galapagos Marine Reserve as a complex social-ecological system. Red arrows represent the social-ecological impact produced by human and climatic drivers of change, while green arrows represent the adaptive responses of the governing system and fishing communities to such drives.

Using a SES approach, in combination with GIS modelling techniques and boosted regression models, I evaluated not only how the social-ecological impact produced by the four types of human and climatic drivers described affected the dynamics of resource users and governing subsystems, but the adaptive capacity of Galapagos fishing communities and institutions to learn, self-organize and respond to the social-ecological changes produced by such drivers of change (Fig. 6.1). It is important to highlight that this dissertation did not evaluate explicitly the impact of marine zoning, and other drivers of change (e.g., El Niño 1997-1998), over the spiny lobster stocks; i.e., the resource subsystem. However, it recognises this topic as a research priority to understand the long-term impact of no-take zones, and climate variability, on abundance and population structure of spiny lobsters across the archipelago, and its management implications.

Finally, I integrated the knowledge produced by this dissertation to provide a set of recommendations to build institutional resilience to realize the potential value of marine zoning to co-managing Galapagos shellfish fisheries, and to improve the capacity of fishing communities and institutions to cope with and adapt to change. The following subsections explain with more detail the main findings, recommendations and applied contributions produced by the research approach used in this dissertation.

6.1.2 Factors influencing the effectiveness of marine zoning and co-management regime on Galapagos shellfish fisheries

I identified the institutional factors that have precluded the transition from a resource-focused to a SES and EBSM approaches in the GMR, including the shortcomings and lessons learned associated to its marine zoning scheme and co-management system (Chapter 2 and 3). My analysis reveals that concrete actions have been taken by local management authorities to assess and manage the protected areas of the archipelago as a SES and to adopt a EBSM approach. The most relevant being the implementation of the marine zoning under a co-management regime, and the participatory development of a social-ecological management plan. The latter for the first time encompasses both the marine and terrestrial protected areas as an integrated management unit. These actions represent an important step forward to address the roots of fisheries management failures that led to the overexploitation of the main shellfisheries of the GMR. However, as in other developing countries, the innovation in research outpaced the innovation in management (Andrew and Evans, 2011).

My review of the origin and advances of fishery science in the Galapagos Islands, before and after the creation of the GMR and its co-management system, suggests that the resource-focused approach is still engrained in the structure and function of local and national fishery agencies. This is making the practical application of a SES and EBSM approaches in the GMR a daunting challenge. Consequently, fishery research about SSF is still biased to the bio-ecological aspects of the fisheries systems, leading to inadequate or outdated information about the human dimensions (socio-economic, cultural and institutional) that affect SSF management in the GMR. Furthermore, the high turnover rate persistently observed in the Galapagos' scientific community and the pervasive loss of institutional memory has degraded the resilience of local fishery research and monitoring programs. This in turn has reduced their effectiveness to properly deal with the social-ecological assessment and co-management of SSF in the archipelago.

Besides the lack of long-term economic and human resources to complete the transition from a resource-focused to a SES approach, there are other institutional and socioeconomic factors that explain why the GMR has been unable to display a higher SSF governability (Chapter 3). This statement is supported by the incapacity of the co-management system to avoid the collapse of the sea cucumber fishery and the overexploitation of the spiny lobster fishery from the late 1990s to the middle 2000s. Such factors include (Chapter 3 and 4): (1) Social fragmentation of local fishing communities, which is reflected in the incapacity of fishing cooperatives to take collaborative actions by themselves, such as: adapt their harvesting and trading strategies, implement self-regulatory mechanisms to exclude outsiders, avoid illegal fishing and mitigate the impact of intermediaries; (2) incapability of exclusive tenure rights implemented (i.e., licenses and fishing permits) to mitigate over-exploitive fishing practices; (3) poor compliance with management regulations due to strong pervasive partnerships between local fishers and Asian intermediaries; (4) loss of credibility and legitimacy in the entire co-management system by fishers, possibly as a result of the implementation of arbitrary management measures that were not based on sound scientific knowledge (e.g., total allowable catch).

