Social and Ecological Interactions in the Galapagos Islands

Judith Denkinger
Luis Vinueza *Editors*

The Galapagos Marine Reserve

A Dynamic Social-Ecological System

Springer

Social and Ecological Interactions in the Galapagos Islands

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Foreword

The ocean covers more than 70 % of our planet and provides key ecosystem goods and services to humans. However, we are undermining this capacity of the oceans due to increasing CO_2 emission, invasive species, pollution, diseases, overfishing, and habitat destruction. This is affecting the structure and function of marine ecosystems on which livelihoods of coastal communities depend upon. Marine protected areas such as the Galapagos Marine Reserve are important tools for conservation of marine resources and storerooms for biodiversity against habitat destruction or direct extraction of resources. For instance, invasive species are reducing the abundance of charismatic fauna that are important to the Galapagos local economy (Chap. 13). Destruction of biogenic structures such as the reduction of corals is detrimental for their associated communities. Chapter 1 provides us with more than 30 years of experience monitoring coral status around the archipelago. Later, Chap. 2 gives us a good insight into the diversity, status, and movement patterns of sharks and rays around the Galapagos, providing us with important knowledge that can help implement better management strategies to protect these top predators which are key for the functioning of marine ecosystems. Later, Chaps. 3, 4, and 13 describe the importance of the Galapagos sea lion and how this species has evolved in an unpredictable environment, with reduced populations due to environmental perturbations and negative interactions with humans.

Efforts to preserve the islands departing from traditional management strategies are not new to the Galapagos. Chapter 7 gives a deep insight of the process that led to the creation of the Galapagos Marine Reserve. As suggested by Castrejón et al. (Chap. 8), we need to change our scientific agenda in the Galapagos to be able to deal with the complex dynamics that affects this social–ecological system.

This is because current and potential impacts affecting marine protected areas are coming not only from land or from the seas close to us but also from remote locations (e.g., radioactive material derived from nuclear plants that were severely damaged after the Japan tsunami in 2011) or impacts exerted on the environment decades ago (DDT used back in the 1940s when the USA established a military base on Baltra Island) (Chap. 12). Therefore, a more holistic view of the interactions between humans, the ocean, and their surrounding environment is needed to change this path and to secure the key ecological and evolutionary processes that shaped Galapagos life. To this end, Chap. 5 proposes a framework to implement Ecosystem-Based Management in the Galapagos Marine Reserve using rocky shores as a pilot case study, an ideal system for the application of EBM approaches, because they are situated at the interface of terrestrial and marine environments and provide important ecosystem services for the local inhabitants.

Shifting management approaches from a marine resource focus to a more holistic social–ecological perspective is also addressed by the analysis of Castrejón et al. in Chap. 8. Clearly, we need to develop a long-term view of the marine ecosystems, aiming to maintain their structure and function, thus ensuring the capacity of the oceans to keep providing us those key ecosystem benefits we get from them. Chapter 9 explains the importance of collaborative fisheries to improve the effectiveness of management. Chapter 11 analyzes the importance of local knowledge to assess the current status and the historical trends of marine resource extraction in Galapagos, which can help to improve fisheries management. In this chapter, Burbano et al. talk about the importance of local knowledge to assess the status of Bacalao, a traditional species of high cultural value.

Furthermore, new economic activities such as Pesca Vivencial or sport fishing are in the rise but need to be well regulated and managed. Chapter 10 describes the transformation of this activity through time.

Geographic information systems that integrate satellite images and data collected by remote sensors are key to understand complex local, regional, and global processes that drive social and ecological systems. Chapter 6 provides us with a good insight of the applicability of GIS for the management of the Galapagos Marine Reserve.

We envision that this book will guide management and conservation actions oriented to maintain, restore, and improve the ecosystems services and goods we get from the ocean, considering the complex issues that affect the delicate nature of the Galapagos Marine Reserve.

Quito, Ecuador

Judith Denkinger
Luis Vinueza

Series Preface

Book Series "Social and Ecological Sustainability in the Galapagos Islands"

When we developed the Galapagos Book Series and selected the initial book topics to launch the Series, we hoped that guest editors and authors would conspire to represent important and fascinating elements of the Galapagos Islands early in the Series. While Book #1, "*Science and Conservation in the Galapagos Islands: Frameworks & Perspectives*," Stephen J. Walsh and Carlos F. Mena, editors (2013), advocates an interdisciplinary perspective for addressing many of the most compelling challenges facing the Galapagos Islands that extend across the social, terrestrial, and marine subsystems, Book #2, "*Evolution from the Galapagos: Two Centuries after Darwin*," Gabriel Trueba and Carlos Montufar, editors (2013), advances our understanding of evolution, a key element of life and adaptation in the Galapagos Islands. Now, Book #3, "*The Galapagos Marine Reserve: A Dynamic Social–Ecological System*," Judith Denkinger and Luis Vinueza (2014), addresses the nature of the coupled human–natural system in the Galapagos Islands and describes some of the key factors that affect social and ecological vulnerability, dynamics, and island sustainability. Further, Book #3 includes chapters that describe the mapping and modeling of fundamental features of the Galapagos Marine Reserve, an assessment of Galapagos fisheries and marine mammals, and the marine environments and processes that inspire us.

It was not until Charles Darwin's famous visit in 1835, which helped inspire the theory of evolution by natural selection that the Galapagos Archipelago began to receive international recognition. In 1959, the Galapagos National Park was formed, and in 1973, the archipelago was incorporated as the 22nd province of Ecuador. UNESCO designated the Galapagos as a World Heritage Site in 1978, a designation to honor the "magnificent and unique" natural features of the Galapagos and to ensure their conservation for future generations. These islands were further deemed a Biosphere Reserve in 1987, and the Galapagos Marine Reserve was created in 2001. The Marine Reserve was formed as a consequence of the 1998 passage of the *Special Law for Galapagos* by the Ecuadorian government that was designed to "protect and conserve the marine and terrestrial resources of the Islands."

Development of the tourism industry has more than tripled the local population in the past 15 years, thereby exerting considerable pressure on the Galapagos National Park and the Marine Reserve. The residential population has grown from approximately 10,000 in 1990 to nearly 30,000 residents today, and international tourism has increased from approximately 40,000 visitors in 1990 to now approaching 200,000. The impacts of the human dimension in the islands have been both direct and indirect, with consequences for the social, terrestrial, and marine subsystems in the Galapagos Islands and their linked effects. Further, the historical exploitation of lobster and sea cucumber, globalization of marine products to a national and international market, and the challenges imposed by industrial fishing outside of the Reserve and illegal fishing and shark-fining outside and inside the Reserve combine to impact the social and ecological vulnerability of the Galapagos Marine Reserve in fundamental ways. In addition, exogenous shocks, such as El Niño events as a disturbance regime on Galapagos corals and marine populations, national and international policies and institutions on regulation and management of the Reserve, and the "pushes" and "pulls" of economic development and population migration, including international tourism, shape and reshape the Galapagos Marine Reserve—its resources, environments, and human uses.

Denkinger and Vinueza (editors) have developed another important book in the Series that contributes a rich and compelling assessment of the Galapagos Islands with a focus on the Galapagos Marine Reserve, fully acknowledging that the Marine Reserve is best studied through the lens of a coupled human–natural systems approach where social and ecological interactions are addressed in a linked and integrative manner. Together with the other books in the Galapagos Series, this book leverages the "frameworks and perspectives" described in Book #1 and the "theoretical and applied contributions" of Book #2 on ecological (and social) adaptation seen in evolution and described by the complex adaptive systems seen in the Galapagos Islands.

Chapel Hill, NC Stephen J. Walsh
Quito, Ecuador Carlos F. Mena

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Part I
Synthesis of Populations, Communities and Ecosystem Processes in the GMR

Chapter 1
Coral Research in the Galápagos Islands, Ecuador

Joshua S. Feingold and Peter W. Glynn

Abstract This chapter summarizes the scientific knowledge of scleractinian corals in the Galápagos Archipelago. A general introduction to coral biology is followed by a brief history of coral research in the islands. Subsequent sections discuss responses of corals to broad-scale impacts, anthropogenic stress on Galápagos corals, and recommendations for management of this important resource. Following an initial period (1835–1960s) of cataloging the species present in the Galápagos Islands, research on coral ecology was initiated by Wellington in the 1970s. Glynn and Wellington more thoroughly examined the surprising abundance and distribution of corals and reef frameworks in the 1980s. Glynn and other workers then documented mass mortalities of corals due to the 1982–1983 ENSO disturbance. Subsequent research focused upon this natural phenomenon and its effect on coral distribution, ecology, and physiology. Most recently, resilience and recovery of coral populations were reported. Compared to most other regions, there is little anthropogenic impact to corals in the Galápagos Islands. However, climate change and ocean acidification have effects, and there is evidence of impacts associated with fisheries and tourism. Recommendations for management decisions conclude this chapter.

Introduction

This chapter summarizes the scientific knowledge of scleractinian corals in the Galápagos Archipelago, providing a review of prior research and a synthesis of new and emerging issues that are relevant to the Galápagos Marine Reserve. There are four sections in this chapter: (1) introduction, including a distinction between coral communities and coral reefs; (2) a brief history of coral research in the islands;

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(3) responses of corals to broad-scale impacts with particular focus on El Niño-Southern Oscillation (ENSO) activity; and (4) anthropogenic stress on Galápagos corals and recommendations for management.

The Galápagos Archipelago sits astride the equator at approximately 090° W longitude at the confluence of several major oceanic currents. Cool water flows from east to west via the South Equatorial Current (as a westward extension of the Peru Coastal Current and Peru Oceanic Current) and from west to east via the subsurface Equatorial Undercurrent (Cromwell Current). The first set of currents creates centers of upwelling along the continental coast, and the Cromwell Current drives upwelling on the western sides of islands, primarily Fernandina, Isabela, and Floreana Islands. Warm, subtropical water flows into the archipelago from the northeast via the Panamá current, primarily affecting the northern (Wolf and Darwin) and central (Pinta, Marchena, and Genovesa) islands. These currents are seasonally variable, depend on the intensity of trade winds, and are indirectly influenced through Pacific basin atmospheric pressure differentials, including significant effects from ENSO. Overall, compared to other equatorial marine habitats, sea surface temperatures are relatively cool in the eastern equatorial Pacific (Chavez and Brusca 1991). Overlaying this general trend are periods of anomalously warm and cool sea surface temperatures associated with the warm and cool phases of ENSO (El Niño and La Niña, respectively) (Feingold 2011).

This complex water mass mixing creates patterns of distinct coastal, benthic environmental zones as identified by Glynn and Wellington (1983). Macrophytic algal communities occur on the western coastlines of Fernandina, Isabela, Floreana, Española, and San Cristobal Islands, and conditions conducive to coral development are present on most eastern and northern coasts of these and other large islands, including Santiago, Pinta, Marchena, Genovesa, Santa Cruz, Santa Fe, and Española. Coastlines with southeastern exposures remain relatively unsurveyed due to high wave energy and surge. Notable exceptions to this general trend occur along the east coast of Fernandina and west coast of Isabela, areas in the protected waters of the Bolivar Channel. Microhabitats in relatively warm, shallow embayments and subtidal lava pools are conducive to coral growth even though surrounding colder and deeper waters are not. Dawson et al. (2009b) developed a habitat suitability model based on sea surface temperature data to document likely locations of coral presence in the archipelago.

The most northerly islands of Wolf and Darwin experience much different environmental conditions than the remainder of the archipelago and support the best developed coral formations. Wolf is 140 km distant from its nearest southern neighbors of Isabela and Pinta, and Darwin is 35 km further north. Their location to the northwest of the main archipelago places these barely emergent oceanic pinnacles in relatively warm, subtropical waters bathed seasonally (January–April) by the Panamá current. Well-developed coral communities and marginal reefs, composed primarily of *Porites lobata*, occur on the east/northeast sectors of these islands in 3–20 m depths.

El Niño-Southern Oscillation (ENSO) results from a wide-scale shift in pressure centers related to feedback cycles within the coupled ocean-atmosphere climate system of the tropical Pacific, potentially influenced by external forcing (Enfield 1989). This causes environmental perturbations across the entire region, with particularly strong effects centered in the east Pacific where the Galápagos Archipelago is located. Very strong events are relatively uncommon; however, two El Niño disturbances of this magnitude occurred within two decades, the 1982–1983 and 1997–1998 events. The most debilitating impacts to corals result from seawater temperature anomalies. Persistent (weeks to months) elevation of temperatures that are only 1–2 °C above long-term means can result in coral bleaching (loss of zooxanthellae endosymbionts and/or their photosynthetic pigments) and mortality (Robinson 1985; Glynn and D'Croz 1990).

Coral Reefs and Coral Communities

Scleractinian corals are calcium carbonate-secreting cnidarians that exist as individuals (single polyps, e.g., *Diaseris*) or form colonies of multiple polyps (e.g., *Pocillopora* and *Porites*). Colonial corals may attain large size (several meters in diameter) through asexual reproduction of polyps and may live hundreds of years. Some colonial species create the main structure of coral reefs and are called hermatypic (reef-building) corals (e.g., *Pavona* and *Porites*). Ahermatypic corals do not substantively contribute to reef structure but may be present as isolated individuals or colonies on hard substrata and as minor components on coral reefs or on unconsolidated sediments. Hermatypic corals are zooxanthellate, that is, they possess endosymbiotic dinoflagellates within their gastrodermal tissues. Zooxanthellae contribute significantly to coral energy needs and enable increased carbonate secretion rates compared to azooxanthellate species. Azooxanthellate species (e.g., *Tubastraea*) are not hermatypic since they do not form reef structure (see below for definition of "coral reef"). However, some ahermatypic corals are also zooxanthellate; they also do not form reef framework even though they possess zooxanthellae (e.g., *Psammocora*).

The term "coral reef" has been utilized in various ways, especially during the past few decades, to include any benthic community with coral as an important structural component. This broad definition includes bioherms (mounded, loose carbonate sediments) formed by corals on unconsolidated substrata and in areas beneath the photic zone. In this contribution, the term "coral reef" is used to denote a structural formation in the photic zone; "if coral populations continue to build upon products of their own making, they are termed structural reefs (true coral reefs); and, if not, they are defined as coral communities" (Glynn and Wellington 1983). Further, this definition requires the accretion of carbonate material vertically towards the sea surface and distinguishes true coral reefs from the way corals are more typically encountered in the archipelago, namely, as widely scattered colonies on basalt substrata. Under these definitions, coral reefs are no longer present in the main part of the archipelago (southern and central islands), with marginal reef development still present at the northern islands of Wolf and Darwin. Specifically, the coral reefs reported by Glynn and Wellington (1983) in the main archipelago

Fig. 1.1 Large *Porites lobata* colony at Wolf Island (11 m depth, June 2012). Measuring stick near the top of the colony is 1 m long

(e.g., Devil's Crown) have mostly disappeared following the 1982–1983 El Niño disturbance. Remaining relict structures are composed of degraded coral skeletons without contributions of living corals to carbonate framework production. Corals at the northern islands have maintained marginal coral reef status with up to 3.5 m of carbonate accretion above their basalt base (Fig. 1.1). The base of another sampled large *Porites* tower from Darwin Island was ^{14}C dated to approximately 500 years, indicating several centuries of growth at this location.

According to Wells (*In*: Glynn and Wellington 1983), there were approximately 13 species of hermatypic (reef-building) scleractinian corals and 31 species of ahermatypes reported from the Galápagos Islands. Hickman (2008) reported 22 species of hermatypic corals, including 9 species of *Pocillopora*, though using a broader definition of "hermatypic" than in this chapter. These numbers vary with advances in coral taxonomy and, after a period of increase, are now poised to decrease with the possible consolidation of species in the genus *Pocillopora*. Morphologically variable forms in this genus that are now considered different species may not be as genetically distinct as once recognized (Pinzon et al. 2013). Only a few species of hermatypic coral are common components of coral communities in the archipelago. These same few species may form structural reefs throughout the eastern tropical Pacific region and include *Pocillopora* spp., *Pavona clavus*, *Pavona gigantea*, and *Porites lobata* (Glynn and Wellington 1983; Glynn and Ault 2000). In addition, several species that form non-reefal carbonate accumulations contribute to coral species diversity and ecologically important communities that are more structurally complex than adjacent sand and rubble benthic habitats. Examples include free-living forms such as the fungiid *Diaseris distorta* and a branching morphotype of *Psammocora stellata* (Feingold 1996). Also, the ahermatypic (non-reef-forming) orange cup coral *Tubastraea coccinea* is an important component of rocky outcrops and vertical walls where it competes for space with other sessile benthic invertebrates such as sponges, barnacles, and ascidians (Witman and Smith 2003). Numerous species of other azooxanthellate, ahermatypic corals are found under ledges, in other cryptic habitats, and at greater depths (Wells *In*: Glynn and Wellington 1983).

Coral Research: A Historical Sketch

According to Darwin (1842), there were no coral reefs in the eastern tropical Pacific, and he made only a few brief references to Galápagos corals during his celebrated visit to the archipelago in 1835 aboard the HMS Beagle (Wells *In*: Glynn and Wellington 1983). Benthic marine organisms were not a focus of his studies and were difficult to observe due to technological limitations to underwater operations that persisted until the latter half of the twentieth century.

Early scientific expeditions to Galápagos did expand our knowledge of corals, and collections made during cruises of the HMS Beagle (1835), R/V Hassler (1872), and R/V Albatross (1888) included about 15 species of corals and the discovery that coral debris contributed importantly to beach sediments in the archipelago (Glynn and Wellington 1983).

A series of scientific expeditions, financed by Allan Hancock, significantly increased existing knowledge of marine organisms in the Galápagos Islands. The voyages of Oaxaca (1928) and Velero III (1931–1938) brought researchers to the archipelago who collected material that formed the basis of a systematic revision of eastern Pacific corals. Durham and Barnard (1952) published additional information on Galápagos corals as part of the Galápagos International Scientific Project.

Following this era of taxonomic cataloging of coral species, attention turned to their ecological role in shallow, nearshore habitats. Coral reefs are widely distributed in the eastern tropical Pacific and are all fringing or patch reefs that grow in shallow shelf waters on suitable substrata (Cortés 2011); however, reef development was and remains limited in the Galápagos Islands. Nevertheless, these low-diversity Galápagos coral communities still increase benthic structural complexity and create carbonate substrata that can be utilized by numerous other organisms. For example, excavating marine mollusks (*Lithophaga* spp.) construct tunnels in massive corals such as *Porites lobata*. Numerous apertures for their siphons can be observed as hourglass-shaped openings among coral polyps. Echinoids such as *Eucidaris*, *Tripneustes*, and *Diadema* shelter within crevices that they themselves may construct. Furthermore, in the first ecological paper on Galápagos coral reefs, Glynn et al. (1979) observed that the endemic echinoid *Eucidaris galapagensis* degraded existing reef structure and interfered with the establishment of new reef frameworks in the archipelago. This sea urchin species was identified as *E. galapagensis* (Lessios et al. 1999) after publication of the 1979 study where it was referred to as *E. thouarsii*. Part of the reason that this distinction was made was because *E. thouarsii* does not have the same bioerosive effects on the mainland or other eastern Pacific locations as does *E. galapagensis* in the archipelago. Coral-associated fish species shelter among the colonies, and several opportunistic coral browsers such as parrotfish and Moorish idols utilize coral as important dietary supplements. Damselfishes, primarily *Stegastes arcifrons*, create algal gardens adjacent to and often encroaching on coral colonies (Fig. 1.2). They are common within aggregations of *Pocillopora* and *Porites*. The obligate corallivorous puffer

Fig. 1.2 Damselfish (*Stegastes arcifrons*) algal lawn adjacent to a *Pocillopora* sp. colony, Concha y Perla lagoon, Isabela Island (2 m depth, June 2012). Note truncated coral branch tips at base and periphery of colony due to biting by the damselfish

fish *Arothron meleagris* is often seen associating with the corals and has particularly high abundances on the *Porites* reefs at Wolf and Darwin Islands.

One benefit to corals in Galápagos is the near absence of the predatory sea star *Acanthaster planci*. This destructive corallivore has been observed on only a few occasions on corals at Wolf and Darwin Islands but never in the central and southern archipelago. Perhaps food resources are too meager, or the relatively cool water does not allow larval development and/or settlement. *Acanthaster* feeding behavior in other parts of the eastern tropical Pacific has resulted in serious impacts to targeted coral prey species (Glynn 2004).

Galápagos coral reefs and coral communities were first documented in detail in the 1970s by Wellington who described reef structures from Devil's Crown and Champion Island, two islets off the north coast of Floreana Island. Wellington (1975) then produced the first broad-based report of marine resources, including corals, for the nascent Galápagos Marine Reserve. Later, more comprehensive studies by Glynn and Wellington (1983) provided archipelago-wide information for Galápagos coral researchers. Their book, *Corals and Coral Reefs of the Galápagos Islands*, documented in detail the distribution and abundance of scleractinian corals throughout the archipelago. This work was fortuitously completed immediately prior to the 1982–1983 El Niño warming disturbance. Since that disturbance event nearly eliminated corals from ecologically meaningful roles throughout the south-central parts of the archipelago, this information now serves as a valuable baseline for contemporary studies. More recently, a summary of the condition and distribution of coral reefs and coral communities in Ecuador was reported by Glynn (2003).

Tectonic uplift is an unusual type of disturbance to corals associated with areas subject to active volcanism such as the Galápagos Archipelago. Colgan and Malmquist (1987) reported on the uplift and subaerial exposure of the nearshore coral community at Urvina Bay, Isabela Island (Fig. 1.3). This event occurred in 1954, and the seafloor was elevated nearly 6 m, exposing an area of several square kilometers. Clearly, subaerial exposure results in the rapid mortality of corals, but even those colonies that were simply raised into shallow water were likely affected.

Fig. 1.3 Uplifted *Pavona clavus* colony (approximately 2 m diameter), Urvina Bay, Isabela Island (June 2012)

The shoaling of the shoreline affected these barely submerged colonies by exposing them to higher solar radiation stress and increased wave energy. Despite the cool conditions in this region of the archipelago, a robust coral community developed in Urvina Bay. One of the uplifted coral colonies (*Pavona clavus*) was approximately 5 m in diameter and dated to 347 years based on annual skeletal density bands and radiometric dating (Dunbar et al. 1994).

Research through the 1980s and 1990s focused on ENSO impacts, primarily the effects of elevated water temperatures (Glynn and D'Croz 1990), on these degraded coral communities. Two strong El Niño warming events (1982–1983 and 1997–1998), one in each of these decades, sparked research in the Galápagos as part of a wider effort throughout the eastern tropical Pacific region. Robinson and del Pino edited a volume on the impacts of the 1982–1983 ENSO to Galápagos organisms, including a chapter (Robinson 1985) on marine life that reported coral bleaching and mortality at known reef sites at Devil's Crown and Champion Island. In addition, there was concern about the possible extinction of the endemic cup coral *Tubastraea tagusensis*. Populations recovered in Tagus Cove on the west coast of Isabela Island, and the species may have recently been introduced to Brazil (Creed 2006; Hickman 2008). However, its congener *Tubastraea floreana* remains on the IUCN red list as critically endangered, with distribution restricted to Cousin's Rock, Santiago, and Isla Gardner, at Floreana Island. Two book volumes edited by Glynn (1990, 2001) contain contributions that elucidated the impacts and longer term consequences of ENSO activity on corals. Studies of this natural phenomenon focused on its effect on coral physiology, ecology, reproduction, and distribution. Also, during this time, the work of international scientists became supplemented and augmented by surveys and monitoring projects at the Charles Darwin Research Station and Galápagos National Park Service. In particular, research by Edgar et al. (2008) identified key threatened marine species in the Galápagos Marine Reserve, including corals. The protection of key biodiversity areas was also proposed. Later, Edgar et al. (2010) documented major ecological phase shifts as a consequence of ENSO impacts through a comparison of historical and contemporary datasets for shallow reef habitats. Seven coral species were recognized as globally threatened, including two species of the important reef-building coral *Pocillopora*. The remaining five species (*Rhizopsammia wellingtoni*, *T. floreana*, *Polycyathus isabela*, *Fungia curvata* (*Cycloseris curvata*), and *Psammocora stellata*) are not structural components of reefs, but nonetheless contribute to ecosystem complexity and benthic structural heterogeneity. Banks et al. (2009) documented the status of reefs at Wolf and Darwin and suggested the implementation of a mooring buoy system to mitigate impacts associated with tourist diving activities.

A recent interesting line of research is focusing on thermal tolerance differences among different clades of the photosynthetic dinoflagellate coral endosymbiont *Symbiodinium*. Baker (2003) reported that different clades of zooxanthellae have differing tolerances to temperature and light levels and distinct photosynthetic efficiencies. Thus, corals that survived the 1982–1983 El Niño were preadapted to survive similar conditions associated with the subsequent 1997–1998 El Niño event. In Galápagos, Glynn et al. (2001) reported only 26.2 % mortality following the 1997–1998 El Niño, compared to 95–99 % mortality associated with disturbances from the 1982–1983 El Niño. Corals with multiple clades in their tissues can benefit from having symbionts that function effectively under a variety of conditions, including seawater warming. However, this form of bet-hedging comes with the price of reduced efficiency (e.g., growth and competitive ability) when conditions are less extreme.

A series of studies dealing with coral reproduction in the Galápagos Islands, and the eastern tropical Pacific, documented high levels of gamete output (fecundity) from sexual reproduction, but with low levels of recruitment. Despite resultant reductions in genetic diversity, the relative importance of asexual reproduction for maintenance of local Galápagos coral populations was emphasized (Glynn et al. 1991, 1994, 2011, 2012). Regarding sexual reproduction, gamete spawning was only observed in the field over a single 2-day period in several colonies of *Pavona gigantea* at Devil's Crown. However, histological examination of collected specimens documented that most species produce mature eggs and sperm that are presumably spawned. No gamete reabsorption has been observed. Asexual reproduction (fragmentation) is a particularly important mode for branching corals such as *Pocillopora* spp. and *Psammocora stellata* and for the brittle fungiid coral *Diaseris distorta*. Though most fragmentation is induced by mechanical stress from external physical forces such as waves and current, *Diaseris* is capable of performing autotomy, a process by which the coral can divide through selective dissolution of skeletal components (Yamashiro and Nishihira 1998; Colley et al. 2002).

Although most of the research on Galápagos corals has focused on reef-building species, there are two free-living (unattached) species that form ecologically significant aggregations that create low-relief three-dimensional structures on sand and rubble substrata. These include *Psammocora stellata*, a small, branching colonial coral, and individuals of the fungiid (mushroom) coral *Diaseris distorta*. *Psammocora* is widespread in the archipelago and can be found adjacent to and intermingled with reef-building species. Its ability to tolerate water motion and high sediment loads allows it to survive in suboptimal coral habitats. Temperature tolerance experiments documented that it is more resistant to bleaching than other Galápagos corals (Feingold 1995). Its designation as threatened (Edgar et al. 2010) in the archipelago may be premature as several impacted populations have recently recovered to near pre-disturbance levels. Also, this species has been observed in a wide variety of habitats (1–30 m depths) throughout the archipelago, perhaps more so than any other Galápagos coral species.

Living populations of the fungiid coral *Diaseris distorta* are known from only one location in the Galápagos Islands, east/northeast of Devil's Crown (Fig. 1.4). Populations can exceed 100 % live cover due to stacking and overlap among individuals. These corals are distributed over a sandy bottom area, also containing rocky basalt outcrops, approximately 1 km^2 in depths between 12 and 34 m. The population was estimated in the 100 s of thousands of individuals (Feingold 1996), but their restriction to one location within the archipelago places them at risk. The ability of this species to auto-fragment allows great potential for population growth through asexual reproduction (Colley et al. 2002). Hundreds of dead skeletons of *Diaseris* were also observed at 11–13 m depth near Xarifa Island in Gardner Bay, Española Island, but despite extensive searches along the adjacent coastline, no living specimens were found. Associated with this coral at Devil's Crown is another fungiid, *Cycloseris elegans*, but populations are much smaller, with less than 100 individuals present in 2012. Like *Diaseris*, dead skeletons of *Cycloseris* were observed near Xarifa Island in Gardner Bay, Española Island, and at relatively high densities. Dead skeletons of *Cycloseris* were also recently (2012) observed at Darwin Island at the base of a poritid reef at 25–30 m depths. This confirms their presence at other locations in the past, but this species is now known from only a single location in a critically small population. Tourists who plan to scuba dive in their habitat at Devil's Crown should be briefed on the threatened status of this species.

In the early twenty-first century, coral scientists participated in a series of cruises supported by the Darwin Initiative Project, sponsored by the government of the United Kingdom through the Department for Environment, Food, and Rural Affairs (DEFRA), culminating in a special issue of Galápagos Research (Dawson et al. 2009a). The authors noted that "The coral reefs of the Galápagos Islands contribute significantly to species richness and diversity in the Galápagos Marine Reserve (GMR)" and that these communities were impacted by climatic disturbances, most notably El Niño-Southern Oscillation.

New scleractinian coral species and records were reported during the Darwin Initiative cruises, including *Pocillopora effusus*, *Pocillopora inflata*, *Pavona chiriquiensis*, and *Leptoseris* sp. (Dawson et al. 2009a). However, recent genetic analyses determined that many species in the eastern Pacific *Pocillopora* clade, including those in the Galápagos Islands, may be morphological variants rather than distinct species (Pinzon et al. 2013). Additionally, molecular genetic evidence suggests that a second species of Poritidae may be present in the archipelago, *Porites evermanni* (Baums, personal communication). The dynamic nature of scientific inquiry, particularly taxonomic revisions, will continue to expand and improve our knowledge base of these important marine cnidarians.

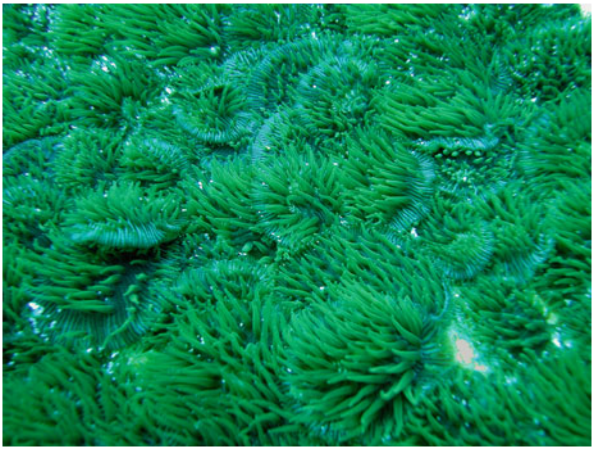

Fig. 1.4 *Diaseris distorta* individuals at Devil's Crown, Floreana Island (15 m depth, June 2005). Polyps were 3–5 cm in diameter

Resilience and recovery of coral populations from ENSO disturbances are themes of recent research and were reported from several locations in the archipelago, most notably the northern Islands of Wolf and Darwin (Glynn and Ault 2000). Recovery was poor elsewhere, with most species maintaining a presence in their respective environments but at low population densities. Glynn et al. (2009) reported that coral reefs in the northern islands of Wolf and Darwin demonstrated significant recovery since experiencing impacts from the 1982–1983 El Niño. In particular, the sections of reef dominated by massive colonies of *Porites lobata* displayed live coral cover exceeding 20 %. In 2007, overall live coral cover on Darwin reef was 21.1 % and 32.3 % in 2012. This increase in coral cover of 53.1 % indicates that recovery is occurring in the area. *Pocillopora* spp. were present on these reefs of the northern islands, though not nearly in the same abundance as before the disturbance. Recent surveys performed by Glynn, Riegl, and Feingold in June 2012 corroborated these observations. Despite focused searches at locations where *Pocillopora* previously (pre-1982–1983 El Niño) formed extensive monospecific stands, no section of the reef was primarily composed of *Pocillopora*. During these surveys, one colony was observed at 28 m depth, greatly below the typical depth for this phototrophic species. In the southern part of the archipelago, Paul (2012) documented decline and recovery of *Porites lobata* at Devil's Crown, Floreana Island, following the 1997–1998 El Niño. From a broader perspective, live *Porites* total tissue area increased from 5.80 ± 2.3 m^2 in 1993 to 6.92 ± 3.4 m^2 in 2011 ($n = 10$ colonies). This was an average increase of 16.2 %; however, the difference was not statistically significant.

A comprehensive study by Edgar et al. (2008) investigated key biodiversity areas (KBAs) and identified marine habitats important in coral conservation and management within the Galápagos Marine Reserve. They noted that two coral species are listed on the 2006 International Union for Conservation of Nature and Natural Resources (IUCN) Red List of threatened species and bear special protection. These included the ahermatypic corals *Rhizopsammia wellingtoni* and *Tubastraea floreana*.

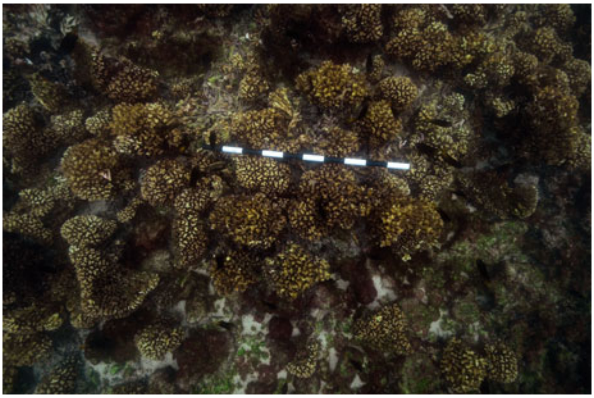

Fig. 1.5 Aggregation of *Pocillopora* sp. at Concha y Perla lagoon, Puerto Villamil, Isabela Island (2 m depth, May 2013). Measuring stick is 1 m long

During a recent research cruise to the archipelago (June 2012), an aggregation of *Pocillopora* sp. (c.f. *damicornis*) was surveyed within the shallow (2–3 m depth) Concha y Perla lava pools at Puerto Villamil, Isabela Island (Fig. 1.5). This previously undocumented population now represents the largest known aggregation with the highest percent cover of this genus within the archipelago. Approximately 1,600 colonies were observed. Total live tissue area was 40.3 m^2, with a mean colony surface area of 248 cm^2. Genetic analysis documented that all of these colonies are a single genet (Baums, personal communication), i.e., they are all members of a single clone. This underlines the importance of asexual reproduction of *Pocillopora* in the Galápagos Islands.

Responses of Corals to Broad-Scale Impacts

Global climate change and associated sea surface warming and ocean acidification are drivers of significant disturbance to corals (Hoegh-Guldberg et al. 2007). Anomalously warm or cool water temperatures cause coral bleaching, the loss of endosymbiotic dinoflagellates (zooxanthellae), with particularly dire results in the Galápagos Archipelago. Since zooxanthellae produce a significant share of the energy requirements of hermatypic (reef-building) corals, their extended presence in low numbers or significant photosynthetic pigment loss during bleaching (Fig. 1.6) resulted in mortalities of 95–99 % following the 1982–1983 El Niño, a particularly severe event (Glynn 1990). As the atmospheric concentration of CO_2 increases, its diffusion into oceanic surface waters results in decreased pH. This ocean acidification lowers carbonate saturation states, making calcium carbonate precipitation more difficult and resulting specifically in decreased coral skeleton density. Since the pool of oceanic water around the Galápagos Islands has considerably lower pH than the rest of the eastern tropical Pacific, the corals living there may be particularly at risk should acidification continue to increase. Also, Galápagos corals may serve as

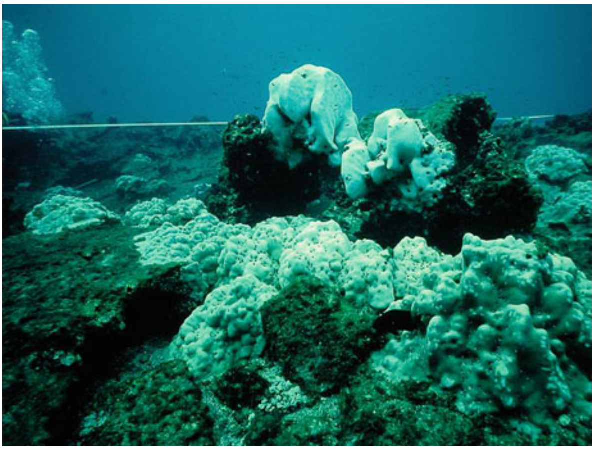

Fig. 1.6 Coral bleaching at Punta Espejo, Marchena Island, during the 1997–1998 El Niño warming event (7 m depth, March 1998). Bleached colonies of *Pavona clavus* are behind bleached and pale colonies of *Porites lobata*, foreground

contemporary harbingers of forthcoming disturbances to other coral environments (Manzello et al. 2008).

Although there is controversy surrounding the linkage between warming associated with climate change and the increased frequency and intensity of ENSO events (Stot et al. 2000; Enfield 2003), two severe events in two decades (1982–1983 and 1997–1998) impacted Galápagos corals. Baker et al. (2008) reported that continued ecological function of these coral ecosystems is in jeopardy due to several factors. These include (a) degree of coral cover loss, (b) challenges associated with acclimatization of surviving species to higher temperatures, (c) maintenance of carbonate structures as a balance between accretion and erosion, and (d) maintenance of resiliency. Resiliency, however, should be less of a problem in the Galápagos Islands compared to other eastern Pacific regions since overfishing of important reef herbivores (fishes and sea urchins) is greatly reduced. By contrast, Edgar et al. (2010) noted that the removal of lobsters and large fish predators magnifies the impacts of ENSO through trophic cascades. In their analysis, they noted that coral cover increases with distance from fishing ports, providing evidence of third-order trophic effects. The overfishing of large predators and resultant “release” of their prey species increase benthic grazing pressure in heavily fished areas. Of particular concern is the persistent large populations of the pencil sea urchin *Eucidaris galapagensis* that may prevent coral settlement and recruitment due to their grazing activities on the benthic substrata (Glynn 1988).

Disturbance by aperiodic ENSO events regularly exceeds the physiological thermal tolerance limits of corals in the Galápagos Islands, contributing to the creation of a marginal habitat for coral survival. These events affect corals and numerous other marine organisms, with anomalously elevated water temperatures during warm-phase (El Niño) and anomalously depressed water temperatures during cool-phase (La Niña) periods (Feingold 2011). Elevated temperatures were associated with bleaching and high mortality (95–99 %) of corals in the archipelago during the very strong 1982–1983 event (Glynn et al. 1988), resulting

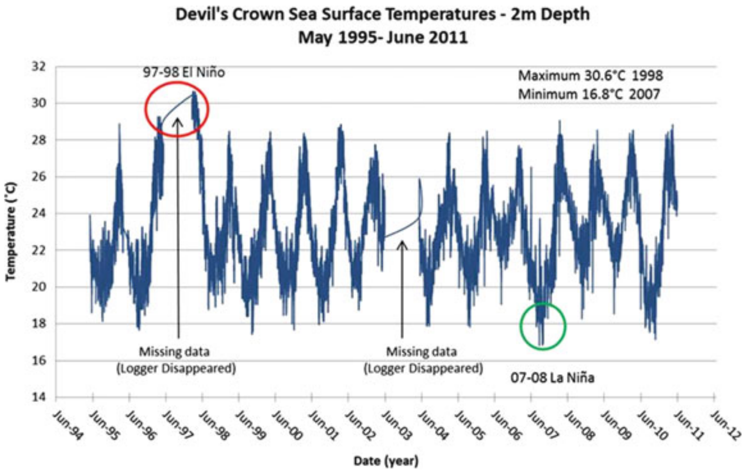

Fig. 1.7 Sixteen years (1995–2011) of in situ seawater temperature data, 2 m depth inside Devil's Crown, Floreana Island. Values were obtained at 30-min or hourly intervals with Onset Instrument submersible data loggers. Note ENSO-related warm (1998 El Niño) and cool (2007 La Niña) conditions

in dramatic losses of coral cover and species diversity (Glynn 1990). Cool conditions in 2007 (Fig. 1.7) also resulted in coral bleaching and mortality in the Galápagos Archipelago (Banks et al. 2009) and at other eastern Pacific locations (Reyes-Bonilla et al. 2002). This La Niña cooling was associated with dramatic losses (95 %) in a recovering *Pocillopora* spp. coral population at Devil's Crown, Floreana Island. However, Paul (2012) reported live tissue cover increases for *Porites lobata* at the same site and depth (Devil's Crown) during extreme cooling associated with the 2007–2008 La Niña event.

ENSO-related coral bleaching occurs when endosymbiotic dinoflagellates (zooxanthellae) either diminish in number within the coral host tissues or lose their photosynthetic pigments. Since zooxanthellae are an important source of metabolic energy, reef-building corals will die unless sufficient populations of the endosymbiont become reestablished when conditions normalize. For example, reef-building species such as *Pavona clavus* can survive up to 60-day periods of bleaching (Feingold 2001); however, the ahermatypic fungiid *Diaseris* can survive in the bleached state for over 180 days (Feingold 1996), perhaps due to its ability to effectively feed heterotrophically (e.g., by ingesting zooplankton). Bleaching severity shows species-specific trends, with some corals being sensitive, bleaching sooner and more completely (e.g., *Pocillopora*) than other more resistant species (e.g., *Psammocora* and *Porites*) (Robinson 1985; Glynn 1990; Feingold 1995). Bleaching occurs when coral is physiologically stressed and is most often associated with positive SST anomalies (warming), although other perturbations such as cooling, lower sea level leading to emersion, salinity decrease, and sedimentation contribute to this stress response.

Bleaching sensitivity is also related to the endosymbiont clade; some zooxanthellae are more tolerant of elevated temperatures than others. For example, in Panama pocilloporid corals with zooxanthellae in clade D did not bleach during the 1997–1998 El Niño event, whereas those with clade C endosymbionts did bleach (Baker 2004). Thus, coral survivors of the 1982–1983 El Niño likely harbored clade D endosymbionts, and when these corals were exposed to highly elevated temperatures again in 1997–1998, they were not so severely affected (Glynn et al. 2001).

Of particular concern to the recovery of coral communities in the Galápagos is the secondary loss of carbonate substrata following coral mortality. This region of the eastern tropical Pacific has much lower pH values (7.88) than the rest of the region that typically exceeds pH values of 8.00. Lower pH causes depressed aragonite saturation levels of 2.49 compared with more typical values of ~3.80 for the tropical surface ocean (Manzello et al. 2008). This results in lower coral skeletal densities than usual, and weak subsequent cementation exacerbates the effects of echinoid bioerosion that typically follows coral mortality (Glynn 1988). Manzello et al. (2008) suggested that skeletal deposition by corals in the Galápagos Islands could thereby serve as a model for other areas of the world at elevated atmospheric CO_2 levels approximately double current values.

Carbonate bioerosion rates in the Galápagos Islands (average of 25.4 kg $CaCO_3$ m^{-2} $year^{-1}$) are among the highest known in the eastern tropical Pacific region (Reaka-Kudla et al. 1996) and are two orders of magnitude higher than values reported from the Caribbean. Glynn et al. (1988) documented extensive destruction of the reef formed by the branching pocilloporid corals at Devil's Crown by *Eucidaris galapagensis* (=*E. thouarsii*) following the 1982–1983 El Niño. This species of sea urchin is a significant bioeroder where it occurs in the Galápagos Islands (Glynn et al. 1979) and at Cocos Island; *Diadema mexicanum* fulfills this role in other parts of the eastern tropical Pacific (Glynn 1988). The pocilloporid framework at Devil's Crown was completely degraded in the following post-bleaching decade from continued grazing of *Eucidaris* that reduced the 1–2 m thick carbonate framework to rubble and sand. Coral colony erosion and loss were also reported for massive species at other locations throughout the archipelago. Several observations documented this destructive process. For example, (a) *Porites lobata* colonies became mushroom shaped from basal bioerosion at Bartolomé Island 6 years after disturbance, (b) a 2 m diameter colony of *Pavona gigantea* collapsed and tumbled downslope from 3 to 32 m depth at Champion Island approximately 10 years after disturbance, and (c) a large *Porites lobata* colony in the anchorage at Santa Fe Island was reduced to rubble during the two decades after colony mortality.

Following these types of disturbances, coral recovery relies on two important reproductive modes, sexual reproduction via planula larvae and asexual reproduction. Asexual reproduction involves two basic processes (a) replication of polyps allowing colony growth and recovery from partial damage through the re-sheeting of surviving colony tissues and (b) fragmentation that allows coral replication through physical or biological processes. Sexual reproduction is important in dispersal and promoting genetic diversity, while asexual reproduction maintains genotypes that were capable of surviving under local conditions, including ENSO disturbances (Colley et al. 2006).

In addition to coral bleaching and mortality, ENSO can have sublethal effects on corals that affect their ability to persist and colonize new habitats in the archipelago. Reproductive activity (gametogenesis) in some important reef-building corals (e.g., members of the Pocilloporidae, Poritidae, and Agariciidae) can be either detrimentally affected or enhanced by El Niño-related seawater warming. Moderate to weak events can improve conditions for reproductive success since reproduction typically occurs under warmer conditions; however, strong events can cause reproductive failure if temperatures increase too rapidly or rise too high (Colley et al. 2006). Some evidence suggests that corals disperse to the tropical eastern Pacific via countercurrents that transport water from the west to the east. During an ENSO warm phase, the velocity and volume flow of these currents increase allowing the more rapid transport of larvae and improved chances for dispersion and recruitment of corals originating in the central Pacific to the eastern Pacific (Glynn and Ault 2000). Also, reproductively active corals on the Ecuadorean mainland (e.g., in the Machalilla National Park) could release larvae capable of traveling to the Galápagos Archipelago, particularly when the Panamá current is seasonally strong (January–April). Upstream conservation of corals, through the use of marine protected areas (MPAs), potentially increases the resiliency of corals in the archipelago.

Anthropogenic Stress on Galápagos Corals

Compared to most other regions in the eastern tropical Pacific, and even globally, there is less direct anthropogenic impact to corals in the Galápagos Islands. This is due to several factors (a) the relatively small human populations on only 4 of the 13 larger islands, (b) the lack of any human habitation in the central and northern archipelago where coral development is most robust, and (c) limited direct extractive use of scleractinian coral community resources. According to Glynn (1994), natural disturbances such as strong ENSO events are of greater concern than anthropogenic impacts. However, anchor damage, extraction of corals (particularly *Pocillopora*) for use as curios, and mechanical damage to corals from fishing activities were mentioned. Also, extractive fisheries have been associated with reduced coral cover and a variety of other ecological perturbations due to trophic cascades (Edgar et al. 2010). The use of marine protected areas (MPAs) was invoked as a mechanism to ameliorate these anthropogenic perturbations. Of greater concern are impacts associated with anthropogenically accelerated climate change, including sea surface warming and ocean acidification. These are broader scale impacts addressed in an earlier section of this chapter and require multinational, comprehensive solutions. In the habitat suitability model proposed by Dawson et al. (2009b), a predictive element is incorporated that takes into account global climate change.

Since corals are generally found as colonies scattered over large areas in the Galápagos Islands, specific recommendations for management must be focused on the few locations with abundant coral cover. The northern islands of Wolf and Darwin are remote, helping to reduce impacts on the *Porites* reefs along the shelves of their respective shorelines. However, increased visitation by divers and continued poaching of fishes (particularly sharks) jeopardize trophic system balance. It is recommended that fisheries bans within the Marine Reserve are rigorously enforced and that the well-regulated tourism is augmented with specific mention of the sensitive nature of Galápagos corals. As suggested by Banks et al. (2009), a system of mooring buoys would mitigate impacts by boat operations associated with tourist diving activities, particularly anchor damage. Dive sites are accessed by small boats that do not anchor (live boating), so the primary concern is with the live-aboard vessels that transport tourists from island to island. Protocols were suggested by Merlen et al. (2009) for mooring buoy deployment throughout the archipelago, and they are now in place at Bartolomé Island and Punta Cormorant, Floreana Island. Moorings at additional locations would provide further benefit, particularly at the northern islands of Wolf and Darwin where anchoring is difficult due to the steep shelf slope.

Corals present at Devil's Crown, Floreana Island, include approximately 30 large (0.5–1.0 m diameter) colonies of *Porites lobata* that survived and recovered from the 1982–1983 El Niño (Fig. 1.8). Nevertheless, these corals experienced a period of live tissue decline following the 1997–1998 El Niño and then showed recovery from 2000 to 2009 (Paul 2012). Also, there are now approximately 20 colonies of *Pocillopora* spp. within Devil's Crown, a location that formerly supported (prior to the 1982–1983 El Niño) an extensive pocilloporid coral reef consisting of thousands of colonies. Following the loss of this reef in the decade following the El Niño event, this population had partially recovered to 167 colonies but underwent decline between 2007 and 2009, likely associated with cool water impacts of the 2007 La Niña event. Banks et al. (2009) reported archipelago-wide bleaching of *Porites lobata* and *Pocillopora* sp. during this period, attributed to "cold shock." Another example of recovery within Devil's Crown concerns a population of *Psammocora stellata* that decreased from nearly 100 % cover in the 1970s to widely scattered colonies following the 1982–1983 ENSO and has now nearly fully recovered (Fig. 1.9). The interior of Devil's Crown is now closed to tourist activities, and this is expected to aid continued recovery by minimizing human impacts. When the area was open in the past, snorkelers were observed standing on coral colonies and causing direct mechanical damage to coral tissues. In addition, sediments resuspended by snorkeler's swim fins settled on horizontal coral colony surfaces. This increased sedimentation stresses corals that must expend metabolic energy to remove the particles. Now that these avoidable stressors have been eliminated, hopefully this will improve coral settlement and recovery. It is heartening news that two (*Porites* and *Psammocora*) of the three monitored coral species that were present at Devil's Crown prior to the 1982–1983 ENSO have recovered.

Corals at the sites of two other former reefs (Champion Island, near Floreana Island, and the lava pools at Punta Espinosa, Fernandina Island) have not fared

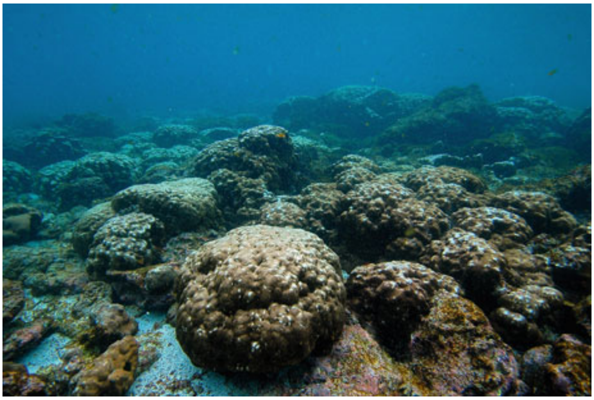

Fig. 1.8 Colonies of *Porites lobata* (2 m depth, June 2011) form an aggregation in the submerged caldera of Devil's Crown, Floreana Island. The colony in the foreground is approximately 1 m in diameter

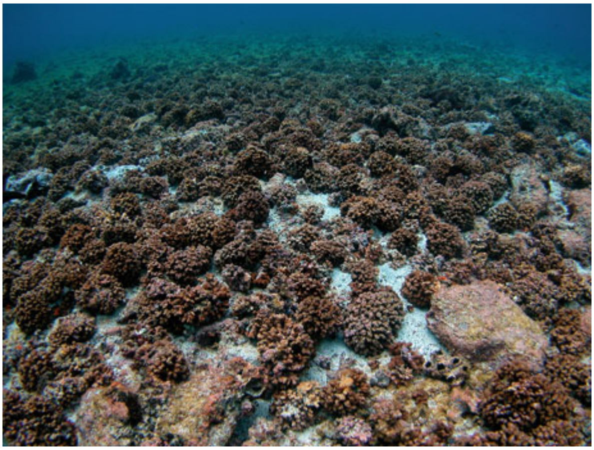

Fig. 1.9 Colonies of *Psammocora stellata* inside Devil's Crown, Floreana Island (3 m depth, June 2007), recovered from impacts associated with 1982–1983 El Niño warming to nearly the same density and distribution as before the event. The largest colonies are approximately 10 cm in diameter

as well. Surveys at Champion Island were performed annually or biannually since the early 1990s. Continued bioerosion eliminated most of the carbonate substrata, predominantly composed of *Pavona clavus* skeletal material. As in other parts of the archipelago, scattered coral colonies are still present, but there are no longer sufficient numbers or densities of colonies to form reef frameworks. A survey of the lava pools at Punta Espinosa in 2002 revealed intact dead skeletons of *Pocillopora* still in growth position, but no living colonies or new coral recruits.

The location of a dense population of *Pocillopora* colonies in Concha y Perla lagoon, so close (~1 km) to a town center (Puerto Villamil, Isabela Island), provides an exceptional opportunity for education and ecotourism. However, their unique genetics (all one genet that is not found elsewhere in the archipelago) (Baums, personal communication) and concerns of potential human impacts mandate their protection. The touristic appeal of these corals, combined with their delicate status in the archipelago, signifies that they are a population of special concern. It is recommended that programs be established to educate the local population and visitors of this unique and sensitive resource. Every effort should be made to prevent any type of anthropogenic insult, such as septic tank leakage or extractive activities, while encouraging its use in local education.

In summary, corals in the Galápagos Islands persist despite experiencing environmentally marginal conditions that are associated with the general cool conditions of the region, and that are punctuated by aperiodic anomalously warm and cool water stressors associated with ENSO activity. The study of these intriguing organisms at the physiological limits of their distribution provides meaningful insights into future challenges faced by corals in a changing world.

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Chapter 2
Elasmobranchs of the Galapagos Marine Reserve

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Abstract The Galapagos Marine Reserve is home to at least 50 species of sharks and rays. Although these species are protected in the marine reserve, they are vulnerable to industrial fishing outside the protected waters, to unintentional bycatch by local fishers inside the reserve, and to illegal fishing. Our knowledge of shark ecology in Galapagos has increased dramatically in the last decade, due to the creation of an interinstitutional research program, which focuses on the spatial ecology of hammerhead and whale sharks. Hammerheads are resident at restricted locations where they school during the day and disperse to sea most nights. Alternatively, mostly large, pregnant female whale sharks visit the northern islands from June through November for only a few days, as part of a large-scale migration.

Longline fishing studies have shed light on the distribution of sharks and their vulnerability to this fishing method. A juvenile shark monitoring program has been created. Scientists have attempted to model changes in shark populations since the creation of the marine reserve. A diver-based census of sharks has been implemented at key sites. The establishment of a regional network, MigraMar, has enabled us to determine connectivity of sharks and mantas between Galapagos and other areas.

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Introduction

Class Chondrichthyes, the cartilaginous fishes, is made up of two subclasses—the Holocephali (chimaeras) and the Elasmobranchii (sharks and rays). These fish differ from the teleosts (bony fish) in many fundamental aspects of their biology (Klimley 2013). In general, they have slower growth rates, later onset of sexual maturity, lower reproductive rates, and longer life spans, all of which can make them particularly susceptible to overexploitation by humans (Myers & Ottensmeyer 2005). Four species of chimaeras have been recorded in the GMR—*Hydrolagus mccoskeri*, *H. alphus*, a further unidentified species of the same genus, and one unidentified species of the genus *Chimaera* (McCosker and Rosenblatt 2010). Little is known about these largely benthopelagic species.

The list of elasmobranchs known to occur in the Galapagos is constantly being updated and revised. For example, both the grey reef shark *Carcharhinus amblyrhynchos* and the longfin mako shark *Isurus paucus* were excluded from a recent list of fish species for the Archipelago, while the white shark *Carcharodon carcharias* and the great hammerhead *Sphyrna mokarran* were included on the basis of plausible yet unconfirmed sightings (McCosker and Rosenblatt 2010). More recently, a previously unidentified species of houndshark was found to be *Mustelus albipinnis*, and both the smalltooth sand tiger shark *Odontaspis ferox* and the deepwater spiny dogfish *Centrophorus squamosus* were recorded (Acuña-Marrero et al. 2013). In the case of rays, there is one unidentified species, *Dasyatis* sp., first photographed and identified as *D. brevis* but now considered as a possible different undescribed species (McCosker and Rosenblatt 2010).

The updated list of elasmobranchs of Galapagos in 2013 includes 53 records, 33 sharks and 20 rays (see Table 2.1). Seventeen sharks and six rays (43.3 % of species listed) are known to have a circumtropical range of distribution; nine sharks and six rays (28.3 %) are eastern Pacific species (one of them, *Sphyrna tiburo*, also has a western Atlantic distribution); three sharks and two rays (9.4 %) are Indo-Pacific species; two sharks and three rays (9.4 %) are species from Peru and/or Chile; and two sharks and three rays (9.4 %) may be Galapagos or Galapagos/Cocos-endemic species.

Elasmobranchs are found in all marine habitats of the GMR, from coastal mangrove lagoons to the deep sea. Human interactions with elasmobranchs occur in the form of tourism—a multimillion dollar industry which attracts scuba divers and non-diving tourists from all over the world (Epler 2007)—and fishing; although sharks are protected within the waters of the GMR, they may be caught by industrial fishers operating legally outside the GMR or making illegal incursions into protected waters. They may also be caught by local fishers as bycatch in the hook and line and gillnet fisheries or as part of an illegal fishery for shark fins (Jacquet et al. 2008; Reyes and Murillo 2007). Finally, there are occasional incidents of shark attacks on humans (Acuña-Marrero and Peñaherrera-Palma 2011).

Our knowledge of elasmobranchs and the role they play in the GMR has increased greatly over the last decade, since the publication of a chapter on sharks

Table 2.1 Shark and ray species reported from the Galapagos Islands

No.	English name	Scientific name	IUCN red list*
1	Pelagic thresher shark	*Alopias pelagicus*	Vulnerable
2	Bigeye thresher shark	*Alopias superciliosus*	Vulnerable
3	Longnose cat shark	*Apristurus kampae*	Data deficient
4	Cat shark	*Apristurus stenseni*	Data deficient
5	Galapagos cat shark	*Bythaelurus giddingsi*	Not evaluated
6	Silvertip shark	*Carcharhinus albimarginatus*	Near threatened
7	Bignose shark	*Carcharhinus altimus*	Data deficient
8	Silky shark	*Carcharhinus falciformis*	Near threatened
9	Galapagos shark	*Carcharhinus galapagensis*	Near threatened
10	Blacktip shark	*Carcharhinus limbatus*	Near threatened
11	Oceanic whitetip shark	*Carcharhinus longimanus*	Vulnerable
12	Sandbar shark	*Carcharhinus plumbeus*	Vulnerable
13	Great white shark	*Carcharodon carcharias*	Vulnerable
14	Deepwater spiny dogfish	*Centrophorus squamosus*	Vulnerable
15	Combtooth dogfish	*Centroscyllium nigrum*	Data deficient
16	Prickly shark	*Echinorhinus cookei*	Not evaluated
17	Cat shark	*Galeus* sp.	Not evaluated
18	Tiger shark	*Galeocerdo cuvier*	Near threatened
19	Galapagos bullhead shark	*Heterodontus quoyi*	Data deficient
20	Cookie cutter shark	*Isistius brasiliensis*	Least concern
21	Shortfin mako shark	*Isurus oxyrinchus*	Vulnerable
22	White-margin fin smooth-hound shark	*Mustelus albipinnis*	Data deficient
23	Speckled smooth-hound	*Mustelus mento*	Near threatened
24	Whitenose shark	*Nasolamia velox*	Data deficient
25	Smalltooth sand tiger shark	*Odontaspis ferox*	Vulnerable
26	Blue shark	*Prionace glauca*	Near threatened
27	Whale shark	*Rhincodon typus*	Vulnerable
28	Scalloped hammerhead shark	*Sphyrna lewini*	Endangered
29	Great hammerhead shark	*Sphyrna mokarran*	Endangered
30	Bonnethead shark	*Sphyrna tiburo*	Not evaluated
31	Smooth hammerhead shark	*Sphyrna zygaena*	Vulnerable
32	Whitetip reef shark	*Triaenodon obesus*	Near threatened
33	Spotted houndshark	*Triakis maculata*	Vulnerable
34	Spotted eagle ray	*Aetobatus narinari*	Near threatened
35	Pacific white skate	*Bathyraja spinosissima*	Least concern
36	Whiptail stingray	*Dasyatis brevis*	Not evaluated
37	Diamond stingray	*Dasyatis dipterura*	Data deficient
38	Longtail stingray	*Dasyatis longa*	Data deficient
39	–	*Dasyatis* sp.	Not evaluated
40	Dusky finless skate	*Gurgesiella furvescens*	Least concern
41	Pacific chupare	*Himantura pacifica*	Not evaluated
42	Giant manta	*Manta birostris*	Vulnerable
43	Spinetail mobula	*Mobula japanica*	Near threatened
44	Munk's devil ray	*Mobula munkiana*	Near threatened
45	Chilean devil ray	*Mobula tarapacana*	Data deficient
46	Peruvian eagle ray	*Myliobatis peruvianus*	Data deficient

(continued)

Table 2.1 (continued)

No.	English name	Scientific name	IUCN red list*
47	Rough eagle ray	*Pteromylaeus asperrimus*	Data deficient
48	Pelagic stingray	*Pteroplatytrygon violacea*	Least concern
49	Velez ray	*Raja velezi*	Data deficient
50	Eisenhardt's skate	*Rajella eisenhardti*	Data deficient
51	Pacific cownose ray	*Rhinoptera steindachneri*	Near threatened
52	Blotched fantail ray	*Taeniura meyeni*	Vulnerable
53	Peruvian torpedo	*Torpedo peruana*	Not evaluated

Sources: Grove and Lavenberg (1997), Zarate (2002), McCosker and Rosenblatt (2010), McCosker et al. (2012), and the Charles Darwin Foundation Datazone Species Checklist (http://checklists.datazone.darwinfoundation.org/ accessed May 21, 2013)

in the Galapagos Marine Reserve Baseline of Biodiversity in 2002 (Zarate 2002, in Danulat and Edgar 2002). In 1997, 2001, and 2003, experimental longline fishing was carried out by the local fishing sector within the GMR, shedding light on the relative abundance and distribution of some of the pelagic sharks (Murillo et al. 2004). In 2006, the Charles Darwin Foundation, Galapagos National Park Service, and University of California Davis began a long-term collaboration to study the movements of certain shark species to determine their spatial dynamics within the reserve and their connectivity with other oceanic islands in the region (Hearn et al. 2008, 2010a, b; Ketchum 2011). As part of this project, divers have been undertaking visual surveys of sharks and other open-water species at some sites (particularly in the northernmost islands) twice yearly since 2007 (Hearn et al. 2010a). Sharks and rays were also included in diver-based surveys carried out by the Charles Darwin Foundation across the archipelago, mainly over rocky coastal reefs at depths of 6 and 15 m since 2001 (Edgar et al. 2004). A number of smaller studies have also shed light on the importance of nursery areas for juvenile sharks (Llerena et al. 2010, 2012; Jaenig 2010) and have attempted to model the recovery of shark populations since the creation of the GMR (Wolff et al. 2012a).

Legislation

Shark legislation in continental Ecuador prohibits shark-targeted fisheries but permits the landing of bycatch taken in other fisheries. The most common species landed at ports on mainland are (in ranked order) pelagic thresher (36 %), blue shark (24 %), silky shark (15 %), smooth hammerhead (11 %), and scalloped hammerhead (5 %) (Martinez et al. 2007). These sharks, among others, are taken as bycatch by the industrial fleet and the artisanal fleet, although claims that they bring up to 30 % of total earnings for artisanal fishers suggest that they may be more of a target species (Martinez and Viteri 2005).