Poor governability of SSF in the GMR has also inhibited by poor institutional adaptive capacity. I used an interactive governance approach to identify the factors that have inhibited the building institutional adaptive capacity in the GMR (Chapter 4). My results suggest that fishery agencies and fishing cooperatives in Galapagos have shown poor capacity to learn, self-reorganize and respond collectively to the social-ecological impacts caused by El Niño 1997-1998, the boom and bust exploitation of the sea cucumber fishery and the global financial crisis. Only Puerto Ayora's fishers have shown individual adaptive responses to cope with the economic crises caused by total closure of the sea cumber fishery and global financial crisis (Chapter 4 and 5). Nevertheless, these adaptive responses have not been adopted collectively by Puerto Ayora's fishing cooperative (COPROPAG) yet. Although, some efforts have been carried out with the support of management authorities and international NGOs (Castrejón *et al.*, 2017).

Based on the comparative analysis of seven co-governance systems (Chapter 4), including the GMR, I identified the enabling conditions required to build institutional adaptability in the GMR's co-management system. I concluded that the governability of SSF is strongly dependent on the social attributes of fishers' organizations, the quality of the interactions between government and other actors, and the institutional adaptability to external drivers of change. Only those institutions that show strong social cohesion, organization and leadership, willingness to change, and work in a collective and collaborative way, are those that displayed a higher institutional capacity for adaptation and innovation. The latter was reflected in the capacity of institutions to take collective actions, based on past experiences and social-ecological memory, to re-organize themselves, create prolific partnerships, change harvesting and trading strategies, and implement self-regulatory mechanisms to prevent over-exploitive fishing practices. As fishing cooperatives in Galapagos lack these attributes, additional research and management efforts are required to build institutional adaptability and better SSF governability in the GMR. In this sense, improving fisher´s organizations social capital (e.g. leadership, social cohesion, organization and entrepreneurial capacity) should be a research and management priority for the GMR management authorities, academic institutions and NGOs.

6.1.3 Impact of no-take zones, and other relevant human and climatic drivers, on the spiny lobster fishery

In Chapter 4, I identified the factors hindering effective implementation of an EBSM approach in the GMR. The most pertinent among these being the lack of attention to the spatial-temporal distribution of fishing effort across the archipelago during the design of GMR's marine zoning. Based on this conclusion, I used GIS modelling techniques and boosted regression models to evaluate how the spatiotemporal allocation of fishing effort in the spiny lobster fishery was affected by the interactions of different human and climatic drivers, including marine zoning implementation (Chapter 5). Evaluating variations in the spatiotemporal allocation of fishing effort hotspots and fishing fleets' core areas and distribution ranges from 1997 to 2011, I determined how the interaction of different large-scale human and climatic drivers influenced the macro and micro-scale spatiotemporal dynamic of fishing patterns around no-take zones in the GMR, using as a case study the spiny lobster fishery (Chapter 5).

My results suggest that substantial changes in the central tendency, dispersion and directional trends of core areas and distribution ranges of Puerto Villamil, Puerto Ayora and Baquerizo Moreno fishing fleets occurred in the spiny lobster fishery due to economic perturbations produced by the boom-and-bust exploitation of the sea cucumber fishery and the global financial crisis, rather than no-take zone implementation. This statement is supported by the poor performance of the NearNTZ variable, as a fishing effort predictor, and by the lack of large variations in the location of fishing effort hotspots since 1997. These results were reflected on the water in the lack of a 'fishing the line' effect around no take zones, which suggests that fishers were not displaced from their traditional fishing grounds nor attracted to no-take zone boundaries.

Lack of a "fishing the line" effect is attributed to the biased location of no-take zones across the Galapagos Marine Reserve in areas with low abundance of the most lucrative species, such as sea cucumbers and spiny lobsters. This fact explains why fishers have shown historically a lack of interest in fishing around no-take zones. These results suggest that the GMR marine zoning did not affect fishing patterns dynamics in the spiny lobster fishery from

1997 to 2011. Instead, the economic perturbation produced by the boom-and-bust exploitation of the sea cucumber fishery and the global financial crisis forced a significant number of fishers and vessels to abandon not only the sea cucumber fishery, but also the spiny lobster fishery between 2000 and 2010. This macro-scale change was reflected on the water in a severe reduction of fishing effort, which together with the combined effect of market forces and favorable environmental conditions contributed to recovery of spiny lobster stocks in 2011.