Over the last two decades, there has been increasing concern about the health of global shark populations. According to Bonfil (1994), 50 % of the estimated global shark catch (760,000 t in 1996) is taken as bycatch and does not appear in official statistics and landings. Added to the problem of underreporting is that much of this catch is not identified to species level, due in part to the practice of finning—removing the fins (which fetch high prices in the Asian market) and discarding the bodies overboard. As a result of this concern, the United Nations Food and Agriculture Organization (FAO) created the International Plan of Action for Sharks (IPOA-Sharks) in 1998, which contains clear guidelines for all nations involved in shark fishing or consumption of shark-based goods and exhorts these nations to develop national plans of action for their shark resources (FAO 2010–2013). Within the Eastern Tropical Pacific, Ecuador has taken the lead in developing a coherent Plan of Action and establishing monitoring programs at major ports (Zarate and Hearn 2008; MICIP 2006).

In 2004, the Ecuadorian Government issued a decree banning the export of shark fins, yet this was overturned in 2007 by Executive Decree 486 which permits the export of fins but places technical restrictions on fishing gear, imposes a monitoring system to ensure that all sharks caught are landed whole, and stipulates that fin removal must occur on land. There has been a great deal of controversy about Decree 486, with alarm being raised by environmentalist groups that without a monitoring and control system in place, shark finning may become widespread. Arguments for the decree state that the previous decree was unenforceable and that it simply served to drive the activity underground.

The first attempts to provide protection for sharks in Galapagos date back to 1989, when the Government of Ecuador banned fishing, transport, and sale of all sharks and their products (MICIP 1989). Once the GMR was created (in 1998), the maximum governing authority of the GMR ratified the original ban in 2000. In addition to enacting regulations which were specific to sharks, the Galapagos Special Law banned all industrial fishing within the 40-nautical-mile (Nm) limits of the GMR and has the authority to ban fishing gear which results in unacceptable levels of bycatch.

In response to the deaths in Peruvian waters of manta rays tagged off the coast of mainland Ecuador, the Ministry of the Environment called for the species to be listed on the appendices of the Convention for Migratory Species Act (CMS). A protected species in Ecuador since 2010 (Ministerial Decree 093, Ministry of Agriculture, Livestock, Aquaculture and Fisheries), Ecuador put forward a proposal to list this vulnerable species on CMS to prompt cooperation with neighboring countries and to facilitate regional management efforts. In late 2011, *Manta birostris* became the first ray species to ever be listed on Appendix I and II of CMS.

To help curb international trade, Ecuador, with support from Brazil and Columbia, proposed manta rays to be listed on Appendix II of CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). This proposal was successfully adopted in March 2013 and will help curb the unsustainable fishing of *Manta* species by requiring the international trade in manta rays come from sustainably harvested fisheries that are not detrimental to the wild populations they exploit. White sharks, whale sharks, and basking sharks were already listed on Appendix II, but in March 2013, the oceanic whitetip shark, the porbeagle shark, and the great, smooth, and scalloped hammerhead sharks were also uplisted to the Appendices of CITES.

Ecuador, well aware of the importance of hammerheads to their country, was also a co-proponent of the hammerhead proposal alongside Brazil, Costa Rica, Honduras, Columbia, the EU and the United States.

Distribution and Relative Abundance

The Galapagos Marine Reserve can be divided into four main biogeographic regions, based on the prevailing oceanographic conditions and reef fish and macroinvertebrate assemblages—far north, north, central, and west—with a further subregion nested within the western region, Elizabeth, characterized by a high degree of marine endemism (Edgar et al. 2004). Marine ecologists at the Charles Darwin Foundation have carried out reef fish surveys around the archipelago since 2001 (Edgar et al. 2004). Their surveys permit some broad observations on the presence of the benthic sharks and rays around the islands (Fig. 2.1).

Unsurprisingly for mostly large, mobile species, many of the shark and ray species are found throughout the GMR. However, the only shark species to be recorded consistently by the subtidal ecological monitoring survey teams in the western part of the archipelago is the Galapagos bullhead shark, *Heterodontus quoyi*. This shark is absent from the warmer, northern bioregions. Mantas and devil rays also appear limited to the cooler and mixed central and western bioregions, while whale sharks in contrast were only recorded in these surveys in the far north. Despite this, it must be noted that recreational and scientific divers occasionally report mantas, devil rays, and whale sharks throughout the archipelago.

While estimating true abundance of sharks and rays from these surveys is not possible, a measure of relative abundance can be obtained by calculating the number of individuals per hectare of habitat based on the transect dimensions (Fig. 2.2). From this data, we observe that the diamond stingray, golden cowray, and whitetip reef shark are most common in the mixed, central region of the reserve, whereas the Galapagos bullhead shark is common in the western region, to which it is almost exclusively limited. Marbled and eagle rays are found infrequently throughout the region, while Galapagos sharks were common in both the central and far north regions.

Underwater visual surveys, focused on large pelagic species, especially sharks, have been carried out at nine sites around Darwin and Wolf Islands at least twice a year and intermittently at sites throughout the archipelago which are generally either dive tourism locations or locations where underwater acoustic receivers have been deployed as part of a shark-tagging research program (Hearn et al. 2008). Notwithstanding the bias involved in these kinds of surveys (e.g., see Bernard et al. 2013), they have been particularly valuable in establishing the relative abundance of sharks which utilize nearshore waters and waters surrounding offshore islets. They have also been used to analyze habitat preference around Wolf Island in particular and to understand the seasonal changes in abundance of certain species in the far northern bioregion. The surveys are carried out by pairs of divers who identify and count all

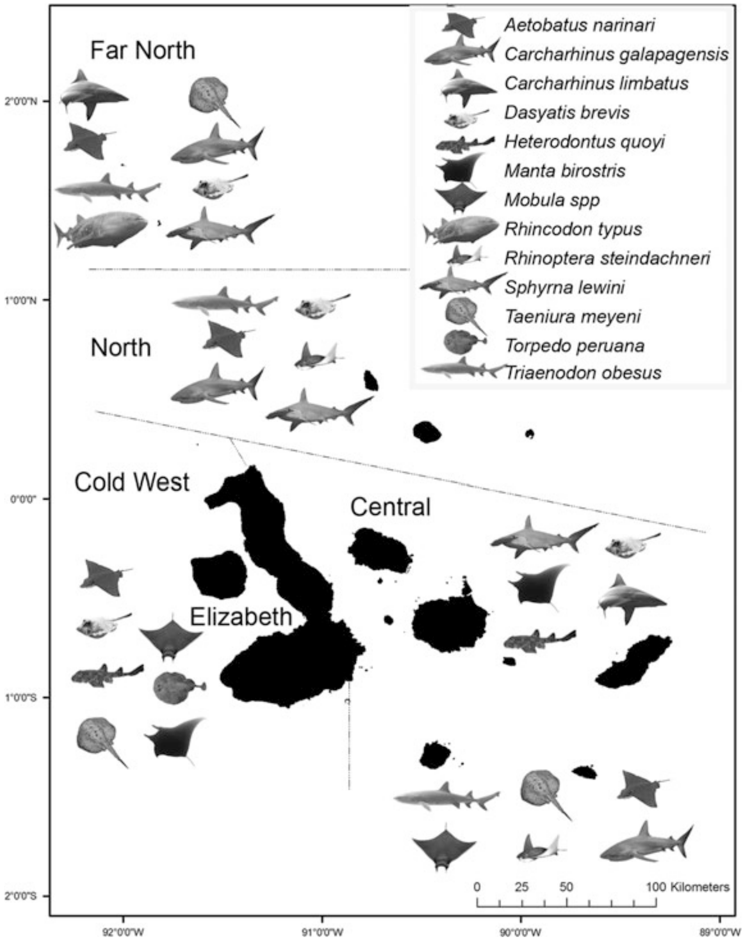

Fig. 2.1 Map showing the distribution of the sharks and rays species most commonly observed and recorded in rocky reef surveys in Galapagos divided in bioregions, as proposed by Edgar et al. (2004). The bioregions of Cold West and Elizabeth have been fused, as data from Elizabeth bioregion was scarce. The species icons are not presented in scale

sharks and other open-water species (manta rays, sunfish, tuna) over a 30-min period at a depth of approximately 15–20 m, with their backs to the coastline.

By far the most commonly encountered sharks by the dive teams were hammerhead and Galapagos sharks (Table 2.2). Hammerhead sharks school in large numbers at upstream current sites at Darwin and Wolf Islands (Hearn et al. 2010a), and these shark hotspots are undeniably populated by numbers not found elsewhere in the archipelago. The diversity of sharks in the far north is also worthy of note. It is not unusual to come across at least five species of shark in a single dive. Along with the ubiquitous hammerhead and Galapagos sharks, silky and blacktip sharks are commonly found at these hotspots, as well as occasional whitetip reef sharks. Other less common species

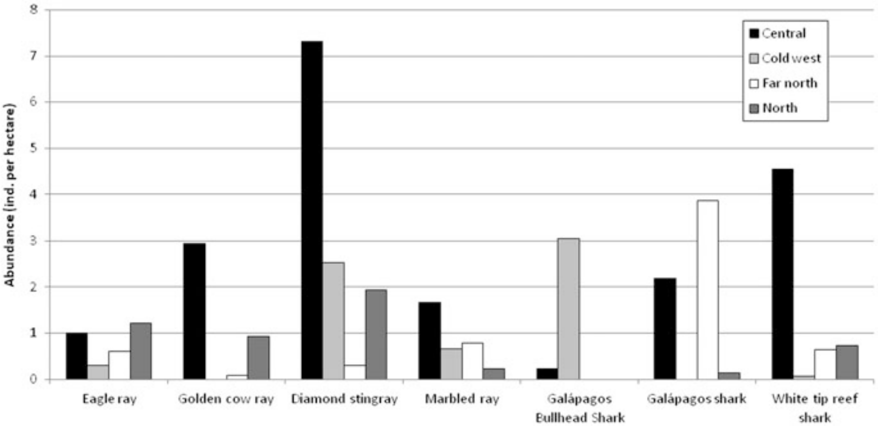

Fig. 2.2 Relative abundance (expressed as individuals per hectare) of selected elasmobranchs, by biogeographic region, from diver-based reef fish surveys from 2001 to 2010 (Source: Charles Darwin Foundation, Subtidal Ecological Monitoring Program)

include the silvertip shark, recorded only once by divers at Darwin, and the tiger shark, which was photographed by the shark-tagging team at Darwin in 2011. Divers rarely see tiger sharks, but it is likely that they are more common around the islands than would be expected based on these surveys. Five adult tiger sharks were caught within a single bay at nearby Cocos Island (Costa Rica) during a 7-day period in 2011, and a further five were caught at a single bay at Socorro Island (Revillagigedos Archipelago, Mexico) around the same time, while in neither case were tiger sharks recorded by scuba divers (Hearn, personal communication).

Whale sharks are observed rarely throughout the archipelago and were only recorded during visual surveys at the Darwin and Wolf Island hotspots, and only from June through November. Yet during this period, at least one whale shark encounter per dive can almost be guaranteed at the Arch dive site, off Darwin Island (Hearn et al. 2012).

If we examine the relative abundance of whale sharks, Galapagos sharks, and hammerhead sharks, only at the two hotspot sites in the far northern bioregion—the southeastern points of Darwin and Wolf, we find that there is a remarkably similar temporal pattern between all three species (Fig. 2.3). All three species display greater abundances in the cooler months of the year (from May through October), whereas in the warmer months, whale sharks in particular are absent, while hammerhead and Galapagos shark numbers are greatly reduced, and the large schools are rarely seen during this time.

Table 2.2 Relative abundance, expressed as individuals observed per diver hour (ind h^{-1}), of six species of sharks recorded during underwater diver surveys for open-water species from 2007 to 2012, by biogeographic region

# Dive surveys	93	483	31
Species/region	Central	Far north	West
Carcharhinus albimarginatus		0.008	
Carcharhinus falciformis	0.063	0.250	
Carcharhinus galapagensis	12.41	4.042	0.250
Carcharhinus limbatus	0.188	0.733	
Sphyrna lewini	2.854	125.7	6.563
Triaenodon obesus	1.396	0.192	
Rhincodon typus		0.683	

Number of surveys carried out in each region is also shown. Source: CDF-UCD-PNG Pelagic Census Database

Key Habitats

Adult Aggregations

Research on the movement patterns of sharks in the GMR has focused mainly on the scalloped hammerhead *Sphyrna lewini*. This species is known to aggregate in large numbers around oceanic islets and seamounts (Klimley and Nelson 1984; Bessudo et al. 2011; Hearn et al. 2010a; Ketchum et al. 2011a). These act as central refuging systems from which foraging excursions take place and at which social interactions occur. Less is known about the other commonly found shark species around the island coasts, such as the silky shark *Carcharhinus falciformis* and the Galapagos shark *C. galapagensis*. No research has been carried out in the GMR directed at oceanic or deepwater sharks.

In 2006, a shark-tagging program was initiated jointly by the Galapagos National Park Service, University of California Davis, Stanford University, and the Charles Darwin Foundation. This involved placing coded ultrasonic tags on sharks (either internally by surgery or externally with a dart) and deploying an array of underwater listening stations (Fig. 2.4) that detect and record the presence of tagged sharks within a radius of approximately 200 m (Hearn et al. 2008, 2010a; Ketchum et al. 2011a).

Between 2006 and 2009, over 100 hammerhead sharks were tagged in this fashion at Darwin and Wolf. Most of these were females, as these form the large schools that predominate at oceanic islands (Klimley 1985). Between 2008 and 2012, a further 15 Galapagos sharks, and a small number of silky sharks, were also tagged at different sites throughout the archipelago.

External tags, while easy to affix to sharks, are also often rapidly shed, as observed from continuous detections of tags at receiver locations. For this reason, it is difficult to make inferences about sharks that were not detected after only a few days—they may have migrated away or simply shed their tags outside the detection range of a receiver. Yet for those tags which did provide long-term information, a high degree of site fidelity was found for almost all individuals to both Darwin and Wolf Islands (Fig. 2.5).

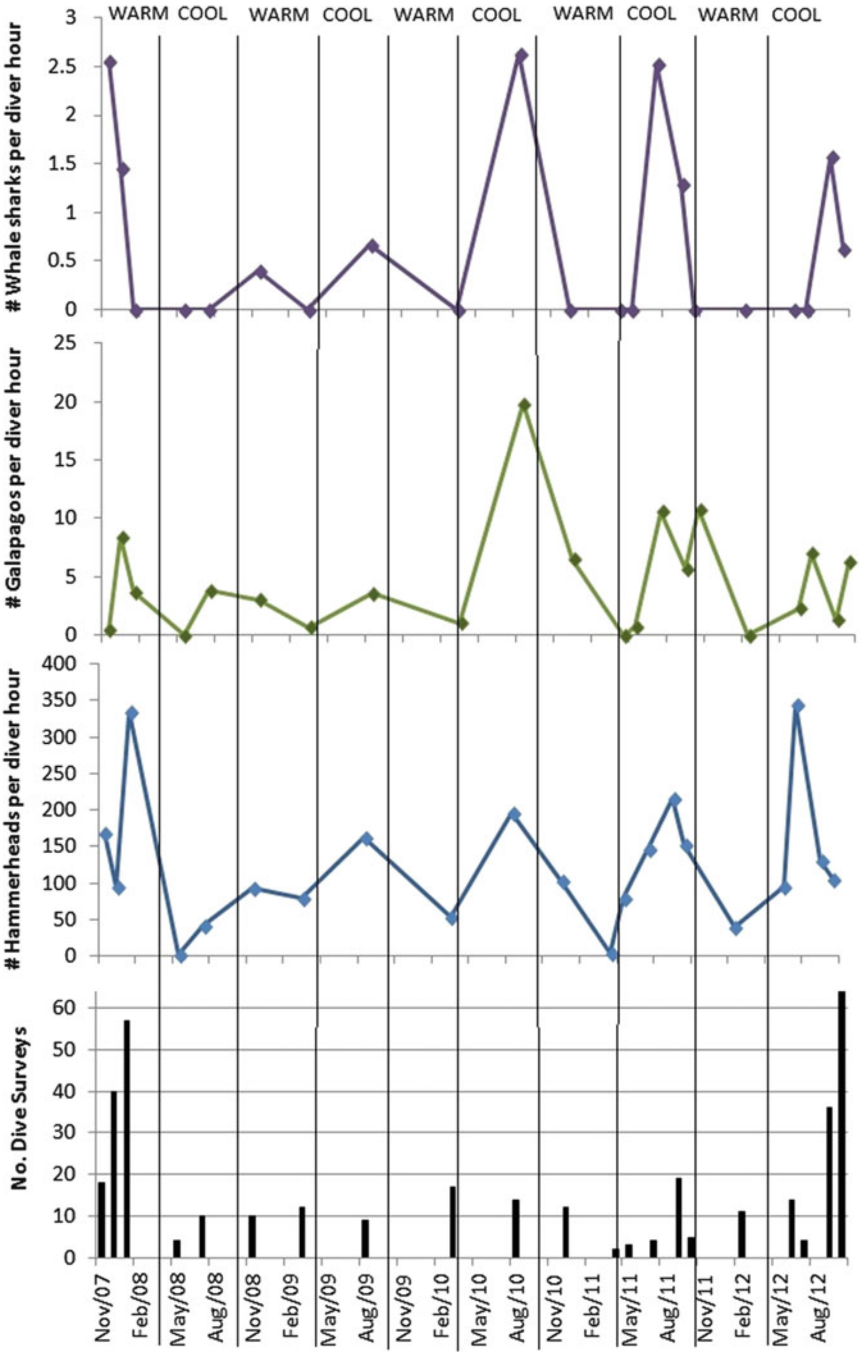

Fig. 2.3 Seasonal changes in relative abundance (expressed as the number of individuals observed per diver hour) of three shark species at the Darwin and Wolf shark hotspots, 2007–2012. From *top* to *bottom*: whale shark, Galapagos shark, and hammerhead shark. *Vertical lines* indicate approximate changes between warm and cool seasons. *Bar chart* indicates the

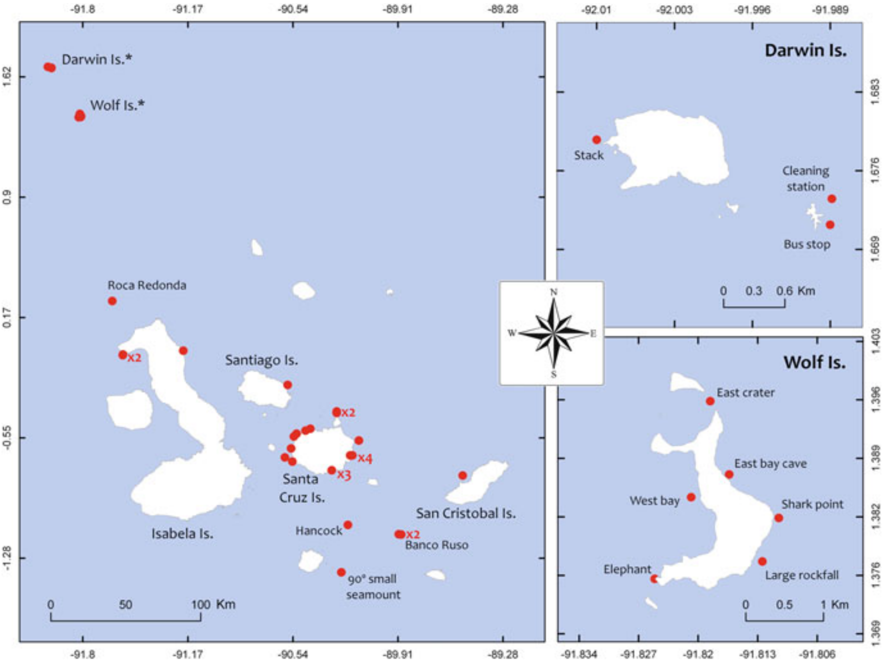

Fig. 2.4 Map showing array of underwater listening stations installed between 2006 and 2012. These stations detect and record the presence of tagged sharks and other species currently being studied in the Galapagos Marine Reserve

Hammerheads did not appear to display group cohesion, in that no clear pattern of presence at islands and movements between islands could be established. As in Mexico (Klimley and Nelson 1984), Ketchum et al. (2011b) found a strong diel signal in the presence of hammerheads at both sites, with frequent nocturnal absences of several hours duration, beginning at dusk. These are presumably foraging excursions—from dietary studies carried out on hammerheads landed at ports in continental Ecuador, it would appear that they tend to feed mainly on oceanic squid, such as *Dosidicus gigas*, that may be found in the open ocean (Castañeda-Suarez and Sandoval-Londoño 2007; Estupiñan-Montaño et al. 2009).

Hammerheads moved continuously between Darwin and Wolf, a distance of 38 km, with no clear seasonal pattern. Six individuals were detected at Roca Redonda (Fig. 2.5), 150 km south of Darwin. Four of these were detected in February 2008, and three were detected again at the island in June, after an absence from the entire array of almost three months. Yet in each case, the sharks were detected at Darwin briefly, before making the southerly movements back to Roca Redonda. Residency at

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Fig. 2.3 (continued) number of surveys carried out at hotspots per month. Source: CDF-UCD-PNG Pelagic Census Database

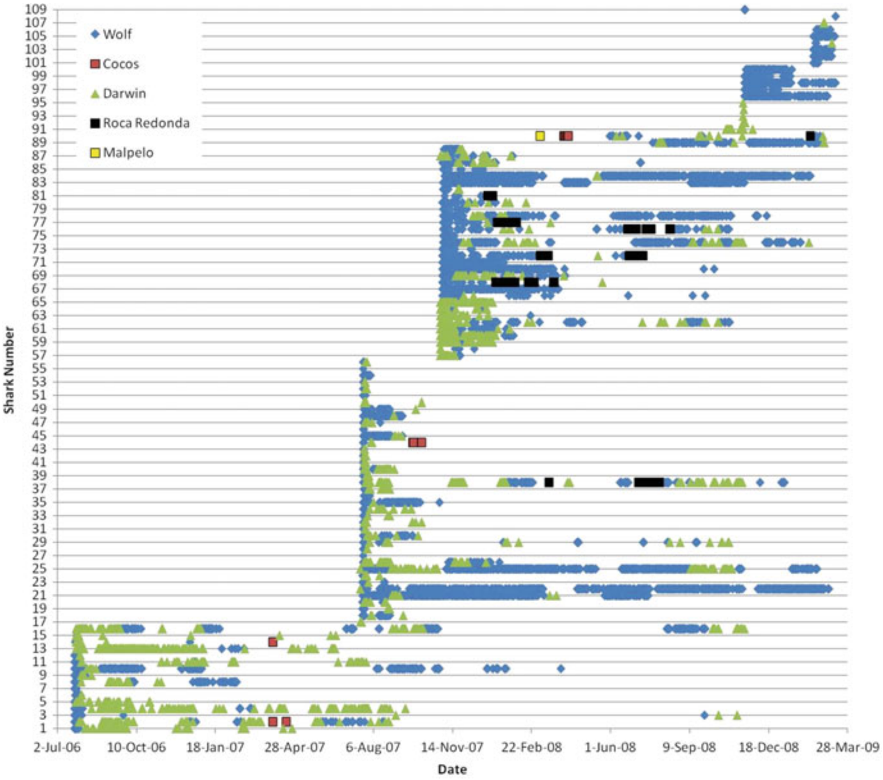

Fig. 2.5 Detection record of hammerhead sharks tagged at Darwin and Wolf from 2006 to 2009 (Source: Galapagos Shark Research Program, Ketchum et al. 2011a, b, c)

Roca Redonda was less than a month, suggesting that their migration was not further south but rather to the north. Other hammerheads that were only detected at Darwin and Wolf were also absent from March through June. In conjunction with diver surveys (see Fig. 2.3), this suggests that many female hammerheads undergo a migration at this time of year. The destination of this migration is unclear—none of the sharks were detected on the rest of the array in Galapagos, yet four were detected at Cocos Island (700 km to the northeast). Neonate hammerheads have not been found in significant numbers at Galapagos, so it is possible that this is a migration to pupping grounds. Scalloped hammerhead sharks, including some neonates, are landed in small numbers in Ecuador especially in March–April (Martinez et al. 2007), yet the largest reported landings of this species, and in particular of neonates, occur in the gulfs and bays of Costa Rica and Panama (Zanella et al. 2009; Rodriguez 2011). If a migratory route were established between Galapagos and this region, this would raise issues about regional conservation measures for this listed species.

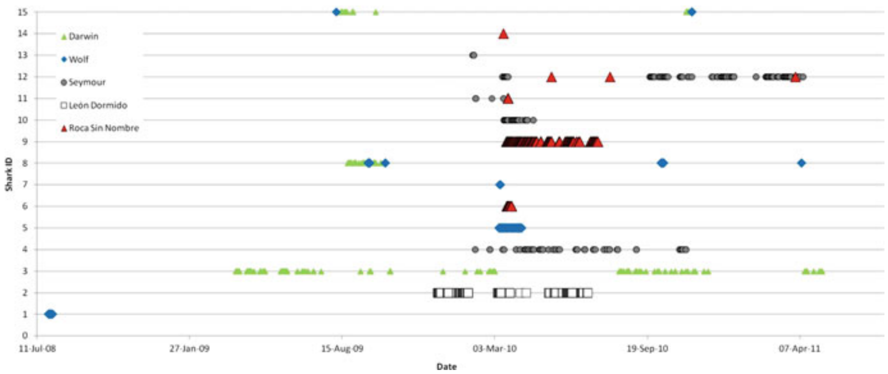

Fig. 2.6 Detection record for Galapagos sharks tagged around the Galapagos Marine Reserve 2006–2011 (Source: Galapagos Shark Research Program, Hearn et al. in press)

Detections of 15 Galapagos sharks tagged at several sites throughout the GMR do not show clearly identifiable residency patterns (Fig. 2.6). Galapagos sharks seemed more loosely associated with the islets and other study sites, displaying a lower number of detections, and diel patterns which were less consistent among individuals (Hearn et al. in press). One shark (#3, Fig. 2.6) was highly residential at Darwin for 2 years but was absent for four extended periods during this time, including two 5-month periods from March to August 2010 and December 2010 to April 2011. Two other sharks moved multiple times between Darwin and Wolf, while in the central archipelago, Roca Sin Nombre and North Seymour were connected.

Both species displayed a strong preference for the current-facing coasts of Darwin and Wolf—indeed, there is greater connectivity in terms of movements of individual sharks between the two up-current sites on both islands than between upstream and downstream sites on the same island (e.g., see Fig. 2.7).

Juvenile Nursery Areas

According to Heupel et al. (2007), a nursery area is a place where neonate and juvenile fish will be more commonly encountered, where they will remain or return for extended periods of time, and that will be repeatedly used by those species in the same fashion year after year. Only three reports have been published specifically on juvenile sharks to date where a set of surveys using 3″ mesh size gill nets in mangrove-fringed bays were carried out around San Cristobal (Llerena et al. 2010) and Santa Cruz Islands (Jaenig 2010; Llerena et al. 2012). During 6 months of sampling at five sites of the northwestern coast of San Cristobal Island, Llerena et al. (2010) caught 95 juvenile blacktip sharks (*C. limbatus*); 75 % were neonate or young of the year (YOY). Subadult and juvenile whitetip reef sharks (*T. obesus*) were also caught, yet only one neonate scalloped hammerhead was caught. Jaenig (2010) reported similar results but for four sites at the northwestern face of Santa Cruz. Over 6 months of

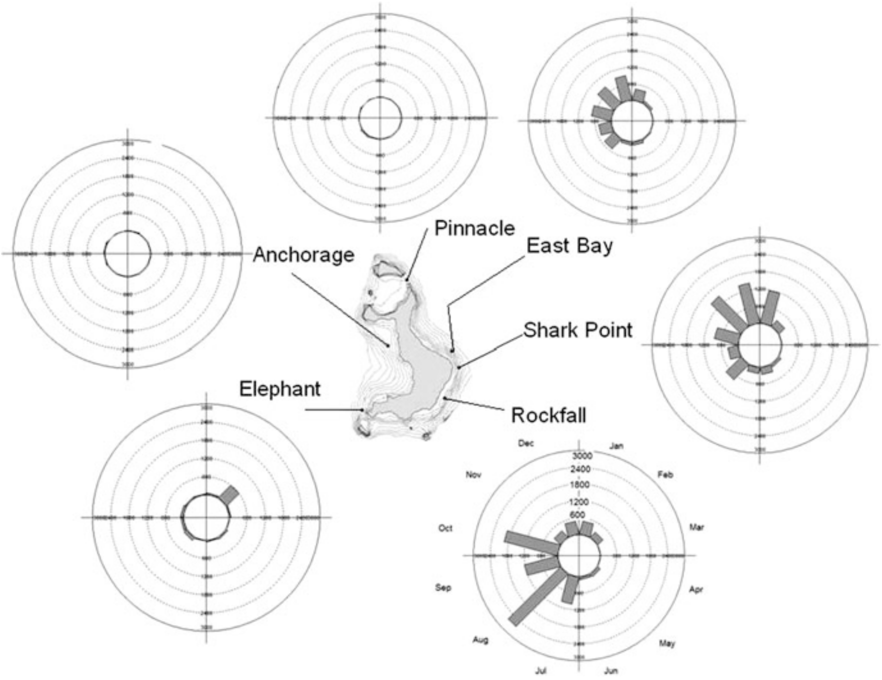

Fig. 2.7 Circular graphs showing the number of detections per month of a female hammerhead shark, tagged at Wolf, at different receiver locations around the island (from Hearn et al. 2010a)

sampling—from November 2009 to March 2010—a total of 296 sharks were caught, made up of 292 blacktips (80 % neonates and 15 % YOY), three whitetip reef sharks, and one scalloped hammerhead shark.

The Galapagos National Park Service began an extended juvenile shark monitoring program around Santa Cruz Island in 2009, yet preliminary results point towards mangrove-fringed areas as nursery grounds for blacktip sharks yet not for hammerhead sharks (Llerena et al. 2012). Although biased by the fishing gears in use, it seems unlikely that hammerhead nursery grounds such as those heavily fished in the gulfs of Costa Rica (Zanella et al. 2009) and Panama (Rodriguez 2011) exist in the Galapagos.

Young Galapagos sharks are frequently seen schooling at small islets offshore from the main islands, such as Kicker Rock (off San Cristobal) and Enderby (off Floreana). These schools are generally comprised of individuals around 1 m in length. Similar-sized Galapagos sharks are also found in the sheltered anchorage at Wolf Island—a single individual tagged here resided at the location for at least 1 month and was not detected at receivers placed elsewhere at the island (Hearn et al. in press). Of all the Galapagos and hammerhead sharks tagged at Wolf, this was the only juvenile and the only individual to display this strong fidelity to the Anchorage site.

Comparative Movement Patterns

Central refuging (Hamilton and Watt 1970), where top predators remain part of the day near their foraging grounds, is a strategy that is used by sharks (Klimley and Nelson 1984). At Wolf Island, Ketchum et al. (2011b) tracked seven hammerheads continuously for ~48 h from a small skiff using a directional hydrophone, from 2007 to 2009. Continuous tracking is labor-intensive and the results are often anecdotal due to the small obtainable sample size. However, it may provide insights into the behavior of individuals. They found that the daytime movements of most individuals were highly restricted to a narrow band of water along the up-current-facing coast of the island, referred to previously as a shark "hotspot" (Hearn et al. 2010a). They used a kernel density estimator (KDE) to measure the core movement area and found that it ranged from only 0.05 to 0.55 km^2 (Fig. 2.8). Possible reasons for the intensity of use of the hotspot were the abundance of food, reduced currents, and vantage location for foraging excursions into open waters (see Hearn et al. 2010a). Additionally, Klimley (1985) mentioned that hammerheads formed schools at specific locations for the purpose of sexual selection and social interactions.

Hammerheads made nighttime movements to nearby offshore locations, presumably to forage, and returned in the early hours of the morning (Ketchum et al. 2011b) in a similar fashion of movement as observed for this species in the Gulf of California (Klimley 1993). These movements were several kilometers and in some cases the shark followed the same route on the return trip back to the island. How sharks navigate is still a mystery and may involve the use of several senses, but in similar movements in the Gulf of California, Klimley (1993) found that hammerheads appeared to orient to areas where there was a high geomagnetic gradient. He suggested that sharks could detect variations in the Earth's magnetic field caused by volcanic activity and use these to navigate between seamounts and volcanic islands.

These offshore movements did not occur every night and were not always to the same locations. Similarly, those hammerheads which had acoustic tags were sometimes present some or all of the night. There is no appreciable pattern to the sequence of nighttime absences between individuals, which suggests that their absences do not respond to an external cue such as moon phase.

One Galapagos shark tracked for 48 h made two complete circuits of Wolf Island and did not move further than 200 m from the coastline throughout the track (Hearn et al. in press).

Whitetip reef sharks are well known to aggregate in several shallow-water sites around the central, north, and far north Galapagos bioregions. A study was undertaken in a saltwater channel south of Academy Bay, Santa Cruz Island, from May 2008 to September 2009. A total of nine transmitters were attached to sharks, and ultrasonic receivers were deployed at the inner and outside areas of the creek to assess their daily behavior and site fidelity. Data from five sharks showed an elevated use of the inner area of the channel during the day, with more use of the external area during the night. However, none of the sharks were detected at the site

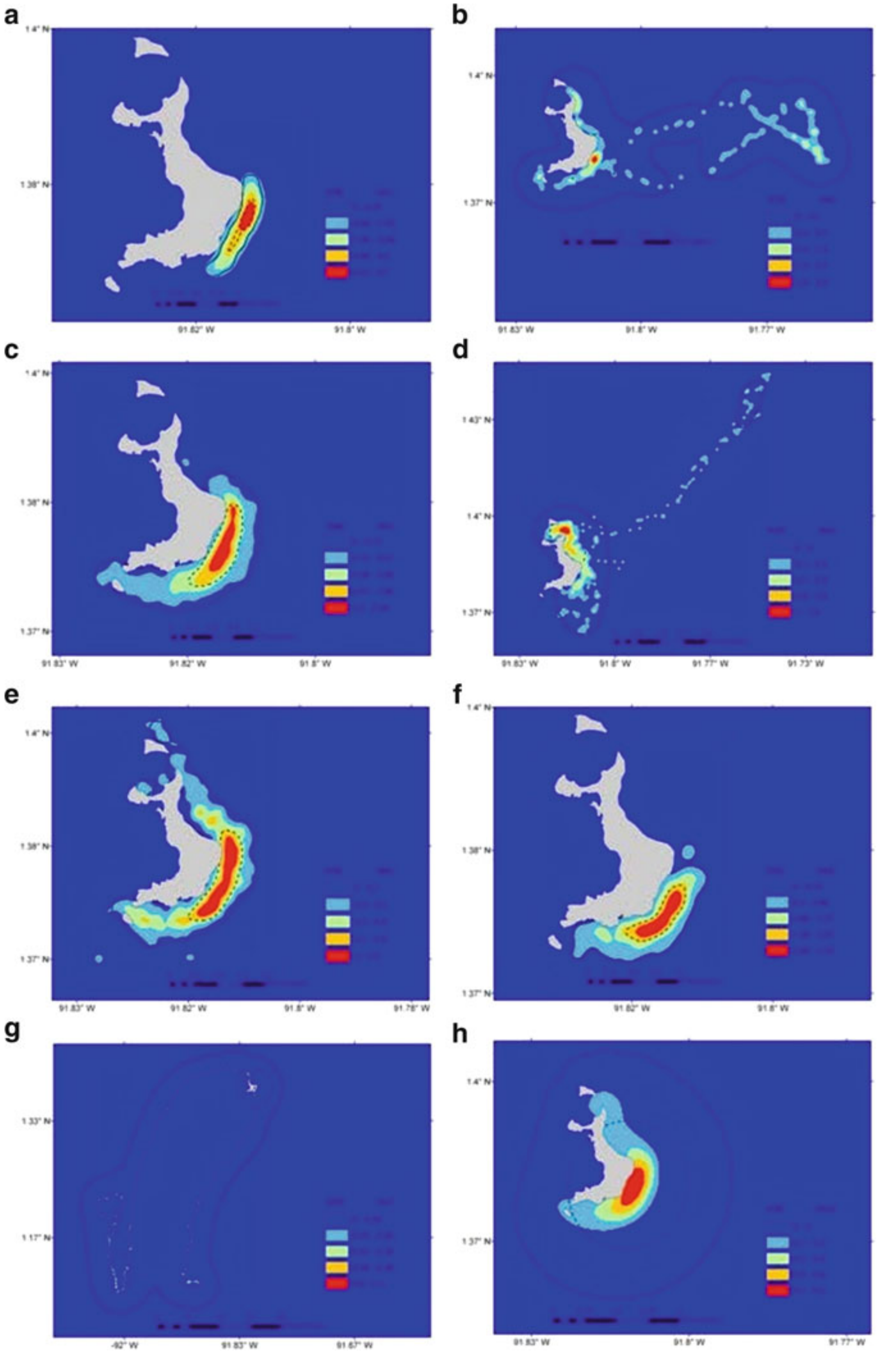

Fig. 2.8 Kernel density estimation (KDE), 50 % UD (*dotted line*) and 95 % UD (*solid line*); for (**a**–**g**) each individual hammerhead shark tracked over ~48 h; (**h**) entire sample of seven hammerhead sharks (from Ketchum et al. 2011b)

every day, suggesting that they may have a number of preferred sites within their home range (Peñaherrera et al. 2012).

Regional Connectivity

Tagging studies of movements of several shark species have been carried out in the Eastern Tropical Pacific as part of the MigraMar network (http://www.migramar.org). An array of underwater listening stations such as those used in Galapagos has been deployed by teams of researchers in Panama, Costa Rica (Cocos Island), and Colombia (Malpelo) as well as on the coast of Ecuador (Fig. 2.9). These have established the existence of connectivity between the three major oceanic island groups: Galapagos, Cocos, and Malpelo (Bessudo et al. 2011; Ketchum et al. 2011b). The first indication of connectivity occurred in 2006, when 2 from 18 hammerheads tagged in July in Galapagos were detected at Cocos Island within hours of each other in April 2007, one of which subsequently returned to Galapagos (Fig. 2.5). Since then, one or two hammerheads per year are detected at a different island group from where they were tagged. In 2008, a hammerhead tagged at Malpelo moved to Cocos and subsequently to Galapagos, where it remained for several months moving between Darwin and Wolf. No sharks tagged at oceanic islands have been detected on coastal arrays.

A small number of satellite tags have been placed on hammerhead, blacktip, and silky sharks. These tags are attached to the dorsal fins of sharks and transmit locations to the Argos (Argos 2007) satellite system when at the surface. These tags have been used in several studies around the world (Hammerschlag et al. 2011), but Galapagos is the first (and to date, only) site where these tags have been successfully placed on scalloped hammerheads (Ketchum et al. 2011c). Eight hammerheads (seven males and one female) were tagged at Darwin and Wolf from 2007 to 2009, and tracks were obtained from seven of these (Fig. 2.10). The female track lasted only 2 weeks and was tracked for approximately 350 km towards the northeast, when her signal was lost about halfway between Darwin and Cocos Island. A male tagged at the same time made a similar move towards Cocos yet returned back to Darwin after a similar distance, where its satellite transmitter ceased to function. Yet this individual also had an acoustic tag, which was later detected at Cocos. One male moved south into the central archipelago and was last detected at eastern Isabela Island, while another male moved almost 1,000 km to the northwest. Bearing in mind the small sample size and its bias towards males, preliminary kernel density estimations show that hammerheads spend significant periods outside the protected waters of the Galapagos Marine Reserve (Fig. 2.11).

Silky sharks ($N = 8$) were tagged at Darwin and Wolf in 2006–2012, with tracks obtained from seven individuals (Hearn et al. unpublished data). Only one shark made a long distance, directed movement out into the open ocean, traveling over 1,000 km to the northwest in only 25 days (Fig. 2.10). The remaining tracks lasted

Fig. 2.9 Map of regional array of underwater listening stations with a list of sharks tagged with ultrasonic tags at different sites. *Green lines* show reported movements between sites; *yellow lines* show suspected movements, as yet unconfirmed by data (from Hearn et al. 2010b)

from 16 to 127 days and all showed a high degree of residency within the reserve and close to Darwin and Wolf Islands (Fig. 2.12).

Although five Galapagos sharks were fitted with satellite tags, tracks were only obtained from three individuals, and one of these was for a single day (Shillinger et al. unpublished data). Little can be inferred from the remaining tracks; other than that, the movements were limited over 60- and 90-day periods, respectively (Fig. 2.13), and that in all cases, there were few detections, suggesting that Galapagos sharks may not spend as much time swimming at the surface as hammerhead and silky sharks.

Six adult (2–2.2 m total length) blacktip sharks (*C. limbatus*) were tagged in July 2006; and tracks were obtained from five of these (Fig. 2.14). Three of the sharks were also fitted internally with ultrasonic tags. Two satellite tracks showed sharks moving south into the central archipelago, while the remaining sharks stayed around Darwin (Shillinger et al. unpublished data). However, one of the sharks, which moved to the central archipelago, was detected at Gordon Rocks several months later and then at Leon Dormido (San Cristobal Island) over a year later. This shark has continued to be detected at receivers throughout the archipelago for almost 6 years (Fig. 2.15), ranging widely from Darwin in the far north to San Cristobal in the far south of the marine reserve.

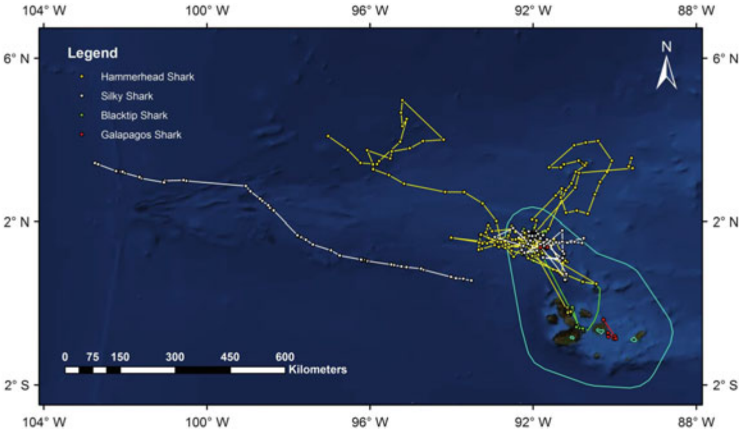

Fig. 2.10 Satellite tracks of sharks tagged at Darwin/Wolf islands 2006–2012. The Galapagos Marine Reserve boundary is highlighted in *blue*. (Source: Shillinger et al. unpublished data; Hearn et al. unpublished data; Ketchum et al. 2011c)

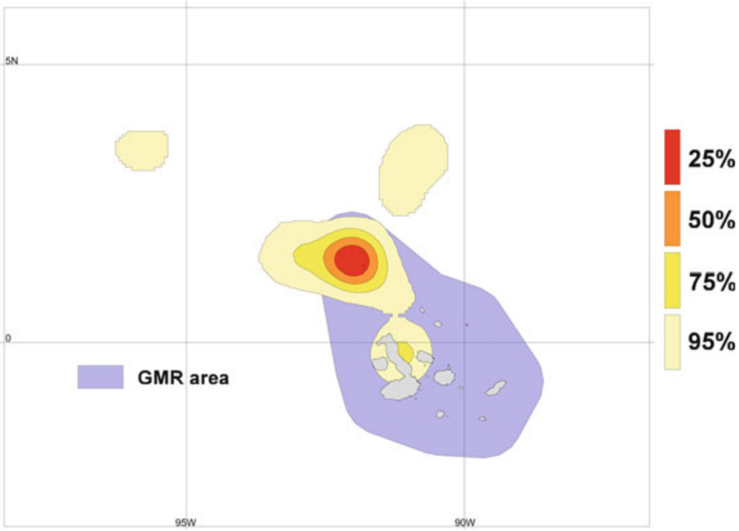

Fig. 2.11 Kernel home ranges (25, 50, 75, and 95 % UD) of the large-scale movements of hammerheads in the Galapagos Marine Reserve. Kernels of all positions from satellite tracking for all individuals ($N = 7$). Source: Ketchum et al. (2011c)

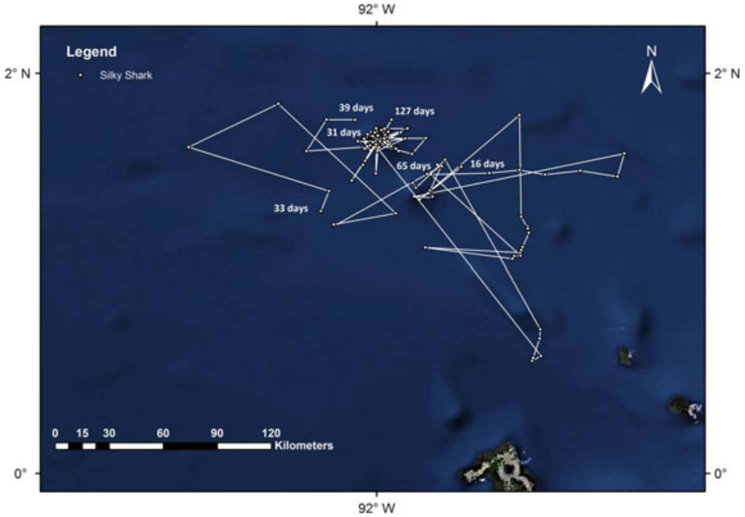

Fig. 2.12 Satellite tracks of silky sharks ($N = 6$) tagged at Darwin and Wolf Islands, which remained in the vicinity of the two islands. The long-distance track from a seventh shark is shown on a previous figure. (Source: Hearn et al. unpublished data)

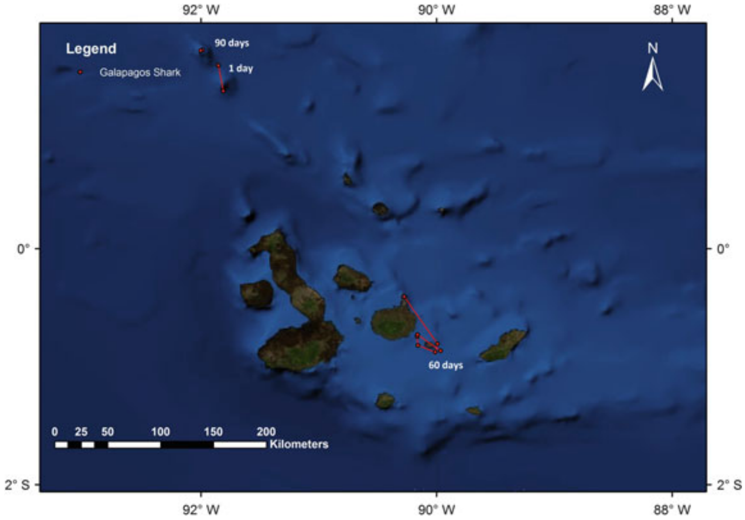

Fig. 2.13 Satellite tracks of Galapagos sharks ($N = 3$) tagged in the Galapagos Marine Reserve. (Source: Shillinger et al. unpublished data)

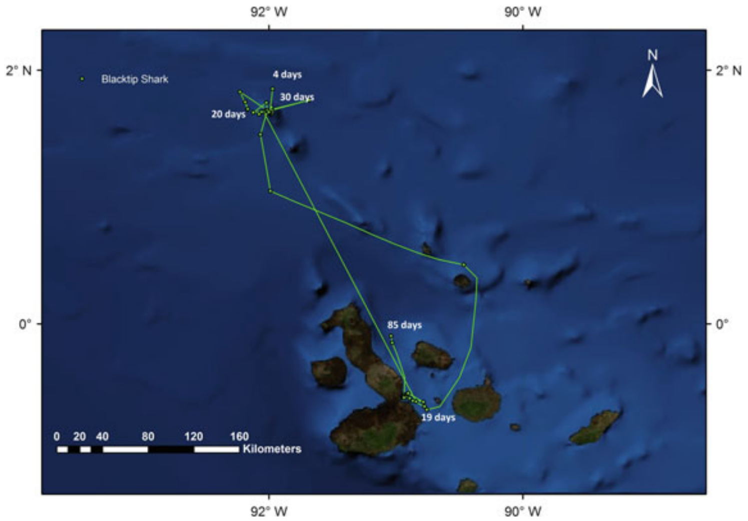

Fig. 2.14 Satellite tracks of blacktip sharks tagged in the Galapagos Marine Reserve. (Source: Shillinger et al. unpublished data)

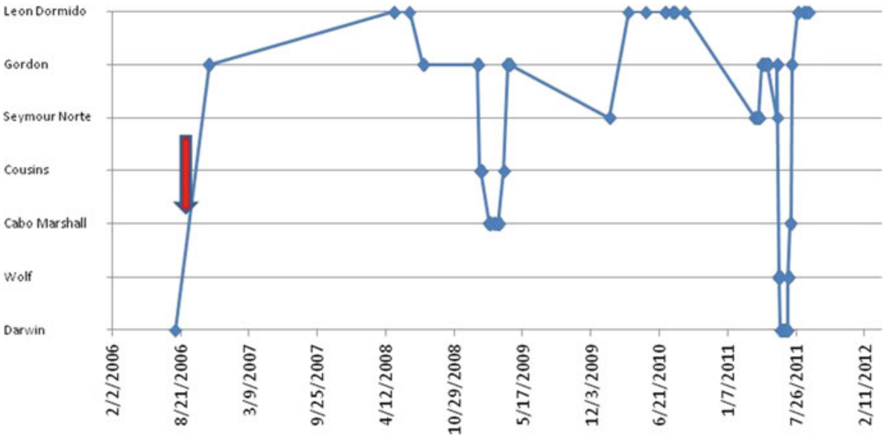

Fig. 2.15 Ultrasonic detections of a double-tagged blacktip shark on underwater receivers array from 2006 to 2012. *Red arrow* indicates when the satellite tag stopped transmitting (after 19 days, at eastern Isabela—see Fig. 2.14) (Source: CDF-PNG-UCD Database, unpublished)

Whale Sharks and Giant Mantas: Visiting Migrants

The whale shark *Rhincodon typus* and the giant manta ray *Manta birostris* (Fig. 2.16) are two of the world's largest elasmobranchs. Both are known to migrate through the Galapagos Marine Reserve, although their level of residency in the reserve is uncertain.

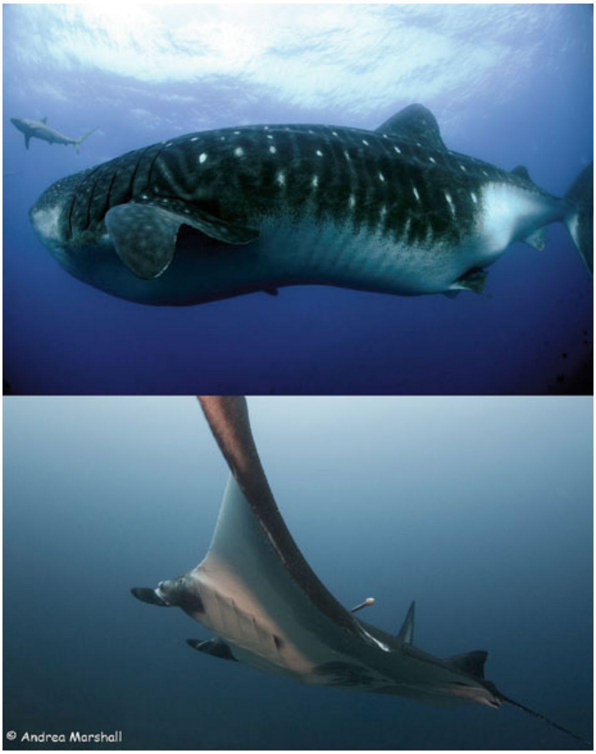

Fig. 2.16 (*Above*) Female whale shark *Rhincodon typus* at Darwin Arch, Galapagos, 2011. Note the distended abdomen, suggesting pregnancy. Source: Jonathan Green. (*Below*) Manta ray *Manta birostris* with satellite tag from coastal Ecuador. Source: Andrea Marshall

The whale shark is the world's largest fish, reaching up to 20 m in length (Chen et al. 1997). The giant manta ray was only recently differentiated from its smaller relative, the reef manta ray (*Manta alfredi*) in 2009, when the genus Manta was split into two visually distinct species (Marshall et al. 2009). It is the largest extant species of ray in the oceans. The giant manta attains maximum disc widths of up to 8 m. Both species are circumglobal and often aggregate in areas of high productivity on predictable, seasonal bases (Kashiwagi et al. 2011; De la Parra-Venegas et al. 2011). Giant manta rays, like whale sharks, are known to "chase" ephemeral bursts of productivity and sometimes appear simultaneously, on mass, in groups of several hundred individuals. On these occasions, they are often exploiting a food resource like a coral- or fish-spawning event. Manta rays may also use these mass-gathering opportunities for other social behaviors like breeding, whereas almost nothing is known about the breeding dynamics of whale sharks.

Both species are predominantly filter feeders specializing in the capture of zooplankton. Highly adapted to their pelagic environment, they forage in surface waters and also at depth. Unlike whale sharks, manta rays seem to spend most of their time in nearshore areas moving only offshore to forage or as they migrate to other areas.

Manta species have very conservative life history traits and are known to be one of the least fecund species of elasmobranchs. With small litter sizes, variable reproductive periodicity in the wild (every 2–3 years on average), and presumed high mortality in early life, manta rays are believed to be high-risk species, sensitive to anthropogenic threats (Marshall and Bennett 2010). Little information exists on the reproductive ecology of the giant manta ray, but current research in Ecuador has identified breeding sites along the mainland and in the islands of the Galapagos. Some of the first pregnant females ever seen in the wild have been sighted in the productive coastal waters off Isla de la Plata in the Machalilla National Park, while others have been reported in the GMR. To date, no one has yet witnessed a birth in the wild, and it remains unclear where these large rays give birth or even where their young spend their first few years of life.

Whale sharks are aplacental viviparous with eggs hatching within the female's uteri and the female giving birth to live young. A 9-m female was caught in Taiwan with 300 young (Joung et al. 1996) suggesting that the whale shark is the most prolific of elasmobranches. Sparse information exists on reproductive and pupping grounds, in addition to our lack of information on migratory routes and home-range sizes.

Currently, Ecuador boasts the largest identified population of giant manta rays in the world. One of the most important aggregation areas for the species occurs along the mainland, in the waters of the Machalilla National Park. Other important aggregation areas occur within the main island group of the Galapagos National Park, where scuba divers can occasionally see them. Manta rays sighted within the GMR are often encountered within the main islands of Isabela, Floreana, Pinzon, Santa Cruz, and Santiago, with some of the biggest aggregations found in areas such as Cabo Marshall, Cuatro Hermanos, and Roca Sin Nombre.

In contrast, whale sharks have become a predictable dive tourist attraction a certain times of year at one location in particular—the Arch at Darwin Island. From observations made by a small number of long-term dive guides at the Galapagos, it became apparent that the frequency of whale shark sightings increased with the onset of the cool "garua" season and the increase in strength of both the Cromwell and Humboldt currents, usually in the month of June. Their disappearance also coincided with the weakening of these currents around December, although occasional sightings occur throughout the archipelago in all months of the year (Jonathan Green, personal communication). Perhaps one of the most significant and surprising pieces of data to emerge was the unusually high percentage of adult female sharks that form the main body of the observed population at Darwin Island. Additionally, most of the females display distended abdomens, suggesting advanced-stage pregnancy (Fig. 2.16).

As a result of two consecutive seasons of fieldwork carried out during different periods of the year, only one male was sighted by the research team (and tagged) in comparison with over 60 females (39 tagged). Males are reported occasionally by dive guides, but such sightings are rare. Even rarer was a female albino whale shark

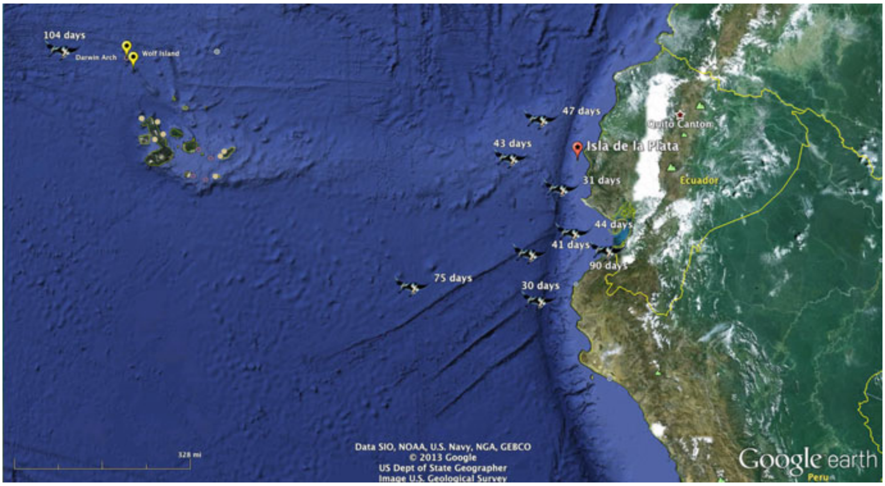

Fig. 2.17 Pop-up locations of giant manta rays tagged at Isla de la Plata in 2010 and 2011. Note that one tag was released west of Darwin Island, 104 days after attachment (Source: Andrea Marshall, unpublished data)

photographed and filmed in 2008 (Antonio Moreano, M/V Deep Blue, cited in the Daily Mail Online, UK, August 28, 2008).

In response to the paucity of information on the habits of these species in Ecuadorian waters, tagging programs were begun at known aggregation sites, of whale sharks at Darwin (Galapagos) and of giant mantas at Machalilla National Park (mainland Ecuador).

A total of 9 pop-up archival (PAT) tags were deployed on giant mantas between 2010 and 2012. The tags were programmed to stay on individuals for periods of time between 30 and 104 days. After spending limited time in the deployment area, the tagged rays radiated out from Isla de la Plata in several different directions, with some individuals making migrations of up to 1,500 km (straight-line distance) from the aggregation site where they were originally tagged (Fig. 2.17) (Marshall et al. unpublished data). Most commonly individuals moved south into Peru, resulting in some of the first international tracks of this species. Unfortunately some of these tracks were cut short when the tagged rays were killed and the tags came ashore with fishermen in Peru. Other rays tagged during the 3-year study moved distinctly west from the mainland towards the Galapagos, even establishing connectivity between the mainland and these offshore islands for the first time. The single-tagged individual that traveled all the way from the mainland of Ecuador to the Galapagos Islands was ultimately tracked to an area of the ocean just northwest of Darwin Island.

Twenty-four satellite tags were placed on whale sharks in 2011 (Hearn et al. 2012). Despite a high level of immediate tag loss (potentially caused by associated species such as jacks or blacktip and silky sharks pulling the tags out or by failure of the tag tethers), certain patterns emerged regarding the residency at

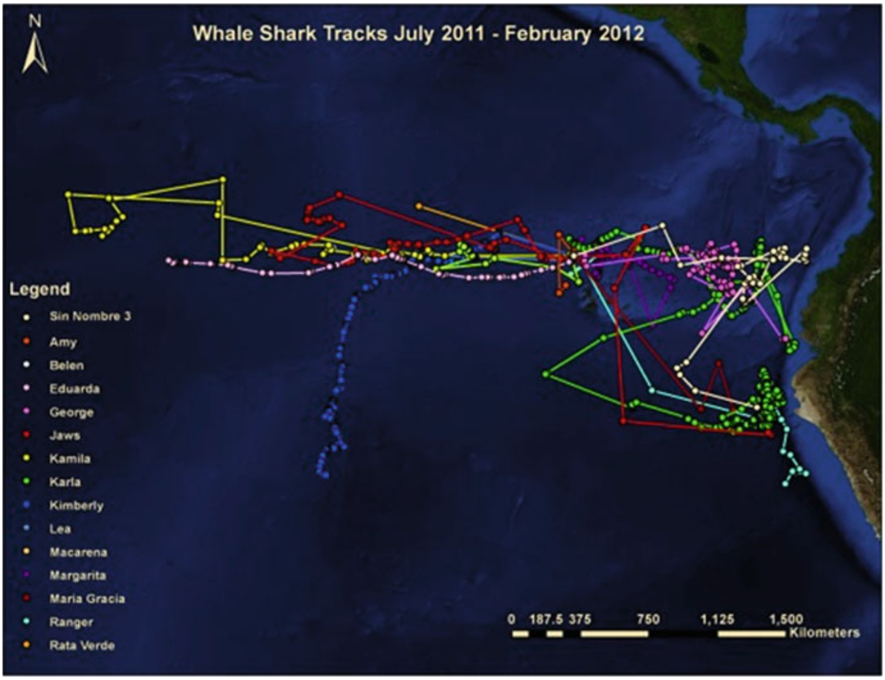

Fig. 2.18 Satellite tracks of whale sharks tagged at Darwin Island (Galapagos) in July–October 2011 (from Hearn et al. 2012)

Darwin and their final destinations (Fig. 2.18). None of the sharks tagged remained at Darwin for longer than a few days. Those sharks tagged early in the season made westerly movements of several hundred kilometers into the open ocean and then returned east late in the season, often passing close to Darwin again, and then heading towards the continental shelf. The sharks tagged later in the season moved to the continental shelf and then remained along the shelf break for extended periods (Fig. 2.18). The mean track time was 53 days, while the longest track was 177 days, which was the only male: "George" tag #108096. Whereas the females had traveled west, the male went to the east, remaining for almost 3 months midway between the Galapagos archipelago and the mainland of Ecuador.

In other words, rather than the previously held belief that a small number of whale sharks were present at Darwin for a period of several months, the reality appears to be that a steady trickle of large, apparently pregnant female whale sharks pass through Darwin for a period of a few days between June and November, continue to move out west into the open ocean, and then return later in the year through Galapagos to the continental shelf of northern Peru—a similar area to where many of the tagged manta rays are headed. The reasons for this migration over several thousand kilometers are not known—yet the predominance of large, apparently pregnant females has led to speculation about pupping grounds. However, neonate whale sharks have not been reported from Galapagos and, with a handful of loosely distribute exceptions, are notoriously absent from studies all over the world (Sequeira et al. 2013). It may be that Darwin acts more of a waypoint than a destination en route to unknown offshore pupping areas.

Human Interactions

Fishing

In three independent studies aimed at evaluating the potential for small-scale longlining to be permitted in the GMR, sharks, mantas, and rays were all shown to be highly susceptible to this mode of fishing (Murillo et al. 2004). Surface longlines from 3 to 19 km in length and with 80–350 hooks were deployed at depths varying between 8 and 30 m, around the southern and western part of the reserve, and left to soak overnight. In 1997, in an experimental fishing trip around Isabela, Fernandina, and Santa Cruz, sharks made up over 53.2 % of the catch. In 2001, the Ecuadorian Navy carried out an experimental fishery with a surface longline and reported that sharks made up 58 % of the catch—these were mostly blue sharks and Galapagos sharks. Mantas made up 1.3 % of the catch.

In 2003, a large-scale surface longline experimental fishery was carried out jointly by the Galapagos National Park Service, Charles Darwin Foundation, and a local fishing sector (Chasiluisa et al. 2003; Murillo et al. 2004). In order to avoid catching coastal sharks, lines were set at least 5 Nm from two polygons making up the central Archipelago and Pinta, Marchena, and Genovesa and 10 Nm from a third polygon made up of Darwin and Wolf.

Sharks made up 77 % of the catch (138 of 178 individuals) in one trip in March (one mobula ray was also caught), whereas sharks made up 27.6 % of the total catch over seven trips from October to December (mantas made up 2.5 %, rays made up 2.1 %). The most common shark in open waters was the blue shark, which at times made up more than 50 % of the shark catch. In comparison, only a handful of thresher sharks were caught (*Alopias superciliosus* and *A. pelagicus*). Galapagos, silky, blacktip, and mako sharks were also caught, along with scalloped and smooth hammerheads (the latter are rarely seen by divers). Thirty-three mantas and mobulas were caught over the seven trips (of which one died), along with 26 rays, including a specimen of *Rhinoptera steindachneri* and six *Dasyatis* sp.

Blue sharks were caught throughout the reserve; hammerheads were more predominant to the north and west of Isabela, while silky sharks were caught to the south (Fig. 2.19). Mantas were found particularly to the north of Isabela in December.

Mortality on longlines was almost three times higher for hammerhead species (32 %) than for silky and Galapagos sharks (11 %). Oceanic sharks were less vulnerable to mortality while hooked (e.g., blue sharks, 8 %), yet no post-release mortality estimations were made.

Given the paucity of the data, the experimental design, and the lack of catchability coefficients, it is hard to reach any conclusions about the relative

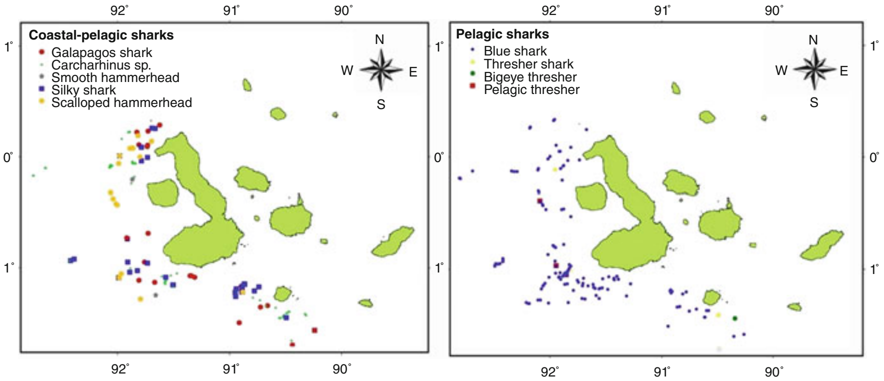

Fig. 2.19 Location of sharks caught during experimental longline fishery (from Murillo et al. 2004). Note that fishing activity was restricted to at least 10 Nm from shore

abundance and distribution of the sharks caught in this study, other than simple presence. The Murillo et al. (2004) study did not provide photographic evidence for each species caught, and therefore only the broadest of interpretations is possible.

Bycatch may also be an issue in nursery grounds. Llerena (2009) reported finding bodies of neonates blacktip sharks during surveys—probably bycatch from the gillnet fishery for mullets.

Illegal Fishing

Shark finning has occurred around the Galapagos since as early as the 1950s (INP 1964) and continues to occur illegally in the waters of the GMR, both by local fishers and by mainland Ecuador and foreign (particularly Costa Rican) industrial vessels (Reyes and Murillo 2007). Over 22,000 shark fins and 680 shark carcasses were seized between 1998 and 2006, from vessels, on the islands and at airports leaving Galapagos or arriving at mainland Ecuador (Reyes and Murillo 2007).

Jacquet et al. (2008) estimated that since 1998, almost 50 % of Ecuador’s shark fin exports could not be accounted for and, based on anecdotal evidence from WildAid (2001), suggested that much of this could have originated from Galapagos. In any case, it is difficult to estimate the real extent of this activity in Galapagos, although shark fin seizures by the Galapagos National Park Service and Ecuadorian Navy continue (DPNG 2013).

Dive Tourism

In recent years, shark dive tourism has, in many places, become an economic and ecologically sustainable alternative to fishing (Rowat and Engelhardt 2007; Vianna et al. 2011; Clua et al. 2011). In Galapagos, the dive tourism industry began in the

1980s by advertising the incredible abundance of sharks and other marine megafauna. Since then, this activity has grown steadily, and the GMR is regularly listed as one of the best dive spots in the world. Scalloped hammerhead, Galapagos, whitetips, whale sharks, mantas, and mobulas are among the most commonly advertised marine species by tour operators.

Worldwide, dive guides and citizen science can be important sources of information for elasmobranch research, playing a key role in establishing relative abundance baselines and population trends in the face of scarce empirical research and fishery landings statistics (Barker and Williamson 2010; Whitehead 2001; Dudgeon et al. 2008; Holmberg et al. 2009). In Galapagos, local dive guides have reported considerable declines in shark numbers over the last decade, attributable to illegal industrial fishing and finning by local fishers (Hearn et al. 2008). Nevertheless, over the past five years, there are increasing reports of blacktip sharks (*C. limbatus*) and tiger sharks (*G. cuvier*) presence among dive sites in the south-central and far north regions. This may be a sign of recovery of those populations—supported by a recent theoretical study on trophic modeling (Wolff et al. 2012a, b). Yet the reality of trends in shark populations is clouded by the lack of a clear long-term monitoring plan.

Dive tourism is also a reliable source of revenue for local economies, and research on the economic dynamics of this activity can be a crucial step towards gaining legitimacy for the protection of these species. One study assessed the daily dive tour operation in Santa Cruz Island and estimated that 92 % of scuba divers traveling under this modality do so with the main expectation of observing sharks close-up in their natural environment (Peñaherrera et al. 2013). Their visit was estimated to generate a total gross income for the dive companies of more than 1.9 million US dollars per year, which pales in comparison with the many millions generated by the live-aboard dive vessels, which rely almost entirely on the marine megafauna at Darwin and Wolf Islands. Attitudes of tourists (both diver and non-diver) are currently the focus of several studies which aim to determine the economic contribution of sharks and rays to the local Galapagos economy (C. Peñaherrera, University of Tasmania, personal communication) and to evaluate comparative regional conservation policies for threatened charismatic species (S. Cardenas, University of California, Davis; personal communication).

Shark Attacks

There have been 17 shark attacks (all nonfatal) recorded in Galapagos waters between 1989 and 2011. Of these, 13 were verified in clinical records and/or through direct sources. The other five attacks could not be verified, but there are sufficient data to support their inclusion in the registry compiled by the Charles Darwin Foundation (Acuña-Marrero and Peñaherrera-Palma 2011).

The increased number of shark attacks in this last decade matches the growing number of visitors. Most attack events recorded in Galapagos (80 %) occurred when the victim was at the surface, which coincides with global statistics that show 82 %

of victims were at the surface (60 % surfing and 22 % swimming) (ISAF 2013). Although all attacks recorded were considered "unprovoked," in at least seven cases, the victim's behavior and/or a set of circumstances that surrounded the events played an important role in the attack, as victims were alone, or bathed in the evening or night, or there was organic waste in the water before and/or at the time of the event.

The majority of cases in Galapagos were "hit and run" attacks, which typically occur with swimmers and surfers in the surf zone and where the shark does not return after a single bite or hit. This type of attack is related with a case of mistaken identity by the shark, which confuses the victim with one of its usual prey, such as sea turtles or sea lions (Klimley 1974). There is only one recorded case of "sneak" attack in Galapagos which can be related with directed feeding behavior, where a surfer was attacked persistently by a shark in a low visibility zone and late in the afternoon, in 2009 at Isabela Island.

In most cases, it was not possible to identify the shark species involved in the attack, due to lack of reliable witness or photograph/video records of the event. The bull shark *Carcharhinus leucas* is often blamed for these attacks, yet it is unlikely that this species is even present in Galapagos (Acuña-Marrero and Peñaherrera-Palma 2011).

Potential Impact of the Marine Reserve

Unsustainable extractive activities are placing many shark populations across the globe at risk (Baum and Myers 2004; Myers and Ottensmeyer 2005), which in turn poses a bigger threat to the health and functioning of marine ecosystems, as the delicate balance in complex marine food webs is upset (Stevens et al. 2000; Myers et al. 2007). Marine protected areas (MPAs) are becoming important tools for limiting the removal of important species and buffering against the resultant ecosystem restructuring that can follow their removal (Agardy 1994; Friedlander and DeMartini 2002; Halpern 2003).

The Galapagos Marine Reserve (GMR) is the largest reserve in the Eastern Tropical Pacific (ETP). This creates an opportunity to examine the utility of MPAs for rebuilding shark populations and the system's resilience in the face of severe environmental change such as El Niño events—which strongly hit Galapagos in 1982/1983 and 1997/1998.

Using the Ecopath with Ecosim modeling approach, Wolff et al. (2012a) constructed a trophic flow model of the GMR pelagic ecosystem for the period of the late 1990s when the industrial fishery was still in place. They used this reference model for simulations of a 50 % reduction in primary productivity during a 10-month El Niño period (occurred in 1998) and of the impact of the fishing ban with the reserve creation. Simulations with Ecosim showed that El Niño suppressed the positive fishery ban effect for about 3 years, showing its bottom-up forcing to be stronger than the top-down forcing by the fishery. After that, simulations on the fishery ban and considering resource-specific resident times in the GMR revealed

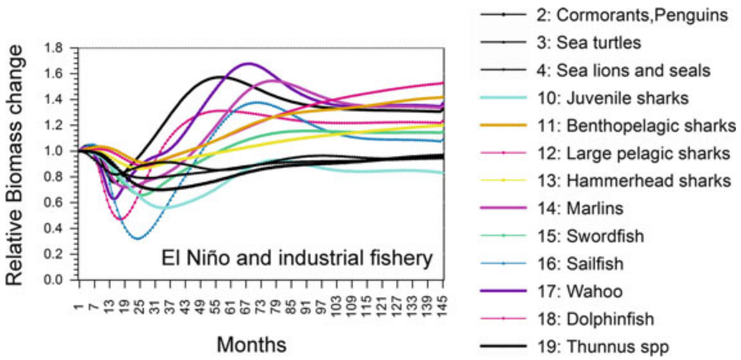

Fig. 2.20 Simulation of the GMR pelagic ecosystem response to the 1998 "El Niño" event and the industrial fishery ban after the creation of the GMR in 1998. From Wolff et al. 2012a

theoretical population increases of the following groups: benthopelagic sharks (37 %), large pelagic sharks (24 %), wahoo (13 %), tuna (13 %), hammerheads (15 %), marlins (6 %), and swordfish (2 %) (Fig. 2.20). Population increase for the above groups was still substantial even if their residence times in the GMR were assumed to be as low as 10 % of adult lifetime.

Published and unpublished monitoring data for marine mammals, birds and sea turtles confirm their population reductions simulated this model. Other trophic models focused on benthic reef systems of Galapagos reported shark-dominated trophic webs and also increased abundances of sharks when closing those systems to fisheries (Okey et al. 2004; Ruiz and Wolff 2011) and after the El Niño 1997/1998 event (Wolff et al. 2012b), suggesting a key role of sharks in the Galapagos marine ecosystems. More importantly, results by Wolff et al. (2012a) suggest that the GMR has, despite a 2–3-year system disruption caused by the El Niño 1997/1998, undergone a substantial recovery process of large pelagic fish and sharks since the industrial fishery was banned 12 years ago.

However, we do not presently have sufficient technical information to demonstrate the success of the GMR in protecting sharks, as distinct from other components of marine ecosystems. There are observational reports that blacktip and tiger sharks are becoming more frequent in the main dive sites during the last 5 years (Jonathan Green, personal communication), which would support these findings. Nevertheless, naturalist and dive guides working in Galapagos still have reported fewer sharks sighted over the last 20 years (Hearn et al. 2008). Consequently, a great uncertainty on the current state of shark populations and the impact of the GMR still exist. This theme is currently being explored as part of a PhD research thesis (C. Peñaherrera, University of Tasmania, personal communication)

A Growing Focus for Research

When the Charles Darwin Foundation and Galapagos National Park Service published their Baseline Biodiversity of the Galapagos Marine Reserve (Danulat and Edgar 2002), little was known about sharks and rays in Galapagos, other than a species list and a notion of the distribution and relative abundance of some of the more common reef-associated species, based on the CDF subtidal ecological monitoring program, on informal scuba dive records, and on seizures of illegal shark catches (Zarate 2002).

Since then, and coinciding with the development of the Eastern Tropical Pacific Seascape (Shillinger 2005) and the National Plan of Action for Sharks, there has been a consistent drive by local and international researchers in partnership, to better understand the role of the Galapagos Marine Reserve in protecting these species within a regional context and to understand their roles within the Galapagos marine ecosystem. Current and future efforts must continue to build on the developments of the past decade.

Underwater visual surveys directed at sharks and rays are currently being carried out by researchers, but the data is limited spatially and temporally. There is a clear need to engage local dive operators and tourists to expand this work via a citizen science model and to establish a baseline of distribution and abundance of the main elasmobranch species throughout the Marine Reserve. Long-term monitoring at key sites can then be established to track changes over time, and various sources of past data, such as old dive logs, photos, and underwater footage, can be explored to attempt to reconstruct past distribution and abundance.

The spatial dynamics of hammerhead and Galapagos sharks are now better understood—and the importance of remote islands and offshore islets to their ecology. Yet with tagging studies, sample size always becomes an issue, and efforts to understand and map potential long-distance migratory routes for these and other species (including whale sharks and giant manta rays) must continue. Other key habitats, such as juvenile rearing grounds, must be identified and mapped.

Genetic studies have shown that scalloped hammerheads form at least three distinct populations in the Eastern Pacific (Nance et al. 2011), yet this analysis was based entirely on samples taken from mainland sites. Further work must incorporate samples from the Galapagos and other island sites (such as Cocos and Malpelo). A similar regional approach should also be taken to integrate movement studies and fishery bycatch data, so that more formal stock assessments of the most vulnerable species can be carried out.

Our growing knowledge of the ecology of elasmobranchs in Galapagos provides a valuable tool for the management of the reserve. Modeling studies suggest that hammerheads can be used as umbrella species to represent the entire communities (Ketchum et al. 2011c). The GMR is managed as a multiuse reserve based on zonation (Heylings et al. 2002). A coastal zonation scheme was agreed upon and implemented in 2002, yet a key component of the scheme—the legal width of the coastal zone—was never decided. Based on the daytime schooling behavior of

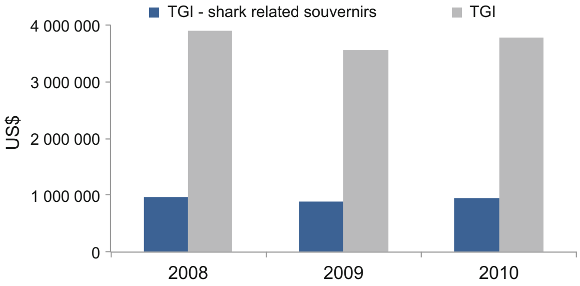

Fig. 2.21 Estimated total gross income (TGI) in Santa Cruz Island from small souvenir stores from shark-related merchandise (*blue bars*) and overall (*gray bars*). Source: Peñaherrera et al. (2013)

hammerheads around Wolf Island (Fig. 2.8), a width of approximately half a nautical mile would ensure that the school was protected from offshore fishing activities, and this would encompass the entire shallow reef community. Similarly, ongoing satellite tagging studies aim to inform decision makers and stakeholders on an open-water zonation scheme, which is part of the GMR Management Plan (Registro Oficial no. 173, April 20, 1999).

It is likely that the threats to sharks and rays in the Galapagos Marine Reserve will continue in the foreseeable future. While there is a market for shark fins, the risk of local illegal target fisheries for sharks remains. The local fishing sector continues to lobby for permission to use longlines. Industrial fishing vessels continue to cross the reserve boundaries, and while the use of satellite and radio monitoring systems may help, a range of enforcement issues must still be addressed (WildAid 2010).

Yet overall, there has been a change in paradigm in Galapagos, which is reflected around the world—sharks are now iconic species. Based on tourist expenditure values published by Epler (2007) and Ordóñez (2007), Peñaherrera et al. (2013) estimated that shark-related souvenir purchase may reach 25 % (US$940,000 average) of the total gross income generated by the small souvenir shops located at Santa Cruz Island in the 2008–2010 period (Fig. 2.21).

At present, Ecuador is leading the way in Latin America with its implementation of a National Plan of Action for Sharks (Zarate and Hearn 2008) and calls for greater protection for sharks and rays. It is playing a key role in the coordination of regional management for sharks, hosting the first and third regional workshops for shark conservation. Galapagos National Park technical staff recently participated at the CITES meeting where giant mantas and hammerhead sharks were placed on Appendix II. Ultimately, as is the case with transboundary migratory species, the status of sharks and rays in the Galapagos Marine Reserve will depend on the actions of Ecuador and its neighboring states.

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Chapter 3
The Galapagos Sea Lion: Adaptation to Spatial and Temporal Diversity of Marine Resources Within the Archipelago

Fritz Trillmich, Jana W.E. Jeglinski, Kristine Meise, and Paolo Piedrahita

Abstract Galapagos sea lions are the smallest sea lion species worldwide. The population consists of about 20,000 individuals, is endemic to the Galapagos Islands and has been separated for about 2.5 million years from the California sea lion. The equatorial environment differs from that of other pinnipeds by terrestrial heat and reduced marine productivity. Growth and development is strongly influenced by marine variability, particularly El Niño events, which also decrease juvenile and adult survival. Large males establish aquatic territories, but smaller non-territorial males also achieve reproductive success. Time at the colony proves the best predictor of reproductive success, which reflects the long drawn-out reproductive season often lasting 6 months. Females mature relatively late at about 5 years and reproduce often only every other year. Juveniles need exceptionally long to become nutritionally independent. The long period of lactation (2–5 years) often leads to competition between offspring born in different years. Adult females dive to great depths (max. 580 m) and mostly forage on shelf areas as well as along the shelf edge. Juveniles need many years to reach adult diving abilities. Increased human-sea lion contact in fast growing settlements and through boat traffic and fishery poses new and potentially highly dangerous threats to the population.

Introduction

Galapagos sea lions (*Zalophus wollebaeki*) are a particularly interesting pinniped species since they occur right on the equator, exposed to thermoregulatory problems ashore and lower marine productivity than more temperate or subpolar species. Nevertheless, their marine environment can be characterized as a local

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productivity hotspot in the equatorial Pacific. As described in more detail in Chaps. 1 and 2, the cold waters of the Humboldt Current and strong local upwelling of eastward flowing undercurrents around the western coast of the islands of Fernandina and Isabela generate the local productivity of the archipelago. Thus, sea surface temperature (SST) becomes an indicator of productivity as it reflects the intensity of influx of cold, productive waters.

The species has settled in the islands a long time ago. Genetic analyses suggest a separation from the populations of the California sea lion (*Zalophus californianus*) for 2.5 ± 0.5 million years. It is now considered a separate species, endemic to the Galapagos (Wolf et al. 2007a). Surprisingly, the sea lions living in the west of the archipelago (Fernandina and western Isabela) proved to be genetically and morphologically slightly but significantly differentiated from the population living in the centre and northeastern parts (Wolf et al. 2008).

The species breeds on all major islands, with highest density in the southern and central parts of the archipelago. Local densities are always low in comparison to California sea lions. Estimates of sea lion abundance vary considerably: An early census in 1978 resulted in a total count of about 8,000 sea lions representing an estimated 30,000–40,000 animals in total (Trillmich 1979; Trillmich, unpubl. data). Alava and Salazar (2006) estimated 18,000 animals, based on a census in 2001, a few years after the major El Niño of 1997/1998. It is not entirely clear why these estimates differ so widely since the census in 2001 also yielded a total of 7,942 counted sea lions and correction factors used for the 1978 and 2001 censuses seem very similar (Alava and Salazar 2006). Trying to err on the safe side, Aurioles and Trillmich (2008) mentioned an estimate of about 20,000 animals for the whole archipelago, following the more recent estimate. However, the evidence on which these estimates are based is very weak given that, for example, the count of San Cristobal was 334 individuals in 1978 (Trillmich and Trillmich, unpubl. data), 917 in 2001 (Alava and Salazar 2006) and 1,496 in 2013 (Diego Paez, Bulletin Parque Nacional Galapagos, 11 Jan 2013). These discrepancies more likely reflect variance in numbers of animals ashore during a given census due to tidal state, time of day and degree of coverage of a given area rather than realistic changes in local population size. Nevertheless, it is clear that during the strong El Niño events (like 1982/1983 and 1997/1998), when food availability for marine foragers is drastically reduced, numbers may substantially decline (perhaps by about a third). During these events pups of the year and adult territorial males were most affected (Trillmich and Limberger 1985; Trillmich and Dellinger 1991; Salazar and Bustamante 2003).

Perhaps in adaptation to or as a consequence of its relatively less productive marine environment, the species is the smallest of all sea lions with females weighing about 60 kg (max. 95 kg) at a length of 156 cm (max. 176 cm). Male weights are less well documented as we never caught any of the largest males (the largest caught was 158 kg, the longest had a standard length of 205 cm). Fully grown males when fattened up for the breeding season may weigh between 150 and 200 kg at a length between 170 and 210 cm.

Sexual size dimorphism is already evident at birth when males weigh about 6.7 kg and females 5.8 kg (Kraus et al. 2013). Mass at birth and initial growth rate during the first 60 days of life decline with increasing SST, and pup mortality increases indicating the close connection between marine conditions and early development (Kraus et al. 2013; Mueller et al. 2011). Birth mass and initial growth rate predict mass at 1 year of age. Thus a head start with a high birth mass benefits both early growth and survival to 1 year. Only about two thirds of all newborns survive to the age of 1 year and roughly 51 % to that of 2 years (Kraus et al. 2013). By 3 years of age, males weigh on average 40.5 kg and females 35.2 kg. However, as most juveniles are rarely seen at their natal colonies at this age, averages of the whole cohort are likely higher. Females begin to mature shortly thereafter. Males start becoming reproductively active at an age of 5. They continue to grow for a long period before reaching final size.

Development to Independence

The development to independent foraging starts late and is exceptionally slow compared to other pinniped species, likely a consequence of the slow growth and development of physiological diving abilities found in this species (Mueller et al. 2011; Trillmich et al. 2008). Juvenile Galapagos sea lions depend on average for the first 2 years of life on maternal input, while slowly shifting from complete reliance on maternal milk to independent foraging. Galapagos sea lion pups are terrestrial at birth and start swimming in shallow open water at around 2–3 months. Substantial diving activity starts at approximately 12 months of age, when juveniles dive on average to depths of 30 m and for 2.5 min (Jeglinski et al. 2012). Successful independent foraging supplementing continuing milk consumption seems to take place even later, on average at around 18 months. Diving performance increases with age and body mass, but 2-year-old juveniles still dive to only approximately 75 % of the average diving depths of adult females (Jeglinski et al. 2012).

Development to independence varies considerably. Annual variation in marine productivity seems to cause differences between cohorts. During mild El Niño conditions, when food availability decreases, the onset of independent foraging was shifted beyond the age of 18 months (Jeglinski et al. 2012). Further, onset of diving and independent foraging varies between colonies, possibly as a consequence of local differences in marine productivity (Jeglinski et al. 2012, 2013; Jeglinski 2013; Piedrahita and Trillmich, pers. obs.). Considerable variation exists between the developmental pace of individuals: Some juveniles were observed suckling from their mothers up to an age of 7 years (unpubl. data).

Mating System and Its Implications for Social Structure

The following descriptions of social structure and behaviour rest largely on our long-term study on the islet of Caamaño. Given the variance in habitats and marine conditions within the archipelago, whether this information is valid for the whole archipelago still needs to be determined.

Galapagos sea lions display the otariid polygynous mating system. Adult males try to monopolize access to females. Due to thermoregulatory constraints, males (as well as females) need direct access to water. Accordingly, the largest and most competitive males defend semiaquatic territories along beaches where females haul out to nurse the young (Trillmich and Trillmich 1984; Wolf et al. 2005). Females come into oestrus approximately 4 weeks after parturition (Heath 1989). The long reproductive season (September–January) and the predominance of aquatic mating make it impossible for males to monopolize access to receptive females. In contrast to other otariid species, they display and appear to depend on being chosen by a female, rather than copulating with each female that comes into oestrus on their territory. Accordingly, reproductive success of Galapagos sea lions within a given season is not highly skewed towards territorial males (Pörschmann et al. 2010). Indeed, non-territorial males sire more than 50 % of the annual number of pups where paternity could be assigned (Pörschmann et al. 2010).

The duration of attendance at the breeding colony best predicts male reproductive success (Pörschmann et al. 2010). Accordingly, large male body size might be selected for to allow extended fasting rather than to increase fighting abilities. The small colony sizes and low density within Galapagos sea lion colonies further suggest comparatively low pay-offs for territoriality. However, males establish territories in areas with highest female densities, thus increasing their chance to encounter receptive females. Further, returning to territories where they previously gained matings increases territorial males' lifetime reproductive success (Meise et al. 2013). For non-territorial males, the probability to encounter oestrus females and mate successfully correlates positively with the size of their home range within a given season and thus with their ability to sneak into foreign territories (Wolf et al. 2005; Meise et al. 2013).

Intrasexual competition among males leads to sexual segregation in the colonies, especially during the reproductive season. Females and their offspring gather along the water's edge where they aggregate in so-called communities. Communities, which exist independent of established territory boundaries, can be best explained by similar space use of group members (Wolf et al. 2007b). Females of the same community show a higher degree of relatedness than individuals from different communities (Wolf and Trillmich 2008) because of a high number of full or half siblings and mother-offspring pairs (even after weaning) within communities.

Males leave their natal areas after they are weaned and gather in inland habitats, which offer shade during the day (Wolf et al. 2005; Meise et al. 2013). Aggregations of close kin are therefore less likely among adult males. Still, the limited availability of shady spots for thermoregulation forces males to rest in close proximity of each other. Clear spatial preferences and high overlap of males' home ranges within the colony provide a chance for long-lasting social relationships among males (Meise et al. 2013).

Female Maturation and Reproduction: Maternal Care and Sibling Competition

Galapagos sea lions reproduce annually as do other otariids, but the breeding season is unusually long, extending over a period of more than 5 months. On Caamaño, it may start in early September, with a peak of birth in early November (Mueller et al. 2011). As the onset of the breeding season varies slightly among colonies on different islands, females in various reproductive stages can be found throughout the year (Villegas-Amtmann et al. 2009).

Adult females initiate their reproductive life at an age of 5–6 years. Despite the annual reproductive cycle, individual females reproduce every 2–3 years. This low reproductive rate, compared to other otariid species, links to the variable productivity of the environment: Increased SST during the first 3 months after mating decreases female pupping probability (Mueller 2011). Also, given the long dependency periods of juvenile Galapagos sea lions, an annual reproduction would necessitate the simultaneous support of an older offspring, a newborn pup and self-maintenance, high costs that females rarely seem able to pay (Trillmich and Wolf 2008; Mueller et al. 2011). Infrequently (around 20 %), Galapagos sea lion females give birth to a pup while still suckling a dependent older offspring (Trillmich and Wolf 2008). This situation leads to sibling competition upon the newborn pup's birth and results in the death of the newborn pup when the older offspring is still around for suckling. Rarely, adult females manage to successfully support both the older offspring and the newborn, leading to the formation of a so-called trio (Trillmich and Wolf 2008).

Non-nursing, pregnant females return ashore 1–2 days prior to parturition (Trillmich 1986). Immediately after birth, females behave highly aggressive and defend the area around the newborn, calling frequently to it. The female stays on land with the newborn pup during a 4–7 days perinatal period. This period helps to establish an exclusive, mutual bond between mother and offspring (Trillmich 1981). Galapagos sea lion females, as income breeders, then resume a foraging cycle strategy, during which they continuously cycle between foraging trips at sea that last between 5 h and 4 days, in general increasing with offspring age (Trillmich 1986; Villegas-Amtmann et al. 2008; Jeglinski et al. 2012) and suckling bouts on land. Galapagos sea lion females lactate year-round. If a dependent offspring dies, lactation will end, but otherwise females will be essentially nursing all their reproductive lives as long as the pup or juvenile offspring survives.

Use of the Marine Environment

Galapagos sea lions are nonmigratory. Rarely, vagrants are recorded from the Mexican, Colombian and mainland Ecuadorian coast (e.g. Ceballos et al. 2010; Denkinger, pers. comm.).

Information on spatial movements and diving behaviour is available for adult females with dependent offspring and juveniles up to 2 years. Despite their small body size, compared to other sea lion species, Galapagos sea lions are exceptionally deep divers: 12-month-old juveniles already dive to a maximum depth of 367 m, and the deepest dive recorded for an adult female was 584 m (Jeglinski et al. 2012, 2013). However, adult females regularly dive to depths between 92 and 178 m for 3.3–4.7 min (Villegas-Amtmann et al. 2008; Villegas-Amtmann and Costa 2010; Jeglinski et al. 2012). Sea lions mix benthic and pelagic diving and forage both at day and at night, but there is considerable variation in foraging patterns within the species. Juvenile sea lions dive predominantly at night and to shallow depths, a likely consequence of their small body size (Jeglinski et al. 2012, 2013). The diving behaviour of adult females, especially diving depth and duration and activity period, differs between individuals (Villegas-Amtmann et al. 2008; Villegas-Amtmann and Costa 2010). To date it is not clear if these behavioural patterns are consistent throughout life or change with age, reproductive status or ecological conditions.

Galapagos sea lions feed predominantly on small benthic and pelagic fish from approximately 12–33 different species and, in some colonies, on cephalopods; a few fish species from the families Engraulidae, Carangidae, Serranidae and Myctophidae dominate the diet (Dellinger and Trillmich 1999; Salazar and Bustamante 2003; Páez-Rosas and Aurioles-Gamboa 2010). There are distinct dietary differences between sea lions in the centre of the archipelago that feed on a large variety of different fish species and western sea lions that mainly feed on sardines (*Sardinops sagax*) (Dellinger and Trillmich 1999), suggesting ecological differences in line with the genetic differentiation found in the species (Wolf et al. 2008). In the western archipelago, Galapagos sea lions are sympatric to the Galapagos fur seal (*Arctocephalus galapagoensis*), but both species exploit very different foraging niches (Dellinger and Trillmich 1999; Jeglinski et al. 2013; Páez-Rosas and Aurioles-Gamboa 2010).

Sea lions forage on the shelf platform of the archipelago and, in the western archipelago, along its edge. Adult females with a dependent offspring travel maximum distances between 50 and 97 km away from their colony, while juveniles cover maximum distances of less than 15 km (Jeglinski et al. 2013; Villegas-Amtmann et al. 2008; Villegas-Amtmann and Costa 2010). These foraging sojourns are short in comparison to other sea lions. Both age groups haul out on numerous sites apart from their home colony, including other sea lion colonies (Jeglinski 2013; Villegas-Amtmann et al. 2008; Villegas-Amtmann and Costa 2010).

Threats to the Species

The life history and population dynamics of Galapagos sea lions are strongly influenced by pronounced climatic variability, and the species has developed adaptations, e.g. highly plastic maternal strategies, providing some resilience against the deleterious effect of environmental unpredictability. Still, an increase in the frequency of El Niño, as has been predicted by some as an effect of anthropogenically induced climate change (Trenberth and Hoar 1997; but see Cobb et al. 2013), could reduce the population below sustainable levels.

The Galapagos Islands have undergone drastic change in the last four decades. The previously uninhabited, remote archipelago is today well connected to the Ecuadorean mainland, permanently inhabited by about 30,000 persons, and receives 180,000 visiting tourists per year (Trillmich 1992; Grenier 2012). The drastic increase of human use of terrestrial and marine resources has the strong potential to influence the Galapagos sea lion population negatively. Possible effects include an increased frequency of disturbance at foraging, breeding and haul out sites, an increased potential for boat strikes, direct physical damage from fishing gear, negative interactions with fishermen and an increased possibility for severe damage to the marine ecosystem by ship accidents as clearly demonstrated by the Jessica oil spill in 2001 (Salazar 2003). Some of the largest sea lion colonies are close to or even within human settlements (Caamaño close to Puerto Ayora and Puerto Baquerizo Moreno on San Cristobal). In the latter colony, pups and juveniles had significantly higher levels of immune activity compared to animals from an uninhabited colony, possibly as a consequence of a higher presence of harmful pathogens or pollution from sewage and chemicals (Brock et al. 2013). Especially the direct contact between sea lions and domestic dogs, rats and cats on inhabited islands poses a direct threat to the population, opening a potential for infectious disease transmission, such as canine distemper virus (Alava and Salazar 2006; Aurioles-Gamboa and Trillmich 2008). Given the high connectivity between colonies in the central archipelago (Wolf et al. 2008; Villegas-Amtmann et al. 2008; Jeglinski 2013), diseases would likely spread from these hotspots throughout the range of the population with a high potential to endanger the whole population.

Likely, the synergy between the drastic consequences of climatic variation and recent, anthropogenically induced and increasingly influential effects poses the largest threat with the potential to critically endanger the small population of Galapagos sea lions.

Implications for Conservation and Management

The continuously increasing interface between humans and wildlife on the islands makes management steps to control and reduce the negative effects on the endangered Galapagos sea lion vital. A direct regulatory measure in the form of strict enforcement of regulations for the management of domestic dogs and dog vaccination programmes (Wolf et al. 2007b; Levy et al. 2008) could significantly diminish the potential for disease transmission. Further, management measures should aim to reduce direct anthropogenic impact (pollution, ship traffic, numbers of tourists visiting the islands) to minimize synergistic effects with the negative impact of inevitable climate change. Here, detailed information on spatial movements and distribution of Galapagos sea lion foraging areas (Villegas-Amtmann et al. 2011; Jeglinski 2013; Jeglinski et al. 2013) can be used as basis for refined zonation and regulation of traffic within the Galapagos Marine Reserve. Given the sparse data on population size and development and associated methodological uncertainties, the recent establishment of a population monitoring scheme by the Galapagos National Park is an excellent first step to provide a firm basis on which to base further management decisions.

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Chapter 4
Flexibility in the Foraging Strategies of the Galapagos Sea Lion Inferred from a Multiple Approach Analysis

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Abstract Studies concerning the foraging behavior of the endangered Galapagos sea lion (*Zalophus wollebaeki*) are essential to understand long-term conservation challenges and predict population fluctuations. This study provides a comparative analysis of variables related to the foraging habits and trophic niche flexibility of *Z. wollebaeki*. Complementary stable isotopes and remote sensors were used to measure space-time variables concerning *Z. wollebaeki* foraging habits among populations in the Galapagos Archipelago. In spatial terms, isotopic values ($n = 321$) showed differences regarding foraging grounds (δ^{13}C: $p = 0.015$). These results also show test subjects maintained equilibrium in the trophic level of their diet (δ^{15}N: $p = 0.152$). The results of this study confirm the evolutionary behavior of *Z. wollebaeki* has resulted in a high level of flexibility in foraging habits. This adaptability affords a higher advantage for survival in the Galapagos: a confined ecosystem with limited resources.

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Introduction

The Galapagos sea lion (*Zalophus wollebaeki*) breeds on almost all islands of the Galapagos Archipelago, with the highest density of individuals at the central and southern islands. Current population estimates are around 18,000 individuals (Alava and Salazar 2006) although an estimate of 20,000–50,000 individuals in 1963 suggests a dramatic decline in the population over the last 30 years. (Heath 2002), mainly a product of fluctuations in regional marine productivity and oceanographic disturbances such as El Niño Southern Oscillation (ENSO) (Trillmich and Ono 1991; Heath 2002). This situation has led the International Union for Conservation of Nature (IUCN) to classify these species as endangered (Aurioles-Gamboa and Trillmich 2008).

The oceanographic variability in the Archipelago causes changes in marine ecosystem dynamics that are reflected from the bottom to the top of the trophic web (Schaeffer et al. 2008; Páez-Rosas et al. 2012). These changes cause some species that are considered top predators to diversify their foraging strategies in response an unpredictable environment (Villegas-Amtmann et al. 2008; Baque-Menoscal et al. 2012).

The highly heterogeneous nature of marine predator foraging habits is caused by both extrinsic and intrinsic factors, including habitat type, seasonal changes, age, and sex (Riedman 1990). In general, pinnipeds feed on a wide variety of prey from different environments that fluctuate at different spatial and temporal scales. These changes are more evident in species in tropical zones where there is major productivity uncertainty, which, in turn, causes changes in the abundance of prey species (Gentry and Kooyman 1987).

The main prey species found in the diet of *Zalophus wollebaeki* from multiple colonies include epipelagic fish (Clupeidae and Engraulidae) of surface and coastal upwelling waters, mesopelagic fish (Myctophidae) found in deep waters of the open ocean, and demersal, benthopelagic, or pelagic fish (Serranidae and Scorpaenidae) found over muddy and sandy bottoms of the continental shelf or in shallow and deep waters between rocks (Chlorophtalmidae) (Salazar 2005; Páez-Rosas and Aurioles-Gamboa 2010).

Stable isotope analysis (δ^{13}C and δ^{15}N) is a useful tool to reconstruct the diet and movement patterns of top marine consumers such as the Galapagos sea lion (Aurioles et al. 2009; Páez-Rosas et al. 2012). This technique allows the researcher to infer the habitat of a consumer (δ^{13}C) (DeNiro and Epstein 1978) and the trophic level at which it is feeding (δ^{15}N) (DeNiro and Epstein 1981).

The δ^{13}C values in an aquatic organism vary based on the habitat of the organism's prey: coastal/ocean or pelagic/benthic (Hobson et al. 1996). Physicochemical and biological factors determine the differences in baseline δ^{13}C values among habitats, including the isotopic composition and concentration of dissolved CO_2 available to primary producers (Hobson et al. 1994; France 1995); the taxonomic composition and growth rate of phytoplankton (Fry and Wainright 1991; Pancost et al. 1997); and the influence of carbon derived from benthic macrophytes in coastal zones that are ^{13}C-enriched compared to phytoplankton in open-ocean pelagic environments (Goericke and Fry 1994, France 1995). On the basis of this stable isotope analysis application, lower values of $\delta^{13}C$ from predator and its prey are expected in offshore environments.

Generally, the $\delta^{15}N$ values allows inference about the trophic level and the trophic breadth of a species (Post 2002; Bearhop et al. 2004), as a result of the accumulation of ^{15}N in the consumer with respect to its prey (DeNiro and Epstein 1981), which is reflected in an isotopic enrichment of $\delta^{15}N$ between trophic levels, generally between 3 and 5 ‰ (Minagawa and Wada 1984). Enrichment between trophic levels also occurs for $\delta^{13}C$, but it is generally of lesser magnitude (0.5–1 ‰), although it can vary depending the taxon, tissue, and diet (Hobson et al. 1996).

Environmental variability, including oceanographic changes, causes changes in the isotope levels of $\delta^{13}C$ and $\delta^{15}N$ at the base of the trophic webs that are reflected in different predators, independent of trophic level (Aurioles-Gamboa et al. 2009). Low $\delta^{13}C$ values suggest a reduction in primary productivity (grams of C per unit of area, per unit of time) that can be related to two factors: (a) the positive linear relationship between $\delta^{13}C$ values and cellular growth of phytoplankton (Laws et al. 1995) and (b) the differences in productivity levels (involved in photosynthesis) in the marine environment that are produced from an increased rate of phytoplankton respiration, which increases the expulsion of CO_2 to the atmosphere that is enriched in ^{12}C (Bidigare et al. 1997).

In turn, low $\delta^{15}N$ values preceded by significantly higher values indicate changes in the diet of the species from prey in major trophic levels to those in minor trophic levels (DeNiro and Epstein 1981). This effect may be related to a decrease in the primary productivity of the environment, causing a cascading reduction in the general biomass resources and leading to changes in the importance of the main prey species of the predators in a major or minor way, depending on the region (Newsome et al. 2007).

The isotopic signature in metabolically inert tissues, such as fur, provides information about the food assimilated by the organism over a 2- to 3-month period (Darimont and Reimchen 2002). Fur from a still-suckling Galapagos sea lions reflects the diet of their mothers, with an isotopic fractionation in $\delta^{15}N$ between mother and pup of approximately 1.7 ‰ (Páez-Rosas 2011; Páez-Rosas et al. 2012). Since the formation of fur in the majority of otariids begins during the final month of gestation (Bauer et al. 1964), samples from pups less than 2 months old may provide isotope information about the mother's diet prior to the birth of the pup.

In this study, analysis of stable isotopes in the fur of Galapagos sea lion and satellite information of the net primary productivity of selected regions of the Galapagos Archipelago was used to determine, at the spatial level, the complex foraging behavior of this species.

Materials and Methods

The regional biogeography of the Archipelago proposed by Harris (1969) and Edgar et al. (2008) was used to divide the foraging regions used by *Z. wollebaeki*. Four breeding rookeries were selected from the following: Cabo Douglas

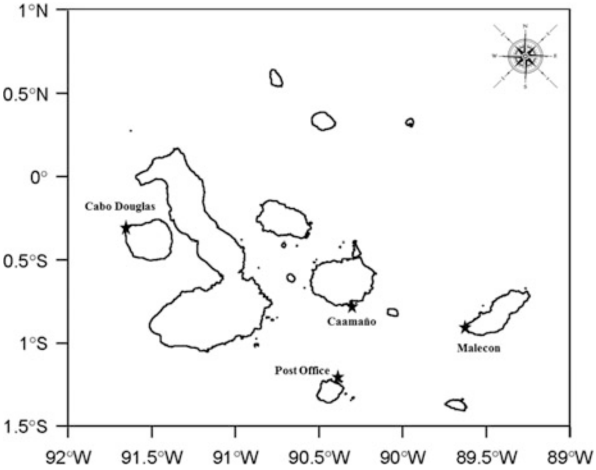

Fig. 4.1 Galapagos Archipelago. Collection sites for samples of Galapagos sea lion fur and scat in breeding rookeries from four regions: western, Cabo Douglas (0°18′12″S, 91°39′10″W), Fernandina Island; central, Caamaño (0°45′9″S, 90°16′1″W), Santa Cruz Island; southern, Post Office (01°13′37″S, 90°36′38″W), Floreana Island; and eastern, Malecón (0°54′8″S, 89°36′44″W), San Cristóbal Island

(0°18′12″S, 91°39′10″W), Caamaño (0°45′9″S, 90°16′1″W), Post Office (01°13′37″S, 90°36′38″W), and Malecón (0°54′8″S, 89°36′44″W) (Fig. 4.1).

Stable Isotope Analysis

In March 2003 a total of 55 fur samples were analyzed from pups of approximately 2 months of age in the four rookeries under study: Cabo Douglas ($n = 10$), Caamaño ($n = 10$), Post Office ($n = 10$), and Malecón ($n = 20$). The age of the pups was calculated based on the growth rate (108 g day^{-1}) reported for this species (Trillmich and Wolf 2008).

Each sample was rinsed with deionized water to remove any unwanted residuals. Subsequently, the samples were dried in an oven at 80 °C for 12 h, and the lipids were extracted using the microwave-assisted extraction (MAE) protocol (Microwave Oven Model 1,000 MARS 5 x CEM) with 25 ml of chloroform/methanol (1:1) solution (Bligh and Dyer 1959). This process was applied because the lipids are enriched in ^{12}C, which in large quantities could negatively skew the isotopic signal of ^{13}C (Tieszen et al. 1983). The sample was homogenized to a fine powder in an agate mortar; then, ~0.5 mg of sample was weighed and placed in tin capsules for δ^{15}N and δ^{13}C analysis.

The isotopic ratios were measured using a continuous flow mass spectrometer (20-20 PDZ Europa, Cheshire, UK) in the Stable Isotopes Laboratory at the University of California at Davis (Davis, USA). The results were expressed in parts per thousand (‰) using the following equation: $\delta^{13}\text{C}$ or $\delta^{15}\text{N} = 1{,}000\,[(R_{\text{sample}}/R_{\text{standard}}) - 1]$, where R_{sample} and R_{standard} are $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$ ratios of the sample and standard, respectively. The standards were PDB (Pee Dee Belemnite) for δ^{13}C and the atmospheric N_2 for δ^{15}N.

Significant differences in the $\delta^{15}N$ and $\delta^{13}C$ values between rookeries were evaluated using a nonparametric analysis of variance (Kruskal–Wallis test) along with the Fisher's LSD test for multiple comparisons. Significance was defined as $p < 0.05$ level. Statistica 8.0 software was used to perform the statistical analysis.

Remote Sensor Analysis

Net primary productivity (NPP) data (gC m^{-2} day^{-1}) were obtained from satellite images recorded in January 2003 at a spatial resolution of 4 × 4 km, provided by a sensor mounted to the SeaWiFS and Pathfinder Global satellite (net primary productivity of C). Information was collected 46 km around the rookeries (Villegas-Amtmann et al. 2008; Páez-Rosas 2011) and was related to the isotopic values determined in each study site.

Even though the samples collected for isotopic analysis were collected in March 2003, we used the NPP values recorded 2 months earlier for two reasons (1) the isotopic turnover rate in the fur is approximately 2 months before collection (Porras-Peters et al. 2008), and (2) there is a delay of approximately 1 month before the energy passes from the phytoplankton to the fish (main prey) (Mercuri 2007). This adjustment was made to diminish the variability when the NPP values are associated with the isotopic values present in the individual sea lions.

Our own functions created in the *R program* were used to process the data. These functions download the data sets into a universal format and plot them in each geographic location using a color scale that corresponds to the value category of each variable.

Results

The $\delta^{13}C$ and $\delta^{15}N$ values from the 50 pup fur samples were compared, and significant differences in the $\delta^{13}C$ values between the rookeries were found (Kruskal–Wallis: $H\,(3,4) = 10.3, p = 0.015$) (Table 4.1 and Fig. 4.2). Cabo Douglas was significantly different from Caamaño, Post Office, and Malecón (all Fisher's LSD: $p < 0.05$), and Post Office differed significantly from Caamaño and Malecón (Fisher's LSD: $p < 0.05$) (Table 4.2). The differences in $\delta^{15}N$ levels between the different rookeries were not significant (Kruskal–Wallis: $H\,(3,4) = 5.2, p = 0.152$).

There is a relationship between the $\delta^{13}C$ and $\delta^{15}N$ values and the net primary productivity (NPP) (gC m^{-2} day^{-1}) recorded in the four regions (Table 4.1). The NPP values were significantly different between regions (Kruskal–Wallis test, $p \leq 0.01$); the western region was different from the rest of the Archipelago (Fisher's LSD, $p < 0.05$). These results suggest the presence of two regions with distinct characteristics in the Galapagos Archipelago (Fig. 4.3).

Table 4.1 $\delta^{13}C$ and $\delta^{15}N$ values (mean ± SE ‰) from fur samples of Galapagos sea lion pups collected in different rookeries of the Archipelago during March 2003

Rookery	Island	Zone	*n*	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	NPP (gCm^{-2}/day^{-1})
Cabo Douglas	Fernandina	Western	10	−15.59 ± 0.60	12.71 ± 0.36	1,906.56
Caamaño	Santa Cruz	Central	10	−16.23 ± 0.13	13.10 ± 0.50	1,590.35
Post Office	Floreana	Southern	10	−16.22 ± 0.26	12.77 ± 0.40	1,571.80
Malecon	San Cristobal	Eastern	20	−16.24 ± 0.22	13.09 ± 0.49	1,272.39
Average				−16.01 ± 0.39	12.91 ± 0.74	

For each rookery is presented the mean value of net primary productivity (NPP) ($gC\ m^{-2}\ day^{-1}$) estimated for this region during January 2003

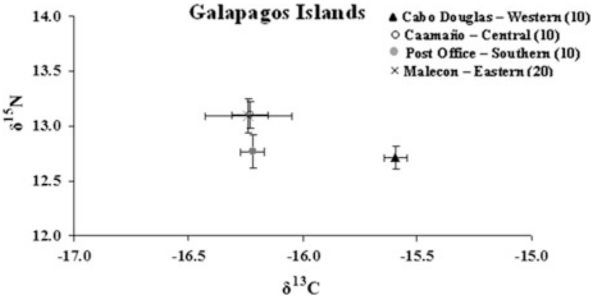

Fig. 4.2 $\delta^{13}C$ and $\delta^{15}N$ values (mean ± SE ‰) from fur samples of Galapagos sea lion pups collected in different rookeries of the Archipelago in March 2003. Each rookery is shown with the geographic region it represents and the sample size in *parenthesis*

Table 4.2 Fisher's LSD test results

Rookery	Cabo Douglas (western)	Caamaño (central)	Post Office (southern)	El Malecon (eastern)
Cabo Douglas		**0.001**	**0.001**	**0.001**
Caamaño			**0.002**	0.057
Post Office				**0.003**
El Malecon				

Significant differences (in bold) in $\delta^{13}C$ values between different rookeries of Galapagos sea lion during March 2003

Discussion

The three main factors determining isotopic values in marine predators are diet, physiology (which affects diet-to-tissue isotope fractionation), and foraging location (Aurioles-Gamboa et al. 2009). By sampling pups of nearly the same ontogenetic stage, we believe that physiological differences between populations will be minimal if the same tissue is used for the analysis, leaving diet and location as the main potentially variable factors. Based on our results we observed spatial differences in the foraging strategies, suggesting the presence of specific foraging areas

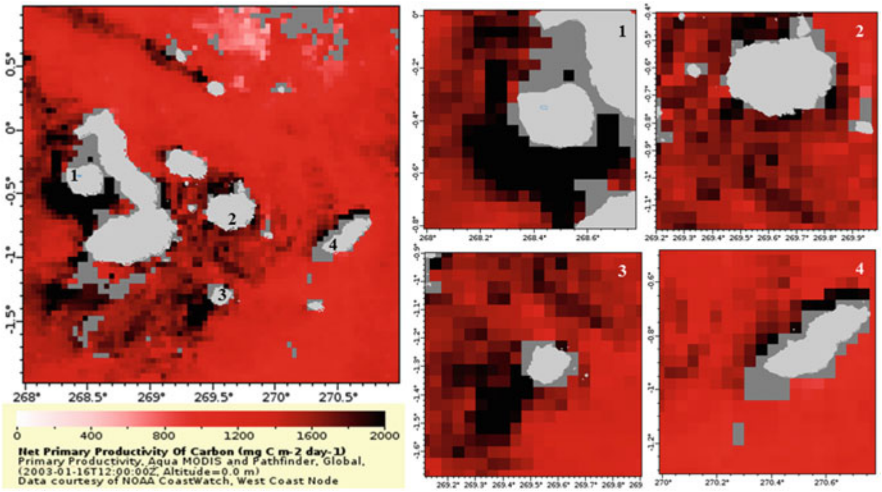

Fig. 4.3 Satellite image of net primary productivity (NPP) (gC m^{-2} day^{-1}) of the Galapagos Islands in January 2003, obtained by the Aqua MODIS and Pathfinder satellite with a spatial resolution of 4 × 4 km and provided courtesy of NASA GSFC (G. Feldman), NODC, CoastWatch West Coast. The sampled rookeries, located in different regions of the Archipelago, are shown (1) Cabo Douglas, western; (2) Caamaño, central; (3) Post Office, southern; and (4) Malecón, eastern

for each rookery, situation that may be related to spatial differences in the prevalence of blooms of the region (Banks 2002; Palacios et al. 2006).

The topography of each region of the Archipelago may be influencing the foraging preferences of the individuals of the various rookeries. For example, Cabo Douglas rookery on Fernandina Island (western region), where the continental shelf is shortest in relation to the other islands and is surrounded by very deep waters (>2,000 m) (Banks 2002), there would be a greater affinity for prey from mesopelagic environments. Conversely, a continental shelf that is shallower than in other parts of the Archipelago (approximately 600 m) (Banks 2002) allows the sea lions to explore diverse environments and consume demersal and benthic fish in the other rookeries.

There are some divergences in the equatorial blooms, which are associated with the intensity of the wind and the equatorial sub-stream, causing lateral differences from the equator to the west of the Galapagos Islands (Pak and Zanveld 1973). Previous studies monitoring the concentrations of chlorophyll *a* have suggested that the western region of the Archipelago (10–30 mg Chl-a m^{-3}) compared to other areas of the Archipelago (1–5 mg Chl-a m^{-3}). However, the islands in the central and eastern regions occasionally tend to be more productive than expected (Banks 2002; Palacios et al. 2006).

The $\delta^{13}C$ results found in our study indicate spatial differences in the sea lion diet around the Archipelago, particularly between the western region and the rest of the islands. There is an isotopic enrichment in the $\delta^{13}C$ values that is produced from the increase in frequency of blooms and the cellular growth rate of phytoplankton (Pancost et al. 1997; Cullen et al. 2001). The phytoplankton blooms enrich the ^{13}C signal, even though the high levels of photosynthesis cause a rapid use and decrease in CO_2 (enriched in ^{12}C) (Rau et al. 1992). In this process, there is discrimination toward ^{13}C, and subsequently, its isotopic signal is increased in the primary producers, which is reflected in the remaining components of the trophic web (Bidigare et al. 1997; Schell et al. 1998).

There were no statistical differences in the $\delta^{15}N$ values, which can be explained in two ways: (a) the predators are sharing some types of prey in different proportions (Newsome et al. 2010), and (b) they are feeding on different prey but of a similar trophic level (Post 2002). Nonetheless, at least two isotopic areas have been reported in the Galapagos Islands (Aurioles et al. 2009). The first area is located in the center of the Archipelago, and the second area is in the western region. These differences can be associated with the topographic characteristics and the distinct productivity levels occurring in each area. Our results follow the trend proposed by Aurioles et al. (2009): the Caamaño (central region) and Cabo Douglas (western region) rookeries have higher and lower $\delta^{15}N$ values, respectively.

However, $\delta^{15}N$ values showed a similar trend of $\delta^{13}C$ values, a situation that could be associated with biological fixation of nitrogens and denitrification processes, aspects that could confuse the time to suggest spatial differences. Isotopic differences occur between zones with contrasting oceanographic and topographic characteristics. The majority of deep ocean areas (>2 km) are homogenous in terms of $\delta^{15}N$ values (approximately 5 ‰), while atmospheric N has lower $\delta^{15}N$ values (approximately -2 to 0 ‰) (Sigman et al. 2005). This difference results in a process that directly influences the isotopic signal of nitrogen in shallower areas. These factors could be associated with differences in upwelling intensity and length of the continental shelf. The western region has the highest productivity and the deepest waters (>2 km) compared to the rest of the Archipelago (approximately 700 m) (Banks 2002; Palacios et al. 2006), which could influence the biological nitrogen fixation and the denitrification processes of these regions.

Our study shows that large differences in $\delta^{13}C$ values and small differences in $\delta^{15}N$ values between rookeries representing different regions of the Galapagos Archipelago are primarily due to differences generated at the base of the food web in their respective ecosystems. However, isotopic differences not statistically significant in $\delta^{15}N$ values deserve further investigation. The simultaneous use of distinct approaches to study feeding habits (e.g., stable isotopes vs. scat analysis) in both predator and their prey may provide a better understanding of the results observed within each region.

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Chapter 5
Ecosystem-Based Management for Rocky Shores of the Galapagos Islands

Luis Vinueza, Annie Post, Paulina Guarderas, Franz Smith, and Federico Idrovo

Introduction

Ecosystem-based management (EBM) is an emerging tool that considers humans as an integral part of the ecosystem (Arkema et al. 2006). EBM is different from other marine management tools (i.e., marine protected areas (MPAs), fishing regulations, quotas) because they typically deal with only one sector, resource, or impact. Primarily due to this, these strategies are not suitable because they fail to acknowledge the complex dynamics that affect social–ecological interactions. Instead, EBM attempts to embrace the complexity that drives the interactions between humans, their multiple impacts, and their environment (McLeod et al. 2005; Tallis et al. 2010). EBM assesses how multiple sectors and cumulative impacts interact to affect the capacity of marine systems to deliver benefits to humans (Arkema et al. 2006; Ruckelshaus et al. 2008).[1] The main goal of EBM is to build resilient social–ecological systems that can secure the long-term provision of ecosystem services and goods to humans (McLeod et al. 2005).

EBM Efforts in Galapagos

The use of EBM approaches in the Galapagos Islands has been present for at least two decades. From the enactment of the Galapagos Special Law (1998), a new management scheme for the marine environments of the Galapagos was established,

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[1] Ecosystem services are those direct and indirect social and economic benefits that we get from the ocean such as food and climate regulation (Granek et al. 2010; Barbier et al. 2011).

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creating the Galapagos Marine Reserve (GMR), one of the largest marine protected areas of the world (138,000 km^2). The main purpose of the GMR was to spatially structure uses of coastal areas to reduce conflicts between sectors (i.e., fishing vs. diving tourism), to protect biodiversity, and to enhance fisheries (Castrejón and Charles 2013; Jones et al. 2013). This was an important stepping-stone in the application of EBM approaches and a shift from a top-down management scheme to a consensus-based co-management system, where stakeholders actively contributed in the process of creation and zoning of the GMR. One important achievement of this process was the banning of the industrial fishing inside the GMR (i.e. exclusion beyond 40 nm), and the granting of exclusive rights to local fishermen on the exploitation of marine resources (Heylings and Bravo 2007; Castrejón and Charles 2013). Additionally, the participatory process resulted in the establishment of a multiuse zoning scheme of the GMR, where 18 % of the coastal perimeter was set aside for no-take reserves (Castrejón and Charles 2013).

Nevertheless, the implementation of the GMR has had some substantial drawbacks. No long-term plan or funding existed to continue with the following phases after the coastal zone was defined. Thus, the demarcation of zones was delayed for 6 years (Castrejón and Charles 2013). While biological and oceanographic information was assembled in the years following its creation (Edgar et al. 2014), few studies have focused on people or interdisciplinary issues, and almost none of the information assembled has been analyzed to evaluate the effectiveness of the GMR (Castrejón and Charles 2013). Most information available for the zonation of coastal waters was based primarily on subtidal rocky reefs; distribution of charismatic species such as penguins, sharks, and flightless cormorants; and the distribution of species of commercial value such as sea cucumbers and lobsters (Edgar et al. 2004). However, ecological patterns (species richness and diversity) as well as biological and evolutionary processes (i.e., growth rates, recruitment, gene flow) were not considered. Similarly, other marine resources of less economic value have been largely ignored, with very little or no information on their population status and little or no management (i.e., fishing regulations) and conservation actions. Those resources include octopuses, whelks, mullets, and endemic chitons, to name a few important coastal resources.

After the creation of the GMR, a series of events have affected the coastal waters of Galapagos, including the Jessica oil spill in January 2001 (Wikelslki et al. 2002), pollution due to untreated sewage from increasing tourism and fast population growth (6.4 %) (Epler 2007), the tsunami generated in Japan in 2011 (Lynett et al. 2013), and invasive species and new emergent diseases (Bataille et al. 2009; Chap. 13). Obviously none of these impacts could have been ameliorated with the current zoning scheme. Furthermore, human-induced climate change and associated impacts, such as more acidic waters, sea-level rise, warmer temperatures, and lower nutrient levels (Harley et al. 2006; Hoegh-Guldberg and Bruno 2010), are likely to affect the Galapagos Marine Reserve as well.

Therefore, to ensure long-term stability of coastal ecosystems and the goods & services they provide, a more holistic approach is necessary—one that considers the complexity of the multiple sectors and impacts that originate from land and sea and how these impacts interact and change at different spatial and temporal scales. Rocky shores are ideal systems for the application of EBM approaches because shores are at the interface between terrestrial and marine systems, are affected by both land- (i.e., coastal development, sewage outflows, invasive species) and sea-based (i.e., oil spills, overfishing, tourism, boat traffic) human impacts (Ruttenberg and Granek 2011), and are subject to natural perturbations of terrestrial or marine origin (i.e., landslides, hurricanes, earthquakes, tsunamis, El Niño Southern Oscillation, floods, sea-level rise) (Vinueza et al. 2006; Lynett et al. 2013; Chap. 12).

In Galapagos, rocky shores are a conspicuous habitat due to the volcanic origin of the islands. They harbor a diverse and unique array of species (i.e., penguins and marine iguanas) as well as important marine resources for subsistence and small-scale fisheries focused on small invertebrates (i.e., chitons, whelks, octopuses) (Molina et al. 2004; Murillo 2010). Furthermore, rocky shores provide several cultural values, from recreational activities (i.e., surf, snorkel, kayak, photography) to scientific research. These end services constitute the natural capital on which the local economy relies. Here we propose to develop an EBM approach for the management of Galapagos rocky shore communities. We delineate a strategy and define and evaluate the risks that rocky shore community experiences. Finally we analyze the cumulative impacts that affect Galapagos rocky shores and provide a series of indicators and management actions to reduce impacts and to build more resilient marine communities (Figs. 5.1 and 5.2).

Methods

We developed an EBM approach for the Galapagos based on a review of current literature, personal observations, and interviews with stakeholders and local authorities to develop a conceptual model in which to evaluate key interactions and potential management interventions. For this particular study, we focused on San Cristobal Island. This island harbors the second largest population of the Galapagos. We reviewed important steps in the application of EBM strategies, taking into account the local reality of San Cristobal Island (Fig. 5.3), and then we characterized a series of ecosystem services and values important to local stakeholders and define a series of indicators to measure their quality. We then constructed a conceptual model (Figs. 5.4 and 5.5) to depict the multiple factors that affect rocky shore communities, considering their origin (e.g., terrestrial vs. marine), intensity, and magnitude at different spatial and temporal scales. Then we built a cumulative impact matrix based on local knowledge, extrapolations from other systems, and conducted interviews to gather information on when these factors interact and become additive, multiplicative, or synergetic (Fig. 5.1). Finally, we developed a series of management actions orientated to secure the conservation of rocky shore communities and their ecosystem services (Table 5.2). We chose the marine iguanas as sentinels because these species are highly

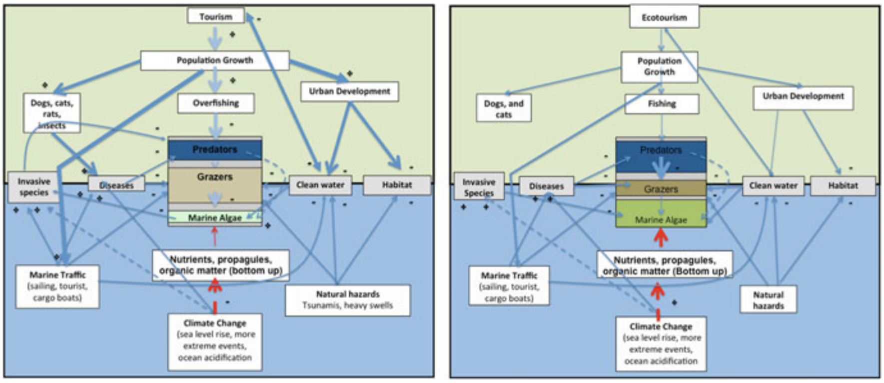

Fig. 5.1 The conceptual model illustrates the connections (with *arrows*) between ecosystem services and stressors (*boxes*) occurring on rocky shores of San Cristóbal Island. The strength of the connection or impact is illustrated by the width of the *arrow*, and the direction of the interaction (positive or negative) is denoted by its *sign*. The model corresponds to a strong warm phase of El Niño event under two different scenarios (**a**) unsustainable tourism which increases human population growth that magnifies a series of direct and indirect impacts, reducing the resilience of Galapagos rocky shore communities. (**b**) Scenario two, an EBM approach to map and reduce human impacts and secure the long-term provision of ecosystem services and goods to humans. Size of boxes reflects the importance of trophic level on the function of an ecosystem. In model (**a**) the *grazer box* is dominated by sea urchins, with lower abundance and diversity of other consumers such as marine iguanas and sea turtles due to increased competition for food

charismatic and occupy a unique ecological niche due to their unique feeding habits and behavior; and secondly, because marine iguanas are affected by both land and sea impacts of human or natural origin.

Our final goal of this chapter is to offer the Galapagos National Park Directorate, the local community, and conservation organizations a framework to implement EBM. While this idea is not new to the archipelago, our proposal offers a simple and tractable approach to implement EBM.

San Cristobal

San Cristobal is located in the easternmost part of the archipelago (Fig. 5.3). This island is closest to the mainland and is the oldest island geologically. According to the last census in 2010, the population of San Cristobal was 7,730 persons. Eighty-three percent (6,672 habitants) lives in the coastal town of Puerto Baquerizo Moreno, around Wreck Bay, located in the southwestern end tip of the island (Fig. 5.3).