Macro-scale changes in fishing effort dynamics within the GMR, in turn altered the micro-scale dynamics of fishing patterns in the small-scale fishing fleet, which was represented by spatiotemporal variations in fishing fleets' core areas and distribution ranges. Next subsection explains how these adaptive responses were shaped by the nature of the spiny lobster fishery, and the geographic and socioeconomic features of fishing communities in which fisher organizations are embedded. Such knowledge provides insights about how fishers' adaptive responses could influence the interpretation of no-take zone effectiveness and the management implications of fishing patterns identified.

6.1.4 Adaptive responses to climatic and human drivers of change

According to Chapters 4 and 5, fishers showed different adaptive responses on land and water, according to the geographic and socioeconomic features of each homeport, in terms of number of fishers, composition of the fishing fleet, and available land-based tourism infrastructure.

My results suggest that the alternate expansion and contraction of fishing fleets' core areas and distribution ranges observed in Puerto Villamil, Puerto Ayora and Baquerizo Moreno during the boom-and-bust exploitation of the sea cucumber fishery, marine zoning implementation and the global financial crisis were caused by two dynamic variables: the revenues produced by the sea cucumber fishery and the previous lobster catch. Higher revenues produced during the reopening and expansion period of the sea cucumber fishery allowed spiny lobster fishers to extend their fishing trips for longer times and farther away from their homeports. This was reflected on the water in the expansion of fishing fleets' core areas and distribution ranges. In contrast, the overexploitation of the sea cucumber fishery led a significant number of fishers and vessels to abandon not only the sea cucumber fishery, but also the spiny lobster fishery between 2000 and 2006. Reduction in fishing capacity and fishing effort was reflected on the water in the contraction of fishing fleets' distribution ranges and core areas during marine zoning implementation.

Reduction in fishing capacity and fishing effort intensified after 2006 due to the economic crisis produced by the total closure of the sea cucumber fishery and the climax of the global financial crisis, which contracted the consumption of lobsters in the United States and European Union. Our results suggest that most fishers who decided to remain in the spiny lobster fishery after 2006, responded to the crisis by re-expanding their distribution ranges and core areas, probably as a strategy to increase their catch rates and reduce competition with their peers. This pattern was particularly notable in Baquerizo Moreno, probably because this homeport has historically comprised the largest proportion of fishers and mother boats. In contrast, Puerto Ayora's fishing fleet showed a contraction of its distribution range and core area during the crisis, probably caused by a remarkable diversification of markets and products. My results suggest that Puerto Ayora's fishers faced the crisis by adding value to their catches and by distributing their fishing effort toward those fishing grounds located near their homeport, which probably increased their revenues by reducing their variable costs (e.g., diesel fuel). The remarkable diversification of markets and products helped fishers to improve revenues by increasing local consumption of whole lobsters and ex-vessel prices. Such adaptive responses were possible thanks to the tourist and land-based infrastructure (hotels and restaurants) of Puerto Ayora, which is much higher than Baquerizo Moreno and Puerto Villamil.

Thus, my dissertation reinforces the notion that crises represent opportunities for learning, adapting, and entering onto more sustainable pathways (Folke, Colding and Berkes, 2003). Even though GMR's marine zoning and co-management system was unable to prevent the overexploitation of shellfish fisheries, my dissertation shows that the economic crisis caused by these events and the global financial crisis, triggered the interest of fishers to diversify their products and markets (Chapter 4). This trend was reflected on the water in the contraction of Puerto Ayora fishing fleets' distribution ranges and core areas, which probably is a complementary adaptive response used by fishers to cope with the economic crisis. Such crisis also encouraged Puerto Ayora's fishing cooperative (COPROPAG) to create partnerships with management authorities and international NGOs, such as Conservation International and World Wildlife Fund, to improve the management and marketing system of the spiny lobster fishery (Ramírez, Castrejón and Toral-Granda, 2012; Castrejón *et al.*, 2017).