Impacts of marine origin affecting Wreck Bay include pollution due to shipping and tourism (oil, litter, and sewage) (Chap. 12) (Figs. 5.1 and 5.5), overfishing for small invertebrates (whelks, octopuses, chitons) (Molina et al. 2004; Edgar et al. 2010), invasive species, large-scale environmental perturbations such as

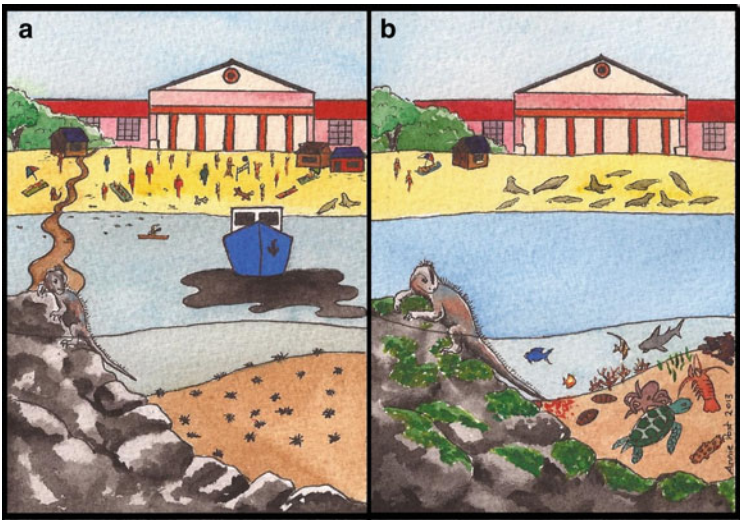

Fig. 5.2 Playa Mann viewed from La Predial, San Cristobal Islands, showing two alternative social–ecological stable states. (**a**) Playa Mann with more than three cumulative impacts overlapping at the same spatial and temporal scales; this results in less attractive locations with ecosystem benefits degraded, particularly during tipping points (extreme El Niño events of 1982–1983 and 1997–1999). (**b**) A system managed under an EBM approach, a spatial explicit approach to reduce human impacts and increase the resilience of the system (high diversity provides complementarity and redundancy against perturbations; this is vital to sustain vibrant economies)

El Niño Southern Oscillation, and impacts associated with human-induced climate change. Drivers from land include increasing urbanization, coastal development, shoreline armoring, sewage discharge and overflow during heavy rains, invasive species, and diseases transmitted by domestic animals and by mosquitoes (Bataille et al. 2009).

Implementation of EBM Scheme on San Cristobal

For successful implementation of EBM strategies, it is key to understand the context or the local reality in which this strategy is going to be applied (Aswani et al. 2012). It is also important to take into account current management regimes and adapt those schemes to the framework of EBM.

Implementation of an EBM will require the cooperation of a number of different sectors due to the complexity of the system and the multiuse nature of the Galapagos. Along with the current participatory scheme of the GMR, where fishermen, tourist operators, managers, and scientists are the main stakeholders, the participation should also involve guides, surfers, kayakers, local community

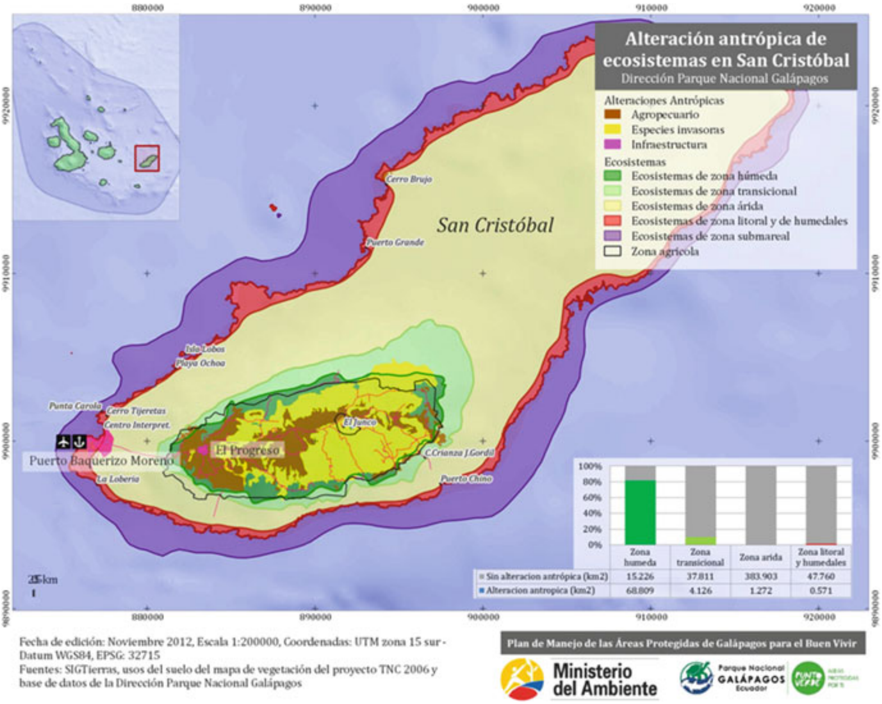

Fig. 5.3 Map of San Cristobal Island showing the different uses and impacts on different ecosystem types (modified with permission of WWF and Galapagos National Park. Map was last edited in November 2012)

members, managers (not only the Galapagos National Park Service but the Governing Council of Galapagos, the Navy, the Quarantine Service), and local, national, and international NGOs (Castrejón and Charles 2013, p. 277).

Scope and Goals of EBM

The first step of an EBM strategy is to define the scope and goals. It is essential to define a common management goal that can unite all sectors. To help define this common goal, it is important for the stakeholders to develop a strong sense of place and understanding of the dynamics that drive these social–ecological interactions. Managing for diverse, vibrant, and resilient social–ecological systems that can secure the long-term provision of ecological, social, and economic benefits that we get from the ocean seems a reasonable and attractive target for different sectors for several reasons: first, because diverse ecosystems are key to sustain human

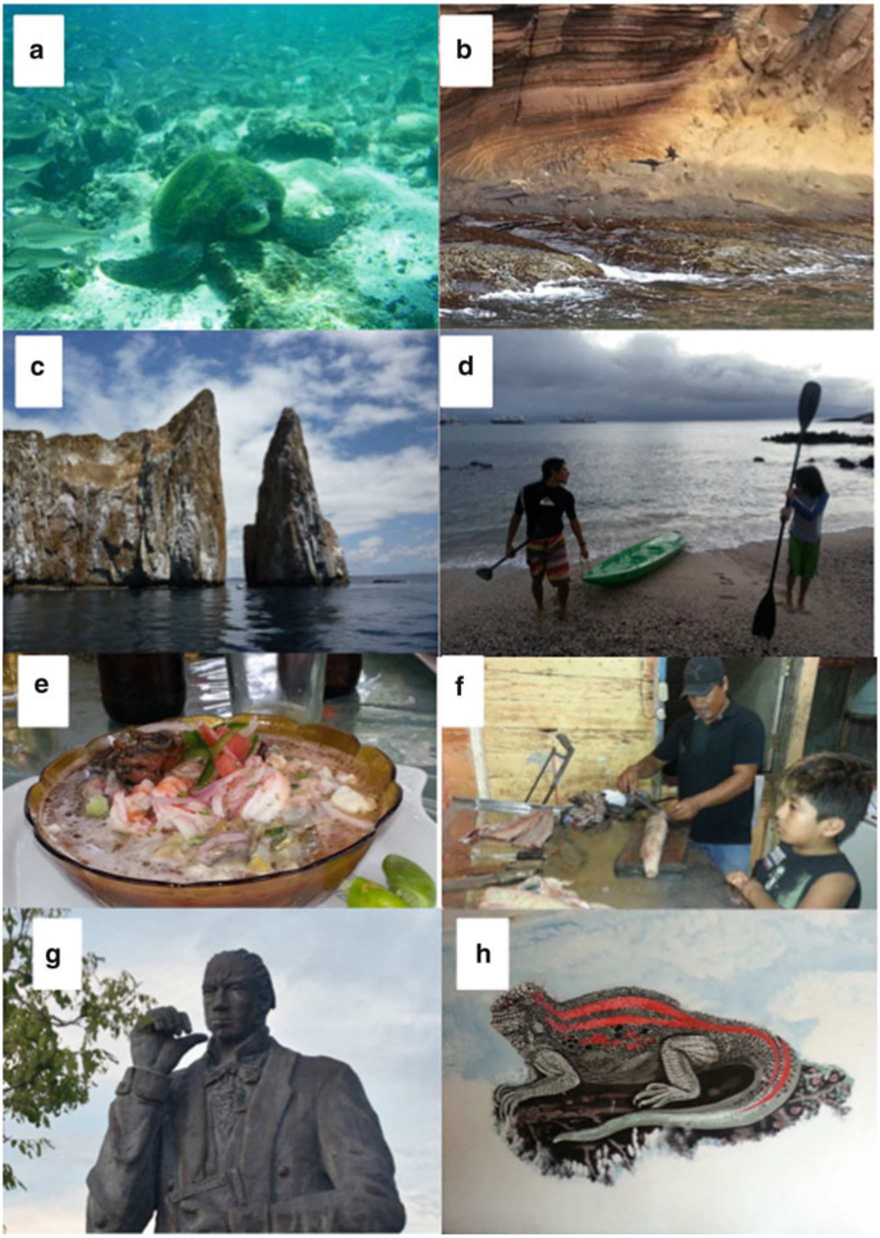

Fig. 5.4 Some important ecosystem goods and services provided by San Cristobal. These include healthy populations of charismatic species, good habitat representation to support different life stages, clean waters to provide safe seafood, and a satisfactory visit of tourist to the islands

Fig. 5.5 Potential impacts to Galapagos rocky shore communities around San Cristobal. (**a**) Shows the boat that brings fossil fuels every week to supply the local demands for electricity and transportation. (**b**) The cargo boat San Cristobal brings supplies to the Islands, including organic food. Cargo ships like San Cristobal are potential vectors for invasive species. (**c**) Playa de los Marinos sowing the overlap of multiple human impacts including pollution due to toxics derived from the hulls of boats, rainwater, and sewage. (**d**) Impacts of the Japan tsunami that hit the coast of the Galapagos in March 15, 2011, causing damage along the coastline. (**e**) and (**f**) Playa de Oro at two different times. (**e**) During the dry season and (**f**) after an important storm that caused sewage overflow and transported litter and pollutants to the coastal zone

populations (Palumbi et al. 2008); second, because vibrant economies characterized by a good participation of different sectors increase support for management and conservation; and third, because more resilient social–ecological systems are better prepared to deal with human (i.e., external markets) and natural perturbations (i.e., tsunamis).

Ecosystem Services

Ecosystem services are those benefits supplied by ecosystems. These include provisioning services, such as the production of food and water; regulating services, such as erosion control and carbon sequestration; supporting services, such as nutrient cycling; and cultural services such as recreation and scientific discovery (Granek et al. 2010). Benefits can also be defined as the sum of what all members of society would be willing to pay for a particular service or good provided by an ecosystem (Barbier et al. 2011). Ecosystem services have an important value for humans and constitute the bridge between social and ecological systems. This link can guide the prioritization of management strategies (Granek et al. 2010). A summary of ecosystem services that are key for rocky shores in the San Cristobal Island is detailed in Table 5.1. Local inhabitants obtain important food resources and freshwater (through desalination) from this system (Table 5.1). Cultural services provided by this system are highly valued by different stakeholders since ecotourism activities are the basis of the local economy (Table 5.1). Intertidal habitats of the San Cristobal Island provide climate and natural hazard regulating services (Table 5.1) as well as other supporting services like nutrient cycling and primary productivity (Table 5.1).

Threats to Galapagos Rocky Shores

Rocky shores around Galapagos are unique due to the high levels of endemism and the occurrence of evolutionary lineages with distinctive adaptations such as marine iguanas and flightless cormorants. However, endemism and high level of specialization make the marine biota of the islands highly vulnerable to natural and anthropogenic stressors that increase in magnitude due to the current loss of isolation from mainland. More flights, trips to and around the islands to transport tourists, people, and supplies, are increasing fuel demands and the risk of oil spills (Zapata and Martinetti 2010; Guyot-Téphany et al. 2013). More traffic increases levels of pollution and the chances for the arrival of invasive species as well as new and emergent diseases (Bataille et al. 2009) (Fig. 5.5).

Those marine endemic species that depend on the strength of upwelling for their growth and survivorship, like marine algae, penguins, and marine iguanas, are the most vulnerable (Edgar et al. 2008; Boersma et al. 2013). The vulnerability of endemic species increases when other stressors come into play by reducing their resilience to these perturbations (Edgar et al. 2010), particularly in populations with low genetic diversity (heterozygosis) such as the Galapagos penguins with only

Table 5.1 Some examples of ecosystem services that are key to users from San Cristobal

Ecosystem service type	Ecosystem service in Galapagos	Ecosystem process and function	Ecosystem functions indicators	Ecosystem condition and biodiversity indicators	Ecosystem service indicator	Benefit/human well-being indicators	Human drivers of ecosystem change (stressors)
Provisioning services	Abundant marine resources (such as octopuses, chitons, and whelks) to support local inhabitants	Suitable habitats for different life stages. Connectivity, maintenance of trophic structure and ecosystem function Resilience to stressors Upwelling	Biodiversity Connectivity Habitat heterogeneity and representation Habitat structure and condition	Fisheries status Condition of stocks Population size structure and density of target species	Average catch Value of coastal products Fish products as a percent of total animal protein in peoples diets	Employment in the fishing sector Per capita cash income from fishing Revenue from fishing	Overfishing Habitat destruction Climate change Ocean acidification Pollution Invasive species Changes in upwelling intensity Sea-level rise
Provisioning services	Freshwater	Clean water			Desalinization capacity/volume of water desalinated	Cost of desalinating sea water	
Cultural services	Healthy populations of charismatic species (e.g., marine iguanas, sea lions, seabirds)	Suitable habitats for different life stages Healthy meta-populations Connectivity Upwelling Biomass and diversity of primary producers Water quality Temperature	Biodiversity Connectivity Habitat heterogeneity and representation Habitat structure and condition	Population size and condition of marine iguanas, sea lions, and seabirds			Diseases Pollution Sea-level rise Invasive species Urban development
Cultural services	Natural habitats to support scientific research	Connectivity Unique lineages High level of endemism Isolation from mainland Maintenance of ecosystem structure and function	Biodiversity Connectivity Habitat heterogeneity and representation Habitat structure and condition		Native/endemic species diversity Species threat categories Species range maps Habitat extent		Diseases Pollution Invasive species Overfishing Habitat destruction

		Suitable habitat for diverse fauna and flora, unique species, and ecological process					Species invasion Urban development Climate change
Cultural services	Aesthetic landscapes for tourism and local recreation	Biomass size spectra	Biodiversity Connectivity Habitat heterogeneity and representation Habitat structure and condition		Willingness to pay for higher entrance fees Willingness to pay for improved water quality local water bodies (proxy)	Tourist facilities on the coast Number of tourists per coastal site Employment in the tourism sector Per capita cash income per tourism Revenue from tourism	Coastal development Pollution (sewage, litter, oil) Uncontrolled tourism and population growth
Cultural services	Aesthetic landscapes for tourism and local recreation	Clean waters	Macroalgae/benthic diatoms richness composition, presence of opportunistic species, cover, physiological state	Turbidity Nutrient levels Number of coliforms Concentration of hydrocarbons		People in coastal areas without access to improved sanitation facilities Coastal beach cleanup data Oil spills impacts	
Regulating services	Climate regulation	Biodiversity Connectivity Habitat heterogeneity and representation Habitat structure	Carbon sequestration capacity of algae				Pollution (sewage, litter, oil) Uncontrolled tourism and population growth Human-induced climate change
Regulating services	Natural hazard regulation	Habitat heterogeneity and representation Habitat structure		Area of intact intertidal habitat	Changes in seasonality of flood events	Population in flood-prone areas	Coastal development

(continued)

Table 5.1 (continued)

Ecosystem service type	Ecosystem service in Galapagos	Ecosystem process and function	Ecosystem functions indicators	Ecosystem condition and biodiversity indicators	Ecosystem service indicator	Benefit/human well-being indicators	Human drivers of ecosystem change (stressors)
Supporting services	Primary production, production of atmospheric Oxygen Nutrient cycling	Biodiversity Connectivity Habitat heterogeneity and representation Habitat structure Biomass size spectra	Macroalgae/benthic diatoms richness composition, presence of opportunistic species, cover, physiological state	Diagnostic pigment (e.g., chlorophyll *a*) concentration			Pollution Uncontrolled tourism and population growth Human-induced climate change

Each individual service, the ecosystem processes and functions of that service, specific services indicators, and human drivers of ecosystem change are listed (Foley et al. 2010; Granek et al. 2010; Barbier et al. 2011; Carr et al. 2011; Desrosiers et al. 2013; Halpern et al. 2012; WorldResourcesInstitute 2013; EPA 2005). New indicators of coastal ecosystem condition

1,042 individuals reported in 2009 (Boersma et al. 2013) and the distinctive population of marine iguanas from Punta Pitt, on the northeast tip of San Cristobal Island (MacLeod et al. 2012) (Fig. 5.4). Here we focus on the human drivers and their impacts on the social–ecological system under study.

Tourism: The Main Driver of Change

Both models of tourism, live abroad and more recently island hopping,[2] have grown at an alarming rate for such fragile ecosystem and have promoted fast population growth with a series of direct and indirect impacts (Epler 2007; Castrejón and Charles 2013). In 2001 the growth rate was 5.8 %; this rate declined to 3.3 % in 2010, 12 years after the Galapagos Special Law that put restrictions on emigration to the islands (Granda and León 2013). This number is still considerably higher than the national growth rate for Ecuador at 1.95 % per year. In the same way, the floating population of tourists is growing fast in the archipelago, from less than 1,174 in 1990 to 2,078 a day in 2010 (Granda and León 2013).

Urban development is now more notorious around the inhabited areas of the archipelago, like Puerto Baquerizo Moreno in San Cristobal Islands due to a new model of tourism called "island hopping." This model is capturing a large proportion of the tourists that are coming to the Galapagos. As opposed to live aboard tours (Epler 2007), most revenues from island hopping stay locally, closer to the objectives of ecotourism by maximizing participation and distribution of benefits to a wider sector of the local population (García et al. 2013). Other benefit of island hopping includes access to sites located at a relatively close range; this can potentially facilitate the implementation of better management practices such as periodic patrolling and monitoring.

It is predicted that most stressors are going to increase with more tourism coming to the islands. These include habitat destruction, increasing pollution, overfishing, invasive species, and diseases directly and indirectly due to the need to satisfy the demands of tourism (Figs. 5.1 and 5.5). However, many of these impacts can be drastically reduced with good practices such as ecotourism, adequate spatial planning, and adaptive management to respond to changes such as alterations in precipitation patterns (Fig. 5.5e, f).

There are multiple initiatives to reduce the ecological footprint of humans on San Cristobal (i.e., recycling, the use of clean energy) or to decrease negative interactions between humans and native fauna, in addition to efforts of controlling tourism activities and promoting scientific research. While these are notable efforts to this end, other activities such as pollution, caused by boats, remain largely understudied.

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[2] Island hopping consists of trips to the islands for 2–4 days or more around each or some of the populated islands of Cristobal, Isabela, Santa Cruz, and Floreana (Quiroga 2013).

There is still a lot of room to improve current practices; simple changes in our lifestyles can have a great impact on endemic populations. For example, people advocate for the use of bikes, not only to reduce fuel demands and diminish disturbance of native species but also to promote a healthier lifestyle. Longer stay on the islands per tourist could also decrease the demand for flights and reduce CO_2 emissions.

Other examples include better management actions to reduce negative interactions between sea lions and humans (e.g., construction of artificial platforms for sea lions, use of nets to restrict access of sea lions to boats) or the reduction of fishing pressure on coastal resources by supporting local consumption of lobsters instead of providing this resource to external markets. San Cristobal can manage these problems in an interdisciplinary manner with the participation of universities and stakeholders. USFQ and the Galapagos Science Center provide a unique opportunity for this kind of holistic research. For example, recent studies of water quality demonstrate the importance to focus on the quality of ecosystem services to provide a pleasant visit to the diverse group of users of San Cristobal, including kayakers, tourist operators, fishermen, local surfers, divers, and scientists (Figs. 5.4 and 5.5).

Ocean-Based Impacts

While fairly infrequent, big oil spills have occurred in the archipelago before and are predicted to increase due to growing demands for oil. The 2001 spill of the *Jessica* was considered only a minor spill (3 million liters of bunker oil and diesel) but was predicted to have far-reaching consequences. Most impacts were considered minor (Gelin et al. 2003; Salazar 2003) or highly localized closed to the spill (Marshall and Edgar 2003). However, 62 % of marine iguanas from Santa Fe died more likely due to starvation after the toxic effects of oil that killed the endosymbionts that help the iguanas digest cellulose (Wikelski et al. 2001). Just 1 year later, a cargo ship ran aground, this time in front of Isabela Island with no apparent damages (Chap. 12). This adds to the chronic but small spills that occur frequently around populated centers. However, there are no specific monitoring routines to measure oil pollution in the ocean or to detect its sources.

Invasive Species

Invasive species are of great concern for isolated archipelagos such as the Galapagos due to the vulnerability of native and endemic species to novel predators and emergent diseases. Invasive species can displace native and endemic species, alter food web structure and ecosystem function, reduce species diversity, and decrease the attractiveness to the islands to tourists and scientists due to the loss of charismatic species, the unique evolutionary lineages, and the homogenization of biota.

While the marine system is connected and open by oceanographic currents, the distance from mainland and the influence of different oceanographic currents divide the archipelago in at least five different biogeographic regions (Edgar et al. 2014, p. 182). However, increasing maritime traffic in order to satisfy the needs of a growing population of permanent and temporal residents (tourist and temporal job residents), jointly with other stressors such as climatic anomalies, overfishing, fluctuations in nutrient levels, and diseases, makes the Galapagos rocky shores more vulnerable to invasive species, particularly basal species, but also to top predators such as the lionfish (*Pterois* spp.) that is having devastating effects in the Atlantic and is now in Panamá.

In the Galapagos, the maximum threshold for establishment and invasion of marine species can happen during the warm phase of strong ENSO events, such as those of 1982–1983 and 1997–1998. During these stressful events, vulnerability to invasive species results because of the reductions in the abundance or even extinctions of endemic species, most of them primary producers that decline due to dramatic changes in nutrient levels and temperature (Laurie 1989; Vinueza et al. 2006; Edgar et al. 2008). Other stressors such as overgrazing and eutrophication can switch the competitive ability of marine organisms and facilitate the invasion of species. This can be highly detrimental for marine iguanas, particularly if highly invasive species of algae establish there permanently, creating alternative stable states that are resilient to changes due to extinction of local species or loss of ecological function of consumers (Vinueza et al. 2006, p. 41).

Current regulations to prevent the movement of organisms via maritime traffic are minimal. While most cargo ships that travel to Galapagos do not use ballast water, invasive species could be transported on ship’s hulls or with the food products carried to the Galapagos. Only 60 % of cargo ships are inspected before they come to the archipelago (Zapata and Martinetti 2010). Furthermore, while most luxury yachts are inspected, most sailing boats are not (pers. comm. Narvaez representative on San Cristobal Island) and are a potential source of invasive species from other parts of the world, particularly if they proceed from ports with high incidence of invasive species.

As suggested by Zapata and Martinetti (2010), the construction of quarantine facilities in Guayaquil will help with the inspection, cleaning of hulls, and fumigation of any type of boat entering the Galapagos. Similar facilities constructed in each port of populated islands would assist in the control and surveillance of incoming boats and to inspect tourist boats traveling between islands.

An early warning system that includes regular monitoring routines to spot for the arrival of potential invasive species should be implemented around rocky shores. Special attention should be directed to highly invasive species and those that represent potential threats to the local flora and fauna. The Charles Darwin Research Station has identified at least 10 species of special concern in the islands (CDF-Marine). A contingency plan should be ready to respond and control any unwanted species.

Fishing

Fishing along intertidal rocky shores in the Galapagos focuses on three main resources, all of them mollusks. These include "churos" (whelks), octopuses, and "canchalaguas" (chitons). While at first, the capture of these resources was for subsistence, this fishery is now expanding to satisfy the increasing demands of locals and tourists for seafood (Fig. 5.4). Removal of these organisms on rocky shores is higher nearby populated centers (Murillo 2010; Molina et al. 2004). The fishery for octopus happens usually during low spring low tides. While the use of chlorine bleach is forbidden, it is a common practice that should be avoided, as it is harmful to other organisms in the intertidal zone and may have residual effects on organisms (L. Vinueza personal observation). The fishery for octopus in the intertidal zone targets juveniles that use this stretch of coast before they reach sexual maturity; thus, intertidal octopuses have not had a chance to reproduce yet, reducing the ability of these populations to recover from overexploitation (Ruiz 2002). For chitons, the fishery usually occurs during full moon. The removal of chitons is reducing their size and abundance nearby populated centers (Murillo 2010).

While there were plans to implement management actions starting in 2004, no regulations exist yet to control these fisheries that are open all year around. Furthermore, key biological and ecological information is needed to support management actions for these species.

Impacts of these fisheries at a community level can be significant (Poore et al. 2012). For example, octopuses and whelks are top predators that can control the populations of other organisms. Chitons are important grazers and their ecological role is likely to be less apparent close to human population centers due to high levels of exploitation. Indirect effects due to the loss of urchin predators could increase competition for marine algae among grazers (Fig. 5.1). This can affect marine iguanas and other grazers at times of high environmental stress such as those experience during the warm phase of El Niño (Vinueza et al. 2006, p. 41; Vinueza, in review, p. 259).

Land-Based Impacts

One of the main concerns from land-based impacts is contamination of nearshore waters with untreated sewage. Input of sewage to the ocean in San Cristobal include pipe discharges, contaminated groundwater, submarine sewage discharge close to Punta Carola, boat discharges, and sewage overflow during heavy rains around Wreck Bay (López et al. 2008; Stumpf et al. 2013). The new treatment plant implemented in 2011 on San Cristobal has a capacity to attend sewage generated by 6,000 inhabitants, less than the current permanent and transient population on San Cristobal (6,672 habitants). Recent analysis demonstrates elevated levels of *Enterococcus* spp. beyond international standards (Stumpf et al. 2013, p. 309);

these levels of organic pollution represent a risk to human health and, jointly with litter, decrease the attractiveness of a site and the level of tourist satisfaction.

It is critical to establish contamination thresholds to determine beach closures and to establish permanent monitoring sites around Wreck Bay. Other places outside Wreck Bay should be included, as well as sites with no or low human impacts around San Cristobal as controls.

Climate Change

Climate change is likely to affect coastal areas in multiple ways. Galapagos is particularly susceptible to variation in the strength of winds and upwelling (Witman 2010, p. 220). Stronger stratification of the water column could result in a reduction in the rates of primary productivity (Chavez 1999, p. 5). Higher sea level will represent a challenge for coastal birds such as penguins (Boersma et al. 2013, p. 328). For example, it is predicted that sea level will rise 2.3 m for each degree Celsius at the end of this century, and this will have important economic costs for coastal communities around the world and for the Galapagos in particular; as most tourism activities are concentrated around the seafront (Levermann et al. 2013).

Furthermore, stronger fluctuations in El Niño Southern Oscillation Cycles could accelerate the decline in population numbers of endemic species and potentially lead to extinction; in the case of intertidal shores, the disappearance of endemic species of algae was notable after El Niño 1982–1983 (Edgar et al. 2010). A recent evaluation by group of experts reported 20 % of all the endemic algal species as threatened (Polidoro et al. 2012). At the community level, higher or lower temperatures could increase or decrease the impact of consumers on benthic marine algae, likely changing patterns of food competition and reducing the structural complexity of marine algae (Sanford 1999, p. 36).

Indicators

In order to assess the status of this social–ecological system, it is key to define a series of social, economic, and biological indicators. These parameters are useful to assess the outcome of management actions and the impacts of human and environmental factors on social–ecological systems (Tallis et al. 2010). Indicators should be focused on measuring the delivery (quantity and quality) of benefits to humans and assessing the impacts of stressors on the system (see Tables 5.1 and 5.2) (Granek et al. 2010).

Table 5.2 Threats to the rocky intertidal system of San Cristobal Island, including indicators and possible management strategies to counteract these threats

Impact	Threats	Consequences	Sources	Scale	Risk level	Management	Indicators
Coastal development	Tourism Population growth	Habitat destruction Changes in the landscape coming from the construction of infrastructure, buildings and facilities Increased vulnerability to hazards	Overdevelopment for tourism Urban development	Local	3+	Spatial planning of the town Raising environmental awareness among the local population	Tourist facilities on the coast Population in flood-prone areas Percent of shoreline armored
Tourism	Litter Trampling Anchoring	Deterioration of the quality of environmental goods and services significant to tourism Disturbance of native fauna and local people	Excessive influx of visitors	Local	2+	Working with the tourism industry and local tourist operators to ensure best environmental practices through accreditation, training and educational programs, and materials. Planning and organized visitations, setting maxima to tourist numbers Raising environmental awareness among the local population	Number of tourists per coastal site Coastal beach cleanup data Monitoring disturbance of native fauna on visitation sites
Pollution (land based)	Sewage Fertilizer Pesticides Toxins Plastics Fuels	Diseases Mortality Decreased population resilience Eutrophication/algae blooms. Blooms can alter the food chain then decay, depleting oxygen and causing fish kills	Towns Farms Poor infrastructure Industry Desalination facilities	Local Regional	3+ if rainy season collapse sewage system (Fig. 5.3)	Public waste system already implemented on San Cristobal Public education Regulations on pesticides and fertilizers used for agricultural purposes on the islands Sound and efficient environmental management of desalinations and tourism facilities and especially hotels (e.g., water- and energy-saving measures, waste minimization, use of environmentally friendly material) can decrease the environmental impact of tourism	Water quality parameters (fecal indicator bacteria such as *Enterococcus* spp., *Bacteroidales* spp.) Nutrient levels (nitrogen and phosphorus) Chlorophyll a, dissolved oxygen, turbidity, conductivity, water temperature Species abundance Species composition Number of tourism facilities implementing green practices

						Raising environmental awareness among the local population	
Pollution (marine based)	Oils Fuels Sewage from cruise ships Antifouling paint Litter	Decreased population resilience Habitat degradation Eutrophication/algae blooms. Blooms can alter the food chain then decay, depleting oxygen and causing fish kills.	Tourist boats Cargo ships Cruise ships Fishing boats	Local Regional	3	Regulations and enforcement of double hulls Regulations to control discharge of waste from vessels and to set out tertiary treatment standards for the direct discharge of waste	Water quality Species abundance Species composition Algal cover Observations Corticosterone levels on bird, reptiles, and mammals Toxics in sea lions
Disease	Outbreaks of novel diseases Epidemics	Decrease in population size Ecological extinction	Introduced species External	Local Regional	4	Vaccinating of all introduced animals on the island Regular organism condition monitoring of charismatic species	Fecal matter Animal observations Population numbers Blood samples of key species, monitoring organism condition
Invasive species	Increased competition and predation	Phase shifts Homogenization of biota Loss of ecosystem structure and function Loss of jobs Reduction in the number of tourist	Mainland Visiting boats Ballast water Ship hulls	Local Regional	3	Stricter checking of ships and planes entering the Galapagos Cleaning of ships hulls before reaching archipelago Removal of or treatment of ballast water before reaching the archipelago to remove invasive species	Number of marine native nuisance species
Domestic species	Increased predation on native and endemic species Increased rate of transmission of diseases to endemic and native species		Mainland Visiting boats	Local Regional	4	Harsher punishments for people caught smuggling animals into the Galapagos Regulations and management plans for all domestic animals including desexed and zoning for diminishing disease transmission to native fauna Stray animals removed Any animal found attacking or endangering endemic fauna to be euthanized	Predation pressure by domestic animals on native species (e.g., marine iguanas) Disease monitoring of native species Number of stray animals Number of desexed animals

(continued)

Table 5.2 (continued)

Impact	Threats	Consequences	Sources	Scale	Risk level	Management	Indicators
Fisheries	Overfishing Removal of key species Changes in species composition Changes in community structure and function	Reduce resilience Loss of jobs Decrease in revenue from tourism		Local Regional	4	Creation of no-take zones Management of fisheries	See provisioning indicators in Table 5.1
El Niño Southern Oscillation	More extreme events Changes in upwelling patterns Reduced nutrients Changes in species composition	Changes in species composition Ecological extinctions		Local Regional	5	Improve management in the rocky intertidal in order to increase the resilience of the system to natural impacts such as El Nino	Intertidal biotic community status and trends Sea surface temperature Ambient temperature
Climate change (sea-level rise, ocean acidification)	Increase SST Increased influx of freshwater Changes in ocean pH (more acidic waters)	Reductions in primary productivity Changes in species composition Ecological extinctions Phase shifts		Regional Global	6	EBM implementation	Intertidal biotic community status and trends Sea surface temperature Ambient temperature

Sources: See Chap. 12; Levin et al. (2013), Stumpf et al. (2013), Wikelslki et al. (2002)

Monitoring

Monitoring these parameters in a consistent manner and in the long term is key—particularly at spatial and temporal scales that are relevant to local (i.e., peaks in visitation, oil spills, heavy rains) and regional dynamics (seasonal, annual and large-scale changes in weather). Also, it is important to analyze the information with an explicit spatial approach that maps the different indicators and the interactions between different human activities and their impacts. The interpretation of this information in an interdisciplinary manner is fundamental to assess the outcome of management actions (Foley et al. 2010; Carr et al. 2011).

Adaptive Management

Adaptive EBM is crucial to respond to unforeseen circumstances such as oil spills or diseases, but also to respond to external threats such as natural disasters (e.g., heavy swells, tsunamis), human-induced climate change, or changes in external markets.

Marine Iguanas

The endemic Galapagos marine iguana (*Amblyrhynchus cristatus*) exhibits a unique mode of life not only among the iguaniids but also among all lizards. Marine iguanas feed exclusively on algae species in the intertidal or subtidal zones, while breeding and nesting completely on land. This species constitutes a key indicator for the condition of rocky shore habitats in the Galapagos (Table 5.1) due to its high degree of specialization and adaptation to this system, factors that also make them less resilient to changes from both natural and anthropogenic origin.

The cool waters surrounding the Galapagos Islands, jointly with Ecuadorian i.e. along the equator, upwelling and the extensive rocky or lava substrates, allow an abundant and diverse flora of macrophytic algae of the types exclusively utilized by *Amblyrhynchus* (Carpenter 1966; Silva 1966). Every few years, recurrent El Niño events decrease the nutrient-rich upwelling, and as a result the amount of algae is greatly reduced, leading to widespread starvation (Wikelski et al. 1997; Laurie 1989). The reliance on one food source subjects marine iguanas to a fairly regular cycle of food limitation and potential starvation every few years; in fact the El Niño-induced starvation is considered the major stressor for adult iguanas because mortality can be as high as 90 % of the population (Romero and Wikelski 2010).

However, with the rapid human population growth that the Galapagos is facing, novel predators such as domestic dogs and cats are growing in numbers, and increasingly becoming a serious threat for most native species, including marine iguanas that are not able to respond to these novel predators. Studies have shown that on San Cristobal Island, marine iguanas experience acute predation pressure by domestic animals leading to high mortality rates (Berger et al. 2007).

Furthermore, this species is highly sensitive of polluted waters. For example, marine iguanas increased stress hormone levels due to fouling from an oil spill. The increase in stress hormone levels predicted a decrease in survival by approximately 50 %, which was later confirmed by field studies (Wikelski et al. 2001).

Summarizing, marine iguanas are vulnerable to changes in water quality, oil pollution (Wikelski et al. 2001, 2002), indirect effects of overfishing (Edgar et al. 2010, p. 106), El Niño Southern Oscillation (Laurie 1989; Vinueza et al. 2006; Steinfartz et al. 2007), and introduced predators such as dogs (Kruuk and Snell 1981) and cats. Of greatest concern are diseases caused by viruses or bacteria due to more detrimental declines on reptiles and birds populations (Chap. 12). For example, native mosquitoes could mediate the transmission of diseases such as the West Nile virus—which has the potential of affecting a series of charismatic species, including marine iguanas, flightless cormorants, and penguins (Bataille et al. 2009).

Cumulative Impacts

Cumulative impact refers to the combined effect of multiple stressors acting on a particular system. The understanding of the impact of these stressors and the interactions between multiple stressors is key for management and conservation efforts (Fig. 5.1); more than 41 % of our oceans are moderately or seriously affected by human impacts (Halpern et al. 2008). However, the combined effect of multiple impacts remains largely unknown (Crain et al. 2009). A recent meta-analysis suggests that when more than three stressors act together, this causes drastic changes in the system due to synergistic effects of multiple factors (Crain et al. 2009). A few places around Wreck Bay experience more than three stressors at any given time. This occurs in Playa de los Marinos, Playa de Oro, and Punta Carola (Figs. 5.3 and 5.5). For example, in both, Playa de los Marinos and Playa de Oro, a channel that directs rainwater from town to the ocean overlaps with a small tide pool that accumulates and likely concentrates viruses, bacteria, and pollutants derived from sewage and from pollutants resulting from the maintenance of boats. These areas are commonly inhabited by coastal birds (such as herons) and sea lions. Another spot where multiple impacts converge is Punta Carola, where sewage outflow previously brought untreated water to the area.

The type and magnitude of cumulative impacts that affect rocky shores in the Galapagos can change spatially and temporally as a result of seasonal (i.e., rainfall), annual, and inter-annual changes in environmental conditions (i.e., temperature, nutrient levels, pathogens) or as a result of changes in human activities and uses (peaks in visitation) (Fig. 5.1). For example, changes in temperature such as those observed during the warm phase of El Niño can increase dramatically the patterns of precipitation and increase sea level 40 cm above average (Wolf 2010). Changes in sea level and precipitation can transport potential pollutants, diseases, and invasive species between terrestrial and marine systems (Fig. 5.1). If combined with an oil spill at times of high visitation, the negative impacts are likely to be magnified both on natural communities (i.e., reduction in abundance and diversity of marine organisms) and human activities (i.e., decreased level of satisfaction for snorkelers, kayakers, and surfers; health risks to intertidal food resources) (Fig. 5.1).

Ecological Restoration

In the Galápagos Islands, attempts to restore aspects of the marine ecosystem lag behind terrestrial efforts. While in some tourist sites and no-take zones a few fish species have increased in numbers, the results are only restricted to some areas with a good level of protection (Castrejón and Charles 2013, p. 277). In order to increase the resilience of this social–ecological system, we need to reduce the stressors present on the islands and to manage for diverse and resilient communities. Control of incoming boats to check for unwanted species is key. The lessening of human impacts through modest rates of development, reduction of impacts from tourism, and the implementation of stricter regulations are also needed. These should help to increase the resilience of the rocky intertidal of the Galapagos Islands so that future natural stressors can be absorbed with greater ease.

Increasing the Resilience of Galapagos Rocky Shores SES

There have been multiple uses of the term resilience since its introduction to ecological literature in 1973 (Gunderson 2000, p. 332). Gunderson (2000) evaluated the numerous definitions for ecosystem resilience and found that it was often referred to either as the amount of disturbance a system could withstand before suffering a change or as the time required for an ecosystem to return to its state prior to the disturbance. Other definitions contain variations of these ideas, including the ability of a system to absorb an impact and reorganize to retain structure and continue to provide the same functions prior to the disturbance (Folke 2004, p. 333). For the purpose of this paper, resilience is defined as the ability of a social–ecological system to return to its original state after a disturbance and maintain the social and ecological systems it provides to humans.

Ecosystems are highly complex and can be heavily affected by human interference (Folke 2004, p. 333). Impacts that may have weak or no effects now could represent a significant problem for the resilience of the system due to a larger population size, particularly for those populations that are endemic or have low abundances (MacLeod et al. 2012; Boersma et al. 2013). In the case of the rocky intertidal system of Galápagos, the balance between goods and services provided by a functioning ecosystem with a collection of rare and unique species requires special attention of management measures and relevant indicators to prevent irreversible change.

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Chapter 6
Remote Sensing of the Marine Environment: Challenges and Opportunities in the Galapagos Islands of Ecuador

Laura Brewington, Brian G. Frizzelle, Stephen J. Walsh, Carlos F. Mena, and Carolina Sampedro

Abstract Analysis of marine and coastal systems is of fundamental importance to environmental scientists, engineers, and managers. Since the 1960s, remote sensing has played an important role in characterizing the marine environment, with particular emphasis on sea surface features, temperature, and salinity; mapping of shorelines, wetlands, and coral reefs; local fisheries and species movements; tracking hurricanes, earthquakes, and coastal flooding; and changes in coastal upwelling and marine productivity. This chapter reviews marine applications of remote sensing worldwide, exploring contemporary satellite systems, research themes, and analytical methods. In the Galapagos Islands of Ecuador, marine remote sensing has been limited to the use of large-scale daily image-gathering systems, such as CZCS, MODIS, SeaWiFS, and AVHRR, due to persistent cloud cover and constrained research budgets. Recent advances in satellite technology and availability, however, offer new opportunities for remote sensing in the Galapagos archipelago and beyond. Moderate-resolution sensors like SPOT and Landsat continue to be relevant for regional-scale evaluations of marine and coastal environments, identifying hotspots or focal areas for the use of more fine-grained imagery like QuickBird, WorldView-2, and aerial photographs. Radar systems like Aquarius and SAR show promise in new lines of oceanographic research, including sea surface salinity and the differentiation of mangrove subspecies. The use of ancillary or in situ data for calibration and validation of remotely-sensed image analysis can overcome the limitations of sensors used in bathymetric applications, while advances in cellular and GPS technology facilitate real-time

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reporting from citizen scientists for integrated monitoring of environmental and social change.

Introduction

Marine remote sensing is a broad field of study with a rich and expanding agenda. Applications include marine ecosystem characterizations, habitat mapping, and assessment of marine biodiversity, natural hazards management, oceanographic conditions, and cross-scale process models of seasonal and annual ocean circulation patterns. A diversity of satellite-based, remote sensing assets is available to generate views of ocean conditions around the globe. Remote observations and measurements of coastal margins, shallow seas, and deep oceans are generated at local, regional, and global scales and for historical and contemporary periods. Corrected spectral information and derived data products offer users considerable options to customize the selection and fusion of satellite remote sensing systems according to desired space-time scales. While historically the challenge was to match research questions to limited availability and iteratively negotiate the questions, data needs, and system availabilities, the challenge now is to select the most appropriate remote sensing systems that provide the optimum combination of spatial, temporal, spectral, and radiometric resolutions to address the defined problem. With these four resolutions, satellite remote sensing systems and associated data types can generate a more nuanced, scaled perspective of marine and coastal environments.

Some early optical systems have been the mainstay of marine, as well as terrestrial remote sensing, buoyed by their broad area reconnaissance capacities, spectral sensitivities, and spatial resolutions. Examples include the Coastal Zone Color Scanner (CZCS) that operated in the visible, near-infrared, and thermal infrared channels; and NOAA's Advanced Very High Resolution Radiometer (AVHRR) that extends the visible and infrared spectral regions into thermal infrared wavelengths of twice-daily imagery, used to assess sea surface temperature on a regional-global scale.

More contemporary systems have a broader range of applications for mapping and monitoring marine environments at a variety of resolutions: the Moderate-Resolution Imaging Spectrometer (MODIS) captures daily images around the globe for assessing ocean color in visible and near-infrared spectral regions at a 1,000 m spatial resolution. Hyperion and the Advanced Land Imager (ALI) have a 30 m spatial resolution and an extensive spectral range, finely sliced into over 200 spectral channels. WorldView-2 is a relatively new system for land and water remote sensing, with very high spatial resolution. TOPEX/Poseidon and Aquarius are altimeters and microwave radiometers, used for characterizing oceanographic parameters, such as sea surface height and salinity. These active systems emit pulses of energy that interact with earth surface features, whereas passive systems simply measure the spectral reflectivity of solar energy. Spectral regions are often associated with key surface properties, strongly influencing response patterns. For instance, the recently launched Landsat 8 is sensitive to plant pigmentation in the visible wavelengths, chlorophyll-a (Chl-a) in the near-infrared wavelengths, and moisture content in the middle-infrared wavelengths. WorldView-2 includes a spectral channel for characterizing bathymetry of marine environments, particularly the nearshore.

In short, marine remote sensing addresses a diverse range of oceanographic parameters, ecosystem conditions, and surface and near-surface features. Challenges imposed by ocean dynamics, the extensive geographic scale of marine settings, and the complex interactions of local, regional, and global processes continue to motivate new applications in marine remote sensing. This chapter is concerned with the following: (1) commonly used derived data products, research themes, and analytical techniques in marine remote sensing; (2) early and contemporary applications of marine remote sensing in the Galapagos Islands of Ecuador; and (3) ancillary data, especially bathymetric measures and local knowledge, and future opportunities for marine remote sensing in Galapagos and beyond, emphasizing data fusion and linking across terrestrial, marine, economic, and social systems.

Key Variables in Marine Remote Sensing

Some of the methodologies used in remote sensing of the marine environment are similar to those applied in terrestrial remote sensing (e.g., classification). However, many studies that utilize marine remote sensing resources rely on a set of variables that have specific application to marine environments. Robinson (2004) notes five primary observable quantities of the ocean environment, discussed below.

Sea Surface Temperature

Sea surface temperature (SST) is the water temperature near the surface of the ocean and plays a critical role in the transfer of heat between the atmosphere and the oceans (Maurer 2002; Emery 2003). It is also tied to atmospheric and ocean circulation patterns, making it an important parameter in global climate models. Since the late 1960s, scientists have used satellite data for deriving regional or global SST measurements. Today there are several active satellites that have the ability to measure SST across a variety of spatial scales and resolutions, using both thermal infrared channels and passive microwave radiometry. Government sources often provide websites for searching and downloading raw and processed satellite data, while other organizations, such as the Group for High-Resolution Sea Surface Temperature (GHRSST), provide fused or value-added SST products. Data fusion is becoming popular as researchers attempt to leverage the benefits of each type of

SST sensor and diminish their weaknesses (Maurer 2002). These products are central to an understanding of oceanographic topics, such as the effects of upwelling on SST (Askari 2001), the relationship of SST and primary productivity (Kahru et al. 2012a), and the role that SST plays in algal blooms (Siegel and Gerth 2000).

Ocean Color and Derived Variables

Ocean color is a characteristic of seawater properties that are composed of phytoplankton, dissolved organic matter, suspended sediments, and, in certain areas, shallow seabeds (Robinson 2004). Many derived variables can be calculated from satellite-based ocean color measurements, including the concentration of Chl-a, which is a direct indicator of phytoplankton presence. Sensor-dependent empirical algorithms, such as those that require log-10 transformations of remote sensing radiance and transformed in situ measurements as inputs, are the basis for deriving Chl-a concentrations from raw images across multiple spatial and temporal scales (Kahru et al. 2012b). Such monitoring allows researchers to understand how physical processes affect biological distributions (Yoder 2000; Tang et al. 2009), such as the distribution of atmospheric aerosols, SST dynamics, inland flooding, and seasonal variances (Nezlin 2000; Siegel and Gerth 2000; Stegmann 2000).

Dissolved organic matter (DOM), like Chl-a, absorbs light in the blue part of the electromagnetic spectrum. It therefore competes with phytoplankton for light resources, and as the concentration of DOM increases, photosynthesis in the surrounding waters decreases. The presence of DOM makes it more difficult to accurately measure Chl-a concentrations via remotely sensed imagery, so much work has gone into developing algorithms that can separate out Chl-a concentrations from DOM and suspended sediments (e.g., Siswanto et al. 2011). DOM algorithms tend to be empirically based, as DOM concentration is seasonal and highly localized, most commonly found in coastal areas (Kowalczuk et al. 2005; Para et al. 2010). DOM has also been related to dissolved carbon from freshwater runoff, allowing for large-scale monitoring of this important indicator of climate change in nearshore environments (Matsuoka et al. 2012).

Suspended sediments and particulates, or total suspended matter (TSM), have similar effects as DOM in that they also inhibit light transmission and reduce phytoplankton growth. TSM is inorganic and has different spectral characteristics than Chl-a and DOM, and measuring the concentration of these elements can give researchers an indicator of water quality. TSM concentrations can be calculated with empirical, physical, or semi-analytical model algorithms, all of which require some level of in situ measurements for calibration of radiance values from passive multispectral sensors such as MODIS (Wang et al. 2012). Similar to DOM, TSM is more commonly found in coastal areas (Li et al. 2003; Binding et al. 2005; Surendran et al. 2006).

Ocean color can also play an important part in the classification of marine vegetation and seabed forms in coastal waters, as well as the creation of bathymetry layers. The reflectance of the sea bottom allows researchers to utilize similar methodologies to those in terrestrial remote sensing, where the water is shallow and transparent and contains little particulate matter (Robinson 2004). Reflectance can provide sufficient data for bathymetric mapping, typically to 20 m, although WorldView-2 imagery has shown the potential to register depths to 30 m (Tøttrup and Sørenson 2011), and various techniques have been developed for producing these maps (Philpot 1989; Stumpf et al. 2003; Haibin et al. 2008; Lyons et al. 2011).

Surface Roughness and Waves

Turbulence in the atmosphere is translated into increased wave activity, and as winds create waves, momentum and energy are transferred from the air to the ocean surface (Janssen 1996; Ly and Benilov 2003). Understanding this transfer of energy is important in properly parameterizing global climate models (Heimbach and Hasselmann 2000), and surface roughness can be directly observed using satellite imagery via both passive microwave radiometers and active microwave sensors (Robinson 2004). The magnitude of surface roughness has a direct effect on momentum transfer between the sea and the atmosphere, which itself influences other broad-scale processes such as atmospheric circulation, wave growth, and storm surges (Johnson et al. 1998; Taylor and Yelland 2001).

Wave spectra, or the combination of wave height and direction, can be derived from roughness variables. Satellite-based measurements of wave height using synthetic aperture radar (SAR) began in 1978 with the launch of Seasat (Heimbach and Hasselmann 2000). A number of current or recently decommissioned platform boast radar altimeters designed for capturing roughness and wave height, including TOPEX/Poseidon, ERS-2, Geosat-FO, Jason-1 and Jason-2, and Envisat. Data on wave heights provides critical information to industries involving shipping, oil exploration, fisheries management, and environmental protection of coastal resources.

Currents and General Circulation

Currents have a direct impact on climate, biodiversity of the oceans, and ocean-related industries. While there are many different means of understanding currents at the local scale, satellite imagery allows us to gather this data along entire coastlines and across oceans. Satellite imaging of currents is calibrated with in situ measurements of moored and floating buoys and ocean drifters. Thermal infrared sensors are one source of data on currents as they provide measurements on SST, which can define current boundaries and be tracked to determine the path and velocity of the current. Ocean color sensors can additionally allow scientists to track the movement of visible features, such as Chl-a plumes, along a current. SAR is used to identify spatiotemporal variations in oceanfronts, allowing for the creation of current tracks, and satellite altimetry has been used to derive ocean height dynamics, improving tidal charts and increasing scientific knowledge of tides and circulation variability (Garzoli and Goni 2000; Klemas 2012).

El Niño-Southern Oscillation (ENSO) events lead to altered currents, rises in sea level, increases in sea surface temperature and salinity, and changes in the thermocline. The Tropical Ocean-Global Atmosphere (TOGA) program, a component of the World Climate Research Programme that ran from 1985 to 1994, facilitated a richer understanding of ENSO events, and since then the use of remote sensing in ENSO research has gradually increased (McPhaden et al. 1998). Numerous studies link ENSO to fisheries (Carr and Broad 2000), surface circulation (Cai and He 2010), SST (Ballabrera-Poy et al. 2002), physical and biogeochemical processes (Hong et al. 2011), seasonal upwelling (Hong et al. 2009), sardine recruitment (Gomez et al. 2012), eastern Pacific leatherback turtle foraging (Saba et al. 2008), Chl-a concentration (Sasaoka et al. 2002; Yamada et al. 2004), and coral bleaching (Carriquiry et al. 2001).

Sea Surface Salinity

Sea surface salinity has strong effects on circulation in coastal zones, and it impacts energy exchange in the air-sea interface (Le Vine et al. 2000). Measurements of salinity can also be used to better understand the impacts of freshwater runoff, ice melt, and large-scale meteorological events such as hurricanes and monsoons (Lagerloef 2000). As recently as 2000, the ability to map salinity with satellite imagery was still beyond the capabilities of current technology. Some L-band microwave systems have been used over the past decade to derive measurements of salinity, though those instruments were not designed with this goal in mind (e.g., Burrage et al. 2008; Martin et al. 2012; Yueh and Chaubell 2012). Promising early results have been derived from NASA's 2011 Aquarius satellite mission, the first designed to specifically measure salinity from space (Le Vine et al. 2013).

Table 6.1 summarizes the specifications for some of the key satellite systems from the 1970s on that have been widely used in marine applications. Even for systems no longer acquiring information, historical archives remain a valuable informational asset.

Table 6.1 Summary of satellite systems, sensors, and data products commonly used in marine remote sensing

Satellite system	Sensors	Country	From	To	Sensor type	Designed for
GOES-1 to GOES-7	VISSR	USA	1975	Mid-1990s	P	SST
Meteosat (1–7)	VISSR	Europe	1977	Current	P	SST
Seasat	SMMR, Scat, SAR, RA	USA	1978	1978	A	SSH, WS, SST
TIROS-N	AVHRR	USA	1978	1981	P	SST
Nimbus-7	CZCS	USA	1978	1986	P and O	OC
NOAA (6–17)	AVHRR/2, AVHRR/3	USA	1978	Current	P	SST
Geosat	RA	USA	1985	1990	A	SSH
MOS-1A/1B	MESSR, MSR, VTIR	Japan	1987	1992	A and P	SST
ERS (1 and 2)	ATSR, ATSR-2, AMI, RA	Europe	1991	2011	A	WH, WS, OC
TOPEX/Poseidon	POSEIDON-1, TOPEX	USA/France	1992	2006	A	SSH
GOES-8 to GOES-15	GOES-IM Imager	USA	1995	Current	P	SST
ADEOS 1	OCTS, NSCAT	Japan	1996	1997	A and P	OC, WS
IRS-P3	MOS	India	1996	2006	P	OC
SeaStar	SeaWiFS	USA	1997	2010	P and O	OC
TRMM	TMI	USA/Japan	1997	Current	A	SST
QuikSCAT	SeaWinds	USA	1999	2009	A	WS
IRS-P4/OceanSat-1	OCM, MSMR	India	1999	2010	A and P	OC, SST, WS
KOMPSAT-1/2	OSMI	S. Korea	1999	Current	P	OC
Aqua	MODIS, AMSR-E	USA	2000	Current	A, O, and M	SST, OC
Jason-1	Poseidon-2	USA/France	2001	Current	A	SSH, WH, WS
ADEOS II	AMSR, GLI, SeaWinds	Japan	2002	2003	A and P	OC, WS, SST
Envisat	ASAR, AATSR, MERIS	Europe	2002	2012	A and P	SST, OC, WS
Jason-2	Poseidon-3	USA/France	2009	Current	A	SSH
SAC-D	Aquarius	USA	2011	Current	A and P L-band	SSS

A active, *M* microwave, *O* optical, *P* passive, *OC* ocean color, *SSH* sea surface height, *SSS* sea surface salinity, *SST* sea surface temperature, *WH* wave height, *WS* wind speed

Key Themes in Marine Remote Sensing

Technologies and analytical methods for marine remote sensing have improved greatly in just the last decade, with greater abilities to detect oceanic and nearshore properties at a variety of scales. The growing number of sensors combined with advances in data telemetry and processing algorithms makes the marine application of remotely sensed data virtually limitless. The following sections describe key themes and analytical techniques in marine remote sensing that have emerged in tropical and island settings worldwide, presenting opportunities for more comprehensive and interdisciplinary research in the Galapagos.

Habitat and Migration

Ocean color and temperature remote sensing have been widely used in studies to characterize large-scale ENSO events in the tropical Pacific, employing passive optical sensors for detecting SST and Chl-a concentrations (Vialard et al. 2002; Baker et al. 2008; Lo-Yat et al. 2011; Boyce et al. 2012) and active altimeters for calculating surface winds and ocean topographic anomalies (Quilfen et al. 2000; Contreras 2002; Karnauskas et al. 2008). Some studies in the tropics linking migrating species with satellite-derived habitat variables are largely qualitative, simply overlaying track data on maps of oceanographic characteristics, without considering how physical parameters might influence migration routes (Hays et al. 2001; Lander et al. 2013). More recent maritime habitat research has applied remotely-sensed parameters to the study of tropical storm impacts and eddy formation (Dong et al. 2009; Han et al. 2012), global current systems as maritime navigation aids (Cervone 2013), coral bleaching (Baker et al. 2008; Krug et al. 2012), changes in submerged aquatic vegetation in sea grass-dominated settings using a Landsat-TM and Landsat-ETM image time series and change detection approaches (Gullstrom et al. 2006; Ferwerda et al. 2007), and the hydrologic impacts of volcanic eruptions within oceanic archipelagos (Mantas et al. 2011). Such analyses can span the full breadth of available spatial, spectral, temporal, and radiometric scales.

The availability of very fine spatial resolution imagery has also led to straightforward, nonanalytical applications in remote locations: a small number of studies have used aerial photography and QuickBird and Worldview panchromatic scenes, combined with simple visual analysis or object-based classifications to detect the presence and abundance of individuals or species colonies in glacial and aquatic environments (Barber-Meyer et al. 2007; LaRue et al. 2011; Lynch et al. 2012; Groom et al. 2011).

Fisheries

Closely linked to species migration research, fisheries science frequently applies a fusion of quantitative and qualitative data, remote sensing platforms, and analytical techniques (Mellin et al. 2009; Stuart et al. 2011). Numerous studies have linked remotely sensed variables such as sea surface height, salinity, SST, and wind speeds to the presence of pelagic species in tropical and subtropical marine environments (Maul et al. 1984; Klimley and Butler 1988; Herron et al. 1989; Zainuddin et al. 2008). Shipboard surveys, where feasible, more accurately predict species presence and abundance, but in the absence of in situ biotic information and particularly across large spatial and temporal scales, remotely sensed data have been instrumental in marine research (Murphy and Jenkins 2010; Chassot et al. 2011).

Vulnerability and Hazards

Vulnerability assessments for coastal regions apply remotely-sensed data to derive indices or generate risk scenarios based on geomorphological or biophysical parameters. Typically these studies are concerned with populated areas located along coastlines, and their vulnerability to climate change impacts (Cazenave and Llovel 2010; Rankey 2011; Scopelitis et al. 2011; AlRashidi et al. 2012) hurricanes and tsunamis (Dall'Osso et al. 2009; Eckert et al. 2012; Kumar and Kunte 2012; Romer et al. 2012), drifting contaminants such as oil spills (Helzel et al. 2011; Leifer et al. 2012), shoreline changes due to coastal sediment dynamics and ENSO events (Shaghude et al. 2003), or a set of the above factors commonly faced by island states or territories (Narayana 2011; Farhan and Lim 2012). A much smaller subset of the hazards literature focuses on man-made impacts to marine systems, such as land use change, runoff, and pollution (Nicholls et al. 2008; Ceia et al. 2010).

Hazards research draws on a wide range of resolutions within the optical sensors, finding that daily coverage satellites like MODIS, SeaWiFS, and MERIS support rapid response to disasters or susceptibility at regional scales, while fine-resolution and hyperspectral imagery prove useful in post-disaster interpretation and adaptive planning (Maina et al. 2008; Leifer et al. 2012). Trebossen et al. (2005) demonstrated that in tropical regions characterized by high cloud cover, continuous collection of radar imagery from satellites like ERS-1, ERS-2, and Envisat can provide frequent updates on shoreline evolution and response to sedimentation and erosion events.

Mangroves

Because mangroves provide shelter from tsunamis and storm events to inland ecosystems (Alongi 2002) and function as nurseries and feeding grounds for fish (Mumby et al. 2004; Nagelkerken et al. 2008), they are frequently described in the hazards and fisheries remote sensing literature (Omo-Irabor et al. 2011; Liu et al. 2013). The proximity of mangroves to human settlements and their availability as an economic resource have prompted some research to apply traditional land use/land cover change scenarios to link livelihood decisions with mangrove use and change in a sustainability framework (Walters et al. 2008; Conchedda et al. 2011). Medium resolution sensors are typically applied to mangrove monitoring at regional to large scales, including SPOT, Landsat, and SAR (Gang and Agatsiva 1992; Aschbacher et al. 1995; Green et al. 1998; Conchedda et al. 2008; Bhattarai and Giri 2011). These studies typically focus on characterizing the spatial extent of mangroves or their increase/decrease over time with respect to climate change impacts, disasters, and anthropogenic processes. Aerial photography has been utilized in mangrove research since the 1990s, particularly before the more widespread availability of high spatial resolution sensors (Chauvaud et al. 1998; Manson et al. 2001). More recently, fine- and very fine-resolution imagery like QuickBird, Worldview-2, GeoEye-1, and IKONOS has been exploited for evaluating mangrove habitat complexity at the smallest scales (Kovacs et al. 2005; Proisy et al. 2007; Heumann 2011a; Satyanarayana et al. 2011; Liu et al. 2013).

Beaches

Aside from particular ecosystems and habitats such as mangroves and coral reefs, marine management relies on having accurate habitat maps across coastal regions to identify areas for zoning and protection (Mumby et al. 1999). Shoreline monitoring via remotely sensed imagery may encompass very small areas, such as individual beaches and dunes, to entire coastlines or islands (Gould and Arnone 1997; Stockdon et al. 2002; Kelle et al. 2007; Fonseca et al. 2010). Historically, the most common shoreline detection technique was subjective visual interpretation (Boak and Turner 2005). At the very local level, Argus video imaging has been used for long-term optical shoreline observation of storm response, seasonal cycling, bathymetric surveys, and anthropogenic processes at individual sites where cameras can be located (Turner et al. 2006; Kroon et al. 2007; Holman and Stanley 2007).

Image Analysis

Classification

There is a broad literature on marine remote sensing classification, the process of categorizing distinct shoreline and seascape features through spectral response patterns. With few exceptions, optical sensors have been the predominant data source in classification studies. Analytical techniques applied to multispectral imagery in mangrove research range from supervised/unsupervised classification, object-based classification, and more sophisticated methods like support machine vectors and fuzzy classifications (Bhattarai and Giri 2011; Long and Giri 2011; Heumann 2011b). The classification of coral reefs is fairly common, with studies using a combination of medium-resolution public imagery and high-resolution commercial imagery to compare and contrast the benefits of each product (Mumby and Edwards 2002; Andréfouët et al. 2003) and hyperspectral airborne imagery to study the effects of scaling up from species-level data to community-level classifications (Andréfouët et al. 2004).

Other classification studies include automated (Steimle and Finkl 2011) and manual (Chauvaud et al. 1998) mapping of marine environments, identification of biological hot spots (Palacios et al. 2006), and habitat mapping for tracking fin whales and striped dolphins (Panigada et al. 2008). Recent work has focused on improving feature classification accuracy and process assessments at the land-water boundary, using fine-resolution sensors to compare and contrast analytical techniques (Fonseca et al. 2010; Collin and Hench 2012). As a cost-effective alternative to Light Detection and Ranging (LiDAR) data, Knudby et al. (2011) verified the utility of optical, object-based models for classifying reef benthos and geomorphology from fine-resolution satellite images. Spatially explicit modeling scenarios utilize both fine- and coarse-grained imagery, but the high costs of QuickBird, IKONOS, WorldView-2, and other sources frequently preclude analysis at the habitat level (Andréfouët et al. 2005; Hamel and Andréfouët 2010).

Indices and Derivatives

There have been few tropical marine studies in which the derivation of indices from remotely sensed imagery was a major component. The multivariate ENSO index was used along with derived net primary productivity to aid in leatherback turtle conservation management (Saba et al. 2008), while the creation of a temperature index was used to better understand the migration patterns of sei whales (Kimura et al. 2005). Improvements in tagging and geo-location technologies have facilitated rigorous statistical analyses of physical characteristics, from bootstrapping techniques (Tremblay et al. 2009), to generalized additive mixed models (Gremillet et al. 2008; Panigada et al. 2008; Peery et al. 2009; Shillinger et al. 2011), and randomization testing (Kobayashi et al. 2011). Complex two-dimensional modeling scenarios have been developed to predict marine habitat use and movement typically at large (1 km pixel resolution or more) spatial scales; while at smaller scales, contemporary research using three-dimensional models that integrate remotely sensed bathymetry and vertical temperature stratification finds that seafloor characteristics explain more variability in habitat use decisions and hot spot formation (Nur et al. 2011; Palamara et al. 2012).

Change Detection

The mapping and change detection of landforms, beach deposition, and erosion at regional scales have been widely achieved using low-cost Landsat and SPOT imagery (Siddiqui and Maajid 2004; Kelle et al. 2007). Photogrammetry and topographic data collection have provided additional opportunities for geomorphological and bathymetric shoreline analysis. For bathymetry at fine resolutions, stereo aerial photography provides a higher resolution complement to optical and LiDAR sensors (Boak and Turner 2005), where over large areas NASA's Airborne Topographic Mapper (ATM) facilitates three-dimensional shoreline characterization and change detection (Stockdon et al. 2002; Sallenger et al. 2003). Two studies used Landsat imagery to map spatial and temporal changes in sea grass distribution (Gullstrom et al. 2006; Ferwerda et al. 2007), while Shaghude et al. (2003) manually identified sediment dynamics in Zanzibar. Tang et al. (2009) used low- to moderate-resolution marine remote sensing platforms to investigate changes in Chl-a distribution and other biophysical variables following the 2005 tsunami. The temporal extent of aerial photography has also proven useful in change detection studies: Fromard et al. (2004) traced 50 years of mangrove habitat transitions using a combination of historic aerial photographs and SPOT imagery, but the spectral limitations of aerial photography preclude complex analyses of environmental characteristics.

Data Fusion

Sensor fusion has gained widespread acceptance for the study of terrestrial and marine environments by integrating data acquired from remote sensing systems of varying spatial, spectral, temporal, and radiometric resolutions. With the vast array of space-based systems, the challenge is to select the most optimum systems to characterize key features of the phenomena under consideration. Underwater topography for coastal areas was mapped through a combination of TerraSAR-X data to characterize ocean waves and QuickBird optical data to map bathymetry in shallow, coastal settings (Pleskachevsky et al. 2011). Askari (2001) developed indicators of upwelling identification caused by eddy interactions with bottom topography by fusing AVHRR, ERS-1, TOPEX/Poseidon/ERS-2, and OrbView/SeaWiFS imagery to integrate measures of SST, ocean color, sea height anomalies, and the appearance of striations that formed along the boundaries of the eddy. MODIS and SeaWiFS have also been integrated to examine changed in the pattern of Chl-a content and sea surface temperature related to the 2004 South Asian tsunami.

The vulnerability and hazards literature currently offers the most comprehensive synthesis of social, marine, and terrestrial data sources, because of the proximity of human communities to vulnerable coastal zones. Coastal inundation presents particular risk to communities, and integrated observation strategies are needed to monitor associated processes such as erosion, flooding, tidal anomalies, and changes in nearshore geomorphology by combining radar and moderate-resolution imagery with data sources on terrestrial rainfall, ocean surface winds, and cloud cover (Morris et al. 2005; Tralli et al. 2005; Brock and Purkis 2009).

Marine Remote Sensing in Galapagos

In the Galapagos Islands, with their unique geographic and geologic configurations in the tropical Pacific, the application of remote sensing in the terrestrial and marine environments has been relatively sparse. Part of the reason for this is the persistent cloud cover and masking effects on data sets acquired by optical sensors. Often, multi-temporal composites are constructed that cover a 10- to 14-day period to reduce the aerial effects of clouds over land and water. Data acquired by radar systems reduce the impact of clouds and water vapor on spectral response patterns. The fact that the Galapagos archipelago is composed of numerous small islands and rocky outcrops has also minimized the relevance of coarse-grained systems, although several islands, including the populated islands, are sufficiently sizeable for the application of data from AVHRR and MODIS.

The earliest remote sensing applications in the Galapagos archipelago began in the 1980s, with the use of the CZCS and AVHRR satellite data for evaluating oceanographic trends in primary productivity, ocean color, and SST during the severe 1982–1983 ENSO event that affected nearly every aspect of plant, animal, and marine life in the islands (Feldman et al. 1984; Legeckis 1986). Subsequent work linked longer-term, larger-scale data sets from sensors like SeaWiFS and MODIS to describe the unique and seasonal oceanographic characteristics of the Galapagos (Palacios 2002; Sweet et al. 2007) and their relationships to corals (Wellington et al. 1996), phytoplankton blooms and biological hot spot formation (Palacios et al. 2006; Pennington et al. 2006; Dasgupta et al. 2009), and ENSO events of varying severity (Leonard and McClain 1996; Wellington et al. 2001; Ryan et al. 2002; Wolff et al. 2012). Calibration of oceanographic and atmospheric models has been facilitated by the use of satellite data records and augmented by in situ data collected within the tropical Pacific (McClain et al. 2002; Sweet et al. 2009; Montes et al. 2011; Karnauskas and Cohen 2012). The fusion of remote data sources enabled Schaeffer et al. (2008) to identify key hotspots for diversity within the archipelago.

There have been two maritime applications of remotely sensed data to link species migrations and habitat use within and around the Galapagos archipelago (Awkerman et al. 2005; Seminoff et al. 2008), and one study employed SeaWiFS data to link productivity to regions affected by the 2001 *Jessica* oil spill, as a measure of toxicity (Banks 2003). Contemporary utilization of imagery from hyperspectral/hyperspatial remote sensing platforms like QuickBird and WorldView-2 to analyze coastal vegetation has yielded promising results for identifying key habitats in Galapagos intertidal ecosystems, such as mangrove forests (Song et al. 2011; Heumann 2011a, b).

Ancillary Data to Calibrate/Validate Marine Remote Sensing

Bathymetry

The generation of accurate oceanographic, hydrographic, biological, and ecological data models is of extreme importance to conservation efforts and the sustainability of marine resources. Detailed bathymetric information is a key variable for coastal and marine modeling, but mapping the seafloor is difficult because it usually represents areas of nonstationarity and complex structures, such as small channels with varying orientations, coastal heterogeneity, and deep canyons within regions of gentle slopes (Magneron et al. 2010). Figure 6.1 shows three-dimensional seafloor and terrestrial surfaces for the Galapagos Islands, based on surveys conducted by the Ecuadorian Oceanographic Institute of the Army (INOCAR) and Geographic Military Institute (IGM).

Traditional bathymetric calculation involves the measurement of ocean depths using shipboard echo sounding (SONAR). Novel techniques include the use of airborne LiDAR and optical data, including spectral and hyperspectral imagery and pixel and/or object-based image processing approaches. With the support of geographic information systems (GIS), SONAR and LiDAR systems allow the generation of digital terrain models (DTM). LiDAR-derived seafloor topography also proves to be a particularly strong predictor for fish and coral richness when utilized in machine learning algorithms like maximum entropy modeling (MaxEnt) and Boosted Regression Tree methods (Pittman et al. 2009; Pittman and Brown 2011). Unfortunately, the use of boat-mounted SONAR and airborne LIDAR systems is limited by their very high cost and the constraints imposed by geographic accessibility.

Compared to traditional shipboard echo sounding, optical remote sensing methods offer more flexibility, efficiency, and cost-effective means of mapping bathymetry (Gao 2009). Newer optical systems like WorldView-2 and the

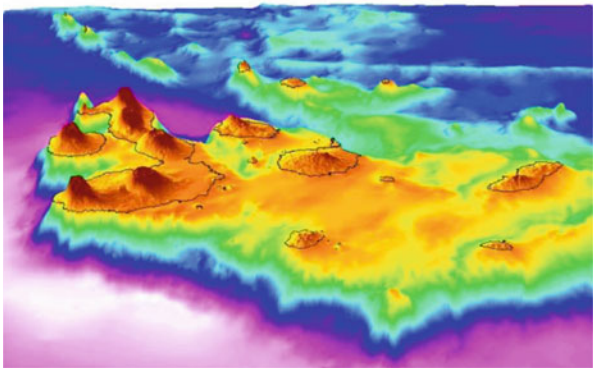

Fig. 6.1 Digital terrain model of the bathymetry and topography of the Galapagos archipelago

Hyperspectral Imager for the Coastal Ocean (HICO) have been used to characterize the seafloor, opening a new frontier in the generation of bathymetric models for coastal areas (Lee et al. 2011; Lucke et al. 2011). Optical and nonoptical remote sensors can detect submerged terrain conditions down to 30 m (Gao 2009), but environmental factors affect the ability of sensors to accurately assess ocean depth, including atmospheric conditions, water turbidity, bottom material, and waves. Because of these uncertainties, the validation of remote sensing data with oceanographic surveys has been deployed with good success. Deidda and Sanna (2012) used the coastal channels in a stereoscopic pair of WorldView-2 images to generate a basic model of depth that was calibrated using a traditional bathymetric survey. Ohlendorf et al. (2011) and Cerdeira-Estrada et al. (2012) used all eight multispectral channels of WorldView-2 to map bathymetry and benthic seafloor, validated with traditional bathymetry data. For the Galapagos Islands, the use of remote sensing for benthic habitats and detailed bathymetry mapping has great potential. Bathymetric surveys can be used to calibrate models that are applied to other areas, where there are gaps in the information needed to characterize coastal features (Fig. 6.2).

Local Knowledge and Citizen Science

Finally, the use of community knowledge and citizen science is now being linked to marine remote sensing data as a complementary source of information about key species. Jaine et al. (2012) integrate data collected by dive operators off the Great Barrier Reef into complex additive, spatially explicit models to successfully predict seasonal manta ray use of a coral reef. In terms of management applications and marine spatial planning, spatial analytical approaches can also integrate fishery demands and local knowledge sources. Howell et al. (2008) report that Hawaii's Turtle Watch program features input from fishers, loggerhead turtle tracking data, and remotely-sensed parameters in three dimensions to maintain a sustainable

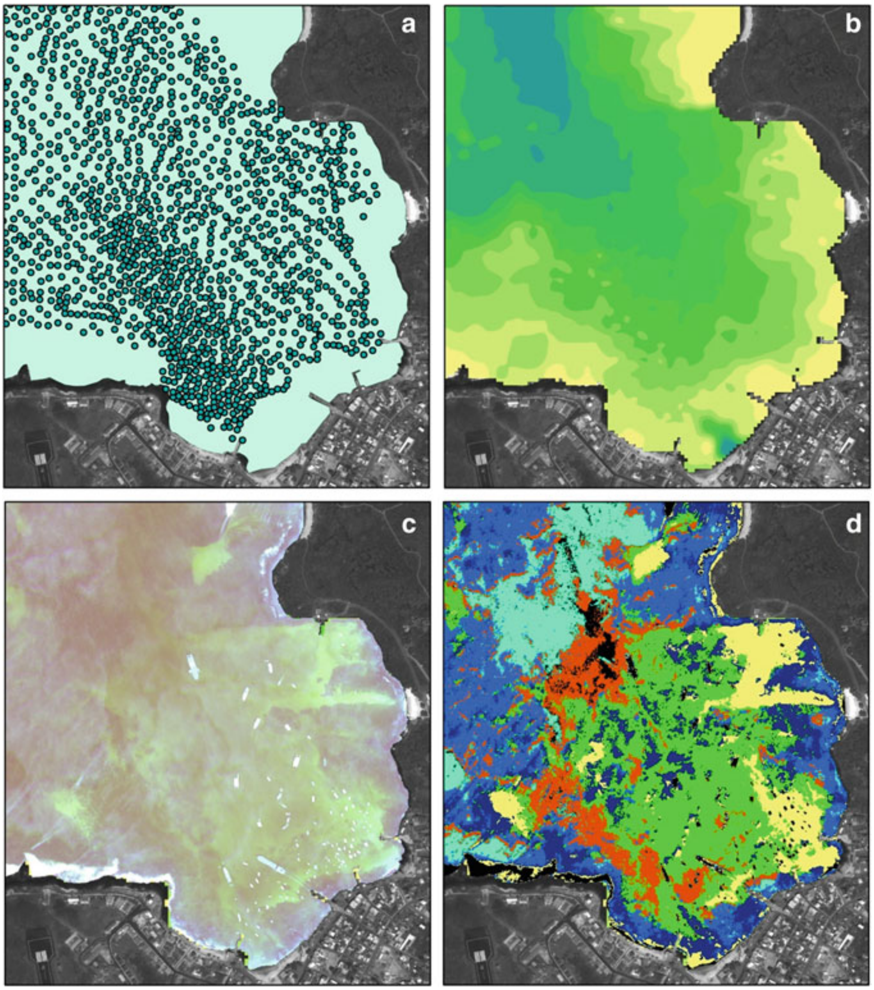

Fig. 6.2 Bathymetric characterizations of Wreck Bay, San Cristobal Island: (**a**) traditional bathymetric survey generated by INOCAR; (**b**) a continuous surface created by interpolating depths of the bathymetric survey, where darker shading represents greater depths; (**c**) a WorldView-2 scene that shows the combination of the coastal, green, and yellow channels, indicating landscape features; and (**d**) an unsupervised classification of the WorldView-2 scene to show different types of conditions at different depths

swordfish fishery, while "ground truth" data using habitat knowledge from resource users can aid in the interpretation of remotely-sensed data (Kloser et al. 2001). One innovative study involved the use of indigenous ecological knowledge to aid a supervised classification of a marine lagoon (Lauer and Aswani 2008). Given the large number of tourism and fishing boats operating in the relatively small Galapagos Marine Reserve, there is great potential for online and real-time mechanisms that support continuous and spatially explicit reporting from tour guides, boat captains, and tourists alike.

Summary and Conclusions

Large area applicability, multi-resolution capacity, repetitive orbits, archival collections, and digital representations for fusion with other satellite assets and disparate spatial data are among the many benefits afforded by remote sensing of marine and coastal environments. The limited remote sensing analyses that have been conducted over the Galapagos marine environment typically employ coarse-grained satellite systems for the study of archipelago-wide attributes (e.g., ENSO events and oil spills). Nevertheless, borrowing from preliminary work in Galapagos and contemporary marine remote sensing literature around the world, marine science and management can benefit from incorporating the following:

Taking advantage of higher resolutions and increasing satellite system options. Marine remote sensing has traditionally utilized active and passive sensors across a wide range of spatial resolutions to capture and analyze data related to biophysical aspects of the oceanic and nearshore environments, as well as climatological phenomena. New systems now provide an opportunity to push the limits of what we can discover from space as sensors with finer spatial resolution, larger spectral resolutions, and shorter temporal resolutions are being launched every year, enabling researchers to interpret marine and coastal environments at scales previously unimaginable. In 2014, for example, WorldView-3 will be launched with improved resolution across all scales. Additionally, there is a growing trend of satellite constellations that work towards a single purpose. In 2016, NASA will launch their Cyclone Global Navigation Satellite System (CYGNSS) that will consist of eight microsatellites that monitor oceanic and meteorological dynamics related to cyclone development. As satellites continue to be launched by government agencies and private companies around the world, researchers can anticipate more affordable, accessible imagery and derived data products.

System fusion (e.g., optical and nonoptical data systems, fine- and coarse-grained resolutions, contemporary and historical periods) and the assembly of data products operating at the pixel and object levels. Operationally, the fusion of multiple systems into single analyses is now the rule rather than the exception as satellite assets are pooled or integrated to more effectively represent space-time scales, with the local being nested within the regional and an assembled image or time series contextualized through annual and/or decadal observations. Field data collection campaigns need to be coordinated to calibrate and validate remote sensing products, using tools and techniques for geo-locating observations. Advanced field electronics and specialized devices, such as data loggers, can also be employed to assess marine variables, such as salinity, temperature, and sediment deposition.

Prioritization of process over pattern. Increasingly, the goal is not only to assess marine patterns but a more complete process understanding that involves spatial organization and variable responses. The movement away from pattern to a richer understanding of marine processes has involved the upscaling of observations and measurements from fine-grained imagery and downscaling from coarse-grained imagery, as well as the extension in time through image time series and the compression in time of short-term marine processes. In coastal areas, satellite assessment of linked terrestrial and marine subsystems acknowledges the integration of, for instance, sedimentation due to deforestation and urban development, beach degradation, and habitat alteration caused by the destruction of fringing mangroves and coral reefs.

Linking to the human dimension. Populated island and coastal environments are increasingly being viewed as coupled human-natural systems, necessitating the union of terrestrial, marine, and social sciences in research. Linking remote sensing systems to the human dimension is vital to discerning the human imprint across the landscape (Crews and Walsh 2009) as well as the importance of human agents and actions. In Galapagos as in other similar settings, residents in coastal and highland communities rely upon a complex household strategy of livelihood diversification in agriculture, tourism, and fisheries to manage economic and environmental uncertainty. They are tied to the onset of ENSO events that comparatively advantage terrestrial systems at the expense of marine conditions, global economic crises, and public policy that impacts the service sector. Changes in ocean temperature and primary productivity create feedbacks from the marine to the social systems through threats to livelihoods and community sustainability.

Remote sensing assets are expanding in number and capacity, and spatial patterns are increasingly being explicitly linked to social and ecological processes. Marine remote sensing will continue to be of pronounced interest and should be implemented as an approach for monitoring high priority variables, processes, and environments. In the Galapagos archipelago and beyond, the integration of increasingly available data derived from fixed-point sensors, floating instruments, aerial photography, local knowledge, and satellite systems will facilitate both discrete and continuous assessments in support of scientific research and management efforts.

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Part II
Coupled Socio-Ecological Marine Systems

Chapter 7
Development of the Galápagos Marine Reserve

Günther Reck

Abstract The Galápagos Marine Reserve, declared 1998, was the result of a long scientific and political process, which spanned several governments, starting 1973 with the first management plan for the Galapagos National Park and the following biodiversity evaluation and conservation proposals by Wellington (1975). Discussions about governance, institutional jurisdictions, and compatible resource uses delayed the legal declaration of a marine protected area, until 1986, when a marine resource reserve was legally established. Until the final establishment of the Galápagos Marine Reserve, however, several initiatives for management planning and conservation failed due to lack of management capacity, interinstitutional agreements, and priority of the marine environment. Thus, even after the creation of the RRMG, new illegal fisheries for sea cucumber joined, increasing pressures due to industrial fisheries, shark finning, and overexploitation of coastal stocks of groupers and spiny lobsters. This recount was build after 40 years of scientific and advisory work experience in the Galapagos Islands, does not pretend to be objective and complete, and may be biased by the weight I have given to different actors and their roles in subsequent phases of development.

The First Steps

Conservation of the Galápagos marine environment was an important topic since the Galápagos National Park was created in 1959 but lagged behind efforts to preserve and restore terrestrial ecosystems. Grimwood and Snow (1966) recommended for the first time a fringe of 1,000 m along the shoreline, within which traditional fishing by the very small local fishing community was thought to be compatible. The “Master Plan for the Protection and Use of the Galapagos

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National Park" (Anonymous 1974) followed those recommendations and stated, from the onset, that "the Province of Galapagos needs to be developed along different lines from other provinces, as 88 % of its land area is National Park, where tourism and scientific research are the predominant interests, and that legislation should be passed to include a 2-mile marine zone around the Park's shores." CDF President Peter Kramer[1] refers to economic needs for the construction of a marine laboratory, "in view of the current proposals to include a large marine zone into the National Park, which could prove as important as the terrestrial zone" (Kramer 1975a, b).

It was evident that the main justification for protecting the marine area was the dependence of the many land-breeding protected marine vertebrates (reptiles, birds, mammals) on the sea for food. The importance and diversity of submarine life was known but much less evident, as this information was dispersed and invisible at first glance. Mentioning the need for zoning of the marine area, Kramer also pointed out that the Park Service and the Darwin Station were currently working on underwater zoning but that years of exploration and research would be required for an adequate census of the rich and varied marine resources of the Galapagos.

Work of Jerry Wellington and Proposal of Marine Extension of GNP 1974–1976

To gather and summarize preliminary information on marine life, the Galápagos National Park Service and the Charles Darwin Research Station asked the US Peace Corps for the cooperation of a marine biologist (Wellington 1975).

Jerry Wellington, with a minimal budget, but strong support by CDRS Director Craig McFarland, gathered an enormous amount of information within 2 years. He did not only systematize existing knowledge from various scientific expeditions over the last century and a half but also conducted an in situ inventory of most coastal intertidal and subtidal ecosystems down to 10 m of depth of all islands.

Wellington's survey concluded that the Galápagos marine communities, in relation to other insular areas, were represented by a high diversity of species, a high degree of endemism, an abundance of many species due to absence of significant human disturbance, and a biogeographic affinity not only to tropical and subtropical American shores but also to temperate areas and western Pacific elements, with a distinct regionalism within the islands, making the Galápagos quite unlike other island systems (Wellington 1984).

By the end of 1974, Wellington already proposed a marine extension to the National Park of 2 nautical miles from the shoreline, which would include the

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[1] Important actors and their function, if not detailed in the text, are mentioned in Table 7.3 at the end of the paper, just as the acronyms (Table 7.4) of the institutions involved in the history of the marine reserve.

Table 7.1 Wellington's zoning proposal

Intertidal	Shoreline	Total protection. Limited noncommercial subsistence use
Special use	Coastline to 2 nm. 96 % of coastline	Existing commercial and noncommercial harvesting under present methodology and exploitation levels[a]
Intensive use	½ nm from identified coastlines	Protection, supervised snorkeling, scuba, and science (tourism and science)
Primitive	1 nm from specific coastlines, small island communities	Protection. Visit only under permit. No extractive exploitation
Primitive-scientific	2 nm specific coastlines	Completely protected. Science, special visits under permit

[a] This referred to the established hand line fishery of the time, with a limited fleet with not more than 150 fishermen involved

largest amount of the various marine ecosystems and associated biodiversity. This 2 nm fringe around all of the islands would protect the scientific, esthetic, and educational values, encompassing the 200 m depth contour and including over 90 % of the characteristic biota. Very importantly, the area would consider existing economic activities, not excluding but regulating them through a zoning scheme and therefore protecting particularly significant and fragile features. The marine zone was also considered to protect cetaceans when approaching inshore areas and, at the same time, could realistically be controlled by the Park Service.

The suggested zonation scheme would allow ongoing artisanal fisheries activities under the direct administration of the park authority in 96 % of the coastline, whereas only 4 % would be totally protected because of their particular biodiversity, especially the relatively rare coral reef ecosystems. The proportion of totally protected coastal areas in relation to the rest was important, as it recognized the importance of coastal shallow water within 2 nm for the traditional fishery (grouper and lobster) and was very specific in the identification of the most fragile and biodiverse habitats. For the purpose of comparison, Table 7.1 shows the description of the proposed zoning classification (Robinson 1984).

First Workshop in San Cristobal on Extension of GNP

Wellington's study also showed the need of a better understanding of the fishery uses of the Galápagos marine area. Plans, within the Subsecretariate of Fisheries Resources (Ministry of Natural Resources), to develop industrial fisheries within the Galápagos and considerations of an industrial harbor in Darwin Bay (Genovesa!) were discussed, and the National Fisheries Institute by the end of 1975 even carried out an experimental bottom long-lining aboard its research vessel M/N Huayaipe. The evidence of high levels of associated seabird by catch (pers. obs.) helped fortunately to discourage such intentions, and the exclusivity of artisanal fisheries could be sustained. But to put such ideas into perspective, it is worth noting that just a few years before (1971) a Japanese industrial vessel still had cooperated with local fishermen in collecting a large amount of green turtles and that fishermen for years afterwards recalled admiringly this type of industrial—artisanal—ventures.

In 1976 the Subsecretariate of Fisheries (SRP) put me in charge of organizing a research team to investigate the local artisanal fisheries through the National Fisheries Institute (INP in Spanish). MacFarland had already been looking for support for fisheries research and offered its laboratories. With a veterinarian from INP we started to investigate the remaining lobster fishery in June 1976, after spiny lobster exportations had been prohibited in early 1976. In the framework of this project, in 1978, new CDRS Director Hendrik Hoeck brought three young biologists from the University of Guayaquil (UG), with a collaborative grant from all parties (INP, CDRS, UG) to join the investigation. Under my supervision, Tito Rodriguez concentrated on the grouper fishery, Juan Alcivar on spiny lobsters, and Mario Hurtado joined ongoing CDRS sea turtle research under Derek Green. The Galápagos National Park Service (GNPS) agreed with the research, although, so far, they had no legal authority on fisheries issues. On the other hand the active cooperation of local lobster and grouper fishermen was essential for the project.

This was the first project of interinstitutional cooperation on marine issues. Despite the declaration of conservation needs for the coastal marine areas, neither public fisheries management and research nor fishermen so far had been consulted on those issues. This joint project formed the base for the first regional workshop in 1978, where initial results were presented to the public and Wellington's marine area conservation and zoning proposal discussed. High-level government officials had come, including Fisheries Subsecretary Mena, INP Director Raúl Icaza, and Head of the Wildlife and Protected Areas Arturo Ponce, and there was a good predisposition to work together for conservation, although the alliance between park administration and fisheries authorities was yet fragile. CDRS, as always, was a driving force in those initiatives.

Even still within a military government, governance of the marine area was a potential cause of conflict between institutions. The National Park administration belonged to MAG, whereas the sea was managed by the Navy in terms of territorial control and navigation and by the Ministry of Natural Resources regarding fisheries management.

The workshop was organized on San Cristobal Island, because this was where most of the Galapagos fishermen lived. However San Cristobal was also conflictive. The National Park and the Darwin Station had relatively little presence. The terrestrial delimitation of the National Park years before had caused many conflicts, and the people on San Cristobal did not have a very positive attitude towards conservation.

There were different appreciations about the potential public acceptance of the conservation plan. The fishermen, numbering a little more than 100, were hardly organized, and no high-stake economic interests were affected. Many of them attended together with other members of the community, as rumors had circulated about the delimitation of the marine area, giving rise to fears about the restrictions proposed by the park administration and CDF.

Under those circumstances, trustworthiness was essential. Unfortunately, the GNPS representative, himself confused, presented the public with the wrong information that fisheries were to be allowed in only 4 % of the coastline and 96 % were to be totally protected, exactly the contrary of what was really intended. Even immediate correction of this misconception could not calm down the public mistrust and protest. According to Robinson's (1984) unpublished appreciation, even if it had been clear to fishermen that really only 4 % of the coastline would be protected, the selection of those areas (including small islands and islets, where grouper fisheries were traditionally important) would have led to hostile reactions. The presentation error was a welcome excuse within an already suspicious atmosphere and consolidated the subsequent opposition of the local fishing community.

Soon it became clear that the governmental authorities so far responsible for this area would not easily accept a simple inclusion of the marine area into the jurisdiction of the Ministry of Agriculture (Robinson 1984 and pers. obs.), postponing efforts for legal inclusion of the marine fringe into the National Park indefinitely.

National Planning Activities in the Early 1980s

After 1978, little progress was made for several years. The main concern was the rapid growth of the tourism industry, and a governmental high-level commission under the leadership of Raul Moscoso was called to make a specific proposal about the GNP's touristic carrying capacity, recommending once again the legal protection of the marine coastal areas of the archipelago (Comisión de Alto Nivel para Galápagos 1981). Despite its international status, the Ecuadorian CDF representative, Juan Black, with excellent contacts within government, always played a catalyzing role in those processes. Concern about the marine area must also be seen as a regional effort to consolidate national sovereignty on the territorial sea (at the time still considered to extend to 200 nm) and discussions about the convenience of joining the Convention on the Law of the Sea (Hurtado pers. comm.).

In 1980 the National Galápagos Institute (INGALA) was created to compensate lack of governance capacities at the local level and to promote local development. However, a decision at governmental level to declare the inclusion of a marine fringe into the GNP was once again opposed based on the apparent inconsistency of the project: the category of National Park in the existing legislation excluded resource exploitation, but at the same time the existing artisanal hook and line fishery received technical assistance and support, promoting better drying techniques. New fishery techniques promoted by INP and SRP, particularly the introduction of long-lining, were rejected because of their already evident incidence on turtle by catch (Hurtado pers. comm.). On the other hand, the proposed inclusion was not based on updated evaluations, and neither the obvious management agency GNPS nor SRP did have the management capacity to assume such a major addition in its obligations (Hurtado pers. comm.; Hurtado and Moya 1982, Memorandum on inclusion of marine area into GNP).

Based on the recommendations of the high-level commission, a master plan for the whole archipelago was initiated. In 1982, an interinstitutional technical commission, within the framework of the master plan, composed by members of SRP, INP, INGALA, CDRS, and GNPS made suggestions about the management and conservation of the marine area (Comisión de Alto Nivel para Galápagos: Grupo técnico 1984).

In the year 1983, the process was strengthened by technical inputs from the Marine Policy Department of Woods Hole Oceanographic Institution, which, among other studies, provided comparisons on governance of the few marine protected areas worldwide existing at that time. Their recommendations reiterated the convenience of a marine park extension and were included into the master plan (Moscoso, Parra pers. comm.; Broadus 1997; Broadus et al. 1984; Comisión de Alto Nivel para Galápagos 1985). WHOI was very active in publishing its conclusions about the marine reserve, insinuating a leading role of this institution in the creation of the reserve. At the national level, the role of WHOI is well remembered; however, opinions about the degree of influence on already existing national processes vary strongly (Moscoso, Hurtado, Parra pers. comm.).

The Galapagos Marine Resource Reserve 1986

Preparation and Declaration

Unfortunately the new Febres-Cordero government (1984–1988) rejected all of the plans prepared under his predecessor, including the master plan with its renewed recommendation for marine conservation. However, projects for massive tourism development in the Galápagos, promoted by investors from Guayaquil, and open anti-conservation attitudes by the new director of the national tourism agency led to international protests. Under this pressure, both the GNP Director Cifuentes and I were invited to join the president during his visit to the islands in early 1985, where he confirmed the government's compromise to preserve the islands. Later in the year, the extraordinary instinct and political skill of Juan Black brought together both government members of the highest level and leaders of the opposition and reach an agreement on island conservation. One of the highest ranking government members, Marcelo Santos, later became an important member of the national group of CDF and an intermediary to the president.

Soon after, a new high-level commission was formed to review the rejected master plan and adapt it to new policies (Gerzón 1987). WHOI once again was invited and had some role in advising the new commission on several issues, including conservation management of the marine area (Broadus pers. comm.).

Another important ally at the time was Agriculture Minister Marcel Laniado, a banker from Guayaquil. With his support the new forestry director, a diver and frequent visitor to the Galápagos, took personal interest in the marine conservation initiative (Sevilla 1987). Government members of the highest level at the same time members of the national group of CDF supported the initiative. Soon after, a group of scientists and managers (including DVSAP Director Arturo Ponce, GNPS Intendant Miguel Cifuentes, CDF's Juan Black and me as director of CDRS) was asked to prepare a report with justifications for a marine protected area in the Galápagos (Ponce et al. 1985; Ministerio de Agricultura y Ganadería 1986).

As can be expected, the arguments related to the biological, ecological, and oceanographic diversity; biogeographic relationships; the high level of endemism demonstrated by Wellington; the dependence of protected land-breeding marine species on resources from the marine environment; and the role as refuge for highly migratory marine mammals and turtles. However, also economic justifications were important: the need of sustainable management of artisanal fisheries resources and exclusive access for local fishermen. At the time, we did not think that banning industrial fisheries was realistic but saw an advantage in proposing exclusivity for the Ecuadorian fleet and rules for their deployment. We also pointed at the importance of the marine environment for the ongoing development and diversification of marine and coastal tourism.

For this reason, the Presidential Decree 1810-A from 1986 declared the "Galápagos Marine Resources Reserve" within 15 nm from the baseline of the archipelago, establishing an interinstitutional commission composed of seven ministries and governmental institutions to coordinate the further process of management. Hurtado (pers. comm.), at the time advisor to SRP and representative of CDF in Guayaquil, mentions the efforts to compromise the support of several ministries, whereas resistance apparently had come mainly from the technical levels within the Forestry Department who feared undue influence of particularly by SRP.

Planning the Reserve: The First Approach

Taking into account the reality of the abovementioned divided jurisdictional responsibilities (conservation, fisheries, marine police functions), the governmental interinstitutional commission named a technical group to elaborate a management plan within 360 days (Galápagos Marines Resources Reserve Technical Team 1987).

The technical commission included the GNPS (Fausto Cepeda), INOCAR (Fernando Arcos), INP (Tito Rodriguez), and INGALA (José Villa). CDRS provided assistance and scientific information and reviewed the final document.

An international commission provided assistance (Comisión Interinstitucional 1987):

- WHOI organized a seminar to evaluate the state of knowledge on the marine resources in the archipelago.
- Michelle Lemay of NOAA cooperated on marine resource management issues.
- The Marine Park Authority of the Great Barrier Reef sent Richard Kenchington who was particularly concerned with governance issues and could draw on the experience with a similarly complicated situation of multiple users in his home area.

Management Issues of the Marine Resource Reserve

As in the years before, governance issues were of particular concern, but also the zoning and therefore geographical distribution of protected/extractive use zones and the proposed management category of the reserve in this context were of great importance as it would identify the proportion of protection versus resource use. As the discussion about those issues was fundamental also for the future definitions of the Galápagos marine protected area, it seems adequate to explain some of the alternatives discussed at the time. Those alternatives were never published but are available as internal discussion memoranda.

Management Category

At the time of its creation, IUCN still used nine categories for protected areas along a broad scale from strict protection to strong human presence and resource use. The category of Resource Reserve was meant to be a preliminary category of urgent conservation, in cases where the final objectives for management were not yet defined and included, among other goals, the maintenance of open options through multiple use management, a situation which applied exactly to the Galápagos. It was by no means clear, how marine conservation and continuing use of resources should be combined. But it was clear that existing fisheries uses must be part of the management scheme.

Governance

Several alternatives were discussed during this time, all meant to provide adequate governance in the marine area where traditional jurisdictional competences that continued existed and where MAG, responsible for protected area management, never before had been active.

1. GNPS, dependent on MAG, in addition to its responsibility to manage terrestrial areas of the park, would also be responsible for a relatively small surface (not more than 10 %) of the RRMG under the category of National Park, whereas the Ecuadorean Navy (through DIGMER) and SRP would control traffic and contamination issues and resource extraction, respectively, for the remaining 90 % of the marine protected area.
2. Another option was the formation of a dedicated marine reserve administration with an associate "local committee" integrated by related Navy, fishermen, park authorities and an interinstitutional coordination with the other agencies in each of the management areas: resource management and scientific investigation and tourism.
3. A third alternative was the creation of a marine department within GNPS, supervised by the superintendant of the National Park but also by a local committee of the agencies related to marine management. Once again, in each department, there would be a close cooperation with all technical agencies (notes by R. Kenchington based on his work with the technical group).

As all public agencies were used to undivided power within their area of competition, none of them was yet really prepared to share their power within their range of jurisdiction in the interest of the marine reserve. Furthermore, with the exception of GNPS the involved agencies had no experience with marine conservation policy or practice.

The initial proposals were therefore intended to permit a slow approach of the Navy and fisheries authority towards marine conservation issues through management responsibilities assisted by technical and scientific bodies and advice. In a first, provisional period, the proposal recommended management according to the first alternative, where the park administration had only limited jurisdiction over restricted areas. Interinstitutional formal agreements should provide the necessary coordination.

Zoning

The basic agreement was that the largest part of the reserve would be a general use area with few restrictions (considering the difficulties to physically control these areas). The main body of the islands (Isabela to San Cristobal from west to east, another block connecting Pinta and Marchena, and finally Darwin and Wolf) would be exclusively allowed for local artisanal fisheries.

Within those areas very special zones, such as bays and reef areas, already defined by Wellington, would be declared as National Park or highly restricted zones. As the Forestry Law asked for a National Park to have a minimum extension of 10,000 ha (based on terrestrial ecosystem principles), the proposal arbitrarily named the whole area of Banks Bay and Bolivar Channel, between Fernandina and Isabela, as National Park.

The technical group worked for 1 year between 1986 and 1987 and finally presented its proposal, including the zoning scheme and the transitional proposals for joint reserve administration by the end of 1987.

The Second Planning Approach: The 1992 Management Plan

In 1987 the marine resource reserve category did not exist in the Forestry Law (Pérez 1987a, b), and no participative management scheme had ever existed before in the country. Intragovernmental rivalry about competencies was once again the main reason why the 1987 Management Plan and its particular administrative and zoning proposition were never approved. A new government in 1988 did not have the Galápagos on its priority agenda, and for some time nobody really felt responsible for the management of the RRMG.

By 1989 problems with fisheries kept increasing. Additionally to a significant increase of the lobster fishery, it became evident that new markets for shark fins were growing and paying well. Sharks had always been taken as incidental catch, and few people cared for sharks. But in Galapagos some fishermen did not hesitate to kill protected sea lions to use as bait for shark fishing. Public pressure on the fisheries administration led the Ministry of Industries and Fisheries, in general rather critical about conservation issues, to prohibit shark fishery, regulate the artisanal fisheries zone, limit industrial tuna fishing to an area between 5 and 15 nm from the baseline, and prohibit nocturnal and spear fisheries and the capture and finning of sharks.

I had the opportunity to propose a first draft of this ministerial agreement 151 during a visit of the minister to CDRS in early 1989, but we had limited expectations in relation to the real short-term effectiveness of legal instruments. SRP did have even less management and control capacity than GNPS in the marine area. It was nevertheless significant that for the first time the fisheries administration assumed a responsibility to legislate within the framework of the existing Resource Reserve, recognizing at the same time the input value for the future management plan.

In 1990, CDF made a renewed unsuccessful effort to gather all RRMG authorities, in order to define institutional responsibilities and priority activities within the reserve. Finally, in 1991, President Rodrigo Borja (1988–1992) established a new high-level commission (CPG) to propose effective legislation and particularly put order into the growing tourism sector.

During the first months of 1992, CPG, under the presidency of Jorge Anhalzer, and with active promotion by CDF, asked me to coordinate a technical working group to update and finish the never-approved draft of the management plan of 1987. As dean of the environmental school, I received the support of USFQ for this task. Mario Hurtado, long-time promoter of marine conservation in and outside the Galápagos, represented CDF. Other members of the group were Fausto Cepeda, coauthor of the

Table 7.2 Proposed management zones of the 1992 RRMG Management Plan

Zone	Description	Management responsibility
1	Industrial fisheries within the 15 nm outer limit and 5 nm from the baseline of the archipelago,[a] industrial fisheries exclusively for tuna within purse seines for the national fleet	SRP,[b] Navy
2	Buffer zone between the industrial fisheries zone (5 nm from the base line) and the artisanal zone, with limited large-scale fishery under special permit	SRP, Navy
3	Artisanal fishery zone with an extension of 2 nm around the main island blocks (Darwin and Wolf; Pinta, Marchena, Genovesa; and around the remaining islands, including Isabela and San Cristobal)	SRP
4	Fishery reserve zone, with special rules for traditional fisheries, located mainly in the west of the archipelago, between Isabela and Fernandina and around Fernandina	SRP
5	Most of the coastline within a narrow band of shallow water, open for established lobster and bait fishery	GNPS,[c] SRP
6	National Park in specific areas with total protection and tourism sites. The large park block proposed in the original scheme was rejected	GNPS

[a] The baseline connected, as it does today, the extreme points of the islands, including Darwin Island in the north

[b] Subsecretaría de Recursos Pesqueros, Subsecretariate of Fisheries

[c] Galápagos National Park Service

previous management plan (CPG technical staff); Arturo Izurieta (head of GNPS); Orlando Crespo (SRP); and Marina Muñoz from the Ecuadorian Navy.

Several legal and institutional aspects of marine management had changed, and the formerly proposed zoning was no longer appropriate. Nevertheless, the 1992 Management Plan adopted much of the previous proposal and formulated in detail the provisions of an interinstitutional management agreement. A local interinstitutional Control and Vigilance Commission (Navy Commander, Subdirector of Fisheries, Park Chief) was to be responsible for coordination.

Major changes were made to the zoning scheme, associated to proposed jurisdiction (Table 7.2).

By openly accepting industrial fishery in the outer area, and maintaining most of the coastlines open for established artisanal fisheries (including the coastlines within the originally planned large marine area in the west), we hoped to avoid significant conflicts about respected traditional fishing rights and practices.

In those years, the possibility and convenience of adhesion to the UN Convention on the Law of the Sea (UNCLOS) were once again discussed, as it implied replacement of the existing 200 nm territorial sea, by an Exclusive Economic Zone (EEZ), a profound change.. Ecuador had interest in increasing its jurisdiction on marine areas further than the internationally accepted 12 nm zone of territorial sea, and the RRMG was an important argument in this context. The convention for creation of the International Maritime Organization (IMO) included the possibility of declaring specially sensitive marine areas, where international ship traffic could be regulated or drastically reduced, particularly for carriers with toxic load. Those areas would

Table 7.3 Individual key players mentioned in the period up to the expedition of the special Galápagos Law (which included creation of the Galapagos Marine Reserve)

Name	Period	Position, function	Role
Juan Black Maldonado, Lic.	1968–1973 1973–1984 1984–1991	One of the two first GNP rangers. Representative of CDRS Secretary general of CDF	Promoter of many initiatives in the 1980s for marine conservation in the Galápagos
Arturo Ponce, Ing.	1968–1992	Head of Wildlife and Protected Areas Department, Ministry of Agriculture	Coauthor justification for RRMG
José Villa, MSc	1968–1998	One of the first two GNPS rangers, later subdirector CDRS, INGALA advisor	Part of team for first management plan for RRMG
Peter Kramer, PhD	1970–1973	UNESCO expert and director of CDRS. Later president of CDF	Coauthor first management plan GNP
Gerald Wellington	1973–1976	Peace corps volunteer	In charge of marine survey
Craig MacFarland, PhD	1973–1978 1984–1994	Director of CDRS President of CDF	Promoter of marine research and RRMG
Miguel Cifuentes, MSc	1974–1998	Superintendant of GNPS. Later president of CDF	Coauthor justification for RRMG. Leading/coauthor of GNP Management Plans (1984, 1996)
Günther Reck, PhD	1975–1998	Guide, INP researcher and team leader, CDRS director, MAE advisor. Since 1990 USFQ full time professor	RRMG management plan coordinator, workshop facilitator, and Galápagos Law coordinator
Raúl Icaza, Dr.	1976–1978	Director, National Fisheries Institute	Supported fisheries research team in the Galápagos
Vice-admiral Mena	1978–1979	Subsecretary of fisheries in the military government	Participated in San Cristobal workshop on marine conservation
Hendrik Hoeck, PhD	1978–1980	Director CDRS	Support of fisheries research
Tito Rodriguez	1978–1987	Member of INP team	RRMG management plan teams
Fausto Cepeda, Lic.	1978–1992	GNPS ranger and later superintendent, permanent Galápagos commission	RRMG management plan teams
Mario Hurtado, Biol.	1978–1997	INP researcher, advisor of SRP, CDF, and Ministry of Environment	Long-term promoter of Galápagos marine conservation
Raúl Moscoso, Dr.	1980–1984	Hurtado government. CDF board member	In charge of high-level commission 1980–1984
David Parra, Arq.	1980–1998	INGALA, presidential env. commission, IDB, Ministry of Environment	Responsible planning officer of regional planning processes

(continued)

Table 7.3 (continued)

Name	Period	Position, function	Role
Felipe Cruz	1982–1998	CDRS researcher, GNPS official. Facilitator for Marine Reserve Plan	Responsible for turnaround in special law debate
James Broadus, PhD	1983–1986	WHOI, director of Marine Policy Department and advisor	WHOI contributions to advance marine conservation in the Galápagos
Roque Sevilla	1984–1988	Forestry Director, Ministry of Agriculture	Promotion of Marine Resource Reserve
Marcelo Santos, Dr.	1984–1988	General inspector of the government. Presidential delegate on CDF Board	Support for CDF initiatives
Efraín Pérez, Dr.	1986–1998	Environmental lawyer	Involved in governance alternatives and advisor to WHOI group
Alfredo Carrasco, Ing.	1987–1998	CDRS subdirector, later general secretary of CDF	Support for management plan and for Galápagos Law processes in the 1990s
Arturo Izurieta, Lic.	1992–1996	Superintendent of GNPS	Planning group for RRMG Man. Plan
Jorge Anhalzer	1992–1998	Head of Galápagos Permanent Commission. Later CDF president	AS CPG head support for 1992 Management Plan process
Rodrigo Bustamante, PhD	1994–1998	CDRS Head of Marine Biology Dept.	Driver of Marine Reserve Management Plan process in 1997
Robert Bensted-Smith, PhD	1994–1998	Director CDRS	Participant in the special law process, support for RMG concept
Eliecer Cruz, Biol.	1996–1998	Superintendent GNPS	RRMG plan and Galápagos Law process participant
Pippa Heylings	1997–1998	Sociologist	RRMG Management Plan co-facilitator

Persons, whose involvement runs up to 1998, may have been active after this date, but only their involvement up to this year is mentioned

include a 40–60 mile zone around the sensible coastlines. Therefore an additional area of 65 nm (altogether 80 nm) was mentioned in the management plan, by suggestion of the Navy (Mario Hurtado, pers. comm.).

This plan was approved by the Presidential Decree of August 1992 during the last days of the Borja government, but its text was not published in the official registry, which limited its acceptance by the new administration. Interinstitutional rivalry and distrust persisted. Despite initial support for the process (Izurieta 1992), the park administration was unhappy about what it perceived as very limited executive power within the Resource Reserve. The new subsecretary of fisheries, on the other hand, opposed the plan on the assumption that it was unilaterally benefitting conservation and not resource use.

Table 7.4 Acronyms of the institutions and organizations mentioned in the article

CAAM	Presidential Advisory Committee on Environment, precursor of MAE, created 1992
CDF	Charles Darwin Foundation for the Galápagos Isles. International NGO supervising work of CDRS under an agreement with the GoE
CDRS	Charles Darwin Research Station on Santa Cruz
CPG	Comisión Permanente para Galápagos, high-level commission created during the Borja government and resuscitated 1997
DIGMER	Direction of the Commercial Fleet, under Navy administration
DVSAP	Department of Wildlife and Protected Areas, part of the Forestry directorate within MAG
GNP	Galápagos National Park
GNPS	Galápagos National Park Service
IADB	Inter-American Development Bank
IMO	International Maritime Organization, London
INEFAN	Ecuadorean Institute for Forestry and Natural Areas 1992–1998, replaced by MAE
INGALA	National Galápagos Institute, ascribed to the president to overview development in the Galápagos, 1980–2008
INOCAR	Oceanographic Institute of the Navy
INP	National Fisheries Institute, Guayaquil
IUCN	World Conservation Union, Gland, Switzerland
LOREG	Special Galápagos Law from 1998
MAE	Ministry of the Environment, created 1996
MAG	Ministry of Agriculture and Livestock, responsible for protected areas until 1992
NOAA	US National Oceanographic and Atmospheric Administration
RMG	Galápagos Marine Reserve, created by special law 1998
RRMG	Marine Resources Reserve, precursor of RMG, created 1986 by decree
SRP	Subsecretary of Fisheries
UG	State University of Guayaquil
UNCLOS	UN Convention on the Law of the Sea
UNDP	United Nations Development Programme
UNESCO	UN Educational, Scientific and Cultural Organization, strong supporter for Galápagos conservation in its initial years
USFQ	Universidad San Francisco de Quito
WHOI	Woods Hole Oceanographic Institution
WWF	Worldwide Fund for Nature

Other criticism was directed towards an excessively complicated zoning scheme. Fishermen had gained influence and power through the newly exploded sea cucumber fishery and were now organized around a very high-value fishery. Besides, they were backed by the influential trader groups of the sea cucumber market and consequently opposed any conservation project, which could limit their freedom. This development made the previous lack of stakeholder involvement in the previous planning process obvious.

The sea cucumber fishery originated profound changes within the Galapagos society and also among politicians: sea cucumber fishing was basically a mining operation which involved not only fishermen but politicians, teachers, guides, and people from all strata of the society who hoped to become rich with this highly paid and initially easy to collect resource. Defying government rules and institutions became rather fashionable, and despite the prohibition of the fishery, it just went on, backed by nearly mafia-like commercialization groups.

In relation to RRMG, this fishery basically demonstrated that:

1. The existence of a reserve by name did not have any influence on the development of new fisheries or any other resource exploitation practices.
2. The lack of management capacity on behalf of the National Park Service could not even control the illegal use of land areas on the extremely fragile island of Fernandina, where sea cucumber fishing camps were built and sea cucumbers were cooked and dried.
3. The fisheries administration was not prepared to exercise its jurisdiction in the fishing zones and supported this economically beneficial activity. Although it participated in the determination of quota, there was neither capacity nor experience for control and management. After a quota of 500,000 sea cucumbers had been established, the lack of control was demonstrated when within 2 months over five million animals had been collected without a timely management response.
4. As the fishermen were becoming more powerful, they found out that aggressive and uncompromising attitudes produced fear and respect among governmental and nongovernmental institutions and therefore were highly successful in obtaining increasing concessions from government.
5. ". . ..the lack of finance, consensus and political decision to define clear mechanisms and responsibilities of the RRMG, prevented the execution of the Plan" (Servicio del Parque Nacional Galápagos 1996).

The 1994 Workshop for Revision of the Management Plan and Processes Leading to Final Marine Reserve Project

CPG continued its labor in the government of President Sixto Durán-Ballen, this time under the direct supervision of the new presidential Advisory Commission for Environment (CAAM). In 1994 CPG, backed by a presidential decree to accelerate planning for Galapagos, with support from UNDP and, in cooperation with CDF, initiated a process of revision of the management plan for RRMG. My role as facilitator and co-organizer of the different preparatory and final workshops counted with the active participation of CDF and once again the assistance of Mario Hurtado. This time the emphasis was on legitimate representation of all important actors and institutions, which was usually very difficult because delegations were instable and not representative of their respective institutional policies. A series of preparatory workshops with fisheries (SRP and INP), tourism, Navy (including INOCAR), and INEFAN (the new Protected Area Administration) on the mainland, and with the communities in San Cristobal and Santa Cruz, were supposed to socialize the existing management plan and ask for institutional positioning for the process.

The result in participation was overwhelming: not only the expected 40 participants came to the final workshop but 90 delegates of many national and local institutions, including mayors, deputies, subsecretaries, tourism operators, and fishermen as well as the heads of the fishing industry and sea cucumber trading delegates. The latter assisted out of fear of decisions which would affect their freedom of action. This was probably the first single massive participatory event in the Galápagos, enhanced obviously by the fact that economic interests of many participants increased the curiosity and expectations (Hurtado et al. 1994).

No definite administration of RRMG was achieved but widespread conscience of the existence of the reserve and the need of its management. Despite massive criticism in the management plan of 1992, it was accepted as a starting point for discussion and adjustments. It was easy to find consensus around integrated conservation and resource goals. Nevertheless, once again discussions concentrated on zoning and governance.

The 80 nm external protection area mentioned in the 1992 plan was thought to be too ambitious to receive international recognition. However, there was a general consensus about the increase of the reserve limits to 40 nm miles from the baseline, with the active support by fishermen's leaders in change of the possibility of exclusive fishing rights within this area. This was later backed up by President Sixto Durán-Ballen (1992–1996) but because of different political circumstances, including a war with Peru in 1995, was not pushed forward for some time. A committee was formed to keep reviewing the extension of particular use or conservation zones.

In general authorities accepted to cooperate on the management of the reserve and to recognize a particular role of GNPS in managing the coastal and marine park zone areas according to the original zonation. However, the Navy and SRP also insisted on the maintenance of their respective jurisdictions and on the celebration of interinstitutional agreements for joint management. RRMG was to be coordinated by CPG, with an administrative committee including Navy, park, and fisheries organizations.

A presidential decree (1731, RO 436, May 9, 1994) finally delegated the administration to INEFAN and SRP, and in early 1995 (forced by the ongoing sea cucumber fisheries, which threatened going out of control), an interinstitutional agreement between SRP, INP, and GNPS defined institutional responsibilities and initiated fisheries monitoring on behalf of INP (CPPS 1997).

In the following period, sea cucumber fishery continued to influence public life and marine policies. At some point, the inclusion of the marine reserve into the Galapagos World Heritage was discussed, but the lack of governance in the marine area, together with uncontrolled growth of tourism, threatened to lead to the inclusion of all of the Galápagos into the World Heritage in Danger list, which was inconvenient for Ecuador.

Discussions on a Special Law for the Galápagos and the Creation of the Ministry of the Environment

In the debate about the future of the Galápagos Province, it became increasingly clear that the islands had to be ruled under special legislation and not like other provinces in the country. By the end of the Duran-Ballen government and the beginning of the Buccaram presidency (1996 to early 1997), voices for a special Galápagos Law became stronger and several law projects circulated, one even pretending to legalize the Biosphere Reserve (declaration 1984) condition of the Galápagos. In most cases the projects however favored local development with privileges for the local population.

A workshop on sustainable development issues was organized at the beginning of 1996, and one workshop group once again dealt with the management of the marine area with strong participation of the fishing sector. Antagonism between fishermen and scientists was at their peak. However, a consensus document resulted, with clear recommendations, how fisheries issues were to be included into an eventual special legislation (CPG 1996). It was important to receive a clear support for the continuation of the marine resource reserve and agreements on how the number of fishermen and fishing fleet should be limited. Many of the recommendations of this workshop were taken into account in the final preparation of the Galápagos Law.

The continuous complaints of the park authorities on lacking power in the reserve led INEFAN in declaring the marine area a "marine biological reserve" (the category "biological reserve" was the only one in existing legislation mentioning marine environments), a desperate effort to establish unilaterally jurisdiction of the marine resource reserve. This decision had no practical consequences: GNPS had no management capacity; there was no consensus with the other authorities; and, last not least, the category of biological reserve (as being the strictest protective category) was incoherent with the existing uses within the reserve.

In the course of 1996, the government created the Ministry of Environment (MAE), replacing the previously existing CAAM, but there was no time for developing policies regarding the Galápagos Islands.

Preparation of the Special Galápagos Law and the Declaration of the Galapagos Marine Reserve

At the beginning of 1997, the Buccaram government was overthrown and replaced by interim President Alarcon (1997–1998), and the newly appointed minister of environment, Flor de Maria Valverde, a university professor from Guayaquil and longtime member of CDF, gave weight to the previous discussions on the Galápagos and pursued the elaboration of the special law. On her request, and Mario Hurtado's advice, I started to create a special Galapagos unit within the ministry, to coordinate with NGOs and international organizations, securing the special support of UNDP, UNESCO, the Inter-American Development Bank (IADB), the CDF, and WWF. Particularly IADB had already been active with a project for technical cooperation for the Galápagos, and the technical group working within this project, David Parra and Edgar Pita, were incorporated into my team and contributed essentially to ongoing activities.

An immediate issue was the pending inclusion of the Galapagos into the World Heritage in Danger list, due to the many problems of local governance, which had become evident in context with the sea cucumber fishery and uncontrolled tourism growth. The government considered this declaration to be undesirable, and the goal was to create adequate legislation and policies to get the province back on track. By April, Presidential Decree 245 (RO 55, April 30, 1997) declared the conservation of the Galápagos a national priority, limited access to the islands (on paper), and created a marine interinstitutional authority (on the base of the concepts of the previous management plan) and a local control committee for the marine area. CPG was updated in its composition to include essential actors (among them the fishermen) for participative law making and was assigned the special task to prepare a law for the Galápagos. With those actions and the determination demonstrated by the government, the inclusion into the "Heritage in Danger list" was deferred to future evaluations by the World Heritage Convention.

An intensive consultation and participation process was initiated, and the Special Galapagos Law (LOREG) was elaborated article by article with the participation of all public instances and stakeholders (including fishermen). This had, with probably one exception, never before happened and was, at least, initially accompanied by a great deal of distrust on behalf of the politically active part of the Galápagos community. I mention this as the destiny of LOREG, and therefore the identification of Galápagos policies in general was closely intertwined with the creation of the Galápagos Marine Reserve.

At the same time of the participative process for the Galápagos Law, at the local level, the marine department of CDF, with the support of GNPS, had initiated a participative process of reviewing and remaking of the management plan of RRMG which in 1994 never had been completed. This time, the best conflict resolution and negotiation techniques available were applied. Felipe Cruz, a Galapagueñan, had been trained as mediator under Harvard Professor Ted MacDonald, later joined by Pippa Heylings, and a core group ("grupo nucleo") was formed, including all essential actors from the marine community. Others document this process in detail (Heylings et al. 2002). In the context of this article, it is however essential to point out how this process was decisive for the success of the Galápagos Law and therefore the creation of the RMG in its present legal condition. The ministry had decided to give unrestricted support to the planning process, although it was originally a nonofficial initiative. In summer 1997, we already had included texts about the creation of a marine reserve as a new management category and had incorporated most of the proposals for participative management of the Galapagos Marine Reserve. When the public discussion about the law proposal in the Galápagos was at its hottest point, and politically motivated opposition intended to destroy and discredit the ongoing process, the affirmation by Felipe Cruz as process leader that the law project had included all of the broadly supported proposals for participative reserve management was a decisive turning point in public discussion and was essential for the following broad support by most of the human population in the Galápagos.

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Chapter 8
Fishery Science in Galapagos: From a Resource-Focused to a Social–Ecological Systems Approach

Mauricio Castrejón, Omar Defeo, Günther Reck, and Anthony Charles

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 interdisciplinary 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.

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

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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 socioeconomic, 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 a key role 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.

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 8.1).

Table 8.1 Historical milestones in fishery 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 HMS Beagle
1864	Ending of the whaling industry
1925	First fishery study conducted by Townsend (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 sign 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 initiate 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
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 Interinstitutional Management Authority; prohibition of long-line fishing; approval of recreational fishing; recognition of Galapagos as a social–ecological system in the GNP management plan

(continued)

Table 8.1 (continued)

Year	Historical milestone
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 observer program; annual fishing calendar; opening of the sea cucumber fishery
2009	Approval of a new fishery 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 plan 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 in order 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 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) (see Chap. 7). 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 (Heylings and Bravo 2007), but neither of these was implemented (see Chap. 7).

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 8.1). 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.

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 interaction 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.

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 (IDP), 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 still 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

Table 8.2 Scientific production of the Charles Darwin Foundation from 2005 to 2011

	Peer review (ISI journals)		Technical reports, thesis, and others		
Year	Non-FR	FR	Non-FR	FR	Total
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

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 adjunct researchers (2007–2011) are included

Source: CDF annual reports (2005–2011)

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 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 peer-reviewed papers published by CDF-based scientists between 2005 and 2011 was fishery related (Table 8.2). 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.

At the international level, the joint contribution of CDF and other local and international institutions (e.g., universities, research centers, NGOs, etc.) to mainstream 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 peer-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 user 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.

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 user 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 the 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 8.2). 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.

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).

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 of 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.

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 socialecological 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.

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; González 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 ambivalent 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 trend 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-Pähle 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 crisis 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 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-Pähle 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, advisement 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 governmental 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-Pähle 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 9
Collaborative Approach to Fisheries Management as a Way to Increase the Effectiveness of Future Regulations in the Galapagos Archipelago

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Abstract For coastal fishing communities, it is becoming increasingly clear that the key to success is community-based comanagement, which incorporates all users and stakeholders in the decision-making processes about fisheries management. Established regulations can easily fail due to lack of enforcement. However, many coastal communities do not have the economic resources for the necessary enforcement and therefore rely on compliance by fishers. There are about 400 local fishers in the Galapagos Marine Reserve (GMR), who depend on the exploitation of coastal resources for their living. Evidence shows that the GMR suffers from lack of compliance; coastal resources have been overexploited and illegal fishing has been observed. The results of interviewing 26 % of Galapagos' active fishers show no trust in scientific studies, lack of income alternatives provided, no dissemination of results, and lack of participation of fishers in the studies. We argue that the abovementioned problems can be tackled by using a collaborative approach, which includes fishing community members in each step of the research process. This would foster a sense of belonging among the Galapagos fishers, who are currently an underrepresented part of the already-established comanagement scheme, which has yet to achieve sustainable fisheries in the Galapagos Islands.

Introduction

The overexploitation of coastal resources has become increasingly evident around the world. Globally, around three billion people depend on seafood as their main protein source, and sustainable fisheries management is the cornerstone of their livelihoods (FAO 2012). Stakeholder engagement and community-based

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comanagement have been recognized to be essential throughout the development of any fisheries management strategy (Gutiérrez et al. 2011; Wiber et al. 2004). Comanagement has many advantages which include the enhancement of sense of ownership to encourage responsible fishing, improved management through the use of local knowledge, and increased compliance through peer pressure and fishers controlling each other (Dietz et al. 2003; Gutiérrez et al. 2011). The enforcement of fisheries regulations, especially in small-scale fishing communities, can be a huge challenge due to lack of resources and therefore largely depends on fishers' compliance. Self-compliance can be greatly augmented through stakeholder education, understanding of need for regulations, and believing in these regulations, which will ultimately result in a more effective implementation of management systems.

Fisheries management relies on fishery science and research in order to obtain the information necessary to create regulations. Because there is a human component inherent to fisheries, the inclusion of fishers in these activities is necessary. Research efforts can involve fishers in joint activities, which can be seen as ranging from cooperative approaches, where a fisher accompanies scientists, to collaborative approaches where fishers are included in all aspects of the research (NCRS 2003; Yochum et al. 2011). For comanagement to function properly, a more collaborative approach to research would be a great advantage in comparison to the less involved cooperative one. This change from minimum involvement in research towards a full immersion in all research activities leads to more transparent communications between fishers and managers, creating a stronger relationship that will result in members of the fishing community being more likely to trust the scientific results. If fishers are allowed to participate and engage in research, and understand how scientific activities are carried out and the reasons behind them, they will be more likely to comply with the management suggestions derived from the research (Johnson and van Densen 2007).

The Galapagos Islands are presented here as an example where comanagement has been established, but has struggled particularly due to the lack of compliance of fishers to fisheries regulations (Castrejón and Charles 2013; Hearn 2008). The Galapagos Islands marine ecosystem, unique for its endemism, has been subjected to heavy fishing (small-scale and industrial) of invertebrates and reef fishes since the 1960s (Reck 1983). However, lack of regulations and the explosive growth of the sea cucumber and lobster fisheries have led to the collapse of the sea cucumber fishery and severe declines in spiny lobster stocks (Bucaram et al. 2013; Hearn 2008). In order to protect the islands' unique biodiversity and stop the overexploitation of these commercially valuable resources, the Galapagos Marine Reserve (GMR) was created. The GMR, which covers 133,000 km^2, was established in 1998, and with it a ban on industrial fisheries and a zonation plan of all coastlines enacted. Along the coastline fishing is permitted in 78 % of the area, with the remaining 22 % made up of several no-take areas and tourist visitor sites (Calvopina and Visaira 2005).

With the creation of the GMR, a fisheries management plan was established based on a comanagement regime to promote sustainable marine resource use.

The objectives of this plan included the creation of refuge zones where fished species could recover from overexploitation and fishing could be regulated through other management tools such as closed seasons, total allowable catch limits, and minimum landing sizes in order to achieve sustainable fisheries. One of the main goals of developing a comanagement scheme, rather than a top-down approach, was to reduce conflicts among the various users (SPNG 1998). However, the major fisheries resources have been overexploited with no signs of recovery and many ensuring challenges, on both institutional and socioeconomic levels, still have to be overcome (Castrejón and Charles 2013; Hearn 2008; Wolff et al. 2012). Today in the Galapagos archipelago, there are 1,035 registered fishers, of which only about 470 are active (GNP Database 2010). This reflects the economic downturn in the Galapagos fishing sector, as fishing has not been profitable for most fishers, who have over the last 10 years left the islands or discontinued fishing commercially. Furthermore, the currently active fishers can still be considered an overcapacity as resources are not recovering and continue to decline. To reduce overexploitation and secure the fishers' livelihoods, alternative income opportunities have already been proposed in Galapagos (Palacios and Schuhbauer 2013).