At the time of writing this dissertation, concrete actions have been taken to design and implement a fishery improvement project (FIP) for this fishery. This can be defined as "*an alliance of multiple fishery stakeholders that come together to agree upon an action plan, which specifies the activities required to facilitate the transition from over-exploited or collapsed fisheries toward fisheries that are ecologically sustainable, economically profitable and socially fair and equitable in a specified timeframe*" (Castrejón *et al.*, 2017).

FIP's action plan for the lobster fishery was designed with the participation of representatives of local fishing cooperatives, management authorities from the GNPS and other government agencies, and researchers from NGOs and universities. They used the results of this dissertation, together with other studies concerning the status, management and marketing system of the Galapagos spiny lobster fishery, as inputs for FIP's action plan design (Ramírez, Castrejón and Toral-Granda, 2012; Viteri and Moreno, 2014; Szuwalski *et al.*, 2016). Thus, a series of activities have been agreed upon and put in place to improve the spiny lobster fishery's value chain, control, monitoring and surveillance system, and the social capital of fisher´s organizations. These actions have resulted so far in the definition of reference points and harvest control rules for the red spiny lobster fishery. Additionally improvement of fishery monitoring, and the diversification of products and markets, have taken place improving the governability and higher revenues for fishers (Castrejón *et al.*, 2017). Furthermore, in alignment with the recommendations of this dissertation, additional actions will be put in place by local management authorities, in collaboration with fishing communities and international NGOs. These will work towards improving the governability of Galapagos fishery system as a whole, including: (1) integrated amendment of fishing regulations, with emphasis on the establishment of a species-specific licensing system that optimizes the distribution of fishing effort across multiple SSF, according to each stock productivity; and (2) experimental testing of an alternative spatially-explicit tenure-based management regime, whose results, if successful, will be used as inputs to reforming the existing legal framework.

6.1.5 Realizing the potential value of marine zoning to co-managing Galapagos shellfish fisheries

Based on the results and recommendations of Chapters 2-5, I identified a set of actions that should be taken by local institutions to realize the potential value of marine zoning to co-managing Galapagos shellfish fisheries.

6.1.4.1 Social-ecological assessment and co-management of small-scale fisheries by building institutional resilience

To complete the transition from a resource-oriented to a SES approach in the GMR, it is recommended to build institutional resilience (Chapter 2). To this end, a paradigm shift in the way science is being conducted and funding obtained in Galapagos is required to create a new institutional approach that mitigates the high turnover rate persistently observed in the Galapagos' scientific community and the pervasive loss of institutional memory. Alternatively, I propose the need for an interdisciplinary public research institution that contributes to assessing and managing small-scale fisheries as a social-ecological system. This paradigm shift is crucial to increase the resilience and adaptive capacity of both local management and research institutions to deal with the human and climate drivers that influence the governance of SSF. Multiple alternative scenarios to improve the quality, relevance, and applicability of fishery science conducted in the archipelago should be developed and analyzed in a participatory way with proper experts' advice and facilitation. The objective should be to identify resilience-building policies that encourage the leadership of Ecuador in the development of its own science and technology. This will enhance the resilience of research programs to meet, in a cost-effective way, the growing requirements of social-ecological research needs in the Galapagos.

To change the structure and function of local fishery research and monitoring programs to properly deal with the social-ecological assessment and co-management of SSF in the archipelago, I recommend following the following participatory process:

1. **Identification of research and management priorities:** identify marine science research and management priorities in collaboration with managers, fishers, scientists, and other relevant stakeholders. To this end, multi-stakeholder workshops should be conducted in the three main ports of Galapagos with proper experts' advice and facilitation.