Tourism in Galapagos is booming and it is the archipelago's main source of income (Epler 2007), with an increase from 40,000 tourists in the 1990s to 185,000 in 2011 (GNP Database 2010). Therefore, it is not surprising that fishers are attracted to this lucrative sector while fishing has become less profitable. Linking fishers to the tourism sector has been attempted in the Galapagos by offering two different alternatives: access to an activity called "pesca artesanal vivencial (PAV)" (recreational fishing for tourists) in 2005 and granting them new permits for tourism operations in 2009 (Palacios and Schuhbauer 2013; Schuhbauer and Koch 2013).

The implementation of the comanagement regime has been a step in the right direction; however, the established objectives have not yet been met mainly due to the lack of enforcement and high rates of noncompliance (Castrejón and Charles 2013). The latter result from the view held by some fishers that fisheries management strategies, especially no-fishing zones, are illegitimate (Viteri and Chávez 2007). The root of noncompliance can be traced back to the lack of credibility and legitimacy that fishers have in the comanagement of the GMR (Castrejón and Charles 2013). This lack of credibility leads to unhealthy relationships between the fishing communities and management agencies (Kaplan and McCay 2004; Hartley and Robertson 2006; Johnson and van Densen 2007), which have the ultimate effect of undermining management actions. These injurious relationships can be alleviated by collaborative research, where close participation by all parties involved creates avenues of communication that ultimately build, rebuild, or strengthen communications (Conway and Pomeroy 2006; Hartley and Robertson 2006).

In this study, we evaluated the perceptions that Galapagos fishers have of scientific research aimed at advising management, their perception towards participation in these studies, and sources of income alternative to fishing. We propose a collaborative research approach as a way to increase the effectiveness of future management efforts in the Galapagos.

Methods

Study Area

The GMR lies 1,000 km off the coast of Ecuador and encompasses a marine area of approximately 133,000 km^2. Three major ocean currents are responsible for its unique dynamics and variability of weather, climate, biodiversity, and productivity. The Galapagos is renowned for its high endemism in both marine and terrestrial ecosystems. Commercial fishing started in the 1940s when the Galapagos sailfin grouper (Bacalao, *Mycteroperca olfax*) represented almost the totality of landings (Reck 1983). In the early 1990s most of the fishing effort switched to sea cucumbers, but by 1994 the fishery had collapsed, resulting in a 5-year moratorium followed by a strict management plan starting in 1999 (Murillo et al. 2002; Reck 2014). As a consequence of this enormous growth in the sea cucumber fishery, the number of fishers in the GMR increased from 392 in 1993 to over 1,000 in 2001, when the official registration for local fishers was closed (Bremner and Perez 2002; GNP Database 2010). However, of these 1,035 registered fishers, only about 400 are currently active. Over the years, levels of conflict between the fishing and management communities have been evident. Some of these conflicts escalated in the past and fishers organized public protests, took over park offices, and even kidnapped giant land tortoises (Finchum 2002). This conflict has origins, according to fishers, in the lack of inclusion of the fishing community in the decision-making process and the lack of communication between the Galapagos National Park (PNG), the Charles Darwin Foundation and the fisher community (Finchum 2002).

Interviews

In order to test the perceptions of today’s fishers towards research aimed at advising management suggestions, we used a questionnaire that was presented to participants. Fishers were approached at the main fishing landing sites on the islands of Santa Cruz, San Cristobal, and Isabela between February and April 2012. Previous conversation with fishers and other scientists informed us of their aversion towards long interviews; therefore we designed a structured and standardized questionnaire composed of 11 questions that would take about 20 min to complete. The questions were designed to explore the perceptions of fishers towards research used to advise management, the way fishers felt about being included in these studies, and preferences for alternative sources of income. Trained personnel administered the questionnaire by approaching fishers at the landing dock and asking permission to conduct an interview. In no case did an approached fisher refuse to participate in the survey. Based on previous work with the fishers and the park rangers, we found that fishers were more easily convinced to participate when approached by personnel not directly involved with PNG, since park personnel are viewed as regulators and enforcers. Furthermore, interviewers who participated in this survey had already gained the fishers' trust by working closely with them and by guaranteeing their anonymous status. We therefore felt that the majority of the answers we were given were truthful. Following each interview, fishers were asked to suggest fellow fishers who could be interviewed; these individuals were sought out and usually found at the fishing dock where they were also asked to participate in the interview. This use of the snowball sampling technique (Goodman 1961) helped ensure an adequate number of responses.

Analysis

Because we used an open questionnaire, fishers were able to broadly express their perceptions in an unstructured way. Open-ended questions were chosen because they can provide details in fishers "own words" and can provide a rich description of the respondent reality (Jackson and Trochim 2002). Answers given by fishers were coded by manually developing a coding scheme based on the frequency of the most common answers. A manual coding scheme was chosen because of the ability of a human reader to detect the subtleties and nuances of the answers given by fishers. Numerical summaries of the coded answers were generated by calculating the percentage of answers within each of the resulting coded categories.

Results

Out of the 400 active registered fishers in the Galapagos Islands, we interviewed a total of 104, accounting for 26 % of the total fishing population. Fishers were interviewed in San Cristobal (58 %), Santa Cruz (40 %), and Isabela (2 %). No fishers from Floreana were interviewed as only three fishers live there. Overall, age ranged from 19 to 80 years, with a mean age of 42.4 years old and a standard deviation of 11.3 years. The median age was also 42 years old. Regarding place of origin, 42 % of interviewed fishers were born in the Galapagos Islands, while the remaining 58 % were originally from mainland Ecuador. Reported place of origin per island and age classes are reported on Table 9.1.

Table 9.1 Reported place of origin, age group, and island of residence of fishers interviewed

		Age class			
Island of residence	Place of origin	Less than 30	31–50	Older than 51	Grand total
Isabela	Manabi			1	1
San Cristobal	Balzar			1	1
	Cotopeal		1		1
	Ensenada		1		1
	Esmeraldas	1			1
	Galapagos	3	21	9	33
	Guayaquil	1	5	4	10
	Loja			1	1
	Los Rios		2	1	3
	Machala			1	1
	Mainland		1		1
	Manabi		2	1	3
	Quito			1	1
	Tungurahua		1		1
	Valencia			1	1
	Unknown		1		1
Santa Cruz	Ecuador		1	2	3
	Esmeraldas		1		1
	Galapagos	4	7		11
	Guayaquil		3	1	4
	Guayas		1		1
	Loja		1		1
	Manabi	3	5	2	10
	Manta		4		4
	Naranjito			1	1
	Puerto Lopez	1			1
	Quito			1	1
	San Borondon	1			1
	Santo Domingo		1		1
	Unknown		1	1	2
	Total	14	60	29	103

Results are based on structured and standardized questionnaire of 104 fishers; one interview did not have any metadata, hence the total of 103

Survey Results

Perception of Fishers Towards Research Aimed at Advising Management

We explored the perceptions that fishers have towards studies aimed at providing scientific data meant to be used to advise fisheries management and policies within the GMR: 51 % of respondents perceived these studies as being bad, 26 % perceived them as good, 22 % had mixed feelings about them, and the remaining 1 %

Table 9.2 Negative perceptions of management and scientific studies in the Galapagos Marine Reserve

Reason	Percent response
No trust in studies	16.7
Studies provide no alternatives	13.1
No dissemination of results	11.9
No participation of fishers	7.1
Aimed to close fisheries	6.0
Limit income	6.0
Studies used to place regulations	4.8
Scientist work for their careers	3.6
Studies are bad	3.6
Bad choice of open or closed fishing seasons	2.4
No need for management	2.4
National park does not enforce	2.4
Conservation interested in money	1.2
Fishers know more	1.2
Studies result in less fishing zones	1.2
Low maximum allowed catch	1.2
Migratory species do not require studies	1.2
No need to close fisheries	1.2
Park makes the wrong decision	1.2
Park oppresses fishers	1.2
Regulations are bad	1.2
Regulations do not respect traditional fishing	1.2
Sea is inexhaustible	1.2
Some regulations are bad	1.2
Things will not get better	1.2
Too late for regulations	1.2
Too many limits imposed on fishers	1.2
Studies used to create closed seasons	1.2
Studies are useless	1.2

Results are based on structured and standardized questionnaire of 104 fishers

did not answer. The main reasons associated with the negative perception to these studies included lack of trust in the studies (16.7 %), lack of identification of alternative sources of income resulting from fishing closures (13.1 %), lack of dissemination of results (11.9 %), lack of inclusion of fishers in studies (7.1 %), studies aimed at closing fisheries (6.0 %), studies resulting in limits to income (6.0 %), and others (Table 9.2).

Among the main reasons associated with the positive perception towards management and scientific studies are the conservation of species (62.0 %), research activities are good (8.0 %), education of fishers (6.0 %), preventing overfishing (4.0 %), and others (Table 9.3).

Table 9.3 Reasons associated with positive perceptions towards management and scientific studies in the Galapagos Marine Reserve

Reason	Percent response
Conservation of species	62.0
Studies are good	8.0
Educate fishers	6.0
Prevent overfishing	4.0
Some regulations are good	2.0
Some studies are good	2.0
Good for socioeconomic development	2.0
Being able to see changes in time	2.0
Research is good	2.0
Information about fished species	2.0
Noticeable increase in populations after closed seasons	2.0
Inclusion of fishers	2.0
Ensure sustainability for future generations	2.0
Based on population needs	2.0

Perception of Fishers Towards Participation in Studies

Fishers were asked what they thought about the inclusion of the fishing sector in studies aimed at producing management regulations. While the majority of fishers think that they should be included in these studies (89.5 %), a few (7.6 %) thought that the fishing sector should not be included, and the remaining 2.9 % did not have an opinion.

The reasons to include fishers in the investigations aimed at advising management included the benefit from using fishers' knowledge (52.9 %), including the needs fishers have (14.7 %), and improving fishers' education (5.9 %). The remaining reasons are given in Table 9.4.

The reasons given by fishers as the rationale for why they should not be included in research aimed at producing management regulations included the lack of trust in studies (14.3 %), data going to the Galapagos National Park (14.3 %), regulations lower the fishers' income (14.3 %), fishers make bad decisions (14.3 %), national park office makes their own decisions regardless (14.3 %), the way things are should not change (14.3 %), and authorities, not fishers, should make the regulations (14.3 %).

Income Alternatives to Fishing

When asked whether they would rather work in a field other than fishing, 60.4 % of interviewed fishers responded positively, while the remaining 39.6 % answered that they would not like to stop fishing. The main alternative activities identified by fishers, who would like to work in something different, include no answer (55.7 %), tourism (22.6 %), public sector (3.3 %), mechanic (3.3 %), driver (3.3 %), biologist

Table 9.4 Reasons given by fishers as to why they should be included in research aimed at producing management regulations

Reason	Percentage
Include fishers' knowledge	52.9
Include needs from fishers	14.7
Increase fisher education	5.9
Increase information gathering	2.9
Understand fishers' way of life	1.5
Fishers are interested	1.5
Studies affect fishers' source of income	4.4
Fishers can help in the search for better solutions	1.5
Prevent management actions from closing all fishing sites	1.5
Fishers can help increase monitoring zones	1.5
Dissemination of results to fishers	1.5
Should also include tourism sector	1.5
Fishers can help make things right	1.5
Fishers should lead conservation efforts	1.5
Fishers can show locations to scientist to ensure captures	1.5
Fishers can prevent species declines	1.5
Find solutions for all	1.5
Fishers can help in creating lax regulations	1.5

Table 9.5 Occupations/activities, alternative to fishing, which fishers reported as the preferred choice for their children

Occupation	Percentage
Tourism	30.8
College	25.3
No answer	14.3
Office work	5.5
Biology	4.4
Public service	3.3
Sailor	2.2
Medicine	2.2
Tour guide	2.2
Anything with good salary	2.2
Science	1.1
Private or public sector	1.1
Fishing entrepreneur	1.1
Conservation	1.1
CDF	1.1
Business	1.1
Anything they want	1.1

(1.6 %), commerce (1.6 %), boat pilot (1.6 %), working on anything on dry land (1.6 %), and private sector (1.6 %). When asked whether they wanted their children to work in the fishing sector, 91 % responded that they would like their children to work in a different sector, 4 % responded that they would like their children to work in the fishing sector, and the remaining 5 % did not answer. The career paths/activities that fishers would like to see their children are on Table 9.5.

Discussion

The few management regulations that exist in the GMR suffer from noncompliance and although a comprehensive management plan was established in 2005 (Castrejón and Charles 2013), it could be argued that current management regulations are not adequate; however, in this study we only discuss the problems attached to noncompliance by fishers to current regulations as well as how this can be improved.

Perceptions Towards Scientific Studies

Our results indicated that only 26 % of the fishers in the GMR are in favor of scientific studies aimed at advising management. Nearly half of the opinions associated with the negative perception of these studies were lack of trust in studies, lack of alternative sources of income provided by these studies, no dissemination of results, and lack of participation by fishers. These reasons represent a common thread, which can be interpreted as the lack of participation of the fishing sector in research carried out to assist in fisheries management in the Galapagos. This lack of participation results in a lack of buy-in to management regulations, which ultimately leads to lack of compliance (Viteri and Chávez 2007). Participation of fishers in research activities can be achieved by means of cooperative or collaborative approaches. In a cooperative approach, fishers join research activities by helping in data collection or guiding scientists during fishing trips. Although these practices are common procedures in Galapagos, the involvement of fishers in developing the objectives and implementing the research is minimal. A collaborative approach, on the other hand, includes fishers in all aspects of the research. Collaborating with fishers in this sense means including them in formulating research questions, choosing a methodology, generating hypothesis, field work (data collection), data analysis, and dissemination of results (NRC 2003). However, for collaborative research to function, both the scientists and the fishers need to be willing to openly participate. The following section explores the willingness of fishers in the GMR to participate in collaborative projects.

Perceptions Towards Participation in Scientific Studies

The dominant perception among the majority of fishers is that they should be included in research activities (89.5 %). This shows great promise in helping enhance future participatory research efforts in the GMR. The use of local ecological knowledge (LEK) has been shown to be a supplementary source to scientific studies in identifying nursery areas or fish diets or when economic resources are limited, as is often the case (Poepoe et al. 2007; Le Fur et al. 2011). Resource-limited scientific endeavors can benefit greatly by using LEK and having the community participate to reduce costs of sampling (Harms and Sylvia 2000; Johnson and van Densen 2007; Hart et al. 2008), increase the sampling frequency (Conway and Pomeroy 2006), and, thanks to the increase in the number of personnel available to collect data, the ability to generate fine-scale data (Harms and Sylvia 2000).

Cooperative projects, involving the fishing community, have several benefits such as increasing the level of participation of fishers to create a sense of belonging, which results in greater compliance with regulations (Viteri and Chávez 2007). Furthermore, these projects often increase communication between the fishing and scientific community, resulting in building or strengthening trust and fostering mutual education and knowledge exchange (Johnson and van Densen 2007). This strengthening of trust is clearly necessary in Galapagos since our results indicated that a majority of fishers had a negative perception of scientific studies and that lack of trust was specifically identified as a major reason. Of course strengthening of trust will not happen overnight, a successful collaborative project will lead to greater trust for successive projects.

Options for Alternative Income

The lack of providing income alternatives to fishers was one of the top reasons why fishers did not agree with current management strategies. Worldwide, alternative income sources for fishers have had mixed results due to the predilection of fishers to continue fishing (Pollnac et al. 2001; Pollnac and Poggie 2008; Cinner et al. 2009). Our results, however, suggest that in the GMR this might not be the case, as 60 % of interviewed fishers responded that they would be willing to change professions, choosing the tourism sector as the main alternative. Furthermore, 91 % responded that they would not like their children to work in the fishing sector.

Alternative livelihood programs have been offered to the Galapagos fishing sector, but unfortunately not been successful. The main reasons why offering recreational fishing and boat-operated tourism to the Galapagos fishers have not achieved their objectives to date are the lack of consensus among stakeholders, the lack of guidance to the fishers during the conversion process, no monitoring, no follow up, and the lack of compliance to the established regulations (Schuhbauer and Koch 2013; Palacios and Schuhbauer 2013).

The problems faced by both programs, however, can be mitigated by developing long-term management plans based on consensus reached by all stakeholders that would reflect the current situation realistically (Schuhbauer and Koch 2013; Palacios and Schuhbauer 2013). Using a collaborative approach in the design of these plans could greatly enhance the compliance and effectiveness of these programs.

Fishers' willingness to change occupation is encouraging, and it suggests that given a stronger role in future consultation processes, they could consider alternative options that will not necessarily be related to fishing.

Drawbacks of Collaborative Approaches

The previous sections discuss the usefulness of collaborative projects, which would alleviate the issues expressed by fishers in the GMR. However, it is important to note that this approach is not without drawbacks that could impede the projects' effectiveness. These drawbacks include the fear by fishing communities that the data they help produce will be used against them (Conway and Pomeroy 2006; Schuhbauer and Koch 2013). Our results agree with this notion, showing that some fishers perceived that scientific studies would result in regulations that would lower their income (Table 9.2).

The fishing sector and scientists might have different goals, and the tendency of different groups to work independently towards different goals can impair the overall effectiveness of the cooperation (Conway and Pomeroy 2006). These different goals are epitomized by fishers aiming to produce fishing regulations that would result in fewer restrictions, even if these regulations do not agree with the current state of a resource but reflect a need for income, whereas scientists might only focus on publication opportunities or preconceived notions that conservation is the ultimate goal. Our survey found that these were indeed valid concerns, as some fishers listed "scientist interested only in their career" and "maximum allowed catch is too low" as reasons why they had negative perceptions of scientific studies (Table 9.2).

There could be misunderstanding about the impact that management decisions could have on the people who are being managed. Fishers' concerns with diminishing income need to be addressed and quantified. Kaplan and McCay (2004) suggest that regulators and managers should be held accountable for the social, cultural, and economic costs that result from management regulations. A collaborative approach requires the inclusion of all stakeholders from the beginning. However, groups or individuals could be unintentionally left out of this process (e.g., minorities or women), while other groups could be included after the initial stages of the process. This could lead to the exclusion of specific needs or interests by parties or individuals, which could directly result in lack of interest and ultimately noncompliance with the regulations.

Disparate technical awareness by participants can limit the efficient communication among all parties involved. This communication should recognize cultural differences (Gilden and Conway 2002) and ensure that all parties are "speaking the same language." A highly technical description of a fisheries model might not be the best way to transmit to fishers the state of a given resource. Collaborative research projects may also suffer from lack of administrative and infrastructure support. Lastly, lack of organization within the fishing community and divergent

Table 9.6 Framework with steps that are key to the success to collaborative research projects (Yochum et al. 2011) and suggestions from this study

Success to collaborative research (Yochum et al. 2011)	Suggestions from our study
Create solid foundations	Fishers in Galapagos identified their desire to be included in decision-making projects. This clearly is the most important step to ensure the success of these projects
Define success	Conservation goals differ from fishers' views. Only through fishers' perception of fairness can compliance be assured. All stakeholders need to be open to compromise
Define roles	Individual constraints need to be addressed. Disparate technical awareness requires extra efforts in education
Define the scope	Goals need to be realistic and each individual needs to understand them. Project objectives should be aligned with available resources
Develop a sampling plan	Building upon the strengths identified by each participant, the research design should incorporate the expertise of all collaborators
Implement project	Identify leaders from each sector who ensure that protocols are followed in a standardized manner and do not represent their personal interest
Evaluate the project	Analyze the collected data in a rigorous manner. Sharing the results, and their interpretation, with all collaborators will require extra effort and education
Communicate the results	This has been identified by fishers as one of the key points leading to their negative perception of scientific studies. Ensuring effective communication through all the steps of collaborative research will undoubtedly result in increases in sense of belonging and added compliance to regulations

interests among fishers make any participatory process extremely difficult (Schuhbauer and Koch 2013).

Despite these limitations, ensuring that collaborative projects are founded on a transparent process that ensures adequate communication between all parts involved can improve the effectiveness of the already-established comanagement and greatly benefit future projects in the GMR.

Applying Collaborative Research in the Galapagos Islands

Our study suggests that fishers still do not trust the science used to establish management regulations, and note lack of dissemination of results and lack of inclusion of the fishing sector in the decision-making process as reasons for this lack of trust. However, the majority of fishers are inclined to be a part of this decision-making process. While cooperative projects are currently being carried out, it appears necessary that future projects should move along the cooperation-collaboration continuum towards a complete inclusion of the fishing sector in all aspects of research. While this has clearly been tried in the past with the zonation of the GMR and the establishment of fishing regulations, evidence suggests that these approaches have not been completely successful (Castrejón and Charles 2013). Yochum et al. (2011) suggests a framework with eight steps that are key to the success of collaborative research projects, and we expand on these steps with suggestions from this study in Table 9.6.

Conclusions

The current perceptions of fishers in the GMR of scientific studies aimed at advising management regulations for fisheries are extremely negative. This can be traced back to a historical lack of involvement and trust that the fishing community has had in these studies. Cooperative research projects have been shown to increase communication between fishing communities and management entities, resulting in an increase in a sense of belonging and ultimately greater compliance. While it is recognized that this approach is not a panacea, it is definitively a step towards successfully managed fisheries in the GMR and an improvement to the existing comanagement regime.

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Chapter 10
The Emergence of Recreational Fishing in the Galápagos Marine Reserve: Adaptation and Complexities

Kim Engie and Diego Quiroga

Abstract In recent years a local experiential sport fishing industry, commonly known as *Pesca Vivencial* (PV), has emerged as a new type of activity in the Galápagos Marine Reserve (GMR). We analyze this new industry, which incorporates a surprising multitude of styles, using a *complex adaptive systems* (CAS) framework. We use CAS (a) to trace feedbacks between the ecological changes and social processes involved and (b) to frame the driving factors behind PV as extending beyond the fishing sector, which makes its logic as a response to the declining profitability of commercial fisheries over recent decades more understandable. The birth of this industry is a "response" and a bottom-up adaptation by fishers to changes in fishing but also tourism and overall GMR management. Focusing on the island of San Cristobal, this chapter will include historical analyses of the development of PV through its initial proposals and its changing forms of uptake. This article contributes to a thin area of research in this new activity so far, understanding the contested politics and livelihood struggles of the local residents involved. More broadly, our use of CAS is novel in that power dynamics within human interactions are part of feedbacks, often underplayed when applied to fisheries change.

Introduction

The nascent industry of *Pesca Vivencial* (PV), or experiential sport fishing, has stirred up both controversy and anticipation in the Galápagos Marine Reserve (GMR) since it gained momentum in 2005. Pesca Vivencial was first conceived as cultural tourism, a demonstrational activity where a visitor would spend a day with a fisherman or a fisherwoman (henceforth referred to as "fisher") and learn

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about their culture and practices (UCOOPEPGAL 2005; Reck pers. comm.). In theory fishers would not notably alter their practices or equipment, while being able to maintain incomes and reduce harvest levels. In practice, we will show that such aims have faltered while conventional high seas sport fishing has in effect become a controversial but increasingly common "type" of PV activity. Sport fishers have long sailed Galapagos waters unregulated (Molina 2005) but are now starting to color how PV license holders perform Pesca Vivencial, since both are being regulated under the PV term through legal modifications that allow targeting species outside of commercial fishing, namely, striped marlin (*Tetrapturus audax*; Schuhbauer and Koch 2013), and have led to acquisitions of new and costly luxury boats by PV license holders (Engie unpub. data).

Pesca Vivencial's implications have become symbolic of larger struggles over the future of this World Heritage Site: fears of ecological exploitation of new species that could diminish conservation effectiveness and of downgrading of the elite tourism market clash with local aspirations to greater access to the multimillion-dollar tourism industry. Taking an environmentally precautionary approach is needed, since fisheries conflicts have only recently become less chaotic than past decades (Ospina 2006; Epler 2007) where (select) environmental degradation was undeniable, particularly around sea cucumbers in the 1990s (Bremner and Perez 2002; Hearn 2008). However Galápagos institutions have struggled with finding alternate livelihood options for fishers that are mutually satisfying to all stakeholders, and political mistrust has set up confrontational dynamics that complicate their implementation (Stacey and Fuks 2007).[1] Pesca Vivencial's implications are clearly ecological, political, and socioeconomic all at once.

This article has two major research questions. First, we ask how the social and environmental impacts of this new economic activity can be understood, at present and into the future. Ideally, because PV's social and environmental implications are intricately linked, they should be jointly examined and contextualized within broader changes in Galápagos society. We do so by applying the concept of *complex adaptive systems* (CAS) to Pesca Vivencial's rapidly changing forms, including sport fishing. Although a highly abstract framework, its potential to serve as a bridging concept for assessing ecological and social change together is strong given its resolutely interdisciplinary philosophy and mechanistic rigor in showing how "entities" in a system can be human and nonhuman while sharing core adaptive dynamics (e.g., Keller 2005). Complex adaptive systems also help to frame PV's driving factors as extending beyond the fisheries sector. To give social dynamics equally serious consideration with ecological dynamics however requires a novel, expansive application of CAS that is the focus of our second research

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[1] In just one example, early PV regulations over motor power put participants in ambiguous legal positions. Motors were not to exceed 135 horsepower (HP) for artisanal fishing. A boat with tourists must have two motors however, which would add up to 150 HP (75 HP each), making them illegal for artisanal fishing and therefore PV, at that time a type of fishing activity. Some fishers interpreted these complications in PV as "intended obstruction(s)" rather than growing pains (Stacey and Fuks 2007: 87).

question, how can power-laden human interactions be better fit within complex adaptive systems?

We recount Pesca Vivencial's social history to trace feedbacks between the ecological changes and social processes involved in its grassroots emergence. Building on work that has begun to describe PV's practices (Schuhbauer and Koch 2013), we connect the contested politics and livelihood struggles of local fishers to PV's potential ecological impacts. Knowledge of such struggles is still thin, although they will be fundamental to how the industry continues to develop. We begin by outlining the theoretical framework of complexity and complex adaptive systems. In section "Methods," we outline our methods. In section "Pesca Vivencial: A Very Brief Social History," we describe the early social history of PV, and in section "Pesca Vivencial: A Complex and Adaptive History," we interpret developments using the concept of complex adaptive systems.

Fisheries as Complex Adaptive Systems

Complexity science, first and foremost, sets itself resolutely apart from traditional reductionist research. Reductionist approaches have long dominated and led to insights in many sciences, epitomized by conducting experiments substantial where simplified conditions are imposed and objects assumed to be stable, non-changing, and independent for easier calculations with traditional statistics (Manson 2001; Michener et al. 2001). However, as environmental concerns grow so does the realization that ignoring the world's interrelatedness does not produce science that is fully prepared for the complexities of ecosystem changes. Massey (2005) has noted that complexity may be part of a larger impulse in twentieth-century science toward multiplicity, pluralism, and acceptance of ambiguity and away from certainty.

What exactly is a complex adaptive system? One variety out of a whole family of complexity theories, the CAS concept describes any system that follows a particular set of processes in terms of organization and behavior, where various diverse entities or agents interact in different ways and of their own accord. Small-scale fisheries have been conceptualized as resembling CAS's to a remarkable degree because of their diverse interacting "parts" (i.e., independent actors and animals), decentralized decision-making structures, and changing environmental conditions (Garcia and Charles 2008; Mahon et al. 2008). Complex dynamics form from the reactions of these independent, diverse entities (human or nonhuman) to varied selective forces, leading to emergence of a multiplicity of pathways. The most important implication of CAS is that there is no "grand plan" for change, recovery, and disturbance—all are instead driven by bottom-up processes. The ability of fishers to work around harvest and gear restrictions to maximize catches, often eliciting even more intricate rules, is well known and an example of bottom-up dynamics that become difficult for "command and control" resource management structures to monitor and control (Mahon et al. 2008). Beyond fisheries, the periodic crashing of financial markets and the suitability of the Earth's biosphere for life are also driven by such bottom-up dynamics (Levin 1998; May et al. 2008).

"That life is complicated may seem a banal expression of the obvious" (Gordon 1997: 3 cited in Thrift 1999), but the development of mathematics flexible enough to acknowledge constantly changing entities, be they people or ants, has helped to provide a radical quantitative alternative to traditional statistics for understanding ecosystems. Prominently illustrating this are debates around single species, bioeconomics models in fisheries, such as "maximum sustainable yield" (MSY) (e.g., Larkin 1977; Allen and McGlade 1987; Wilson 2006). Maximum sustainable yield is a calculation that uses species-specific growth rates and a logistic growth model to provide the maximum yield that can be taken from a population indefinitely, in theory. Controversial aspects are its base assumption that marine species fluctuate around some "normal" value and its inability to consider the effects of species interactions (e.g., Larkin 1977). In addition, population dynamics in the ocean are more "loosely" regulated or weakly converge around an equilibrium point than on land (Wilson 2006), and "by studying the equilibrium solution of deterministic equations [MSY and MEY], we immediately rule out the possibility that the long term situation may be *dynamic*—that a fish population may always change and never attain a stationary state" (Allen and McGlade 1987: 147, italics in original).

Recognizing a need to move beyond single species management, which we argue is a type of reductionist approach, a dominant response has been to improve governance perceptions of ecosystem change in hopes of enabling institutions to avoid ecological crises by reacting more quickly (e.g., Berkes 2006; Garcia and Charles 2008; Mahon et al. 2008). One way scholars have done so is by using CAS to ask how institutions and individuals can learn and adapt faster to ecosystem changes, conceptualized as feedback loops (e.g., Allen and McGlade 1987; Garcia and Charles 2008; Mahon et al. 2008).

Fisheries, Complexity, and Power

The fisheries complexity literature still shows no explicit delineation of feedback loops connected to human behavior *besides ecological signals* or of the inherently political nature of fisheries governance (but see Berkes 2006). Who decides how to react to ecosystem change? Who bears any socioeconomic consequences, and do particular outcomes benefit some more than others? Such questions can be raised while retaining analytic focus on ecosystem impacts. Mahon et al. (2008: 106) note, "the capacity to self-organize and adapt does not necessarily result in sustainable or fair resource use systems," which "…will depend on the balance of power among stakeholders and their appreciation for these issues." How power imbalances affect ecological outcomes is rarely outlined empirically however. To address these shortcomings, we draw from political ecology, defined as research on "…linkages in the condition and change of social/environmental systems, with explicit consideration of relations of power" (Robbins 2004: 12).

We see room to incorporate power dynamics into fisheries complexity feedbacks more than has thus far been attempted, by distinguishing between the degree of control that different actors exert over various aspects of a fisheries system such as legal regulations and options over gear, rights structures, or access. Such control is often exposed through regulatory debates and individual business choices. In examining the history of Pesca Vivencial's rise, we thus note *who* benefits from ecological, political, legal, or economic modifications and which modifications have persisted. We interpret the visible outcomes of negotiations as indicators of actor influence and power. Such an interpretation treats power as the ability of individuals and groups to constrain each other's actions and opportunities (Dahl 1957), an admittedly limited but useful definition that will still enrich current applications of complexity to fisheries.

Such an analysis goes beyond an often proximal focus on social dynamics in fisheries social science. Bioeconomic models, (e.g., Bucaram and Hearn 2014), characterize fisher behavior (e.g., seasonal fishing participation) and drivers (e.g., fuel prices, yearly seafood price) in the short term. Taking a step further means seeing fishers as people living in a society and not only as people that harvest fish. It was once common to note that while Galápagos environments have been intensely studied, social science scholarship was rare. Such claims no longer hold (e.g., Ospina 2006; Constantino 2007; Grenier 2007), but there is still a need to engage this social science with ecological research at the fine scale of specific species and populations of concern (e.g., striped marlin) and to trace specific mechanisms of connection.

Methods

This work is part of a larger project on the shifting livelihoods of Galápagos fishers, based on field research and semi-structured interviews with fishers, managers, and scientists conducted in the spring and summer of 2012 (Engie unpublished data). Our focus is the island of San Cristobal, the birthplace of the commercial fishing fleet and the local recreational fishing industry. We draw heavily from interviews with 18 fishers in San Cristobal, 2 in Santa Cruz, and 2 in Isabela involved in Pesca Vivencial via license ownership, vessel ownership, or partnership in business operations. We ascertained information on occupational dynamics via questions from a larger individual survey of active, part-time, and former fishers on issues relating to their livelihoods and the general state of change in Galápagos fisheries. Due to the open-ended nature of research, not all fishers were asked all of the same questions. However the data gathered gives various understandings of PV as individually practiced. We ascertained attitudes and motives from open-ended interviews and participant observation around town with fishers as well as scientists, managers, conservation professionals, shopkeepers, tour operators and workers, and seafood brokers, including staff at nongovernmental organizations and the Galápagos National Park (GNP). Participant observation helped us to experience local perspectives in a more passive manner than in an interviewer–interviewee setting, in which unspoken power relationships can manifest in unobserved ways (Bernard 2002). Much of our conclusions are from our body of interviews, anonymous unless given express permission to identify people, as well as participant observation. Therefore few interviewed sources are directly named in this paper. Coauthors draw more broadly from interviews with 184 people in total, including 18 on Santa Cruz, and also from continuous conversations with fishing and cooperative leadership over the course of the last 6 years and document analysis of proposed rule sets and statements.

Pesca Vivencial: A Very Brief Social History

To understand the breadth of its implications, it is necessary to trace the evolution of PV in vision and practices. The following sections outline some of Pesca Vivencial's history, as a guide to better understand how PV developed as well as to think through complex feedbacks.

Setting the Stage

Two major dynamics in the 1990s and early 2000s strongly shaped the emergence of PV. First, PV was proposed in the midst of dramatic ecological and economic shifts in Galápagos fisheries that began in the 1980s (Zapata 2006; Hearn 2008; Schuhbauer and Koch 2013), with nearshore fisheries catch rates generally declining in both abundance and size in the primary fisheries of sea cucumber, lobster, and demersal fish (Hearn 2008; Toral-Granda 2008). In the 1990s and 2000s, clearly unsustainable fishing levels fueled intense conflicts between fishers and managers that were rooted in exponential growth of an export market for easily harvested sea cucumbers, previously thought worthless (Epler 2007; Hearn 2008). These years also coincide with the largest economic crisis of the century in Ecuador from 1995 to 2000, uncontrolled migration from the mainland, and the realization that highly valuable sea cucumber stocks were still in great abundance in Galápagos after their stocks had been depleted off of the Ecuadorian coast (Ospina 2006).

By 2005 the sea cucumber "gold rush" that had paralyzed the archipelago was well past its heydays (Bremner and Perez 2002; Hearn 2008). However people previously unassociated with fishing had swelled the first official roster of registered fishers, lured to the job by high sea cucumber profits or to simply lay claim on future options and potential industry buyouts (Bucaram and Hearn 2014, Engie unpublished data). While many fishers and opportunists have left, there is still an overcapacity in the sector.

A second major ongoing issue has been continuing attempts by fishers to break into tourism. With nearshore fisheries showing signs of decline for decades, the most obvious contender to replace or supplant local fisher livelihoods was the massive tourism-based economy, estimated to have a total value of $418.8 million USD in 2007 (Epler 2007), of which 62.9 million entered the local economy (Taylor et al. 2006). While increasing numbers of fishers are indeed leaving the sector for wage labor on tourism vessels, our interviews noted that this option has been viewed as suboptimal and not providing a living wage equal to a fishing livelihood until recently. Older fishers also noted that their possibility of being hired as a sailor declines given labor market competition. Even though land-based tourism has been growing at the expense of cruise-based tourism (Quiroga 2013) and has wider local participation, fisher perception of inaccessibility of the lion's share of the tourism market is unmistakable.[2] In part due to their failures, Pesca Vivencial's originators utilized their fishing skill sets, knowledge of the ocean, and ready possession of boats and aquatic permits (for fishing) to try and break into the tourism market in a novel way when they perceived other avenues closed.

A key point to note about fisher perspectives around Pesca Vivencial is that they represent the desire for *equity and fairness* on top of replacing lost fishing incomes in a 1:1 manner. Although tourism revenues make the Galápagos one of the wealthiest provinces in Ecuador, the rising tide of prosperity has not lifted all boats but rather engendered a "bitter social mobility" among fishers and other residents (Ospina 2006). Both Pesca Vivencial and sport fishing represent access to the rich tourism economy in a way that was unavailable before, and for this reason both have been championed as democratic activities to develop by various fishing factions.

The Stakeholders and Visions of Pesca Vivencial

An important point to remember in the GMR is that *fishers are not the only stakeholders affecting fishing*. Many other stakeholders share overlapping space, including the Galápagos National Park (GNP), the Ecuadorian Navy via the Directorate General of the Merchant Marines (DIGMER), the National Association of Tourist Businesses in Galápagos (ASOGAL in Spanish), smaller tourism vessels and operators, seafood merchants, scientists, and students. The first two have direct oversight in fisheries rule making with jurisdiction over managing fisheries resources and maritime security and traffic, respectively. The others influence local fisher options by indirectly affecting markets or from lobbying influence

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[2] Carlos Ricaurte, largely credited as one of Pesca Vivencial's creators, viewed breaking into tourism as an inherently political process and one in which established routes such as converting his vessel to a tourism operation were closed to him, as proven by his unsuccessful application for a bay tour permit in 1997.

over zoning or other resource use rules. Illegal industrial fishing interests from outside the GMR likely affect fish abundance as well. However, all of these groups are not often considered when discussing fisheries change.

Galápagos fishers themselves are not homogeneous but have varying political interests and coalitions, sub-fishery participation and techniques, and vessel ownership status (e.g., Wilen et al. 2000; Zapata 2006; Murillo et al. 2007). We emphasize these intricacies because as soon as Pesca Vivencial was proposed, its systematically hybrid fishing and tourism character triggered the involvement of stakeholders in tourism, marine safety, and others, forcefully illustrating how each marine activity in the GMR must go through various jurisdictional layers. The figure below shows the organization scheme and the major stakeholders in Galápagos fisheries (see also Chap. 8) (Fig. 10.1).

Stakeholders held multiple visions of what the activity should and could be from the beginning, although all visions share some commonalities: to provide alternate income sources for Galápagos fishers, to engage in some kind of cultural exchange, and to achieve a more sustainable fishery (Table 10.1).

As originally conceived fishers would not alter their typical fishing practices or equipment but simply demonstrate them to interested tourists; the proposed name Pesca *Artesanal* Vivencial (PAV) stressed the continuity with typical artisanal practices. This version of PV was a *commercial fishing* activity that did not focus on giving tourists their own recreational fishing experience but offered a glimpse in the world of a fisher, although tourists might participate in fishing at times (Reck, interview, 2012). Molina (2005: 2) called it “demonstrational artisanal fishing.” In addition, the activity was not necessarily thought of as a replacement to commercial fishing but could be a supplement that freed the fisher to catch less (Reck, interview, 2012). This idea was discussed during the creation of the GMR’s first set of Fisheries Regulations written at the establishment of the GMR in 2000, although PV was not ultimately incorporated. It thus predates 2005, when UCOOPEPGAL, the provincial-level cooperative of Galápagos fishers, first presented PV largely unchanged to the JMP and AIM (Table 10.1). In their presentation they noted that a vacationing tourist would accompany a fishing vessel for a day while “conversing about the life of the fisherman, one’s happiness and difficulties in a true spirit of intercultural exchange” (Table 10.1; UCOOPEPGAL 2005).[3]

Sport fishing on the other hand, long conducted in sporadic and unregulated fashion in the Galapagos since the 1950s (Molina 2005; Epler 2007), was immediately suggested instead of PAV inside and outside of the fishing community. However supporters of PAV were wary of any market labeled and practiced as sport fishing eventually being captured by outside and inside elites, as has happened in tourism to some extent (e.g., Epler 2007). Fishers were far from united; some may have been opposed to a recreational fishery outright from the beginning, while

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[3] This idea also draws continuity from the 1970s and earlier, before the rise of large cruise ships, when tourists commonly paid fishermen to take them around the islands and to participate in fishing activities (Stacey and Fuks 2007, interviews).

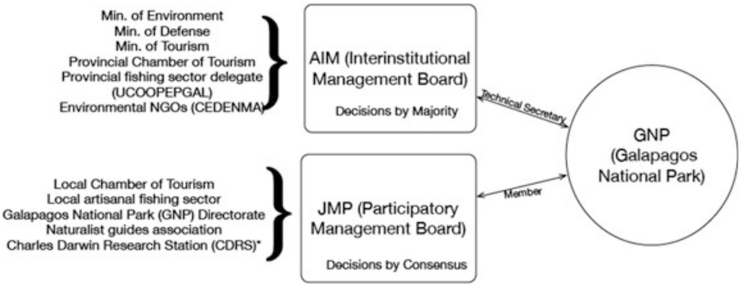

Fig. 10.1 The participatory management structure within the Galápagos Marine Reserve. Spanish acronyms are used for the AIM, JMP, CEDENMA, and UCOOPEPGAL. Modified from Heylings and Bravo (2007). *The CDRS serves an advisory role to the GNP and no longer has voting power

others championed either sport fishing or PV (Reck, pers. comm). Still others have consistently advocated sport fishing instead of PV because of its established global market appeal. Finally, *some* opportunity is simply the goal for many who support any development of Pesca Vivencial, sport fishing, or some combination.

Finally, visions of PV continue to evolve in step with the fishing practices that were ultimately allowed (details in section “Between Two Worlds: Tourism and Fisheries” below), so that many local license holders now associate PV with sport fishing, if we define that as being oriented toward giving a tourist their own recreational fishing experience. However our fisher interviewees still differentiated PV from sport fishing elsewhere, strongly at times, by the following characteristics: being in the hands of local ownership, having a broad base of target species that is always catch and release (after a 50 lb trip limit), and ability to be conducted on a wide variety of vessels beyond luxury sport fishing yachts. In mainland Ecuador in contrast, sport fishing has historically been an elite activity in which comfort was essential and luxury vessels valued (Molina 2005).

Regulatory Evolution

We argue that legal recognition is a significant marker of the establishment of an activity in the GMR, where “there is a long history of officials turning a blind eye toward certain unofficial or non sanctioned forms of tourism. If a major controversy does not arise, regulations are often then formulated and the activity permitted. Cases in point include the status of land-based diving operations, sport fishing that exists but is not legally sanctioned, and large cruise ships based elsewhere that sporadically run cruises through the islands” (Epler 2007: 52).

Historical contingency likely aided PV’s uptake in 2005. The speed with which the idea was quickly taken up by was clearly at least partially due to its potential as a viable economic alternative for commercial fishing that could reduce harvests, although stakeholders harbored varied reservations (see below). The fishing sector

Table 10.1 Regulatory evolution of Pesca Vivencial, from the proposal as first presented by fishing sector representatives (top row), followed by major changes in subsequent legislation

Event	Goals and objectives	Legal classification and zoning	Vessel requirements	Manner of cultural transmission	Activities	Monitoring and implementation
Presentation by UCOOPEPGAL to JMP, July 21–22, 2005	1. Establish income for Galápagos fishers 2. Improve knowledge of the reality of Galápagos fishing 3. Foster intercultural exchange	A fishing activity, called Pesca Artesanal Vivencial (PAV) No further framework yet proposed	1. Fibra with fishing license, 6.5–9.5 m length 2. Security equipment required by DIGMER	*The fisher*: presents attractions and dangers of the sea, demonstrates fishing techniques, reminds all of targeted species, fishing spots, security norms. Lunch onboard as a time for sharing histories, dinner in the house of the fisher with their family	1. Line techniques (capture of bait fish, shore fish, and tunas with hand lines and lures) 2. Submarine fishing (diving)	
↓ ***Major changes*** ↓						
Provisional Regulations, July 28, 2005	The Galápagos fisher... *uses their own work infrastructure and vessels* ... to sell their fishing culture (emphasis added)	Relevant laws: LOREG,[a] Constitution, Special Fishing Regulations in the GMR Exclusively in fishing zones (2.3)	Additions: 1. Emergency oxygen equipment for diving 2. Vessel owners present cooperative membership	*Art. 21:* Fishers will participate in training courses to offer good service, to be offered by various organizations	Additions: Resting site for snorkeling or swimming While diving, tourists can only observe, not fish	*Implementation:* Shared among the GNP and fisher groups *Monitoring*: Fisher groups, with support of GNP Fisher groups also define regulations for species not currently in the Fishing Calendar

Feb 23, 2011	Same as Provisional Regulations, but language omitted about fishers' use of their own vessels		Additions/ changes: 1. All boats allowed except wooden, between 7.5 and 12.5 m length 2. Vessel cannot have a permit for other tourist activities		Additions: 1. Trolling (dragging a baited lure behind the boat) 2. Fishing rod, with reel or without 3. Nets	GNP controls monitoring, control and registration of vessels and fishers GNP defines regulations for species not currently in the Fishing Calendar based on technical studies
JMP meeting, Oct 4, 2012		A touristic activity, called PAV				
Nov 9, 2012	*Reform of Fishing Regulations that eliminates any mention of PAV*					
Res. 7, GNP, Jan 18, 2013		A touristic activity, called Pesca Vivencial (PV) Inclusion of RETANP with above statutes. Resting sites in zones 2.3 and 2.4[b]	Additions/ changes: 1. Vessels can be used for *either* artisanal fishing or PV, but not for both 2. Cabin now mandatory	Fisher and Naturalist Guide Guide will relate safety at sea, development, techniques and regulations of fishing, and conduct in the GMR	Additions: PV vessels will be able to travel among ports	*Monitoring:* GNP will establish participatory monitoring

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[a] The Special Law for Galápagos, or Ley de Régimen Especial para la Conservación y Desarollo Sustentable de la Provincia de Galápagos (LOREG in Spanish)

[b] In the Provisional zonation rules of the GMR, zone 2.3 are the areas where artisanal fishing is allowed, and zone 2.4 is designated for special, temporal management

was placing mounting pressure on governance institutions to help find viable economic alternatives after the sea cucumber collapse. In December 2004 Pesca Vivencial was included within an official baseline list of acceptable alternatives for the fishing sector, of which local cooperatives subsequently decided PV was the highest priority (Zapata 2006). Approving Pesca Vivencial may also have been partially a political trade-off by decision makers, as our interviews with AIM members reveal. Managers saw PV as something that could be a concession to local fishers for accepting the elimination of long-lining, which many fishers advocate and had previously been allowed. Despite its extractive impact on fish populations, Pesca Vivencial was seen as an activity with a comparatively lower ecological impact than long-lining. A subset of international NGOs, government, and those in fishing communities thus became united in pushing forward PV as a legally sanctioned activity once the idea reached the JMP in 2005 (Table 10.1). "Consensus was achieved thanks to the existence of a common objective, where different stakeholders reached a win-win solution. The conservation sector (GNP and CDF) win as fishing effort is reduced, decreasing pressure on the marine ecosystem, the fishing sector (Fishing Cooperatives) win as they have found an alternative economic activity that will allow them to gradually abandon extractive activities, the tourism sector (CAPTURGAL and the naturalists guides) win as this mechanism has reduced the level of conflict and allows the members to obtain higher incomes" (Zapata 2006: 47; translated from Spanish).

In retrospect it is fair to say that collective efforts to approve Pesca Vivencial were achieved not through actors sharing a common vision but through sets of actors that happened to see different needs met through a common action. However, these diverse reasons may also help to explain the protracted negotiations that began as soon as PV was given a legal nod of approval in 2005, which eroded consensus (section "Between Two Worlds: Tourism and Fisheries").[4]

Between Two Worlds: Tourism and Fisheries

A dilemma of whether to categorize PV as a fisheries or tourist activity surfaced during the approval of provisional rules and has been by far the most significant regulatory debate.[5] To help resolve concerns over tourist passenger safety, environmental NGOs helped mediate a trial PV trip in Puerto Ayora in 2006 (Zapata 2006). While considered a success in demonstrating feasibility, it also marked a

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[4] These disputes extended even into the fishing community, where debates over initial exclusion of two of the three types of fishing boats as potential PV vessels delayed approval of provisional rules by several months. Beyond this many fishers took a "wait-and-see" approach because of a lack of clarity on PV's market potential (Zapata 2006).

[5] Objections were raised by ASOGAL and DIGMER during the AIM meeting where PV was introduced in 2005 (Zapata 2006). ASOGAL's approval is needed on all marine activities in the GMR, giving added weight to its objection.

seminal moment—official agreement that Pesca Vivencial vessels had to be converted away from basic fishing boats to accommodate tourists safely.

Molina (2005) noted the following governance issues:

- According to Section 40, article 2 of the GMR management plan, fishing vessels cannot be used for tourism activities, and tourism vessels are prohibited from fishing.
- Fisheries monitoring, specifically regulating catch sizes, is the responsibility of the GNP, and "this should not be done by the Fishermen's Ecological Organization (EFO) from Isabela" (p. 15).

Regulations and Park-fisher partnerships in 2005 were thus not well set up to accommodate an activity hybridized across fishing and tourism, and neither perhaps to entrust the fishing sector with capacities to self-monitor. Molina (2005: 15) also noted that "tourists should not be required to sign a document freeing a boat owner from liability in the case of accidents (common in fishing)."

As one AIM participant decidedly put it, the dual concerns raised over safety and jurisdiction were "the knife in the back" of PV as it was originally conceived.[6] This is because (1) as outlined above from a governance standpoint, demonstrational fishing was difficult, and (2) economically, these debates fundamentally changed how local fishermen could participate in PV. First, the decision will trigger regulations under RETANP (Special Regulation for Tourism in National Protected Areas, or Reglamento Especial de Turismo en Areas Naturales Protegidas in Spanish), the national law that regulates tourism. It states that vessels must have certain characteristics of other tourism boats and therefore narrows the accessibility of PV to most Galápagos fishers, most of whom do not have the capital to set up their vessels to cater to tourists like established Galápagos tour agencies. Traditional boats used for daylong artisanal fishing trips are fiberglass or wood-hulled, often uncovered, and contain no restrooms, cabins, or many other features comfortable for tourists. While not technically necessary, some license holders have bought more luxurious sport fishing boats which comply with safety measures while catering to customer comfort at levels competitive with sport fishing ventures elsewhere.

Categorizing PV as a tourist activity has also influenced inter-actor relations. Because boats must be outfitted with expensive insurance, safety, and navigation equipment, significant start-up capital is needed. This need might contribute incentives to make certain types of engagement in the PV industry more likely, such as the "testaferro" phenomenon (see below), made fertile with a constant pressure from nonresidents seeking entry into a market seen as potentially extremely lucrative. People who are not licensed fishermen have entered the activity by partnering with local fishers where they can. This dynamic combines with a risk aversion of

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[6] The total lack of knowledge about the economic viability and market potential of PV was also an issue (Zapata 2006), although the debate over whether to categorize PV as a tourist activity was immediate and overshadowing.

many local fishers to borrowing money, given negative experiences with falling behind on bank loans and losing or nearly losing homes or land in the past (Engie unpublished data).

Some license holders have partnered with outside investors or family members who finance and own the vessels in all but name and run PV operations in a variety of partnership arrangements. The majority of the time the local fisher is a minority partner in the business and profit sharing, which has spawned the terms “straw owner” (Schuhbauer and Koch 2013) and the Spanish “testaferro,” negatively implying exploitation. However, it is unclear how negative these arrangements are for fishers, some of whom work on the vessels regularly or have aligned with several PV license holders in larger tour agencies. Arguably in all cases, fishers have increased their income and economic security for the present, while remaining connected to the sea. Interviews imply that a significant proportion of all PV license holders in San Cristobal are in such arrangements.

In sum, PV gradually became less associated with commercial fishing and is now dominantly perceived as a touristic activity that some fishers engage in (Table 10.1). As a result, however, the pool of people potentially most likely to succeed in PV, and possibly to apply for licenses in the first place, may *not* be the same pool of commercial fishers who now seek to leave the fishery. The implications of these developments remain to be decided—some may worry that PV will not help reduce commercial fishing harvests or provide alternate livelihoods to fishers. On the other hand, participation in local tourism may increase for Galápagos residents in general, touching upon an equally important concern for social equity. In accord with the worries (or hopes) of both sides, both things seem to be happening (Table 10.2).

Fishing Practices and Participants

Because PV has never actually been practiced as a demonstrational, commercial fishing activity, some believe “there is no PV in Galapagos” (interviews, 2012), meaning that all license holders are involved in various types of sport fishing. Putting aside debates over the definition of PV for the moment (Engie unpublished data), fishing practices under the name of PV have bifurcated into two main styles, the nearshore fishery or “pesca chica” and the high seas fishery or “pesca grande” or “pesca de altura.” Importantly, on San Cristóbal the majority of operators offer and engage in both of these styles to capitalize on any opportunity in a market many perceive as sluggish and to expand activity beyond the few months of the year when billfish can be found in greatest numbers. The pesca chica is closest in vision to the original proposal for tourists to participate in traditional Galápagos fisheries. Multiple species are targeted, with bottom fish such as groupers caught around coastal areas using fishing rods as well as traditional *empates*, consisting of a fishing line held in one’s hand with a baited hook at the end. Empates may also be demonstrated around deeper water seamounts in the high seas fishery. However, no one makes a living solely based on such trips, and our observations imply that this trip type is the minority of all PV outings. The “pesca de altura” immediately differed from the version first presented by UCOOPEPGAL delegates (Table 10.1). More closely resembling sport fishing in other areas, it mainly targets larger striped marlin and tunas that swim midwater, using the method of trolling fishing poles from the boat through deeper waters. Commonly targeted environments are underwater seamounts or “bajos” that are scattered around the Galápagos platform where marlins can be most reliably found (see Schuhbauer and Koch 2013). Beyond a profit motive, the high seas trips seem to be promoted also because they are popular and familiar to tourists.[7] Even when clients are interested in learning about the *empate*, they also want to use familiar rods and reels during a costly day trip.

The demographics of license holders are highly diverse and reflect how PV is being taken up by people who see various opportunities to better their lives. Different people engage for different reasons. Three out of 16 interviewed fishers in San Cristobal were full-time commercial fishers when they began PV activities. Two fishers have become passive recently in the past 5 years, one by choice and one reluctantly for family needs. An additional two have transitioned during the last 5–10 years to fishing only occasionally or on weekends. When the opportunity arose, both wanted to enter PV and retain fishing ties. Some license holders have roots in fishing families but went on to full-time careers elsewhere, still fishing on weekends and participating in long trips when possible over the years (Table 10.2). Pesca Vivencial represents the possibility to stay connected to their fishing culture. For all, in an economy where job security is never assured, PV has provided an additional activity where they may leverage their property (in vessels and commercial licenses) and fishing skills for a safer and more diversified livelihood. Strengthening the local tourism economic base, those involved are now well poised for market growth, and their privileged access over mainlanders for the limited number of licenses has given some an edge they may not have been able to begin competing without.

Feedbacks: Bringing Together the Ecological and the Social

With the limited data available, some inferences can be made about the ecological impact of Pesca Vivencial fishing practices. For the immediate future, ecosystem capacities do not appear to be limiting to PV and sport fishing growth *broadly*, although yearly fluctuations in marlin catchability have impacted business. Generally speaking, while nearshore fisheries are strained, it is likely that PV does not add greatly to this strain overall with its 50-lb trip limit, with the critical caveat of monitoring and enforcement into the future. For tunas and striped marlin although abundance is unknown, circumstantially there is less concern, although far from

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[7] The high seas trips being offered in 2011 were around $1,200/day, and nearshore trips were only slightly less.

Table 10.2 Summary of select involvement among surveyed fishers involved in Pesca Vivencial in San Cristobal

Personal role in PAV[a]	# of people	Years since fishing full-time[b]	# of people
Owner	1	0	3
Owner, operator	1	1–2	1
Owner, fisher (as mate or captain)	3	3–5	1
All	11	6–10	2
		>10	5
		N/A	2

Days at sea in the PV in 2011	# of people	Occupational diversity	# of people
1	1	PAV, commercial fishing	4
4[c]	2	PAV, other jobs	3
5	2	PAV, commercial fishing, other jobs	7
6–7[c]	1	PAV, other business owned	4
8	1		
≥20	7		

Numbers in each column indicate the frequency of responses. In 2012, these questions were posed about Pesca *Artesanal* Vivencial, in accordance with the name at the time

[a] Including two not currently operating

[b] Unclear for four respondents

[c] Trips, instead of days at sea

none. As one scientist put it, "…it's more acceptable, probably, to do a kind of sport fishing for billfish than (to) do grouper fishing (recreationally)," because of the concern for strain on nearshore stocks (Hearn 2008; Toral-Granda 2008). In addition the banishment of the industrial tuna fleet from the GMR's waters in 2000 drastically cut harvest levels that the PV fleet could never replace.[8] Similarly the seamounts of the Galápagos oceanographic platform that are within the GMR have been largely untouched by the local commercial sector because of their distance from ports and a lack of any developed market for consuming their species. However there is little information regarding the biodiversity and vulnerability of these seamounts.

In the immediate sense, fluctuating abundances clearly affect yearly business cycles, particularly of migratory marlin. All interviewees noted that a particularly low abundance of marlin in 2011 affected their sales. Although eventually other species might pose constraints on PV and sport fishing, there is likely an envelope of industry growth. Notably, interviewees were united in their view that legislative ambiguity and lack of support overshadowed ecological constraints.

There are important interisland differences as far as the possibilities and limitations of Pesca Vivencial. Because Santa Cruz is the hub of tourist activity with over two times the hotel capacity and restaurants and bars (Epler 2007), PV fishers there

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[8] Ospina (2006) noted that in 1998 one midsized Ecuadorian industrial tuna vessel had a capacity of 600 net tons, while the large boats of the Galapagos artisanal fishing fleet combined comprised only 50 tons.

have more opportunity to sell tours to passing tourists and are concentrating on small and medium size pelagic and demersal fish. In both Isabela and Santa Cruz, PV is mostly nearshore because of the greater distance and difficulties to get to the seamounts. In San Cristobal where fishers have closer proximity to seamounts, people have invested more in luxury boats, and more clients are of the type that come looking for big game fishing. Conversely there is little walk-in interest. The place-based contexts of proximity to seamounts and local tourism flows are thus both becoming geographic influences for the type of fishery conducted and therefore ecosystem impacts.

As is evident through the above sections, feedbacks between fishers and marine ecosystems run in both directions and on immediate and long-term timeframes. Many other ecosystem impacts will depend on how trends in the PV industry continue to develop, as discussed below.

Pesca Vivencial: A Complex and Adaptive History?

One way to trace how ecological and social change connect to each other around Pesca Vivencial's rise is to conceptualize humans and fishes as "entities" in one connected complex adaptive system with open, porous boundaries and subsystems. Is the PV industry truly a complex adaptive system? We take Levin's (1998) three essential properties of a CAS and apply each one to a different aspect of Pesca Vivencial's development. Stripped to its essential components, a CAS has "(i) s*ustained diversity and individuality* of components, (ii) *localized interactions* among those components, and (iii) an autonomous process that *selects* from among those components, based on the results of local interactions, a subset for *replication or enhancement*" (Levin 1998: 432). While these descriptions are highly abstract, they simply mean that, using ecosystems as an example, there are selective forces that each individual feels, which influences their actions and the outcomes of those actions.

Levin's first two dynamics are clearly visible in the history of Pesca Vivencial, made up as it is of fiercely independent fishers, institutions, and interest groups that have chosen various visions, business models, fishing practices, and vessel types, and show shifting political alliances. Let us discuss the third dynamic from the perspective of ecological change translating to social change. Overall, lower densities of sea cucumbers (Toral-Granda 2008) and a need to dive to ever-deeper depths for them (Engie unpublished data) have ended the era of easy, high profit margins in fishing. This ecological limit, combined with growing monitoring and restrictions compared to previous decades (Ospina 2006), means that a less open-access, easy profit fishery could thus be a reality that Galápagos society has and must continue to adapt to. We interpret human response as influenced by the power differentials between stakeholders, which, along with ecosystem change, act as "autonomous selection processes."

In actuality like other heavily managed systems (i.e., agricultural), a fishery is not a true complex adaptive system since fisher choices are not completely autonomous (Levin 1998). However since small-scale fishers operate as largely independent units, they approximate CAS dynamics in many ways even within management policies such as spatial zonation that broadly structure actions.

In many ways the CAS metaphor is quite amenable to tracing the political negotiations that resulted in present-day regulations, which make sense of the version of Pesca Vivencial that ultimately was "selected" out of different visions from 2005 to the present. It helps us understand the uptake of the practices that emerged as arising from actions of diverse individuals on their "local" level that, over time, were unpredictable, individualistic, and uncoordinated. Historical contingencies (e.g., political expediency and declining abundance of commercial fishing stocks) eventually became amplified at local (in terms of individual businesses) and institutional (in terms of regulations) levels in different ways. PV is the social "emergence," so to speak, of an opportunity that fishers created for themselves (with much support) in a growing tourism economy, as other opportunities became closed, given the degradation and limited space left in the sea cucumber and lobster fisheries in the early 2000s, but also (a) their perceived limited political and occupational avenues and (b) growing monitoring and restrictions on fisheries use, all factors noted as influential by the concept's creators themselves. The activity shows no signs of being orchestrated by some "grand plan", on the contrary one could say that as an emergent process, PV continued from the bottom-up despite the efforts of government regulators to control and even stop it at various times.

We note that the CAS framework is not without limits. On the one hand, complexity has no normative stances on societal concerns, unlike terms such as resilience and sustainability. On the one hand complexity escapes the ambiguities of having to define terms like "benefits" and "sustainable" and is impressively flexible enough to be productively hybridized with many other styles of explanation, as we do here with political ecology. However such neutrality around social change also makes complexity of little utility *alone*, in understanding the base drivers of environmental politics or diversity or understanding why things are diverse at the "beginning" of study. We simply establish the existence of diversity as one element that subsequently generates complex and adaptive dynamics. In addition the very unpredictability of its emergence would likely have left PV as something that could not have been foreseen by managers or researchers.

A constantly changing system means that tracing every feedback loop is impossible. However, particular social-ecological feedbacks, and their political dimensions, are discussed in more detail in the sections below.

The Multiplicity of Complex Adaptive Feedbacks

Perhaps what most strongly marks the appeal of a complex adaptive systems framework is its emphasis not only (or even mainly) to understand these social dynamics but to link them to ecosystem change in traceable ways and via specific mechanisms.

Much of Pesca Vivencial's implications hinge on its future development. It would be tempting to place the bulk of analytic attention on conditions that might make potential "alternate states" more or less likely. Potential states, or sets of implications, that sport fishing opens in the GMR include (a) too rapid expansion in pursuing billfish that might result in a depletion of apex predators in GMR food webs.[9] On the social side, a potential ability of sport fishing interests from abroad to enter the market (i.e., via testaferros) taps into an institutional fear of (b) a loss of control and sudden, irreversible changes toward less sustainable development, including downgrading of the high-end Galápagos tourism market to promoting the area as a generic island playground, which is an unwanted "perverse model" of growth (González et al. 2008).

However, taking complexity's implications seriously means that an equal or greater focus on individual approaches to practicing PV is needed. Complexity prompts us to consider the multiple trajectories that are simultaneously unfolding in a place. One of the major messages of complexity theories is the importance of attending to variance as much as averages, "anomalies" as much as trends, and the whole as much as points.

Let us review one of the most pondered and unproven causal chains concerning Pesca Vivencial: whether commercial fishing effort on coastal fish stocks will decline in part because it is transferred to the PV, through either helping commercial fishers diversify incomes or to leave commercial fishing entirely. This hope has been a prominent reason for institutional support. While it is unknown how commercial harvests have changed because of PV, it appears to have become a complementary rather than an alternate activity for the three interviewed PV license holders that were previously full-time fishers. However, one such interviewee was pursuing strategic partnerships with new tour agencies locally and abroad in 2012. Over time this license holder aims to quit commercial fishing for the PV full-time as their business expands to support them. Other license holders interviewed still hope that PV will one day replace their commercial fishing activities, though they did not have active leads on new partners. Out of the 17 asked of their future job preferences in an open-ended question, 8 declared a preference to work exclusively in the PV if their business supported them. Nine more stated a preference for doing more work in PV. Therefore although speculative, we hypothesize that the present pattern of complementarity to commercial fishing activities is not environmentally

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[9] There is also concern among biologists about the true survival rate of catch and release fish, although many released in good condition survive the immediate future (Domeier et al. 2003).

negative, broadly speaking. The nascent industry is only starting up, and its potential to economically replace fishing has not enjoyed much time and legislative clarity.

As implied above, not just particular properties (i.e., PV as complimentary to commercial fishing) but the trajectories they are on (i.e., whether people are acting to replace commercial activities with PV or not) are key to determining ecological change moving forward and the degree of social equity in generated wealth, in connected ways. In addition, whether particular ecological impacts will end up dominating others into the future will depend on the social structures that end up accompanying them.

Political Dimensions of Complex Adaptive Feedbacks

How were power and environmental politics incorporated into PV's social-ecological feedbacks? We highlight several major avenues where political dimensions are apparent.

First, we suggest that the very uptake of PV and then its sport fishing orientations were by no means inevitable. Many fishers and conservation interests were long wary of both PV and sport fishing, the former because of uncertainty of a market (Zapata 2006) and the latter as clashing with the philosophy of a marine reserve (interviews, 2012). Beyond this, the fishing community has always held strong enthusiasm for other tourism alternates as ways to reduce extractive activities, such as owning and operating vessels or guiding (Stacey and Fuks 2007). Despite all the indications of a collective will to channel resource use otherwise then, we have argued that over time the perceived lack of space in such routes, along with growing restrictions around fishing and a tourism industry that now dominates the Galápagos economy, helped push the PV industry into existence as a path of lesser resistance.

The social consequences of uneven tourism development in the Galápagos go beyond an absence of jobs to the innovation of new ideas, which are negotiated by people according to their political and social positions. These ideas then feedback to redirect resource use and, therefore, environmental change.

After its legal establishment, the influences of power differentials in its evolution are apparent on several levels. On a sector level, the regulatory debates around PV illustrate the ultimate power of tourism and the continued tight alignment between tourism and conservation interests in the Galápagos (Grenier 2007). Despite the wellspring of good will toward fishers, staying true to the original vision of Pesca *Artesanal* Vivencial would have required crossing and hybridizing highly entrenched and power-laden governance boundaries between fishing, tourism, and monitoring activities. Operationalizing the current vision of PV, situated as it is under the governance of tourism institutions, does not complicate these boundaries. Tourist safety issues are still handled by the Ministry of Tourism and DIGMER, fisheries monitoring via catch sizes is still the purview of the GNP, and educating tourists about the flora, fauna, and proper behavioral protocols within the GMR is still channeled through certified naturalist guides, just as on all other tourism vessels in the GMR (AIM Res 007-2013, Table 10.1).

However, this PV version also prioritizes tourist safety and industry reputation in a world-class destination, while greatly weakening the access of the new activity to many fishers. Among these equally legitimate goals, the outcome shows that tourism interests won out, and other avenues were left unpursued—for instance, the possibility of building capacity among fishers to be empowered to explain their own Galápagos fishing culture, which will now be the domain of the accompanying naturalist guide as fishers look on, many of whom have not shared in this fishing culture (AIM Res 007-2013, Table 10.1). While events were more complex than a simple privileging of tourism interests, in fact the outcome does so and shows the tourism industry's greater power even while many in the fishing community welcome these changes for giving a (hopefully) clearer pathway for industry growth.

Pesca Vivencial's history also illustrates the differential power of the fishing sector in different arenas. Galápagos fishers have significant political capital, which enabled their idea to broadcast and which generated much support, not least exclusive rights to Pesca Vivencial permits and funding for pilot projects that have truly helped some fishers in starting up operations by paying for safety equipment (Zapata 2006). However as a group, fishers overall have relatively shallow financial capital. For instance while some fishers earn incomes on par with many other professions in the Galápagos, many lack savings and collateral (e.g., Castrejon 2011) to invest further in their PV businesses, let alone enter in the first place. Even *beyond* financial capital, the number of trips our interviewed operators and license holders were involved in ranged widely, between being at sea just 1 day to more than 60 days in 2011(Table 10.2).[10] The subsequent divergence of business growth trajectories may imply that after obtaining licenses and eventually outfitting boats, some fishers lack capacity in strategic business and social networks, which are vital to staying competitive in the tight Galápagos tourism market and which distinguish those with the most PV business from the rest. Within the industry therefore, it is clear that differences in individual capital, skill sets, and motives all affect how PV has grown, and for whom.

Conclusion

We began this article by asking how ecological and social changes connect in the rise of PV and how power-laden human interactions could be fit within the complex adaptive systems framework.

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[10] Since data is self-reported the accuracy is not guaranteed, but regardless of exact numbers unevenness in the days worked in the Pesca Vivencial is undoubtedly a feature of the social landscape.

While PV and sport fishing both expand the number of exploited species in the GMR as currently practiced (notably striped marlin), they are also partial reflections of a local desire to participate more substantially in the multimillion-dollar Galápagos tourism industry. Because they were not inevitable, PV and sport fishing within it should thus be understood as by-products of social struggles *as well as* of much-commented environmental declines in commercial fishing. Therefore continuing to attend to the contested politics and livelihood struggles of the local fishermen involved is critical, along with strengthening knowledge on ecosystem impacts.

We present this case study as an example of using complex adaptive systems to reflect upon changing politics and proliferating resource use practices, a still uncommon application of complexity theories. While issues of power, poverty, or social injustice have been treated lightly in complex systems work, we should also ask: can they be better addressed? Constructive critiques are vital since there is strong interest in a research agenda delineating social-ecological feedbacks in the Galápagos (Watkins 2008) and conceptualizing change via alternate stable states (González et al. 2008).

Ultimately Galápagos marine ecosystems and fishers change together in linked ecological and social ways, whether characterized in a CAS or other framework. Complexity has undoubtedly helped consider Pesca Vivencial's "failures and opportunities" (Schuhbauer and Koch 2013) in a broader and more connected way and proved useful in understanding its varied implications. It also helps to make sense of Pesca Vivencial's unexpectedly dynamic regulations and plurality of fishing styles.

When both ecological and social research is fitted to the CAS framework, power, at least broadly, will be rendered traceable and linkable to the ecological, with the hard linkage being Pesca Vivencial's fishing practices, empirically grounded in geographic particularities. Even while data on ecological impacts remains sparse, tracing out the social dynamics has helped us to hypothesize how social processes connect to ecological change beyond the short-term profit motive often emphasized in fishing research, to the rule sets, interest groups, and ability to attract clients that affects the growth of different fishing practices within the Pesca Vivencial/sport fishing umbrella. We hope that this article represents only the beginning of potential research agendas that study ecological change in marine systems directly linked to sociopolitical aspects of fishing.

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Chapter 11
Shifting Baselines in the Galapagos White Fin Fishery, Using Fisher's Anecdotes to Reassess Fisheries Management: The Case of the Galapagos Grouper

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Abstract This study links social and ecological aspects of the white fin fishery in San Cristobal Island. This is a traditional fishery focused at first on the Galapagos grouper (*Mycteroperca olfax*), a top predator and an iconic species of the archipelago as part of a traditional dish to celebrate Easter on the continent. We used anecdotal information and perceptions provided by three generations of fisherman to understand the impacts of fishing on the dried and salted fishery. Significant differences were found among fishers' groups surveyed and interviewed for this study. The oldest group indicated a greater past abundance of the Galapagos grouper than the other two younger age groups. The close relationship between fishers and their activity have generated certain knowledge about marine environments, its species, and the dynamics developed in their fishing areas, creating a perception of changes in this fishery.

Introduction

Overfishing, pollution, habitat destruction, diseases, and human-induced climate change are affecting marine ecosystems in profound ways (Jackson et al. 2001; Pauly 2000; Pauly et al. 2002; Jacquet and Pauly 2007). Among them, overfishing can alter dramatically the structure and function of marine ecosystems. This is because fishing at first usually focuses on top predators that play key ecological roles in marine systems (Pauly et al. 1998; Pitcher 2001; Myers and Worm 2003; Pauly et al. 2005; Worm et al. 2006). Scientists and natural resource managers usually lack accurate and necessary data related to fisheries and fishing pressure, as well as information related to the biology of species necessary for sustainable fishing activities. Moreover, our perceptions about the ocean are constantly

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changing (Roberts 2003). Given this gap of knowledge, Pauly (1995) in his *shifting baseline syndrome* of fisheries highlights the importance of understanding how each generation of fishers perceives marine changes, fish depletion, and the intensity of human impact over the marine ecosystems through time.

Unconventional sources of information such as historical accounts, archaeological data, genetic analysis, and anecdotal information had been used to recreate the status of marine resources prior to exploitation (Pinnegar and Engelhard 2008; Sáenz-Arroyo et al. 2006; Rochet et al. 2008; Lotze and Worm 2009). Critical information gathered from fishermen on environmental, ecological, and biological variables (*fishers' ecological knowledge*, *FEK*) could be used to understand how these changes affect marine resources and influence fishers' activities. In turn, this information can support more assertive management actions to preserve marine ecosystems (Neis et al. 1999; Johannes et al. 2000; Crowder 2005; Murray et al. 2006; Wilson et al. 2006; Grant and Berkes 2007; Schafer and Reis 2008).

In the Galapagos Islands, fishing is an important economic activity and, although the number of fishermen has declined steadily since the 2000s, still represents an important source of income in the local economy. During the nearly 70 years of continuous fishing in the Galapagos, fishermen have developed an important link with marine resources creating social-ecological relationships where the access, use, and control of these resources have been marked by climatic, socioeconomic, political, and management regimes (González et al. 2008; Tapia et al. 2008, 2009). In this sense, San Cristobal is the island with major fishing tradition in Galapagos, and the largest number of boats and fishers engaged in this activity (Reck 1983; Castrejón 2008).

With few exceptions (Reck 1983; Granda 1995; Ruttenberg 2001; Okey et al. 2004; Hearn et al. 2005; Peñaherrera 2007; Peñaherrera and Hearn 2008; Bustamante et al. 2008; Castrejón 2008; Sonnenholzner et al. 2009; Edgar et al. 2010), the impacts of fishing in the Galapagos are still poorly understood for most species, and key historical information regarding the status of these species prior to fishing pressure is largely unavailable. The Galapagos grouper locally known as *bacalao* (*Mycteroperca olfax*, Serranidae) is a species that plays an important role in the composition of the marine ecosystem and is vulnerable to fishing pressure because of its restricted distribution and its special life history characteristics (e.g., slow growth, long life span, complex life cycle, reproductive conditions, and its role as a top predator in the trophic cascade, occupying the 4.5 trophic level) (Reck 1983; Coello and Grimm 1993; Nicolaides et al. 2002).

For decades *bacalao* was the most valuable commercial species in the composition of the white fin fishery in Galapagos. It was the main supply for dried and salted fish used in the preparation of *Fanesca*, an Ecuadorian traditional dish consumed during the religious holiday of Easter. However, with the emergence of fishing of other species (e.g., lobster and sea cucumber) and tourism, the presence of the Galapagos grouper in the catch composition of this fishery is significantly lower than decades ago and highly variable (Granda 1995; Peñaherrera 2007; Gagern 2009).

In the Galapagos, fishers' ecological knowledge could provide important information to determine changes in the status of marine resources across time, especially when biological data is lacking. With this context, the objectives of this research were as follows: first, to briefly describe the dynamics of the white fin fishery in San Cristobal Island and, second, to identify signs of shifting baselines from a representative element of this fishery, such as the Galapagos grouper.

Using anecdotal and quantitative information from three generations of fishermen, this research tries to find out the differences in perceptions across generations of fishermen about the Galapagos grouper. A good understanding of the different views within the fisheries communities would contribute to the generation of comprehensive plans for better conservation and fisheries management.

Research Site

Our research focused on the artisanal fishing fleet of San Cristobal, Galapagos Islands. The Galapagos Marine Reserve (GMR) is one of the largest marine protected areas in the world. It comprises the coastal and marine area within a range of 40 nautical miles (nm) surrounding the archipelago and inland waters (50,100 km^2). The Galapagos Archipelago includes both a marine protected area of approximately 138,000 km^2 and a land National Park of 8,000 km^2. The National Park encompasses 97 % of the land territory of the Galapagos, while the remaining 3 % is spared for human habitation (Heylings et al. 2002).

The archipelago has a wealth of marine and coastal habitats characterized by the interaction of a set of oceanographic, climatic, and geological conditions where the confluence of the Peru, Panama, and Cromwell currents allows the existence of ecosystems that harbor distinctive marine communities (Bustamante et al. 2002). There are about 444 fish species, out of which 41 are endemic, representing 9.2 % of the total species recorded (Peñaherrera 2007).

San Cristobal has the second largest population within Galapagos (7,475 persons, INEC 2010). Fishermen represent 3.6 % of the total population, with fishing being one of the main economic forces after tourism, conservation, and the public administration. In recent years, the profitability of fishing has declined as a result of overfishing of the sea cucumber and the spiny lobster fishery. In the whole archipelago, there are a total of 1,023 fishermen registered in the Galapagos National Park, and in Puerto Baquerizo Moreno, San Cristobal, there are 520 fishermen, which comprises 50.8 % of all the fishermen of the islands (Castrejón 2008).

Methods

To assess the status of the white fin fishery, we gathered fisher's anecdotal information and we quantified fishers' perceptions about changes in the Galapagos grouper past abundance.

We sampled active fishermen registered under any of the two cooperatives and also retired fishermen that belong to the first families who participated in this activity in the 1940s and 1950s and whose historical knowledge extends as far back as the beginning of the activity.

Snowball sampling method was used (Goodman 1961) where key informants led us to other individuals and these in turn to others, creating a chain of information. The first group of respondents, indicated by key informants, was located randomly for a start sample in the pier where they spend most of the day, in the fishing cooperative, and in the Central Park. For in-depth interviews, we located the oldest fishermen. Interviews were conducted one-on-one at home and fully recorded.

In order to quantify how the experiences of fishermen have changed over time, we consider primarily the methodological approach used by Sáenz-Arroyo et al. (2005a, b), Bunce et al. (2008), and Parson et al. (2009) who first tested quantitatively and qualitatively shifting baselines in coastal and island environments. Surveys and interviews were conducted between January and March 2010. First, we implemented a closed-question questionnaire to 124 fishermen who accounted for 24 % of the fishing population. The questionnaire was structured in two sections (1) social features of the fisherman, including demographic, social, and economic characteristics, and (2) information on fishing activities, including the perceived changes in this fishing type on the marine ecosystem and possible implications.

Upon completion of the survey, we conducted semi-structured interviews with key players involved in fisheries, identified by their knowledge and experience in their activity. We quantified the perception of fishermen regarding fishing decline and changes in the state of the marine ecosystem from a representative element, in this case the Galapagos grouper.

Active and retired fishermen came from three age groups: young (15–35 years, $N = 41$), middle age (36–50, $N = 49$), and older (≥ 51 years, $N = 34$). Initially, in order to determine the degree to which the fishermen of San Cristobal perceive the decline of white fin fishery and identify shifting baseline signals, fishermen were asked to (1) list white fin fish species they believed have declined during their fishing time, to later compare the perception of declining species cited by older fishermen to younger ones. To facilitate identification of species, we developed a guide with 68 color images of fish of commercial interest, placed by family and identified with the common and scientific names. This guide was developed from the one generated by the Charles Darwin Foundation (CDF) (2005) of fish species in the Galapagos Marine Reserve. (2) To assess the status of the Galapagos grouper, specifically, fishermen were asked to detail the best catch in relation to the biggest individual that they have ever captured and the total amount of pounds of grouper fished in their best fishing day. Fishermen also estimated the length of the largest grouper they have captured, showing the distance from his fingertips to the shoulders, or using both arms if the individual was longer. The length of the fish was rounded to the nearest centimeter and converted to biomass using conversion values length–weight ($W = aL^b$) (Hart and Reynolds 2002) with constant factors for this species published in FishBase (2009) (http://www.fishbase.org/search.php).

Furthermore, 23 interviews were conducted with fishermen whose fishing participation is recognized for their experience and knowledge. The interviews were held in San Cristobal and Santa Cruz. The information generated in the interviews was digitally recorded and transcribed in full. Data was organized by age and name. Fishermen' comments collected in the interviews were organized by themes, and identified the most representative observations in relation to changes on the status of this fishery over time. Data was analyzed using SPSS Statistical Analysis Program (IBM Statistics v17).

Results

Fishermen Characterization

Currently, Puerto Baquerizo Moreno has the largest number of boats (212 among small and big ships) and fishermen engaged in fishing (520 fishers). Fishermen can be classified in three groups: full-time, part-time, and casual fishermen with over 50 % of the fishermen doing fishing full time. Also, most fishers are generalists; this means that they change target species based primarily on the availability of the marine resource, market demand, and management measures established by the Galapagos National Park. Under their control, a fisherman with fishing license (PARMA) can capture any fishery resource whose extraction is legally authorized. The fishing method most often used is the handline known as *empate*, followed by the lure or drag (*señuelo* or *arrastre*) and the hookah diving or air line diving. The use of different fishing gear and its adaptations with certain modern materials is determined in part by the regulations of the Galapagos Marine Reserve and by the fishers' needs to improve their fishing efficiency. During their fishing trips, most fishermen use fiber boats towed by a bigger boat when they go on long trips.

Here we describe fishermen by their age class to explore the influence of age in fishing behavior and perceptions:

Old fishermen ($\geq$51 years, $N = 34$): 61.8 % of them migrated to Galapagos in the early 1930s. At the time of their arrival, their age ranged between 1 and 10 years old. For those that are alive, they have lived in the islands for more than 70 years. They started fishing between 1940 and 1960; consequently, 61.8 % of the old fishers' group has between 30 and 50 years of fishing experience. 50 % of fishers in this group currently go fishing on trips from 15 to 20 days as the other age groups; but the other percentage used to go fishing on trips mostly from 8 to 12 days. 47.1 % of the old fishermen are dedicated exclusively to the white fin fishery.

Middle-aged fishermen (36–50 years, $N = 49$): 51 % of this group were born in the Galapagos, and the other percentage mostly arrived at an early age. They began fishing mainly between 1970 and 1990; only the 20.4 % started in the 1990s. Almost 70 % of fishermen have more than 10 years of fishing experience, and only 20.4 % are dedicated exclusively to the white fin fishery. Important to note, 85.71 % of fishermen in this group fish on long trips from 15 to 20 days.

Young fishermen (15–35 years, $N = 41$): like middle-aged fishermen, half of them were born in the Galapagos; a second subgroup of migrants arrived to the islands with the sea cucumber fishing boom in the 1990s, and a third more recent group of fishermen have seasonal participation in fishing combined with work on other activities, such as tourism and construction. 68.3 % started their activity between the 1990 and 2000, and 87.8 % have between 10 and 20 years of fishing experience. They prefer to go fishing on a daily basis (usually four times a week). The few young fishers that go on long trips reported mainly fish from 15 to 20 days as the other groups.

In terms of economic status and expectations, most fishermen focused their fishing effort on the white fin, sea cucumber, and spiny lobster fishery (young = 85.4 %, middle-aged = 69.4 %, old = 41.2 %), but more recently, fishermen have been diversifying their activity because they believed that the cost-effectiveness of fishing has declined, as more than 70 % of fishermen reported decrease in profitability. Over 30 % of fishermen reported a decline in fishing landings compared with previous years. In addition, between 20 and 25 % recognize that prices in the local markets fluctuate widely and are controlled by intermediaries that take advantage of the situation. As a result, fishermen prefer other more lucrative activities, such as tourism, and recently middle-aged fishers are working in construction.

Almost 40 % of young and middle-aged fishers reported being interested in fishing other types of species like shark and sea urchin. Although they recognized that the National Park would never accept these fisheries, they believe that these species would give them profitability because they are in high demand by the market. On the other hand, the 64 % of the older fishers are not interested in fishing other type of species.

Fishers' Perceptions of the White Fin Fishery Depletion

Out of the 124 fishermen surveyed, 113 perceived a decline of up to 21 species as part of the white fin fishery. On average, 14 species were perceived as having declined. From them, a total of 10 species were mentioned in all the age groups (Table 11.1). *Mycteroperca olfax* and *Epinephelus mystacinus* (Misty grouper) were perceived as the most depleted species by fishermen. Additionally, other species were mentioned by an important percentage of fishermen in each age group: young fishermen identified *Acanthocybium solandri*, the middle-aged indicated *Seriola rivoliana*, and the old group described *Epinephelus cifuentesi* as the species depleted in their catches. Also, young fishermen reported as depleted three

Table 11.1 List of species most mentioned as depleted by the three fishermen groups, which shows the differences in perceptions between each age group

			Age groups (young, middle-aged, old)					
Family	Species	Common name	Total freq.	*J* ($n = 41$)	*M* ($n = 49$)	*O* ($n = 34$)	Trophic level	Habitat
Serranidae	*Mycteroperca olfax*	Galapagos grouper	108	32	45	32	4.5	Demersal, marine
	Epinephelus mystacinus	Misty grouper	55	17	22	15	4.5	Bathy demersal, marine
	Dermatolepis dermatolepis	Leather bass	16	4	4	8	4.5	Reef-associated, marine
	Paralabrax albomaculatus	White-spotted sand bass	17	5	5	7	4.5	Reef-associated, marine
	Epinephelus cifuentesi	Olive grouper	21	4	6	11	3.96	Demersal, marine
	Hemilutjanus macrophthalmos	Grape-eye sea bass	1	1	–	–	4.16	Demersal on rocky bottoms
Scombridae	*Thunnus albacares*	Yellowfin tuna	3	2	1	–	4.34	Pelagic-oceanic, oceanodromous, brackish, marine
	Thunnus obesus	Bigeye tuna	1	1	–	–	4.49	Pelagic-oceanic, oceanodromous, marine
	Acanthocybium solandri	Wahoo	17	7	6	4	4.4	Pelagic-oceanic, oceanodromous, marine
Scorpaenidae	*Pontinus clemensi*	Mottled scorpion fish	15	6	4	5	3.64	Demersal, marine
Mugilidae	*Mugil galapagensis*	Galapagos mullet	17	3	6	8	2.46	Demersal
	Xenomugil thoburni	Thoburn's mullet	17	3	6	8	2.29	Pelagic-neritic, marine
Malacanthidae	*Caulolatilus princeps*	Ocean whitefish	1	1	–	–	3.9	Reef-associated, marine
	Caulolatilus affinis	Bighead tilefish	1	–	–	1	3.74	Demersal

(continued)

Table 11.1 (continued)

Family	Species	Common name	Age groups (young, middle-aged, old)				Trophic level	Habitat
			Total freq.	*J* ($n = 41$)	*M* ($n = 49$)	*O* ($n = 34$)		
Lutjanidae	*Lutjanus argentiventris*	Yellow snapper	3	1	–	2	4.03	Reef-associated, marine
	Lutjanus novemfasciatus	Dog snapper	5	1	2	2	4.1	Reef-associated, marine
Labridae	*Semicossyphus darwini*	Galapagos sheephead wrasse	3	1	1	1	3.81	Reef-associated, marine
Haemulidae	*Xenichthys agassizii*	White salema	4	2	1	1	3.36	Reef-associated, marine
	Xenocys jessiae	Black-striped salema	3	2	–	1	3.4	Reef-associated, marine
	Haemulon scuderii	Grey grunt	1	–	–	1	4.2	Reef-associated, marine
Carangidae	*Seriola rivoliana*	Almaco jack	14	3	8	3	4.5	Reef-associated, marine

species that were not mentioned by the middle-aged and the older fishermen (*Thunnus obesus*, *Caulolatilus princeps*, and *Hemilutjanus macrophthalmos*); and old fishermen reported two species (*Caulolatilus affinis* and *Haemulon scudderii*), which were not described by any fishermen of the other age groups.

As expected, fishermen with more fishing experience recalled a greater past abundance of species. According to their perception, species started to decline in different periods of time. Old fishermen reported that the declining of white fin species started around the 1960s (70.5 %), and others from the same group said it started around the 1980s. Similarly, middle-aged fishermen reported the 1980s (77.5 %), and young fishermen mentioned the 1990s (70.7 %). The older group attributes the decline to the *Sociedad Pesquera de Galápagos*, *Predial*, which increased the number of boats and fishers because the demand for Galapagos fish raised the pressure in this fishery. The amount of fish that fishers caught at that time exceeded the type of fishing that was mainly for local consumption.

They perceived that fishing was more productive and profitable back then. Old fishermen sensed that the time they spend and the distance they had to travel to fish were smaller before. At that time, fishing operations lasted 8–12 days, enough to bring a good catch; also they could chose the size of the fish they sold and gave away smaller fish to relatives and friends. Likewise, they used to cut the head and tail before salting and drying the fish. Nowadays, they have to travel longer distances and spend more time to find fish, and the fish merchant is the one who dried the fish.

Old fishermen perceived a higher reduction in the number of species, across time, compared to the other age groups of fishermen surveyed. Figure 11.1 shows an ANOVA test that compares the perceptions of the three age groups.

Interestingly, the three groups agree that the main reason for the decline of the white fin fishery is the overfishing. They believe that the continuous fishing pressure on these resources over the years is affecting their abundance. Old fishermen reported that they previously fished only 6 months a year for the salt and dried season; but today, fishing occurs all year round, so species do not have enough time to grow and reproduce. Moreover, fishermen recognize that economic and political pressures within fishing cooperatives increased the number of fishermen and boats, creating more competition and therefore more pressure on fish stocks. Older fishermen indicated that there are some fishers, especially from the young group, who fished species at their reproductive stage or when they have not yet reached sexual maturity. Some noted that there are fishermen who use underwater guns and the Hawaiian spear for white fin fishery, which is not allowed by the GMR regulations.

*Fisher's Perceptions of Decline in Indicator Species (***Mycteroperca olfax***)*

Despite the lack of statistically significant differences in a reduction in the size of the Galapagos grouper across age groups (one-way ANOVA, $F = 0.868$,

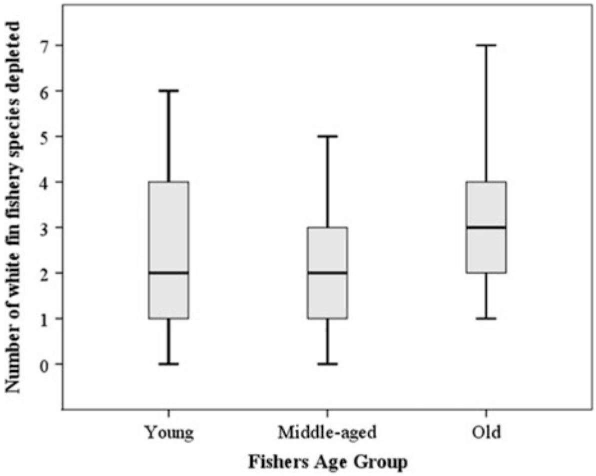


Fig. 11.1 Number of species that belong to the white fin fishery listed as depleted by three generations of fishermen (one-way ANOVA, $F = 3.210$, $p = 0.044$, HSD significant differences between the young and old age groups, $p \leq 0.05$)

$p = 0.422$), we found statistically significant differences in their best day's catch (Fig. 11.2). Older fishermen reported to have fished a higher amount of fish on their best fishing day. The study also found significant differences in the estimated weight of this species (biomass) across time (Fig. 11.3).

Fishermen observations indicate that 67.49 % species perceived as declined belong to the Serranidae family. From the 124 fishermen surveyed, 108 reported the Galapagos grouper as the species with the highest decline (33.44 %). Different age groups argue different reasons for changes in the *bacalao's* abundance, including overfishing, environmental change, and increased presence of sea lions in the fishing banks, among others. 70 % of old fishermen attributed this species decline to overfishing; on the contrary, only 29 % of young and 23.7 % of middle-aged fishers mentioned this reason as the main cause of this species' decline. Even though these were the most frequent responses within each age group, these percentages of fishermen did not represent a majority in each age group. The old fishermen perceived and explained the system dynamics in a distinct way compared to the other fishers' age groups.

Discussion and Conclusions

This chapter provides insights about the shifts of fishermen perceptions regarding marine resource status and trends through time of the white fin fishery across age groups in San Cristobal Island. The dynamic socio-ecological relationships between fishermen and marine resources have been developed across time in Galapagos (González et al. 2008), and fisher knowledge can complement scientific information and provide practical data that can be used in fisheries management

Fig. 11.2 Best catch of Galapagos grouper indicated by three generations of fishermen, recalling their best fishing day in terms of fished pounds (one-way ANOVA, $F = 20.897$, $p = 0.000$, Games-Howell significant differences among the three groups of fishermen, $p \leq 0.05$)

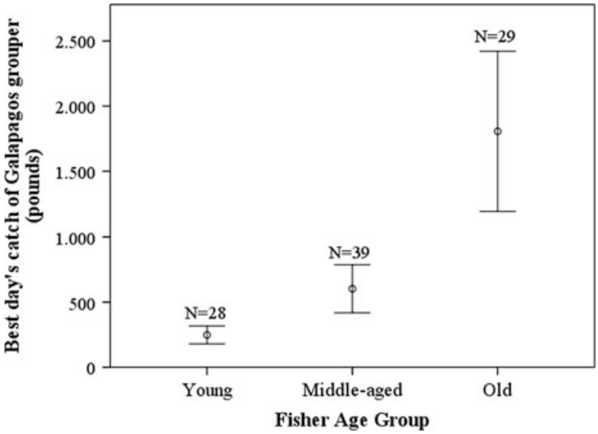
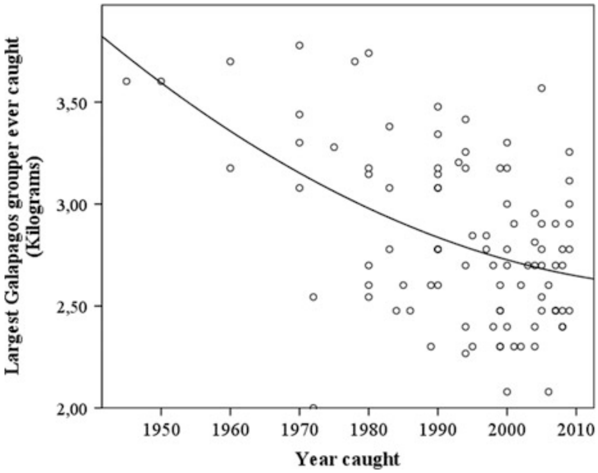


Fig. 11.3 Estimated weight of the Galapagos grouper (biomass) ever caught plotted against the year in which fishermen recalled the year of most abundance (second-order regression *line* shown $r^2 = 0.229$, $p = 0.000$)



(Johannes 1998; Silvano and Begossi 2005; Grant and Berkes 2007; Zukowski et al. 2011).

Due to the lack of continued fisheries data, often the only information available is fishers' anecdotes about past abundance, and its use is helpful to fully comprehend the extent to which fisheries have transformed marine ecosystems over the years (Johannes et al. 2000; Murray et al. 2006). Understanding the reciprocal interactions between fishers and marine resources, the knowledge and experiences produced around these interactions are necessary to understand the impact of fisheries on natural system and the changes that certain impacts of natural system can produce on fisheries dynamics (Perry and Ommer 2003). In this sense, fisher's anecdotes can make a valuable contribution to scientific knowledge about the state of the abundance of marine populations (Rochet et al. 2008; Ainsworth et al. 2008).

In our study, fishermen report that the composition of catches in the white fin fishery has changed across time. This is consistent with what has been seen along the years. Reck (1983) and Granda (1995) reported almost the same number of species in their studies (41–38, from 17 families); but Molina et al. (2004) reported an increase in 56 species from 18 families. Currently, the exploitation has been focused on 68 species belonging to 27 families, mostly Serranids, Scombrids, and Mugilids (Castrejón 2008). Recently, Gagern (2009) shows that there are enormous changes in the composition of landings, and the most significant change applies to the Galapagos grouper, which used to be the unique objective in the white fin fishery.

In San Cristobal, according to fishermen's perceptions, the relationship between white fin fishing resources and users has been very dynamic. At the begining of this fishery, the target species were different. They started fishing mainly the Galapagos grouper, and later diversified their fishing to other associated species, mainly Serranids. Over the years, young fishermen have expanded much more their target species, focusing not only on the coastal-demersal fish catch as the older fishers used to do but much more on pelagic species.

Regarding the dynamics and trends of the Galapagos grouper as a fishing resource of the white fin fishery, our results provide important insights which could complement scientific information for this fisheries management in the Galapagos Islands. In San Cristobal, 76 % of the fishers from the older group started their activity in the decades of 1940 and 1960, way before Reck initiated his research on the status of the white fin fishery (handline fishery) in 1976,[1] which is considered the baseline study of this fishery providing important information of catch composition and biological data of the *bacalao*. Until this period of time, this fishery lacked scientific data, except for fishers' historical and anecdotal information. In this sense, most of older fishermen reported that changes in the Galapagos grouper abundance started around the decade of the 1950s, almost three decades before Reck's study (1983), thus shifting the baseline of this fishery decades earlier from the first scientific information gathered on this resource.

Shifting baselines could be possible in the San Cristobal white fin fishery because, as Pauly (1995) observed, most marine ecosystems were assessed by scientists only after many species had declined and the historical amnesia has contributed to this phenomenon, where our perception of what is natural shifted toward more degraded ecosystems. As result, it is hard to assess the present state of marine ecosystems and suggest some management actions without knowing about the extent and drivers of past changes (Roberts 2003; Lotze and Worm 2009).

This chapter shows signs of shifting baselines among generations of fishermen regarding the white fin fishery impacts on target species (Figs. 11.2 and 11.3), which is a consistent result with similar studies carried out in other marine ecosystems (Sáenz-Arroyo et al. 2005b; Bunce et al. 2008). Fishers' perception on the

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[1] Quiroga and Orbes (1964) and Barragan (1975) presented technical reports about the white fin fishery fleet composition and the fishing method, but they did not present information about the catch composition and the status of the species in the handline fishery at that time.

species decline and changes in the abundance of the Galapagos grouper are indicative of the historic pressure of this fishery, highlighting evidence of its change. The difference among fishers groups regarding the decline of *bacalao* in the composition of this fishery could be related to several factors, such as overfishing, reduction in breeding success due to biological changes associated with fishing pressure, environmental variations that affect species biology, and changes in fishing effort in areas with lower abundance of this species. Gagern (2009) has shown that there are enormous changes in the composition of landings since its beginning (he has considered as a baseline Reck's study—1983) and noticed that since 1983 until 2008, the Galapagos grouper shows a decline in total catches.

In relation to the size of the Galapagos grouper gathered through fishers' anecdote information, there are some inconsistencies. Although older fishermen recalled having caught larger individuals, no statistical differences were found and some of their estimation on the Galapagos grouper size in their best fishing day is 37 % greater than the maximum adult size indicated for this species (93.5 cm; Reck 1983; Gagern 2009[2]). It is important to note that perceptions are not exact, and inaccurate estimates could be due to several factors, such as the general tendency of people to exaggerate past events and romanticize "better past times," the inability to recall exact details, the difficulty in numerical calculations, and illiteracy (Sáenz-Arroyo et al. 2005a).

We found differences among the three age groups recalling their best fishing day (Fig. 11.2). The older fishermen recalled have landed a greater amount of *bacalaos* than the young groups. Additionally, the older group reported have caught the largest Galapagos grouper in the period of 1950–1980 when it started to decline gradually (Fig. 11.3). According to Reck (1983) the average of yearly landings of Galapagos grouper were 124.811 kg fresh weight; on the other hand, Gagern in 2009 only reported 61.086 kg, showing a notable decrease in the landings of this species.

Anecdotal reports from semi-structured interviews carried out to old fishermen showed that key events influenced greatly the way fishing was made in San Cristobal, in the early stages of the fishing activity. Some events, such as the creation of the freezing plant *La Predial* (1945–1955), the establishment of the American naval base in Baltra during the World War II (1945), and the continued technical development of fishing in the following decades, which reached its greatest progress in 1960 when the North American ships began to buy fish directly from the local fishers. The high seasonal demand and high prices for salted Galapagos grouper during October to March across decades also drove fishing efforts. All these events triggered not only the number of fishermen and boats that made up the Galapagos' artisanal fishing fleet but also their perception toward the *bacalao* fishing.

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[2] Gagern's study presents a comparative analysis with Reck about the status of *Mycteroperca olfax*. His results show length distributions similar to Reck.

Later in the 1990s, more profitable fisheries developed such as the sea cucumber (*Isostichopus fuscus*) and the spiny lobster (*P. penicillatus* and *P. gracilis*) and moved the white fin fishery to third place in importance. However in the last decade, the marine reserve restrictions, coupled with the low profitability of the new fisheries, the growing demand for fresh frozen fish to be exported outside of the Galapagos which is uncontrolled and unrestricted so far, and the increased demand of local fish to satisfy the ever-growing tourist industry are factors that have intensified the pressure on the Galapagos grouper fishery.

Despite the special management regime of the Galapagos Islands, the coastal marine ecosystem has been changed by fishing activities and climatic events such as *El Niño* (Ruttenberg 2001; Bustamante et al. 2008). Top predators represent more than 66 % of the total biomass flow and more than 60 % of the total number of trophic connections (Bustamante et al. 2008). According to Vinueza et al. (2006), the Galapagos marine ecosystem seems to be characterized by the role of the top species and their strong interactions in the trophic chain, which would be higher if fishing pressure decreased, and also by environmental incidence on these ecological processes. In this sense today, Ruttenberg (2001) considered likely that the sequential decline, mainly of species that occupy the top levels in the food chain, had led to significant changes in the structure and functioning of coastal marine environments of the archipelago.

The Galapagos grouper is one of the main predators in Galapagos, Malpelo, and Cocos Islands in Costa Rica (Nicolaides et al. 2002). Currently, the species is considered vulnerable by the Red List of Threatened Species of the IUCN. The Galapagos grouper occupies the top level in the trophic chain along with other species such as sharks, whales, seabirds, and sea lions, among others (Mills et al. 1993; Bustamante et al. 2008). Therefore, its depletion could affect the structure, function, and diversity of marine subtidal ecosystems.

Nicolaides et al. (2002) reported that 21 % of *bacalao* was below the size of sexual maturity (female); their results showed fewer males in relation to females, suggesting a depletion of larger animals (males). Probably fishermen catch them before they undergo the sex change from female to male which characterizes most Serranids, affecting their reproductive success and population size. This species has an annual reproductive cycle with its spawning peak between the months of October and December. Like other groupers, they form spawning aggregations that coincide with increases in the sea surface temperature which mark the cold-warm season change (Reck 1983; Coello and Grimm 1993). These months were reported by fishermen as the most productive; therefore, fishermen focused their fishing effort on these aggregations likely decreasing the reproductive success of this species.

Taking in consideration the vulnerable ecological characteristics within the white fin fishery resources, the signals of shifting baselines, the differences in perceptions across age groups of fishermen, and the diversification of target species in later years, the following points should be further investigated: first, the importance of including fishermen age and age groups as significant variables within the management strategies of natural resource management and conservation in the Galapagos fisheries. This chapter has shown that different age groups have different perceptions and attitudes toward the species and fishing in general. Age groups might have to be treated differently because they have different expectations and behaviors but also different fishing techniques, experiences, and knowledge levels. Second, it is especially important to monitor more the representative species catches in this fishery, as they may be affected too by historical fishing pressure as the Galapagos grouper. *Epinephelus mystacinus* (Misty grouper), *Paralabrax albomaculatus* (White-spotted sand bass), *Dermatolepis dermatolepis* (Leather bass), *Epinephelus cifuentesi* (Olive grouper), and *Hemilutjanus macrophthalmos* (Grape-eye sea bass) are also species that have a long history of suffering high fishing pressure. In order to prevent the decline in more top predators, it is important to study the biology of each species, integrating to studies of fishermen's perceptions in order to prevent further undesired changes in the ecosystem function that will not only affect the availability of marine resources but also would have social and economic consequences, since a significant part of the population is engaged in this fishery.

Finally, the white fin fishery has never been restricted as the sea cucumber and the spiny lobster fisheries. Throughout time, the composition of this fishery has dramatically changed, and top predators have been affected by the continuous fishing pressure. These species play an important role in the function of the marine ecosystem, and their decline draws attention of urgent management actions on this fishery. There is recognition from the users of the marine resources, about changes in the status of this fishery. The number of threatened species has increased, especially Serranid species. In order to keep the well functioning of the marine ecosystem and satisfy the social and economic needs of the fishermen household, it is important to ensure the representativeness of every species because the only way to keep the fish populations in good conditions is to have a sustainable fishing activity.

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Appendix

Table 11.2 Fishermen' comments from the older group, recalling past abundance of species in the white fin fishery

Fisher group	Comment
Old (>51 years), $N = 34$	Fishers fished white fin species all year round and this creates pressure in this fishery. Its species have decreased because of its over exploited.
	There is no depletion, there is the same amount of species, but divided amongst more fishers because now there are more fishers than before.
	The fishing activity has diminished a lot. The majority of the people who were fishers have changed to other activities as tourism.
	This fishery has been depleted. When I first came, the white fin fishery was good, in 8 days we already brought the catch. There is a decrease of species.
	This fishery has diminished a lot. Today fishers do not bring as much fish as before. Years ago, we did not fished in the farthest islands, but now fishers traveled around the all Archipelago looking for good places to fish.
	Before, fishers used to fish only for 6 months, and then they rested the other months, now they fish all year round and do not let the species grow.
	Today fishers spend more money than what really earn from this fishery. It is more difficult to fish because you need more days to catch a better amount of fish.
	Species have decreased because there are more fishers and fishing boat.
	The fishing volume is not the same as before. In 12 days you could make a good catch, now we have to go further, and even do it that, we do not bring enough fish.

Table 11.3 Comments extracted from the interviews to the middle-aged and older fishermen about changes in the abundance and size of the Galapagos grouper, an indicator species of the whitefish fishery

Fishermen age	Comments
38	Bacalao has been fished a lot, there is over exploitation. It has changed in abundance and size, before they were bigger than now. The same as the bacalao is happening to the Misty grouper.
38	There is almost no bacalao left, it is not like before; many sea lions compete with the fishers for this species and they also scare them away.
41	There are changes in its abundance there is not as much as before. There are some changes in its size. Sometimes when you catch them they are big but not huge.
47	Nowadays the bacalao has declined in quantity and size; all the boats go to the same place and fish the same species. Also there are people who use underwater guns on the white fin species and this fishing method scares the fish to deep water.
54	Before there was a lot of bacalao and you did not need to go as far as today, possibly climate change and over exploitation have finished this fish. There is no respect for the size of the fish, some fishers do not let them grow and now they fish all sizes.
61	The bacalao has decreased because the growing presence of Sea lions and the continuous fishing activity. Before you only caught quality bacalao, small fish were returned to the sea. Now you get more species and even the small ones.
62	There are ships from the continent which are fishing inside the Marine Reserve pressuring more the marine environment. Before you caught bacalaos in all areas and picked the better ones, the little ones were returned to the sea, but now you have to get whatever falls in the hand line.
65	Today there is more pressure in the dried and salted fishery because it takes from 7 to 8 months long.
65	Before the 6 months fishing for the whitefish fishery was respected, there were bigger fish and more abundant. Now there are many fishers from here and other places that fishes all year round.
66	The quantity of bacalao has dropped. If you go to the bottom, you can find big ones but not so many like before. Many fishers and boats do not let them grow.
71	Before they were bigger, now they are smaller, you cannot see as much as before. It has been fished a lot and without a banning period it is over. Before you let the smaller ones go, now you pick them all.
73	I fished during the time where there was a lot of bacalao. The dried and salted fishery has been done a lot and it has diminished. Now you do not see bacalao as before. Formerly you only fished bacalao and you sold it dried and salted without the head and tail. Today fishers dried and salted the complete body.
76	There is less bacalao than before and it is because some fishers catch them with a Hawaiian spear and underwater gun and this scare the aggregations. Older fishers used to catch them with the hand line, but nowadays some young fishers use other methods because it takes less time fishing with them.
76	Too many exploitation of the bacalao, it does not get bigger in size or in quantity, before we were few fishers and we picked less, now there are a lot of fishers who pick more.
79	Before we used to fish bigger fish. Now there are small and the quantity has changed.
83	Before we used to fish only bacalao, people did not want other fish. The size also has diminished. In my times you only picked the big ones and returned the small ones to the sea, today there are more fishers and boats and they do not let the bacalao grow.

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Chapter 12

Pollution as an Emerging Threat for the Conservation of the Galapagos Marine Reserve: Environmental Impacts and Management Perspectives

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Abstract The Galapagos Marine Reserve (GMR) is one of the most fragile marine ecoregions to be preserved to benefit global biodiversity. Ongoing continentalization and increasing human population diminish the degree of isolation of the Galapagos, jeopardizing its socio-ecological system. While tourism and fisheries activities stand by the islands' economy, several anthropogenic stressors threaten the marine ecosystem. An environmental assessment and literature survey were conducted to characterize the coastal marine pollution impacts caused by human-made activities. The assessment revealed that municipal waste incineration of organic waste and plastics in open dump areas is a potential source of unintentionally produced persistent organic pollutants such as dioxins and furans. Plastic is one of the most abundant solid wastes at sea and shorelines, representing 25 % of the total marine debris. More than 50 % of current-use pesticides applied in the agriculture zone of the inhabited islands were identified as endocrine-disrupting chemicals, underlying potential health effects in the endemic fauna. Oil spills and traces of hydrocarbons threaten the long-term survival of marine species due to the current reliance on fuel transported from Ecuador's mainland coast. Concerted local and global management strategies are strongly needed into the decision-making processes to protect the GMR from chemical and biological assaults.

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Introduction

Since Charles Darwin wrote *On the Origin of Species* in 1859, the Galapagos Islands have become a living laboratory for the study of natural history. The roots of their unique nature can be attributed to their remote, oceanic geography. The Galapagos comprises an archipelago with 13 major volcanic islands, situated approximately 1,000 km from the Ecuadorian coast, between 01°40′N–01°25′S and 89°15′W–92°00′W. At present, over 2,900 marine species have been identified, of which close to 20 % are endemic to the Galapagos (Bustamante et al. 2002a, b).

Several ocean currents influence the regional climate and drive the population dynamics of native and endemic species. The most important oceanic surface currents are the Panama (El Niño) current, coming from the northeast and bringing warm, nutrient-poor waters, and the Peru (Humboldt) current, arriving from the Southern Ocean and transporting cold, nutrient-rich waters. Both current systems merge to form the South Equatorial Current (SEC), which drives surface marine waters to the west of the islands and which has been proposed as the major mean of transportation bringing species from mainland Ecuador to the Galapagos (Banks 2002; Bustamante et al. 2002a). In addition, the Equatorial Undercurrent or Cromwell current, rich in nutrients (i.e., dissolved iron), flows from west to east enhancing upwelling conditions around the western platform of the Galapagos.

Only two seasons occur in this region, a warm, wet-rainy season from December to May or June and a cold, dry (*garúa*) season from June to November or December (Snell and Rea 1999; Banks 2002). Periodically, El Niño event can disrupt the Galapagos regional climate, where in the last 20 years it has become more intense, reflecting an increase in the magnitude and intense peak frequency (Snell and Rea 1999; Mendelssohn et al. 2005; Sachs and Ladd 2010).

The Galapagos National Park (GNP) and the Galapagos Marine Reserve (GMR) have been designated a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Natural Heritage Site and Biosphere of the Earth, containing a unique biodiversity and endemism that provides strong evidence of evolutionary theory such as natural selection, adaptation, speciation, and radiation processes. These tropical remote islands still conserving 95 % of its biodiversity were recently enlisted as a heritage in risk in 2007 due to the rising number of invasive species, emergent human population growth, and increasing tourism (Watkins and Cruz 2007). As a complex social-ecological system, the resilience of the Galapagos Islands might be still seriously at risk due to the unsustainable development model and the unresolved social-ecological crisis preventing the reorganization of the system and leading it towards an undesirable state despite predominant legal, political, and management decisions (González et al. 2008).

Under this premise, the human and ecological footprint on the Galapagos Islands is unraveled as the geographic opening of the islands in terms of continentalization, defined as an anthropogenic process reducing the degree of isolation of this fragile ecoregion due to the ongoing reliance on and massive influx of energy, fuel, and materials transported from continental Ecuador, jeopardizing the long-term preservation of the islands (Charles Darwin Foundation 2010; Grenier 2010). Thus, both the GNP and GMR are constantly facing the trade-offs between development and conservation in concert with the social dimensions and political climate triggered by regional economic interests and globalization.

History reveals that subsequent to the declaration of the Galapagos as a national park (≈7,900 km^2 of the terrestrial Galapagos Islands) in 1959, Rachel Carson published her well-known publication *Silent Spring* in 1962 to draw global attention to the potential effects of man-made chemicals, in particular pesticides, on wildlife populations (e.g., raptors and songbirds) and human health (Carson 1962). Interestingly, two decades before the publication of Carson's famous book, the Galapagos were already a strategic location occupied by the US military forces between 1941 and 1946 during World War II (Woram 2005), establishing a military base on Baltra Island (adjacent to the semi-urbanized Santa Cruz Island) in 1943 (González et al. 2008). While it is a fact poorly documented, the implications of this military presence had a considerable anthropogenic pressure in the Galapagos environment, including impacts to the endemic vegetation and land iguanas (*Conolophus subcristatus*). In addition to this preceding human footprint, Americans used the organochlorine pesticide, DDT (dichlorodiphenyltrichloroethane), to eliminate introduced rats (e.g., black rats, *Rattus rattus*) in the islands (Alava et al. 2011a, b). Yet, this effort was unsuccessful as the invasive rodents were not eliminated, but the legacy of the past use of DDT still persists in the marine environment of the islands, as demonstrated recently by the biomagnification of this pollutant in the Galapagos sea lion food chain (Alava and Gobas 2012).

Coastal development, fisheries overexploitation, and chemical and biological pollution have been identified as the major threats to the world's oceans and marine protected areas (Boersma and Parrish 1999). In these islands, most of the resident population obtains their economic incomes either directly or indirectly from the ecotourism, which is the major economic activity, based on the observation of native fauna and flora of the islands, while others are benefited from exploitation of reef fishes, lobster, sea cucumber, and even illegal shark finning (Merlen 1995; MacFarland and Cifuentes 1996; Bensted-Smith et al. 2002; Carr et al. 2013). However, intentional (operational) and unintentional (accidental) releases of hydrocarbons (e.g., oil, diesel, gas) occur regularly around the islands from ships, with the former occurring in the long term causing chronic degradation and the latter resulting in acute impacts to the marine environment (Lessmann 2004). While oil spills offer perhaps the most visible example of pollutant impacts on sea life, less visible and more insidious global toxicants of concern involve persistent organic pollutants (POPs), which have recently been assessed in few organisms in the Galapagos (Alava 2011).

During the last 15 years, the Galapagos Islands Archipelago has undergone drastic economic, social, cultural, and ecological changes. The principal cause of these changes has been economic growth driven by tourism whose gross income has increased by an average 14 % each year (Watkins and Cruz 2007; González et al. 2008). Tourism and population growth stimulate the arrival of more flights and more cargo ships, diminishing the degree of isolation of these remote islands and, therefore, increasing the potential arrival of invasive species (Watkins and Cruz 2007) and augmenting the risk of pollution.

The coastal environment and food webs in the Galapagos are at risk due to anthropogenic impacts. Contamination by both chemical and biological pollutants is critical to the long-term conservation of Galapagos biodiversity and native wildlife. Coastal waters that are contaminated with persistent chemicals and pathogens can lead to human illness, reduced fisheries quality and quantity, and impacts on the health of marine wildlife, having serious obvious social and economic consequences. Conversely, coastal waters that are protected from environmental pollutants provide food to humans and wildlife and provide a foundation for biodiversity, the human population, and the ecotourism sector. In 2000, Ecuador's economy obtained US $210 million from Galapagos tourism alone (Fundación Natura and World Wildlife Fund 2002). For the Ecuadorian government and the people of the Galapagos, therefore, a rigorous evaluation of past, current, and potential environmental impacts is a crucial part of the social and economic integrity of the archipelago.

In this chapter, an environmental impact assessment and literature review was conducted to explore evidences of current environmental and marine pollution pressures that are threatening the conservation of the Galapagos Marine Reserve and its endemic wildlife. By identifying local and external pollution sources and their potential impacts to the health of wildlife populations, we aim to contribute with a new impact assessment baseline and recommend precautionary mitigation strategies to support the environmental management plan of the Galapagos Marine Reserve.

Declining Wildlife in Galapagos: Impact of Environmental Stressors

Several populations of endemic wildlife and marine species (e.g., marine mammals, seabirds, and marine iguanas) are being affected by both natural and anthropogenic factors in the Galapagos (Fig. 12.1). In general, the Galapagos wildlife is affected by different natural stressors, including density-dependent (i.e., predation, competition, food shortages, disease, territory) and density-independent factors (the El Niño–Southern Oscillation (ENSO) and natural disasters, i.e., volcanic activity and tsunamis), as depicted in Fig. 12.1. Thus, it is of particular importance to differentiate those human-made activities affecting wildlife from natural variation and regulatory forces (i.e., population regulation), keeping populations at balance (i.e., equilibrium) after facing drastic fluctuations. In addition, while there are several lines of evidences showing that anthropogenic pressures such as introduced species, chemical and biological pollution, solid waste, urban sprawl (i.e., habitat fragmentation), and illegal fishing are affecting native and endemic species, the impact of

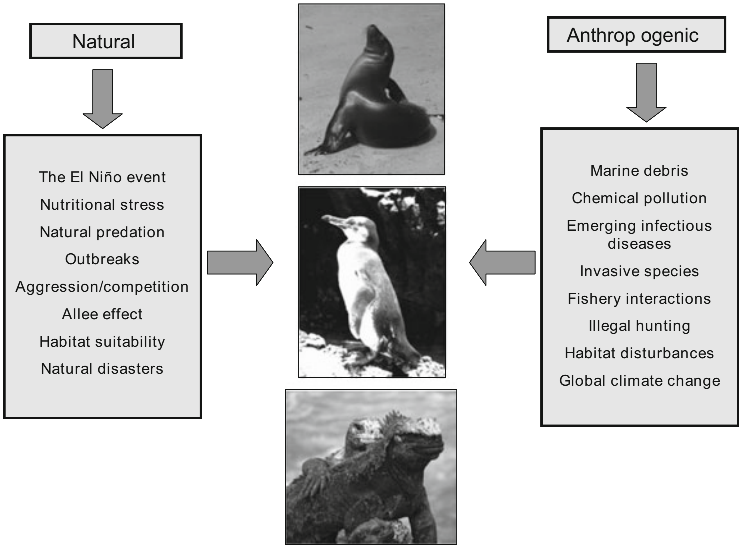

Fig. 12.1 Environmental stressors, including both natural and anthropogenic factors, influence the population dynamics of marine wildlife in the Galapagos Islands. In this illustration, three endemic species, including the Galapagos sea lion (*top*), Galapagos penguin (*middle*), and marine iguana (*bottom*), are shown as examples of organisms undergoing cumulative anthropogenic environmental impacts (*right box*) and affected by density-dependent factors (*left box*). Adapted and modified from Alava (2011). Photos: J.J. Alava

anthropogenic climate change cannot be ruled out as looming threat for these species in the long term.

The El Niño phenomenon has affected endemic seabird populations, including the flightless cormorants (*Phalacrocorax harrisi*) and Galapagos penguins (*Spheniscus mendiculus*). For instance, the 2004 penguin population (≈1,500 birds) was estimated to be less than 50 % of that prior to the strong 1982–1983 El Niño event (Vargas et al. 2005, 2006, 2007). Although the impact of climate change on several large-scale ocean-climatic fluctuations (i.e., ENSO episodes) is difficult to predict due to uncertainty, it has been suggested that global climate change may result in continued, more frequent, and intense El Niño events coupled with higher sea-surface temperature, increased precipitation, sea level rise, acidification, and reduction in upwelling in the Galapagos (Timmermann et al. 1999; Mendelssohn et al. 2005; Sachs and Ladd 2010). Therefore, it is likely that the most significant threat from climate change is its potential to affect the frequency and severity of ENSO events, impacting not only Galapagos seabirds and coastal waterbirds (Vargas et al. 2006; Wiedenfled and Jiménez-Uzcategui 2008) but endemic pinnipeds, including the Galapagos sea lions (*Zalophus wollebaeki*) and Galapagos fur seals (*Arctocephalus galapagoensis*) (Trillmich and Limberger 1985; Trillmich and Dellinger 1991; Alava and Salazar 2006; Salazar and Denkinger 2010), as well as the Galapagos marine iguana (*Amblyrhynchus cristatus*) (Laurie 1989; Laurie and Brown 1990; Wikelski and Thom 2000).

Bycatch and plastic threaten the critically endangered Galapagos albatross (*Phoebastria irrorata*) and Galapagos petrels (*Pterodroma phaeopygia*) in oceanic waters outside the limits of GMR (Alava and Haase 2011). Additional anthropogenic and catastrophic factors such as introduced predators (particularly rats, cats, and dogs), competition from fisheries, introduced diseases (i.e., emerging infectious pathogens), and oil spills could further contribute to population declines or accelerate the probability of extinction of Galapagos seabirds (Vargas et al. 2005, 2006; Wiedenfled and Jiménez-Uzcategui 2008; Alava and Haase 2011).

Typical examples of endemic marine mammals mostly affected by these factors are Galapagos sea lions and fur seals, which have declined from 40,000 and 30,000–40,000 to 16,000 and 6,000–8,000 animals, respectively, since the late 1970s, without showing signs of recovery in most of the islands (Alava and Salazar 2006). This implies a decline of 60 % for Galapagos sea lions and 80–85 % for Galapagos fur seals from the late 1970s to 2000 (Alava and Salazar 2006). As a result, these two species are listed under the IUCN endangered (EN) category (Aurioles and Trillmich 2008a, b).

Whereas the effects of oceanographic—climate episodes, including the El Niño events, are well known as a cause of declining in sea lions, fur seals, and seabirds, the role of marine pollution has not been fully investigated although it is among them. The best well-known case of mortality in an endemic species associated to marine pollution was the chronic toxic effects of the 2001 Jessica oil spill's residues that affected the vulnerable population of marine iguanas, as documented elsewhere (Wikelski et al. 2001, 2002; Romero and Wikelski 2002).

With a fair understanding of the distinction between natural forces acting and shaping the evolution in these species and those created by human activities, the following sections are focused on the anthropogenic impacts affecting wildlife populations, including marine fauna, and the GMR.

Pollution Sources and Impacts in the GMR

Anthropogenic Impacts: Characterization and Assessment

The fundamental source of this chapter is Alava (2011), complemented with information and data compiled and analyzed from the existing scientific literature, technical reports, and lines of evidences from field observations. A characterization matrix of anthropogenic impacts resulting in major conservation threats and environmental effects for marine and terrestrial components of the Galapagos Islands is available in Alava (2011). A synthesis focused on management implications for the GMR is also provided at the end of this assessment. Based on the identification of threats and impacts, the overall impact assessment is described as follows.

Table 12.1 Population and waste production in three islands of the Galapagos based on the last human census conducted in 2010

Island (years of surveys: waste production)	Population: 2010 census[a]	kg/day/person (1990s/2008)	% OM (1990s/ 2008)	2010 estimated range tonnes/year
Isabela (1998[b]/2008[c])	2,256	(0.6/0.6)	(≈70/86)	494
San Cristóbal (1997[b]/ 2008[c])	7,475	(1.3/0.6)	(>70/61)	1,637–3,547
Santa Cruz (1995[b]/2008[c])	15,393	(0.8/0.6)	(≈60/40)	3,371–4,495

Database for waste production per capita per day and organic matter (OM) composition was obtained and adapted from Fundación Natura and WWF (1999), Kerr et al. (2004), and De la Torre (2008)

[a] Database for the 2010 human population census for the Galapagos Islands was retrieved from INEC (2011)

[b] Data for 1995, 1997 and 1998 was obtained from Fundación Natura and WWF (1999) and Kerr et al. (2004)

[c] Data for 2008 was obtained from De la Torre (2008) cited by WWF and Toyota (2010)

Human Population Growth: Production and Incineration of Solid Waste

The human population has recently increased in the Galapagos, having approximately 25,800 people, without considering tourists, by 2010 (Table 12.1; Table 12.7 in Appendix) with an annual population growth rate of 6.4 % during the period 1990–1998 (Fundación Natura et al. 2000; Kerr et al. 2004; Epler 2007). Between 1974 and 1998, the population in Galapagos showed more than a threefold increase, from 4,078 to 15,311 inhabitants (Epler 2007), and nearly doubled during the period 1990–2001, from 9,785 to 18,640 inhabitants, according to the updated data retrieved from National Institute for Statistics and Censuses (INEC 2011), as shown in Table 12.7 in Appendix. Likewise, tourism has drastically increased with a rise in the number of visitors to Galapagos from 40,000 in 1990 to 145,000 tourists in 2006 (Watkins and Cruz 2007; Epler 2007). At this level, Santa Cruz is currently receiving the highest number of tourists per year in the Galapagos and exhibiting one of the highest levels of degradation in its vegetation because of the accelerated urban and rural development (González et al. 2008; Watson et al. 2010).

With a persistent increase in the human population growth in the Galapagos, the projected population in this decade will range from 26,570 in 2011 to 33,000 in 2020 (Table 12.7 in Appendix), as forecasted by INEC (2011). As population increases in these islands, the waste generation has been increasing in magnitude, resulting in increasing burning of solid waste and production of smoke. For instance, Santa Cruz has two landfills in the center of the island, where the first one is already closed and the second one was created in 2000 due to the rapid increasing volume of trash. Total human population in 2010 and waste production for three of the islands harboring urbanized centers are shown in Table 12.1.

From 1995 to 1997, the generation of solid waste in San Cruz and San Cristóbal ranged from approximately 0.8 to 1.3 kg/day/person (Table 12.1; Fundación Natura and WWF 1999), which exceeded the national waste production average of 0.4–0.7 kg/day/person for continental Ecuador at that time (Fundación Natura and WWF 1999; UNEP 2009). According to a recent survey, the waste production in both islands seems to have decreased to 0.6 kg/day/person by 2008 (De la Torre 2008), while the waste production in Isabela has not changed from 1998 to 2008, showing a constant production of more than 490 kg/day/person. It also appears that the proportion of organic matter (OM) estimated from the total waste production was higher in San Cristóbal (>70 % OM) when compared to Santa Cruz in the 1990s but showed a reduction (60 % OM) in 2008. On the contrary, the percentage of OM in Isabela changed from 70 % in 1998 to 86 % in 2008, underlying an increase in the consumption and disposal of organic waste and materials (Table 12.1).

Currently, San Cristóbal and Santa Cruz produce about 10–13 tonnes of waste per day, respectively (Fig. 12.2). Using the waste production per capita data reported in Table 12.1 and the population projections (Table 12.7 in Appendix) by INEC (2011), the maximum production of waste in the Galapagos is expected to be 30 tonnes/day by 2020, from which more the 50 % will be accounted by Santa Cruz and about 40 % by San Cristóbal (Fig. 12.2), if best management practices for solid waste are absent. Yet, the production of waste does not include the untreated trash from the daily arrivals of cruise ships (i.e., about 87 cruise ships around the islands) to Puerto Ayora (i.e., the capital city of Santa Cruz), where the waste is subsequently transported to and dumped at the landfill. It is estimated that the waste produced and disposed from tourism boats in Santa Cruz is 2 tonnes/day, while those arriving to San Cristóbal and Isabela disposed 0.8 and 0.3 tonnes/day, respectively (De la Torre 2008; WWF and Toyota 2010).