2. **Development of a marine social-ecological research plan for Galapagos:** local management authorities should assemble an interdisciplinary scientific steering committee made up of local and external experts in social-ecological assessment of SSF in MPAs. This group should be responsible for outlining a plan for Galapagos, using an integrated conceptual framework for long-term social-ecological research, as suggested in Chapter 2. They should incorporate the research and management priorities identified by local management authorities and stakeholders and follow the guidelines provided by the GNPS social-ecological management plan. The research plan must include a long-term strategy and policies to mitigate the high turnover rate persistently observed in the Galapagos' scientific community. Additionally, it should include a strategy to systematize the fishery information produced (datasets, reports, papers, maps, etc.) to facilitate public access to local, national and international research and management institutions. Finally, a follow-up mechanism for revision and adaptation, and an estimated budget for its implementation should also be included in the plan.

3. **Evaluation of local fishery and marine science programs:** once the social-ecological research plan for Galapagos has been reviewed and approved by relevant decision-making co-management bodies, the next step should be evaluated the local fishery and marine science programs. The objective should be determining if local institutions have the scientific capacity (human resources, infrastructure, and

equipment) required to implement the research plan. If that it is not the case, proper policies, actions and funding should be put in place by the Ecuadorian government to gradually acquired such capacity.

4. **Investment proposal:** to attract the investment required to implement the social-ecological research plan for Galapagos, it is recommended that an investment proposal be developed. This document should inform potential investors, such as philanthropists, multilateral development banking institutions and private impact investors, about the cost and benefits produced by the social-ecological research plan, including information about the return and risk levels associated to such type of investment.

This participatory process could help local institutions to improve gradually their scientific capacity to properly deal with the social-ecological assessment and co-management of SSF in the archipelago.

6.1.4.2 Marine zoning adaptation and area-based co-management

Considering that the GMR marine zoning is a spatially-management tool that has not contributed to the sustainability of Galapagos shellfish fisheries, as explained in Chapter 3 and 5, I suggest improving the design and management effectiveness of the current marine zoning scheme by implementing a combination of a coastal network of no-take zones with co-managed harvested areas that allocate exclusive spatial fishing rights to local communities. The adoption of this broad-based and integrated social-ecological management approach should take into consideration the spatial-temporal dynamics of fishery resources, fishing fleets and fisher response to regulations, as well as the spatial distribution of key biodiversity areas.

Based on the results and recommendations presented in Chapter 5, I recommend the following key steps to implement the above broad-based and integrated social-ecological management approach:

1. **No-take zones**: Strategic re-distribution of no-take zones across the GMR by taking into consideration the spatiotemporal location of fishing effort hotspots and fishing fleets' core area and distribution ranges, as well as the spatial distribution of key biodiversity areas. To be effective no-take zones should be implemented in areas that ensure the protection of a proportion of the breeding stock and critical recruitment and nursery habitats.

2. **Territorial Use Rights for Fishing (TURF):** Experimental implementation of TURFs in the southern part of Isabela Island, the western part of Santa Cruz Island and the southeastern part of San Cristobal Island. According to my results, these three places are strategic because each is used exclusively by one fishing fleet and each is located near the corresponding homeport and over most of those fishing grounds with the highest yields. These features will reduce the likelihood of potential conflicts among different fishing fleets arising over competition for the same ocean space, and will facilitate surveillance, control and monitoring activities and creates an economic incentive for TURFs co-management. The strategic implementation of TURFs should also consider the spatial-temporal distribution of spiny lobster stocks, and other fishery resources, and key biobiversity areas.

3. **Area-based co-management:** Introduce an area-based co-management approach by geographically defining new management areas, based on fishing fleets' core area and distribution ranges, and by creating specific co-management councils for each management area. Each co-management council should be made up exclusively of those fishers, and other relevant stakeholders, who would be most affected by implementation of no-take zones, and/or the experimental allocation of TURFs, inside their fishing fleets' core area and distribution ranges.

To create the enabling conditions to implement this broad-based and integrated social-ecological management approach two key research effort are required: (1) determine the geographic location of spiny lobters critical recruitment and nursery habitats to ensure their protection by no-take zones; and (2) evaluate the long-term impact of no-take zones on abundance and population structure of spiny lobsters across the archipelago to justify the strategic redistribution of conservation areas across the archipelago.

An area-based co-management, based on the experimental implementation of TURFs, could be useful to ensure a strategic distribution of no-take zones across the archipelago, to minimize the impact of zoning on fishing communities' livelihoods, and to promote the involvement and participation of local stakeholders in the planning, implementation, monitoring and enforcement of TURFs and no-take zones. This is turn could help to improve the acceptance, legitimacy and compliance of the new marine zoning scheme, as long as decision-making on implementation of spatially-explicit management tools is participatory, inclusive and transparent.

The results and insights provided by this dissertation have been shared with Galapagos management authorities and stakeholders to inform the first comprehensive and integrated management effectiveness evaluation of the GMR's marine zoning, led by the GNPS with the support of local and international NGOs. This is a participatory process initiated in 2014, which was expected to conclude before 2016. However, political instability created by the Ecuadorian presidential election occurred in February 2017 delayed its conclusion. At the time of writing this dissertation, the GNPS has reinitiated the process to agree upon the new GMR's marine zoning scheme, which is expected to be completed in 2018. As recommended in Chapter 3 and 5, the adaptation of marine zoning is taking into considerations the distribution of key biodiversity areas, fishery resources, and fishing and touristic fleets. All these management actions reflect the willingness of local authorities and fishers to improve SSF governability by building institutional adaptability and resilience, which is a participatory process still in progress.

6.2 Lesson learned beyond the Galapagos Marine Reserve and future directions

The results and lessons learned through the long-term integrated and spatially-explicit assessment of this case study provides general insights potentially relevant for other MPAs interested on adopting ecosystem-based spatial management (EBSM), marine zoning and other alternative management approaches to improve the govermance and sustainability of small-scale fisheries.

The most important lesson learned is that, even though there is a growing recognition worldwide that the implementation of MPAs in combination with co-management regimes can be an effective solution for rebuilding depleted marine fish populations, their effectiveness to enhance the resilience of governing systems to respond to the social-ecological impacts produced by external drivers of change should not be taken for granted. This alternative approach is not a panacea, i.e., a one-size-fits-all solution that can be applied in all contexts. Its resilience will be tested when the fishery system must cope with the social-ecological impacts produced not only by extreme climatic events associated to global climate change, but the globalization of markets, and other types of perturbations, such as the establishment of new institutions, regulations or policies, or the development of new fisheries.

Based on the results provided by this dissertation, I identified four additional key lessons learned that must be taken into consideration to realize the potential value of marine zoning to co-managing small-scale fisheries in multiple use MPAs:

1. No-take zones must be designed and implemented using a broad-based and integrated social-ecological approach, which takes into consideration not only the spatial-temporal dynamics of fishery resources and the spatial distribution of key biodiversity areas, but also the dynamics of fishing fleets, and fishers' adaptive responses to regulations. Otherwise, no-take zones will not be useful management tools for rebuilding depleted marine fish populations and conserving marine ecosystems.

2. To be successful, a co-management regime must be built over a strong social capital (Gutiérrez *et al.* 2011). In consequence, a strategic and integrated long-term plan-based approach must be adopted to improve fishing communities' social capital in terms of leadership, social cohesion, organization and entrepreneurial capacity.

3. Allocate proper fishing rights, create suitable incentives, and implement effective enforcement mechanisms to encourage the conservation of fishery resources and to increase the credibility and legitimacy over marine zoning.

4. MPA effectiveness assessment should not take for granted that any change on fishing patterns was caused exclusively by MPA implementation. Instead, it must be explicity recognized that, in addition to MPA implementation, fishers usually cope with the interaction of different human and climatic drivers of change acting at different spatial and temporal scales. These include not only extreme climatic events associated to global climate change (e.g., hurricanes, El Niño, etc.), but socioeconomic perturbations produced by the globalization of markets, the development and/or collapse of alternative fisheries, among other factors.

The long-term integrated and spatially-explicit assessment of the spiny lobster fishery from the Galapagos Marine Reserve also provides general insights about three key topics: (1) the challenges associated to the practical application of SES and EBSM in developing countries; (2) the usefulness of GIS techniques in combination with boosted regression models to evaluate and predict how fishing effort distributions respond to different human and climatic drivers in a multiple use MPA; and (3) the importance of comprehensive analysis of fishers' adaptive responses to drivers of change to reduce the risk of conducting biased marine zoning effectiveness assessments.

The institutional and socioeconomic challenges associated to the practical application of SES and EBSM in the GMR is a clear example of the divergence between the rapid advances in fisheries research worldwide and the real-world legal, policy and organizational constraints of SSF management typically observed in developing countries (Andrew and Evans, 2011). Such divergence is produced by the inadequate structure and function of national fishery departments, which in most cases lack the expertise and resources required to manage SSF and multiple-use MPAs as SES. The SES framework provides guidance about how to assess the social and ecological dimensions that influence resource use and management. However, its operationalization remains elusive due to lack of straightforward and practical tools and guidelines about how to conduct integrated, interdisciplinary and spatially-explicit diagnosis of SSF as SES (Leslie *et al.*, 2015). To overcome these challenges, future research should focus on developing straightforward and practical guidelines to answer two basic research questions: (1) What process should be followed by conventional fishery departments to adopt a SES approach in its structure and function? and (2) How the SES approach can be applied on the ground by national fishery departments to assess and manage SSF in multiple-use MPAs?

However, additional interdisciplinary and transdisciplinary research efforts are required to create a portfolio of case studies that demonstrate how the theory behind the SES approach can be applied on the ground, considering the inherent characteristics of SSF in developing countries. An illustrative example of these type of guidelines has been recently published by Berkes et al. (2016). This guidebook is designed to educate practitioners on the theory and rationale behind SES analysis and to show them how this framework can be applied to real world case studies. Furthermore, capacity building programs should be built on this type of guidelines to train decision-makers, scientist and practitioners on the assessment and management of SSF as SES. Hopefully, these initiatives will help to operationalize the SES approach in developing countries.

On the other hand, to our knowledge, this dissertation represents the first study that illustrates how GIS techniques can be used in combination with boosted regression models to evaluate and predict how fishing effort distribution responds to different human and climatic drivers inside a multiple use MPA. This type of study is usually unfeasible in developing countries due to the dearth of fisheries data (Horta e Costa *et al.*, 2013a; Soykan *et al.*, 2014). However, availability of long-term fishery related data for the Galapagos spiny lobster fishery allowed me to evaluate how spatiotemporal distribution of fishing effort hotspots and fishing fleets' distribution ranges and core areas were affected by the interaction of different human and climatic drivers during a 15 years' period. Then, using BRT models, I predicted fishing effort as a function of geographic, oceanographic and socioeconomic variables, which were selected based on the human and climatic drivers identified as relevant for this study. This analytical approach is innovative because it shows the importance of conducting a comprehensive analysis of a diverse set of drivers and explanatory variables to understand how fishers´ adaptive responses vary according to the magnitude, extent, periodicity and intensity of press and pulse perturbations. This dissertation demonstrate that such perturbations are represented not only by establishment of new governance instruments, such as marine zoning and co-management regimes, but also by the social-ecological impact produced by different climatic and human events, such as El Niño, the boom and bust exploitation of a new fishery or a global financial crisis.

Finally, this study illustrates how fishers' adaptive responses are also shaped by past crises, social-ecological memory and the socioeconomic features of fishing communities in which fishers' organization are embedded. Therefore, a comprehensive understanding about how local fishing communities coped with the interactions of different human and climatic drivers is fundamental to reduce the risk of conducting biased marine zoning effectiveness assessments, which could lead to wrong conclusion about the role that no-take zones played on a fishery recovery, as it was revealed by this dissertation.

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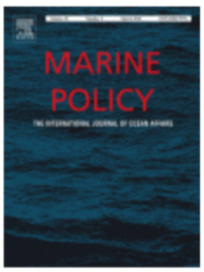

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