The disposal of municipal waste in open dumps in rural areas close to coastal zones of urbanized islands of the Galapagos is an environmental issue of concern (Kerr et al. 2004). The leachate and incineration of local, municipal organic solid waste, polyvinyl chloride (PVC) plastics, and bleached paper without appropriate treatment represent an unquantified source of toxic POPs such as dioxins (i.e., polychlorinated dibenzo-*p*-dioxins, PCDDs) and furans (polychlorinated furans, PCDFs), which enter aquatic systems (Czuczwa et al. 1984; Czuczwa and Hites 1984). These are unintentional by-products and POPs generated from anthropogenic sources by incomplete combustion or thermal processes involving organic matter and chlorine. In continental Ecuador, the estimated total emission of dioxins and furans is about 98 g TEQ/year, from which uncontrolled combustion processes contribute approximately 51 % (Ministerio del Ambiente 2006). Therefore, as current practices do not prevent the by-production of PCDDs and PCDFs, an as yet uncharacterized risk exists to the terrestrial and aquatic biota in the human centers of the islands.

Most of the solid waste is organic matter, ranging from 60 to 70 % in the 1990s and from 40 to 86 % in 2008 (Table 12.1), and it is disposed of in open areas assigned for this purpose. These areas are a short distance from the main ports, 4 km

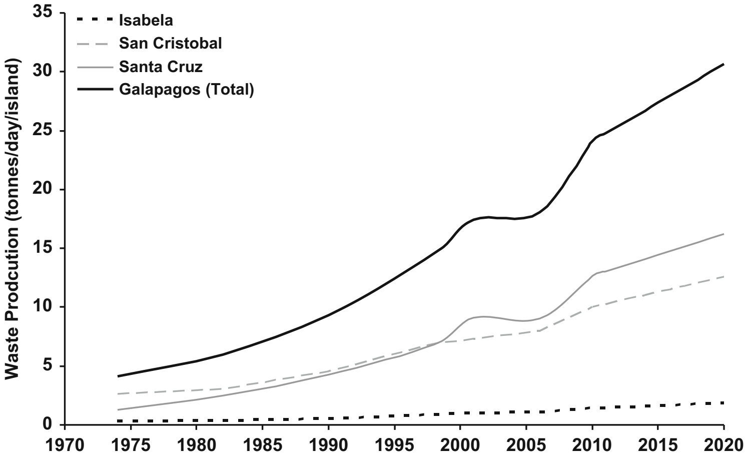

Fig. 12.2 Estimated and predicted production of solid waste in the Galapagos Islands, including the production per island for the three major islands harboring human centers (i.e., Isabela, San Cristóbal, and Santa Cruz), from 1974 to 2020. Predicted data for the period 2010–2020 were based on annual forecasts for the expected human population from 2010 to 2020 in the Galapagos, as projected by INEC (2011)

from Puerto Ayora and 3 km from Puerto Baquerizo Moreno (Kerr et al. 2004). Efforts have been carried out to improve the waste management of municipal organic waste to avoid the generation of dioxin and chronic accumulation of trash by implementing recycling programs (see WWF and Toyota 2010) and banning the burning of this kind of waste in open areas close to harbors and coastal zone, but there is still much to be done in this regard.

The Solid Tide: Marine Debris

Anthropogenic debris has become part of the oceanic environment, and it is now found from the poles to the equator and from shorelines, estuaries, and the sea surface to ocean bottom (STAP 2011). Not even the remotest places on Earth, with fewer people or without human presence, escape from this harmful environmental problem (Derraik 2002; UNEP 2009; STAP 2011). Marine debris is generated from both sea-based and land-based sources and is defined as “any persistent, manufactured or processed material used by humans and deliberately or unintentionally discarded, disposed of or abandoned in the marine environment, including the transport of these materials to the ocean by rivers, drainage, storm water and sewage systems or by winds” (UNEP 2005a, b, 2009; STAP 2011).

Marine pollution by debris in Galapagos waters is emerging as a significant concern for biota. A beach–shoreline cleanup program around the Galapagos in 1999 retrieved 22,140 kg of debris, with plastics and metals being the predominant objects, accounting for 25 and 28 % of the total (Fig. 12.3; Fundación Natura and

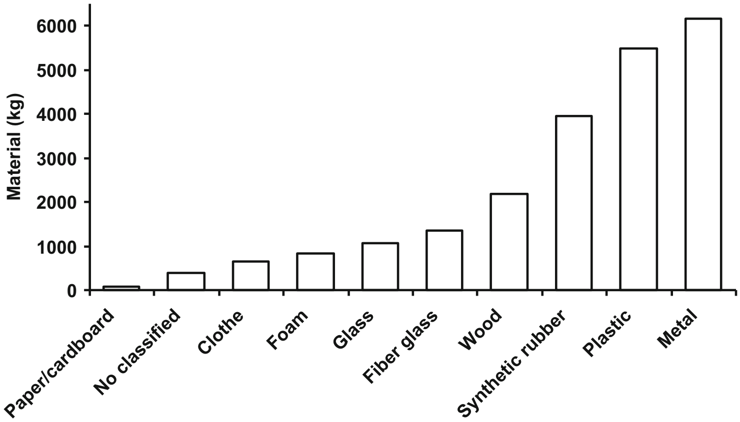

Fig. 12.3 Amount of marine and coastal debris collected in Galapagos during shoreline cleanups in 1999 (Data adapted from Fundación Natura and WWF 2000). See legends for definitions of items: plastics (bags, plastic wraps, containers, bottles, and plastic mesh); metals (cans and aerosol can containers); synthetic rubber (gum, waxes, gloves, shoes, tires, and toys); wood (boxes and tables); glass (bottles, containers, and light/fluorescent bulbs); foam (buoys, floaters, packing material, and disposable dishes); and paper/cardboard (boxes, cups, containers, and newspaper)

WWF 2000). At sea, the accidental or deliberate disposal of solid waste (e.g., plastic, fishing gear) from both tourism and fishing vessels represents a threat for marine vertebrates such as large pelagic fish, sea turtles, cetaceans, sea lions, fur seals, and seabirds (Alava 2011). For example, Galapagos sea lions have been found to interact with floating objects and debris on the sea surface, including hooks, plastic, nylon, and rope (Fig. 12.4; Alava and Salazar 2006). Fishhooks were the predominant object (22 %) affecting sea lions, followed by plastics, which represented almost 20 % of the total. Similarly, the impact of entanglement with debris and other items related to anthropogenic sources accounts for 20 % of environmental threats observed in sea lions residing in San Cristóbal (see Chap. 13).

Although plastic ingestion causes serious problems in some species of seabirds (i.e., albatrosses, petrels, and penguins) in other remote, oceanic regions of the world, including the Pacific Ocean (BirdLife International 2008a, b), this kind of pollution currently appears to pose a minor impact to Galapagos endemic species such as the Galapagos albatross (*P. irrorata*) and Galapagos petrel (*P. phaeopygia*) (Alava and Haase 2011). However, seabirds can mistakenly forage on plastic debris floating on the ocean's surface instead of normal prey and ingest it alongside diet items, causing intestinal damage and obstruction, malnutrition, and starvation (Cadée 2002; Derraik 2002; BirdLife International 2008a). For instance, more than 13,000 plastic pieces are floating per km^2 of ocean surface (UNEP 2005a, b). Thus, it is imperative to assess the impact of marine plastic not only on endemic and threatened seabirds residing in (e.g., Galapagos penguins, Galapagos petrels)

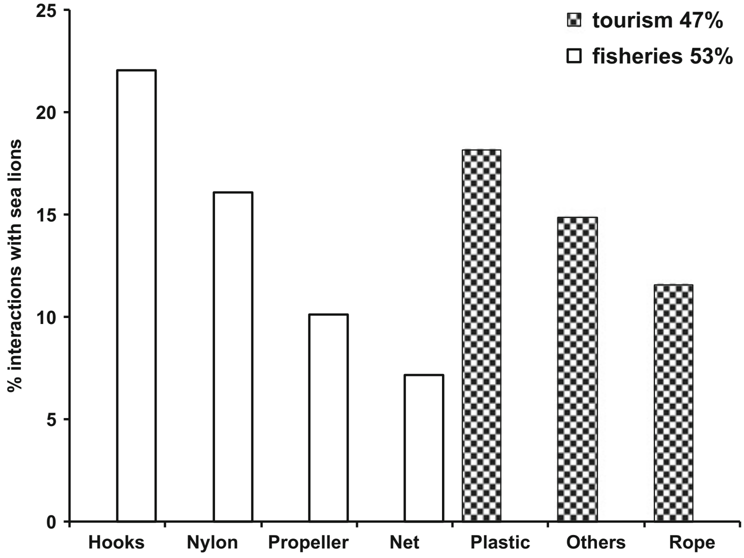

Fig. 12.4 Type and sources (tourism and fisheries) of the objects interacting with Galapagos sea lions in marine and terrestrial environments of the Galapagos (Data adapted from Alava and Salazar 2006; Merlen and Salazar 2007)

and/or foraging outside (i.e., Galapagos albatross) of the GMR boundaries but also on marine mammals, sea turtles, and marine iguanas with the aim to monitor potential health effects in these susceptible species in the long term.

The impact of marine debris, especially plastic materials, particularly causes concern because no appropriate solid waste management programs exists on board vessels (i.e., fishing boats, merchant-transportation ships, and recreational-tourism cruise ships), although the level of municipal waste collection is high and fairly organized in the islands. Finally, more local efforts are required to strengthen educational outreach addressed to human communities from the Galapagos' semi-urbanized centers to mitigate and avoid littering and ensure a low or zero impact on the marine environment. These programs and stringent regulations should be implemented on the local and incoming marine means of transportation, as well.

The Black Tide: Marine Pollution by Oil Spills and Hydrocarbons

Oil spills are one of the major threats to marine ecosystems, both in offshore and coastal zones. The transportation of crude oil or refined products results in the spill of an average estimated between 150,000 and 160,000 tonnes of petroleum worldwide annually (National Research Council 2003; ITOPF 2005). Biodiversity, fisheries, and ecotourism can be threatened when oil spills of severe magnitude occur. The use of fuels such as diesel, high-octane gasoline, and liquefied petroleum gas

Table 12.2 Consumption of diesel (17.6×10^6 L) and gasoline (4.4×10^6 L) by sector in the Galapagos in 2001 (Data adapted from Fundación Natura 2003)

Economic sector	Diesel in L (%)	Gasoline in L (%)
Tourism (inboard, outboard and bus engines, tourist hotels)	10.6×10^6 (60)	1.012×10^6 (23)
Fishing (outboard engines, truck motors)	0.704×10^6 (4)	1.364×10^6 (31)
Overland transportation (motorcycle/car/truck/bus engines)	0.352×10^6 (2)	1.804×10^6 (41)
Electricity (electric power facilities, diesel generators)	4.60×10^6 (26)	No usage (0)
Institutions (car engines and diesel generators)	1.41×10^6 (8)	0.220×10^6 (5)

transported from continental Ecuador has increased risks in the Galapagos. In 2000, a total of about 22 million liters of fuel (20 % gasoline and 80 % diesel) was delivered to the Galapagos (Fundación Natura 2003). Tourism and electric power generation are the major energy usage sectors for diesel consumption, whereas fishing (i.e., outboard motors) and motor vehicle transportation consume most of the gasoline in the islands (Table 12.2; Fundación Natura 2003).

During the last two decades, several oil spills have taken place in the Galapagos (Table 12.3). A major oil spill that threatened a significant part of the Galapagos Marine Reserve was the *MV Jessica* spill on 16 January 2001 at the entrance of Naufragio Bay (89°37′15″W, 0°53′40″S), San Cristóbal Island. The oil tanker released almost 100 % of its total cargo consisting of 302,824 L of IFO 120 bunker fuel (Fuel Oil 120) and 605,648 L of Diesel oil #2 (DO#2) (Lougheed et al. 2002; Edgar et al. 2003). In early July 2002, a second oil spill took place in the Galapagos, when a small tanker (*BAE Taurus*) sank and spilled diesel fuel in waters off the coast of Puerto Villamil, Isabela Island. Fortunately, no sign of fuel was found on the beaches or on marine animals (including sea lions) due to the mitigation efforts conducted by the GNP and Charles Darwin Foundation/Research Station (CDF/CDRS). Other low-magnitude oil spill events have also occurred (Lessmann 2004).

In addition, the Galapagos sea lion (*Z. wollebaeki*) was an impacted species of concern within the CDF and in the GNP monitoring and management plans for marine fauna since some colonies were relatively close to the Jessica oil spill (Salazar 2003a). About 79 oil-affected individuals, showing different degree of oil presence on their bodies, were rescued, cleaned, and released, and one fatality was recorded. On the other hand, no significant declines in the numbers of individuals were observed in the rookeries monitored after the spill (Salazar 2003a).

Measurements of hydrocarbons in sedimentary shores of the Galapagos right after the *Jessica* oil spill showed low levels or no detectable concentrations (Fig. 12.5), ranging from 0.4 to 49.0 µg/g dry weight, with evidences of residual hydrocarbon contamination from sources other than the oil spill, and suggesting absence of heavy oiling contamination (Kingston et al. 2003). In general, concentrations of dissolved and dispersed oil hydrocarbons measured in water samples from five bays of the Galapagos Islands about 1 year before the aftermath

Table 12.3 Inventory of oil and diesel spills in the Galapagos from 2001 to 2006

Boat/tanker	Date	Site	Quantity (L)
Motor Yacht Iguana	June 1988	Santa Cruz Island	189,265
MV Jessica	16 January 2001	Naufragio Bay, San Cristóbal	908,472
BAE Taurus	4–7 July 2002	Puerto Villamil, Isabela Island	7,571
MV Galapagos Explorer	13–14 September 2005	Academia Bay, Puerto Ayora, Santa Cruz Island	Not reported[a]

[a] 151,412 L of fuel was estimated to be contained in the boat, but actual volume spilled was not reported

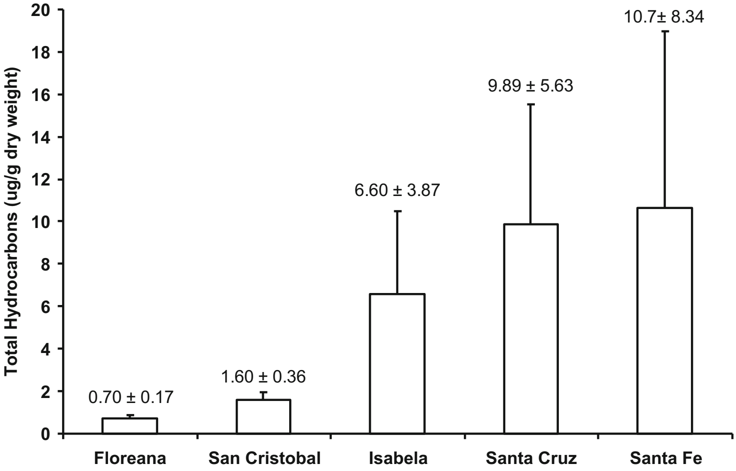

Fig. 12.5 Mean of total hydrocarbon concentrations measured in sediment samples collected from oil-impacted sandy shores of five islands of the Galapagos Islands after the 2001 Jessica oil spill. Error bars are standard errors (Data adapted from Kingston et al. 2003)

(Fig. 12.6) were below threshold levels, that is, 3–10 µg/L (Rodríguez and Valencia 2000).

Recent studies of the endemic Galapagos marine iguanas (*A. cristatus*) found elevated plasma corticosterone levels, impaired development (i.e., reduction of growth), and high mortality in individuals exposed to low levels or residual hydrocarbon traces during and/or after the *Jessica* oil spill (Wikelski et al. 2001, 2002; Romero and Wikelski 2002). This suggests that even low levels or traces of oil hydrocarbons have critical negative effects for marine endemic species of the Galapagos. Although no oiled seabirds were recorded at the time of this oil spill (Lougheed et al. 2002), researchers doing fieldwork in Española Island found five oiled Nazca boobies (*Sula granti*) in January 2001, one oiled Galapagos albatross (*P. irrorata*) in June 2001, and two oiled Nazca boobies in November 2001, confirming that these birds were polluted by spilled oil (Anderson et al. 2003).

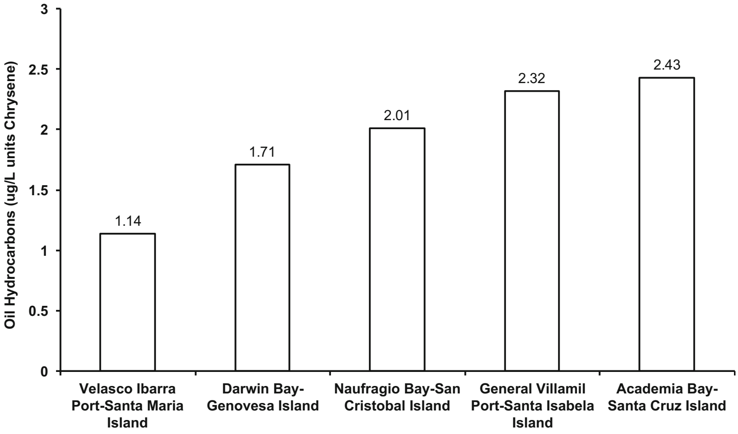

Fig. 12.6 Concentrations of oil hydrocarbons detected in marine water from fives sites of the Galapagos Islands (Data adapted from Rodríguez and Valencia 2000)

Fortunately, most of the populations of endangered seabirds such as Galapagos penguins and flightless cormorants were not affected by the direct impact of this spill; however, the chemical exposure of these birds to chronic residue levels of oil hydrocarbons in the long term is unknown.

The Silent Pollution: Impact of Persistent Organic Pollutants

The Galapagos Islands and surrounding ocean waters are susceptible to the global pollution by POPs, which are defined as "a set of organic compounds that: (a) possess toxic characteristics; (b) are persistent; (c) are liable to bioaccumulate; (d) are prone to long-range atmospheric transport and deposition; and (e) can result in adverse environmental and human health effects at locations near and far from their sources" (UNEP 2002). The set of pollutants listed as POPs by the Stockholm Convention on Persistent Organic Pollutants includes organochlorine pesticides (i.e., OC pesticides) such as aldrin, chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex, and toxaphene, as well as industrial chemicals, including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and HCB, which is a pesticide as mentioned above, but it can also be a by-product of pesticide manufacture (UNEP 2002, 2005a, b). New compounds have recently been added to the POP list, including emerging compounds such as polybrominated diphenyl ethers or PBDE flame retardants (i.e., treta-, penta-, hexa-, and heptabromodiphenyl formulations) and perfluorooctane sulfonate compounds or PFOS (i.e., perfluorooctanesulfonic acid and perfluorooctane sulfonyl fluoride).

It is likely that organic contaminants transported from Asian, South American, and Western industrialized countries are atmospherically delivered to these remote tropical islands. This implies the need of research and field studies to elucidate the fate and transport of POPs in the Southeastern Tropical Pacific region, where the Galapagos are located. In semi-urbanized centers (i.e., Santa Cruz and San Cristóbal), the presence of electric facilities/equipments and the grid electric wires' system containing transformers, capacitors, and cooling insulator fluid to provide energy to human settlements are likely to represent potential sources of PCBs. PCB-contaminated oil/dielectric fluid found in transformers and tanks of the grid electric system and facilities of human centers of the Galapagos are likely to be the minor, local sources of these contaminants, which need a management plan to treat and remove them from the islands (Ministerio del Ambiente 2006). To our understanding, Aroclor mixtures have not been yet identified.

In Ecuador, PCBs have never been produced for any chemical industry. Ecotoxicological and bioaccumulation studies on PCBs and DDTs have never been conducted at continental Ecuador, except for some recent measurements of these industrial compounds in oil/dielectric fluid used in transformers and capacitors/tanks of some electric station facilities of the Guayaquil's Electric Corporation (CATEG) (CEMA 2005). The PCB levels found are below 10 mg/L (CEMA 2005). More recently, the preliminary national inventory of PCBs in Ecuador reported a total volume of about 5,473,000 L of PCB-contaminated oil-fluid used in abandoned, unused, and used electric transformers by the electric corporations (Ministerio del Ambiente 2006). The global distribution of POPs, their persistence in the environment/biota, their risk to both human and biota, and, in some cases, continued production (deliberate or inadvertent) emphasize the need for an integrated approach to manage issues of POP production, waste, remediation, and exposure (Tanabe et al. 1994; Ross and Birnbaum 2003).

In the past, the biomonitoring and ecotoxicological risk assessment of POPs was never conducted in the Galapagos; therefore, data on concentrations, patterns, distribution, and fate is scarcely available for these contaminants. Despite of the potential conservation impact and risk in the Galapagos Islands, environmental pollution by POPs has not fully been characterized in wildlife from this archipelago. Given that it is well documented that marine mammals are key biological compartments to assess the concentrations, fate, distribution, and toxic effects of POPs (Ross and Birnbaum 2003; O'Shea et al. 2003), the Galapagos sea lion, which is a resident species and top predator of the Galapagos marine food web, was previously proposed as a potential coastal sentinel to biomonitor and investigate marine pollution and bioaccumulation by POPs in the Galapagos (Alava and Salazar 2006), as illustrated in Fig. 12.7.

Within this context, some recent studies assessing the concentrations of PCBs, PBDE flame retardants, DDTs, and several other OC pesticides in the Galapagos revealed that Galapagos sea lions are not exempt from the global contamination by POPs, as reported in Table 12.4. The dominant pollutant of concern found in Galapagos sea lions was DDT with mean concentrations of 281 μg/kg lipid, ranging from 16.0 to 3,070 μg/kg lipid in 2005 and 525 μg/kg lipid (range 16.3–1,666 μg/kg

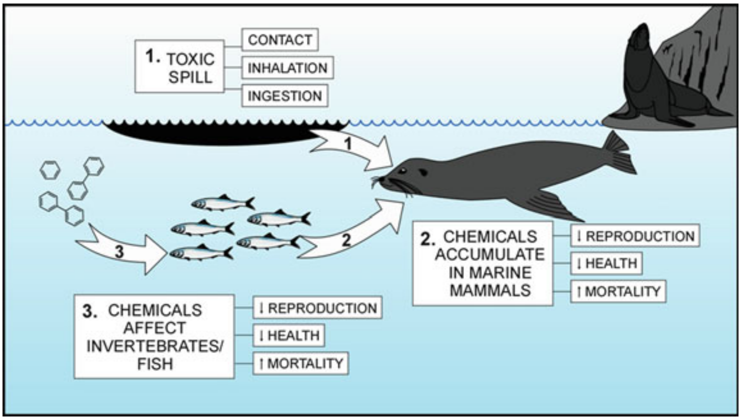

Fig. 12.7 Galapagos sea lions and several other species of epipelagic marine organisms (e.g., cetaceans, seabirds, marine iguanas, sea turtles) can be exposed to chemical assaults, including oil spills, which can possess acute and chronic toxic effects, and persistent organic pollutants (1), which can be accumulated mainly through dietary ingestion and by inhalation, causing potential health effects (2) due to contamination of diet items (fish preys) in the food chain (3). The prey can be also affected by contaminants (3). Adapted from Alava (2011) and Alava et al. (2011b)

lipid) in 2008 (Alava et al. 2011a), while PCBs measured in Galapagos sea lion pups were relatively lower and exhibited mean concentrations of 104 μg/kg lipid, ranging from 49 to 384 μg/kg lipid, in 2005 (Alava et al. 2009), and 113 μg/kg lipid, ranging 16.0–380 μg/kg, in 2008 (Alava and Gobas 2012).

POPs were also found in two fish prey species of Galapagos sea lions (thread herrings, *Ophistonema berlangai*, and mullets, *Mugil* sp.; Table 12.4), underscoring the biomagnification of these contaminants in the food chain of the Galapagos sea lions, as recently demonstrated by Alava and Gobas (2012). The presence of POPs in this endemic marine mammal was of particular importance, as a considerable weight of evidence in toxicological research indicates that environmental pollution by POPs is affecting and jeopardizing the health and survival of pinnipeds (e.g., harbor seals, California sea lions) and cetaceans (e.g., killer whales and belugas) (Ross 2002; Ylitalo et al. 2005; Loseto and Ross 2011; Buckman et al. 2011).

For instance, the exposure to POPs has been linked to effects on the immune (impairments in T-lymphocyte proliferation/count and phagocytosis) and endocrine systems (i.e., disruption of vitamin A and thyroid hormones) in harbor seals (Ross et al. 1995, 1996; Simms and Ross 2000; Tabuchi et al. 2006; Mos et al. 2006), in grey seals (Hall et al. 2003; Jensen et al. 2003), and in California sea lions (Debier et al. 2005). Recently, the deleterious effects of high levels of POPs (PCBs and DDTs) have been significantly linked to high prevalence of neoplasms and carcinoma, associated with mortality, in California sea lions (Ylitalo et al. 2005).

While threats associated with oil spills are visible and unlikely to cause a long-term decline of the Galapagos sea lion population due to their metabolic capacity to biotransform polycyclic aromatic hydrocarbon (PAHs) or nonhalogenated

Table 12.4 Concentrations (mean and ranges) of POP compounds (μg/kg lipid weight) measured in Galapagos sea lion pups and fish in the Galapagos Marine Reserve

		Galapagos sea lion				
POPs	Year	Males	Females	Thread herring	Mullet	Source
DDTs	2005	293 (51.0–1,200)	274 (16.0–3,070)	NC	NC	Alava et al. (2011a)
	2008	533 (16.3–1,666)	516 (71.2–1,230)	4.00 (0.70–6.05)	3.00 (0.82–6.80)	Alava and Gobas (2012)
Mirex	2005	3.20 (0.55–7.70)	3.22 (0.11–13.0)	NC	NC	Alava, unpublished
	2008	6.40 (0.85–24.0)	8.60 (2.50–21.0)	0.33 (0.25–0.40)	0.04 (0.03–0.1)	Alava and Gobas (2012)
Dieldrin	2005	15 (1.30–60)	11 (1.15–103)	NC	NC	Alava, unpublished
	2008	22.0 (9.00–63.0)	31.0 (9.00–83.0)	0.60 (0.01–0.90)	0.88 (0.40–1.30)	Alava and Gobas (2012)
β-HCH	2005	ND	ND	NC	NC	Alava, unpublished
	2008	26.0 (7.75–78.0)	34.2 (18.3–52.0)	0.44 (0.23–0.62)	0.50 (0.04–0.65)	Alava and Gobas (2012)
Chlordanes	2005	45.5 (16–123)	38 (2.35–382)	NC	NC	Alava, unpublished
	2008	90.5 (19–255)	107 (48–180)	1.70 (0.48–2.50)	0.87 (0.37–1.50)	Alava and Gobas (2012)
PCDFS	2005	ND	ND	NC	NC	Alava et al. (2009)
	2008	NA	NA	NA	NA	
PCDDs	2005	ND	ND	NC	NC	Alava et al. (2009)
	2008	NA	NA	NA	NA	
PCBs	2005	122 (49–384)	93 (53.2–353)	NC	NC	Alava et al. (2009)
	2008	91.0 (16.0–282)	136 (50.0–384)	9.35 (5.40–14.0)	28.0 (1.20–138)	Alava and Gobas (2012)
PBDEs	2005	35.0[a]	ND	NA	NA	Alava et al. (2009)
	2008	NA	NA	NA	NA	

NC: samples for this species were not collected; ND: chemical compound was not detected in the organism; NA: chemical compound was not analyzed

[a] Only one sample exhibited PBDE concentrations

hydrocarbons, the possible negative impacts (e.g., long-term chronic toxicity and sublethal effects) of POPs and other contaminants on health endpoints of this species are becoming more evident (Alava et al. 2009, 2011a, b; Alava and Gobas 2012; Fig. 12.7). For instance, the impact of antifouling paints (e.g., tributyltin, TBT) in marine fauna from major ports and marinas harboring vessels in the Galapagos has not yet been assessed. This also implies the need of baseline research on POPs for other marine species (e.g., sea turtles, marine iguanas, and seabirds) in the Galapagos.

Interestingly, a new eco-toxicological study based on skin biopsies collected from sperm whales (*Physeter macrocephalus*) inhabiting Galapagos waters revealed the highest expression levels for cytochrome P450 1A1 (CYP1A1), an enzyme used as a biomarker to assess exposure to organic pollutants such as PAHs and PCBs, relative to other studied regions of the Pacific (Godard-Codding et al. 2011), although questions linger to whether the chemical exposure to pollutants in this stock of sperm whales originates from local/regional sources or represents a global signature. Meanwhile, the Galapagos sea lion represents a novel marine mammal to be used as a potential biological compartment and eco-marker of coastal pollution by assessing the concentration and effect of POPs (i.e., measurements of POPs in blubber or blood samples and biomarker endpoints of the immune/endocrine systems).

Agriculture and Pesticide Use

In the Galapagos, agriculture occurs on all four human-inhabited islands (Santa Cruz, Santa Cristóbal, Floreana, and Isabela), mainly in the highlands, where the highly biodiverse humid zone has largely been cleared (Table 12.5; Snell et al. 2002). Currently, approximately 3.96 % (23,400 ha) of land area has been dedicated for agricultural use in the Galapagos, and the proportion of humid zones is diminishing (Kerr et al. 2004). While organic agriculture is partially practiced in the Galapagos (Dr. Alan Tye, pers. comm., former Head Scientist of the Department of Plant and Invertebrate Science, Charles Darwin Research Station), conventional agriculture is the norm, where farmers use insecticides, herbicides, fungicides, and fertilizers to control pests, which can lead to runoff and the contamination of coastal food webs.

As seen in Appendix Table 12.8, some current-use pesticides (CUPs) are applied to agricultural areas (highlands) in islands with human centers (MIT 2008). According to this list, no legacy organochlorine pesticides (OC pesticides such as DDTs, dieldrin, mirex, heptachlor, and chlordanes) are currently used in the Galapagos. However, DDT was used in significant amounts by military personnel from the US Navy (former American Air Force and Naval Base in Baltra, Santa Cruz Island, during the World War II) to eliminate introduced rats in human housing from urbanized areas and into the islands between 1940s and 1950s (M. P. Harris, Centre for Ecology and Hydrology, Banchory Research Station, Banchory, UK, pers. comm.; M. Cruz, GGEPL-Galapagos National Park, pers. comm.). More recently, a pyrethroid, the insecticide deltamethrin, is being used to control the dengue mosquito vector (*Aedes aegypti*) in the Galapagos (Dr. Hugo Jurado, pers. comm., National Center for Tropical Medicine, University of

Table 12.5 Total areas for agricultural and habitat (humid and transition[a]) zones in km^2 and the proportion of clearance affected by agriculture occupancy in humid and transition zones in four islands of the Galapagos (Adapted from Snell et al. 2002)

Island	Agriculture	Humid zone	% Affected	Transition zone	% Affected
Santa Cruz	122	118	74	127	26
San Cristóbal	82	83	93	40	9
Floreana	5	31	15	39	2
Isabela	52	641	8	1,323	0
Sierra Negra[b]	52	370	14	460	0

[a] Transition zone: woodland communities dominated by *Pisonia floribunda*, *Psidium galapageium* (Guayabillo woodland), and *P. galapageium* and *Scalesia* tree spp. (Scalesia–Guayabillo forest)

[b] This is a specific site represented by a volcano on Isabela Island where the human settlements are located

Guayaquil, and Technical Director of the National Malaria Eradication Service Centre (SNEM), Guayaquil, Ecuador).

Many of these pesticides have been identified as causing reproductive and endocrine-disrupting effects (see EDC in pesticides listed in Table 12.8 in Appendix) in both wildlife and human populations (Colborn et al. 1993; Colborn 1998; WWF Canada 1999; Lyons 1999). Furthermore, chlorothalonil and its metabolites are highly toxic to fish, aquatic invertebrates, and marine organisms. Levels lower than 1 mg/L can cause negative effects in rainbow trout, bluegill, and channel catfish (see review by Verrin et al. 2004). Similarly, malathion is extremely toxic for aquatic invertebrates, to some species of fish (<1 mg/L), and to some aquatic life stages of amphibians, whereas carbaryl is moderately toxic to fish (1.3–10 mg/L) (Verrin et al. 2004). There are also two herbicides of concern including glyphosate (commercially known as Rodeo or Roundup) and paraquat (Gramoxone). Glyphosate is a broad-spectrum nonselective herbicide to control grasses, broadleaf weeds, and woody plants, inhibiting amino acid biosynthesis (Ecobichon 2001), while paraquat is a widely used, nonselective contact herbicide, inhibiting photosynthesis in plants (Ecobichon 2001; Sedigheh et al. 2011). If both herbicides were extensively used in agricultural land and rural areas in the Galapagos, these substances might have eliminated and caused deleterious damage to native and endemic species of plants.

The application of pesticides in the agricultural zones of these human-inhabited islands may also introduce dioxins (i.e., PCDDs) and furans (i.e., PCDFs) to the marine environment, as these have been found as contaminants in a number of pesticide products. While no risk assessments have been carried out to elucidate on the levels and potential health effects of CUPs in the Galapagos, there are reasons for urgent concern and research in this subject.

Biological Pollution and Invasive Pathogens

Biological invasions are considered a leading cause of extinctions in terrestrial and marine ecosystems of marine protected areas (Boersma and Parrish 1999; Bax et al. 2003) as emerging marine diseases in marine organisms have been linked to anthropogenic factors (Harvell et al. 1999). For the purpose of this review, biological pollution is defined as the "accidental or deliberate introduction of viruses, bacteria and parasites, as well as terrestrial, exotic species of vertebrates, invertebrates and plants." Information on terrestrial exotic species (i.e., animals and plants) is not discussed in this review since it has been well reported elsewhere (Snell et al. 2002).

The introduction of exotic marine species and pathogens (viruses, bacteria, and parasites) represents major threats for biodiversity and ecosystem functions, with potentially serious implications for fisheries resources, tourism, and human health in marine protected areas and biosphere reserves (Carlton 1989, 1996; Carlton and Geller 1993; Bax et al. 2003). For example, both ballast water and hull fouling are the major pathways releasing alien organisms from transportation or recreational ships and tankers in threatened and fragile ecosystems (Carlton and Geller 1993; Bax et al. 2003). The Hawaiian Islands represent an extraordinary example of the negative effects of the biological invasion on endemic and native species (Vitousek et al. 1987). This is supported by the fact that Hawaii contains a large proportion of the imperilled US endemic birds (43 %) and plants (40 %) threatened by alien species (Gurevitch and Padilla 2004). Similarly, alien pathogens represent 34 % of the birds affected by aliens of all kinds (Coles et al. 1999), and 91 of approximately 400 marine species present in Pearl Harbor are aliens (Gurevitch and Padilla 2004). The Galapagos Islands are facing a similar fate unless control and conservation strategies take place to mitigate biological invasion. The number of registered introduced species in the archipelago has increased 10 times from 112 species in 1900 to 1,321 in 2007 (Watkins and Cruz 2007). This does not include introduced pathogens. Among the invasive pathogens, viruses, bacteria, and parasites are the ones possessing serious risk to the endemic fauna.

Some introduced viral diseases from domestic animals such as avian virus or avipoxvirus by domestic birds, fowlpox virus infecting chicken, and canine distemper virus (CDV) epidemic in domestic dogs have threatened endemic species of birds (e.g., Darwin's finches) and marine mammals (e.g., Galapagos sea lions) in the Galapagos (Wikelski et al. 2004; Salazar et al. 2001; Cruz et al. 2002). For instance, a serological survey and DNA screening assessment for infectious disease pathogens conducted in Isabela Island revealed that domestic dogs and cats are exposed to many pathogens, including parvovirus, parainfluenza virus, adenovirus, distemper virus, *Dirofilaria immitis*, *Wolbachia pipiens*, *Bartonella* sp., *Ehrlichia*/*Anaplasma* spp., and *Mycoplasma haemocanis* in dogs and panleukopenia virus (67 %), *Toxoplasma gondii* (63 %), calicivirus (44 %), and herpesvirus 1 in cats (Levy et al. 2008).

Thiel et al. (2005) has recently found the presence of canarypox-like viruses in pox-like lesions of endemic passerine birds (yellow warblers, *Dendroica petechia*; finches, *Geospiza* spp.; and Galápagos mockingbirds, *Nesomimus parvulus*) from the inhabited islands of Santa Cruz and Isabela. A seroprevalence of 66 % (29/44) to adenovirus group 1 has been found in Galapagos albatrosses (*P. irrorata*) inhabiting Española Island (Padilla et al. 2003).

In the Galapagos, a CDV outbreak killed about 400 domestic dogs on Santa Cruz and Isabela Islands accounting for 69.2 and 31 %, of the CDV cases, respectively (Cruz et al. 2002). In San Cristóbal Island, only one case of CDV was found.

A serological survey determined the seropositive response of antibodies against CDV (50 % or 7/14), parvovirus (14 % or 1/7), and adenovirus (canine hepatitis virus, 100 % or 1/1) in the canine population of Santa Cruz during 2001–2002 (Cruz et al. 2002).

Newcastle disease, Marek's disease virus (herpes), and mycoplasmosis detected in domestic chickens farmed on the islands (Vargas and Snell 1997) have the potential to cause declines of the flightless cormorant (*P. harrisi*), lava gull (*Larus fuliginosus*), and Galapagos penguin (*S. mendiculus*), species with small population sizes. West Nile virus (WNV) is expected to reach Ecuador anytime, and there is a high probability risk of its introduction into Galapagos unless strict control and preventive strategies are implemented prior to the arrival of the disease (GGEPL 2004). If WNV is introduced into Galapagos, it is likely to cause catastrophic mortality of endemic birds, reptiles, and mammals, leading to irreparable ecological and economic damage to the islands (GGEPL 2004). One of the three mosquito species found in the Galapagos, the black salt marsh mosquito (*Aedes taeniorhynchus*) (Bataille et al. 2009a), has been recognized as a vector of the WNV and other diseases in other regions of America (see Bataille et al. 2009a for references) and thus a potential threat to Galapagos wildlife and humans. Disease introduction is most likely to occur through the inadvertent human transport of infectious mosquitoes or infected vertebrate hosts, particularly by airplanes or boats, as that occurred in the Galapagos with *Culex quinquefasciatus* (Bataille et al. 2009a, b) or in Socorro Island off the Mexican coast (Carlson et al. 2011). The incidental transport of mosquitoes by boat or of infected vertebrate hosts is also significant risks for WNV invasion.

A serological survey of sea lions from different colonies of the Galapagos Islands in 2001 revealed that no CDV antibodies were present in this species (Salazar et al. 2001; Alava and Salazar 2006). This indicates that they have not had any recent infection by morbilliviruses and that they are vulnerable to infection by this genus of viruses. Mortalities among pinnipeds caused by morbilliviruses CDV and phocine distemper virus (PDV) have been documented in harbor (*P. vitulina*), grey (*H. grypus*), Baikal (*Phoca sibirica*), and Caspian *(P. caspica*) seals in industrialized regions (Osterhaus et al. 1988, 1989, 1990; Dietz et al. 1989; Visser et al. 1991; Kennedy et al. 2000). For instance, about 10,000 Caspian seals died due to CDV in 2000, and more than 23,000 and 30,000 harbor seals died in 1988 and 2002, respectively (Härkönen et al. 2006).

Recently, several kinds of viruses and bacteria have already been detected in endemic seabirds and pinnipeds of the Galapagos. For example, while antibodies to avian adenovirus type 1 and *C. psittaci* were found in 31 % (21/68) and 11 % (7/65) of flightless cormorants, respectively, 75 of 84 (89 %) Galapagos penguins had antibodies to *Chlamydophila psittaci*, but chlamydial DNA was not detected via polymerase chain reaction in samples from 30 birds (Travis et al. 2006a, b). Galapagos albatrosses showed a seroprevalence of 9 % (4/44) to avian encephalomyelitis; however, cloacal swabs were negative for *C. psittaci* DNA (Padilla et al. 2003). *Salmonella* sp. was reported in domestic pigeons (introduced rock doves, *Columba livia*) in San Cristóbal and may cause severe disease in species such as Galapagos doves (*Zenaida galapagoensis*) and other native birds (Harmon et al. 1987; Wikelski et al. 2004; Padilla et al. 2004).

A serological survey determined that five out of six domestic dogs were seropositive (83 %) to *Leptospira* on Santa Cruz in 2001–2002 (Cruz et al. 2002). This implied that Galapagos pinnipeds may be at risk of infection by this bacterial pathogen. Shortly after, health surveys showed that Galápagos sea lions were susceptible to nine strains of the bacterium *Leptospira*, whereas Galápagos fur seals were susceptible to two strains, but there was no immunological response to brucellosis (Salazar 2002, 2003b). Using PCR analysis, the presence of *Leptospira* DNA was confirmed in 70 % of tissue samples (i.e., kidney and placenta) collected from dead sea lions, including three newborn pups, in San Cristóbal (Guevara 2011).

Recently, a conjunctivitis associated with bacillococci bacteria, with a 60–100 % prevalence in Galapagos sea lion pups, appears to be related to the presence of a new species of ocular parasite (*Philophthalmus zalophi*) (Dailey et al. 2005). Among parasites, *Haemoproteus* sp., the only hemoparasite identified, was found in 89 % of the Galapagos doves sampled but not in the rock doves (Padilla et al. 2004). In marine mammals, ectoparasites such as lice (*Antarctophthirius microchir*) and nasal mites (*Orthohalarachne diminuata*) were identified in various individuals of pinnipeds (Salazar 2002, 2003b). Domestic and feral animals introduced from the continent poses a major threat as potential sources for horizontal transmission of ecto- and endoparasites to local endemic species.

Avian malaria (i.e., *Plasmodium relictum*), the major parasitic disease that caused severe mortality and decimated a significant proportion of Hawaiian's endemic avifauna since it was introduced in the early twentieth century (Wikelski et al. 2004), was reported for the first time in the blood of 19 Galapagos penguins sampled between 2003 and 2005 in five islands of the archipelago (Levin et al. 2009). Although the vector was not confirmed in that study, the line of evidence pointed to its only possible vector, the mosquito *C. quinquefasciatus*, recently established on the Galapagos Islands (Peck et al. 1998; Whiteman et al. 2005).

Despite the fact that there were no reports or detection of *P. relictum* in the islands (Wikelski et al. 2004; Thiel et al. 2005), Miller et al. (2001) suggested a connection between this mosquito and the absence of penguins in the shores of one of the islands where this parasite was later found in penguin samples. Another protozoan, *Trichomonas gallinae*, was reported in domestic pigeons on San Cristóbal and may cause severe disease in species such as Galapagos doves (*Z. galapagoensis*) and other native birds (Harmon et al. 1987; Wikelski et al. 2004; Padilla et al. 2004). Because the Galapagos endemic species were not exposed to alien parasites transmitted by invasive species prior to human occupation of the islands, they are more susceptible to the pathogenesis generated by parasitic diseases with potential risk at the population health level.

Long-term assessments and monitoring of marine water quality in coastal and maritime environments are scarce in the Galapagos Islands (Walsh et al. 2010; Stumpf et al. 2013). Yet, overflow from rudimentary septic tanks (i.e., latrines or cesspools) and runoff of sewage waters around the islands threaten the water quality near urbanized centers and increase the risk of fecal contamination in coastal waters (Okey et al. 2004; Moir and Armijos 2007; Walsh and McCleary 2009;

Table 12.6 Values of fecal and total coliforms (colony-forming units (CFU)/100 mL) at coastal marine sites, Galapagos (Data from Rodríguez and Valencia 2000), relative to the current recreational marine water quality standards (US Environmental Protection Agency 1986)

Sites	Fecal coliform	Total coliform	US EPA (1986) fecal coliform standard (200 CFU/100 mL)	US EPA (1986) total coliform standard (1,000 CFU/100 mL)
Academia Bay (Las Ninfas Lagoon), Santa Cruz Island	15	240	Not exceeded	Not exceeded
Naufragio Bay, San Cristóbal Island	8.8	16	Not exceeded	Not exceeded
Santa Maria, Isabela, and Genovesa Islands	5.0	2.0	Not exceeded	Not exceeded

Stumpf et al. 2013). In 1999, a microbiological survey of total and fecal coliform bacteria conducted in several coastal marine sites of the Galapagos reported concentrations ranging from 2 to 240 CFU/100 mL and from 5 to 15 CFU/100 mL, respectively (Table 12.6; Rodríguez and Valencia 2000). At that time, these levels were below the Ecuadorian Water Quality Guidelines for the Prevention and Control of Environmental Contamination passed out in 1989.

However, recent water quality monitoring in Las Ninfas Lagoon conducted in 2005, 2007, and 2008 revealed that the contamination of marine water by fecal coliform bacteria has changed from 15 FCU/100 mL in 1999 (Rodríguez and Valencia 2000) to 480 CFU/mL in 2008, with a maximum peak of 1,458 CFU/mL in 2007 (López and Rueda 2010), exceeding both the Ecuadorian national environmental legislation to protect public health (TULAS 2003) and the fecal coliform guideline of the Environmental Protection Agency (US EPA 1986), as illustrated in Fig. 12.8. This trend underlines the health risks by bacterial contamination in recreational marine waters for public health and aquatic biota in this site. More recently, the use of molecular methods in a small-scale study has determined the presence of elevated levels of fecal contamination (>104 cell equivalents (CE)/100 mL) by *Enterococcus* spp. (i.e., mean, 1.38×10^2 CE/100 mL) and *Bacteroides* spp. (i.e., mean, 4.74×10^5 CE/100 mL) in Puerto Baquerizo Moreno (San Cristóbal) and Puerto Ayora (Santa Cruz), as reported by Stumpf et al. (2013). Furthermore, the impact of spillover pathogens and antibiotic-resistant bacteria in endemic organisms inhabiting this remote area warrants further microbiological and pathological research.

Because of the presence of livestock, antibiotics are used for cattle ranching and domestic farms in rural zones (Francisco Torres, pers. comm., Centro de Estudios de Medio Ambiente, Escuela Superior Politécnica del Litoral, Guayaquil, Ecuador). Antibiotic resistance results from the broad and indiscriminate use of antibiotics, both in humans and in animals (Pruden et al. 2006). Residual antibiotics from animals' feces as well as from of septic tank overflow and sewage effluents may enter coastal marine areas. This may had antibiotic resistance in both human-introduced pathogens and natural strains of bacteria (i.e., antibiotic-resistant pathogens). Recently, antibiotic resistance genes (ARGs) from tetracycline and sulfonamide have been categorized as

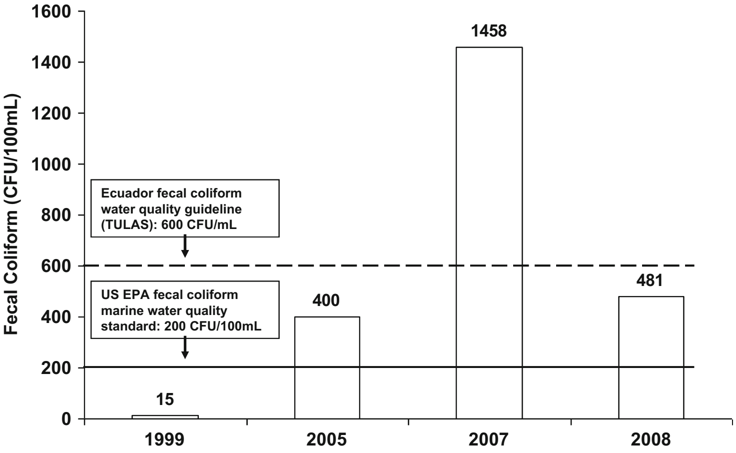

Fig. 12.8 Trends of fecal coliform levels (CFU/mL) measured in Las Ninfas Lagoon (Santa Cruz) for 1999, 2005, 2007, and 2008 (Rodríguez and Valencia 2000; López and Rueda 2010). The *dashed line* represents the fecal coliform benchmark for Ecuador according to the Ecuadorian national environmental legislation to protect public health (TULAS 2003). The *solid line* indicates the US EPA fecal coliform standard for marine waters

emerging contaminants, showing higher concentrations in urban/agricultural impacted river sediments (Pruden et al. 2006).

The threat and development of emerging infection diseases and microbial invasions can be further exacerbated in endemic fauna exposed to immunotoxic and endocrine disruptor chemicals (e.g., POPs, CUPs, xenoestrogens) causing impairments in the immunological (e.g., decreased proliferation of white cells) and endocrine (e.g., disrupted regulation of thyroid hormone) systems and making them more susceptible to pathogens. Likewise, new studies on ecological immunology in Galapagos sea lion pups found evidences of changes in the immune activity (i.e., humoural and cellular immune activities), which was negatively correlated with life history and health endpoint parameters in a sea lion colony exposed to anthropogenic environmental impacts (Brock et al. 2013). Sea lions in the human impacted colony exhibited higher antibody concentration changes and were under greater immunostimulatory pressure than those in the comparison colony, indicating implication risks for individual fitness, colony stability and emerging infectious diseases (Brock et al. 2012; Brock et al. 2013). This can be worsened in nutritional stressed animals due to the stress caused by more frequent and stronger climatic events such as the El Niño episodes. More recently, the massive die-off of small cetaceans (i.e., long-beaked common dolphins, *Delphinus capensis*, and Burmeisters porpoises, *Phocoena spinipinnis*) stranded along the Peru's northern coast was linked to cumulativeadditive anthropogenic impacts (e.g., pollution, underwater noise, pathogens) exacerbated by the El Nino event (Alava 2012). Thus, there is an urgent need to strengthen monitoring activities and preventive actions to reduce the Galapagos fauna exposure to some of these stressors.

Management Implications and Research Needs

Environmental pollution in the Galapagos has typically been described in the past as an aesthetic and minor issue of concern rather than a significant conservation problem (Snell et al. 2002; Bustamante et al. 2002a, b). However, human population growth due to migration and tourism, introduction of exotic and invasive species, solid waste generation, lack of sewage systems, and water pollution are some of the central degrading activities challenging the resilience of the Galapagos Marine Reserve and National Park in the last three decades (Merlen 1995; MacFarland and Cifuentes 1996; Watkins and Cruz 2007; González et al. 2008). The threats for the Galapagos conservation and mitigation strategies in terms of environmental pollution are summarized as follows.

Conservation Threats

The Galapagos is a heritage at risk not only because of the massive tourism, human migration, and invasive species but due to potential chemical assaults and the spreading out of pathogens, as described in this review. A series of major events in recent years, including oil spills, increased generation of solid waste, expansion of agriculture and tourism sector, and the emerging of new pathogens and other biological pollutants, should serve as a wake-up call for decision makers in the Galapagos.

Of important concern is the release of solid wastes (e.g., plastics) and leaking of hydrocarbons from tourism ships and the fishing industry, which are likely to be the major local sources of contamination in the Galapagos marine environment. Both large and small fuel spills take place on a regular basis in the islands during the transport and delivery of fuel to tourist boats (Lessmann 2004; Okey et al. 2004). The existence of localized sources (waste incineration in open dumps in the recent past) and atmospheric inputs (continental or global inputs) might be contributing to the migration and deposition of POPs to the Galapagos environment, as evidenced for the levels of PCBs found recently in Galapagos sea lion pups and fish.

The cumulative ecotoxicological pressure coming from these threats can play a dramatic role as an unnatural or anthropogenic selection force shaping evolution in endemic species of the Galapagos. Unnatural selection has already been identified as a human environmental alteration that may be replacing natural selection or non-anthropogenic factors as the major driving force of evolution in Darwin's finches (Deem et al. 2010). If anthropogenic stressors continue contributing to the perturbation of natural habitats and behavior of species, the natural evolutionary forces normally ruling speciation and radiation can be lost in the long term and, therefore, difficult to characterize, monitor, and preserve in its genuine state unless management and mitigation strategies are urgently implemented to minimize and reduce anthropogenic factors in the Galapagos.

Management Actions and Mitigation Measures

Several laws, regulations, policies, and plans have been enacted recently by the Ecuadorian government in benefit of the conservation and management of both the GMR and GNP (e.g., Special Law for the Conservation and Sustainable Development of the Galapagos Province, 1998). However, the control and management of environmental pollution in the Galapagos warrants additional efforts. At continental Ecuador, efforts have already been undertaken through the Ecuadorian Guidelines for the Control and Management of Environmental Pollution.

Meanwhile, the lessons learned from the oil spill cleanups and from the remedial actions taken in response to them were a topic of particular importance for the Ecuadorian government and regional commissions involved with marine protected areas and environmental pollution. Because of this, regional authorities paid more attention and concern, and the Galapagos was recently designated as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organization (IMO) in 2005 under Resolution MEPC-135(53) to prevent marine pollution by spills and hazardous contamination coming from ships. At this level, the application of the precautionary principle would help to avoid and mitigate pollution in the Galapagos Archipelago.

More recently, the local waste management in the Galapagos is being improved by implementing an educational outreach camping and a recycling system, including an oil recycling program, to reduce waste through the Waste Management Blueprint initiative (WWF and Toyota 2010). Solid waste containing a substantial amount of OM needs to be treated appropriately by banning the incineration of this kind of waste in open areas close to harbors and coastal zone to avoid the generation of dioxins. Although the upgrade of a water treatment plant to improve the quality of domestic effluents and treatment of sewage discharged into coastal waters of Puerto Baquerizo Moreno was implemented in 2011, testing for fecal indicator bacteria is critical to verify the efficacy of the system (Stumpf et al. 2013). Further monitoring of coastal water quality is required in suspected hot spots of bacterial contamination and nonimpacted areas for comparison purposes around urban centers of the Galapagos.

Additionally, the implementation of an environmental impact assessment and monitoring program of current-use pesticides (CUP) and past-use pesticides in the urban centers should be a priority task to include in the regional management plan and environmental monitoring of the Galapagos Marine Reserve and National Park; the aim is to assess the levels and potential health effects of these chemicals to wildlife, aquatic/marine organisms, and humans. Local effluents need to be controlled to avoid biological pollution and spread of infectious diseases to local wildlife and native human. Alternative approaches to dispose and treat sewage water effluents and oil leaking are required at the domestic and economic sectors (fisheries and tourism). Local hotels and restaurants should incorporate best management practices (BMPs) through environmental management systems (EMS), which will promote green certification as an added value. The periodical maintenance and monitoring (i.e., environmental audits to fix irregularities) of outboard motors, boat engines, and oil tankers can contribute in the reduction of marine pollution by hydrocarbons.

The management of POPs (i.e., dioxin/furans generated from organic waste incineration, pesticides) and biological pollution so far analyzed in this review needs to be focused both at the local/regional and international levels regarding environmental and marine policy. Ecuador is a recent signatory country of the Stockholm Convention since May 2001 and ratified it on 7 June 2004. Since then, the National Plan for the Implementation of the POP Management in Ecuador was undertaken in this country by commencing with a national inventory of POPs, including PCBs, dioxins/furans, and OC pesticides (Ministerio del Ambiente 2006). Therefore, the use of international policy instruments such as the Stockholm Convention on Persistent Organic Pollutants and the Convention on Long-Range Transboundary Air Pollution (CLRTAP) POP protocol must be emphasized to protect this semi-pristine, remote area of the world.

We propose the use of endemic marine species such as pinnipeds (Galapagos sea lions and fur seals) and seabirds (e.g., Galapagos albatrosses, Galapagos penguins, and flightless cormorants) to assess and biomonitor the current exposure levels, patterns, fate, and effects of contaminants in the Galapagos. These charismatic, top predator species can be used potentially as regional sentinels of marine pollution and coastal health in these remote islands. For example, the ecotoxicological research on POPs (e.g., dioxins/furans, PCBs, DDTs, and other OC pesticides) can be focused in the measurement and assessment of these compounds in blubber biopsies and blood samples of sea lions, seabirds, and marine iguanas to elucidate both local and regional contamination.

In addition, biomarkers such as vitamin A, aryl hydrocarbon receptor (AhR), estrogen, and thyroid hormones can be evaluated through ecotoxicogenomics (i.e., assessment of toxicological gene endpoints related to stress response) to examine potential endocrine disruption, immunotoxicity, and associated health effects by POPs in the Galapagos sea lion and endemic seabirds. This needs to be accompanied by ecotoxicological and bioaccumulation modeling to predict and better assess these contaminants (i.e., toxicity, persistence, and bioaccumulation/biomagnification) in marine food webs. This should be coupled with the use of model bias and uncertainty analyses, as a tool to account for variability and uncertainty. In fact, the use and application of models has tremendously contributed to the progress of science in environmental toxicology and chemistry and contributed to the management of toxic chemicals by helping to understand their origin, behavior, distribution, fate, exposure, and toxic impacts on the environment (Gobas and Muir 2004).

Galapagos is the last remote, evolutionary natural lab to protect and conserve for future generations. While it is not too late to undertake international and local environmental stewardship and management strategies to mitigate and control pollution, the presence of anthropogenic stressors and coastal marine pollution is a sign that the GMR is not immune to contamination.

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Appendix

Table 12.7 Human population inhabiting three major islands in the Galapagos and total population

Year	Isabela	San Cristóbal	Santa Cruz	Galapagos (total)
1974	446	2,014	1,577	4,078
1982	630	2,377	3,138	6,201
1990	864	3,499	5,318	9,785
1998	1,427	5,295	8,512	15,311
2001	1,619	5,633	11,388	18,640
2006	1,780	6,142	11,262	19,184
2010	2,256	7,475	15,393	25,884
2011*	2,392	7,899	16,285	26,576
2012*	2,464	8,095	16,725	27,284
2013*	2,538	8,293	17,169	28,000
2014*	2,614	8,493	17,619	28,726
2015*	2,690	8,693	18,070	29,453
2016*	2,765	8,890	18,517	30,172
2017*	2,842	9,085	18,963	30,890
2018*	2,918	9,278	19,404	31,600
2019*	2,995	9,473	19,852	32,320
2020*	3,073	9,667	20,302	33,042

Bold years are real censuses conducted by the National Institute for Statistics and Censuses (INEC), while years with asterisks reflect predicted data from 2011 to 2020 forecasted by the INEC (2011)

Table 12.8 Current-use pesticides (CUPs) applied to agricultural lands in the Galapagos

Pesticide type	Chemical class	Chemical product (trade name)	EDC[a]	LOAEL or LEL[b] (mg/kg/day)
Insecticide	Mixture of avermectins[c]	Avermectin B1 (Abamectin)		0.40
	Neonicotinoid	Acetamiprid		N/A
	Pyrethroid	Cyhalothrin-lambda (Karate)	EDC	1.5
		Deltamethrin	EDC	N/A
	Carbamate	Carbaryl (Sevin)	EDC	15.6
	Thiourea	Diafenthiuron		N/A
	Organophosphate	Malathion	EDC	0.34
Herbicide	Chlorinated phenoxy compound	2,4-D Amine (Salvo)[d]	EDC	0.75
	Phosphanoglycine (glycine's aminophosphonic analogue)	Glyphosate (Rodeo, Roundup)	EDC	30.0
	Bipyridylium herbicide (quaternary ammonium)	Paraquat (Gramoxone)	EDC	0.93
	Pyridine[e]	Picloram (Grazon and Tordon)	EDC	35
Fungicide	β-Methoxyacrylates[f]	Azoxystrobin (Heritage)		N/A
	Chloronitrile	Chlorothalonil (Bravo, Ole)		3.0
	Dithiocarbamate[g]	Maneb	EDC	15
	Dithiocarbamate	Mancozeb	EDC	N/A
	Substituted dimethyl aniline	Metalaxyl		25
	Copper compound	Copper hydroxide		N/A
	Copper compound	Copper sulfate pentahydrate		N/A
	Nonmetal chemical element	Sulfur (micro-ionized)		N/A

Sources: Alava (2011), Massachusetts Institute of Technology (2008)

[a] EDC, endocrine-disrupting chemical according to Colborn et al. (1993), Colborn (1998), and WWF Canada (1999)

[b] LOAEL (lowest-observed-adverse-effect level), the lowest exposure level at which there are biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group; LEL (lowest-observed-effect level), in a study, the lowest dose or exposure level at which a statistically or biologically significant effect is observed in the exposed population compared with an appropriate unexposed control group (Integrated Risk Information System (IRIS) Database. http://www.epa.gov/ncea/iris)

[c] Containing more than 80 % avermectin B1a and less than 20 % avermectin B1b. Avermectins are a family of macrocyclic lactones, including insecticidal or anthelmintic compounds derived from the soil bacterium *Streptomyces avermitilis*

[d] 2,4-Dichlorophenoxyacetic acid is a plant growth deregulator, interfering with auxin action (i.e., auxin herbicide)

[e] Chlorinated derivative of picolinic acid used in combination or formulations with 2,4-D or 2,4,5-T (Agent Orange) against perennials on non-croplands for brush control. Picloram is also a plant growth deregulator, interfering with auxin action

[f] Derived from the naturally occurring strobilurins

[g] Ethylene-(bis)-dithiocarbamate (EBDC) group of fungicides

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Chapter 13
Assessing Human–Wildlife Conflicts and Benefits of Galápagos Sea Lions on San Cristobal Island, Galápagos

Judith Denkinger, Diego Quiroga, and Juan Carlos Murillo

Abstract Human–wildlife interactions shape perceptions and the conservation of wildlife populations. San Cristobal Island is the main fisheries port in the Galápagos archipelago and hosts one of the largest sea lion colonies. Local tourism and the population have grown drastically over the past decade and so does human impact on Galápagos sea lions. Here, we analyze human perceptions of the endemic and endangered Galápagos sea lion, using interviews and behavioral observations of sea lions' responses to humans.

There is overall agreement that sea lions should be protected, but some fishers do not share this view nor are compliant with protection efforts. Direct anthropogenic impacts in the form of sea lion entanglements in fishing gear and debris (nylon, plastic), diseases, and fishers' aggressions toward sea lions have substantially increased in the past 2 years. Sea lions are highly tolerant to human presence, but they flee when approached at distances closer than 4 m. Injuries and death of sea lions caused by humans increased dramatically over the last 5 years. To improve conservation, it is essential to investigate the dynamics and challenges of human–sea lion interactions on San Cristobal. Socioeconomic activities influence these perceptions, and possible reasons explaining the different attitudes toward these animals are shaped not only by economic interests but by the symbolic and political context in which these positions take form.

Introduction

Human–animal interactions shape perceptions of wildlife, which can be complex and multidirectional, based on people's productive strategies and on cultural schemata (Descola 1992). Most studies on human–wildlife interactions concern the

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threat that animals pose to human economic and subsistence bases (Ezealor and Giles 1997; Wang et al. 2006). Yet, human perceptions of conservation icons interfering with daily activities are poorly studied. Interactions between people and Galápagos sea lions (*Zalophus wollebaeki*) on San Cristobal Island, Galápagos, where sea lions live in the town center, Puerto Baquerizo Moreno (i.e., the second largest city and the capital of the Galápagos Province), are part of the day-to-day life of both sea lions and humans. Predation by wildlife on prey that has an economic value has been identified as the main driver of people's negative attitudes toward predator species (Sekhar 2003; Walpole and Goodwin 2001). Marine mammals preying on commercial fish populations, or on aquaculture facilities, cause conflicts worldwide (Read 2008), including the Galápagos Marine Reserve. Here, we explore the relationship between humans and endangered Galápagos sea lions (IUCN Category A2a; Aurioles and Trillmich 2008) on San Cristobal Island.

Sea lions spend most of their lives in nutrient-rich oceans but rest and breed on land. They are normally restricted to temperate areas rather than to tropical or subtropical environments such as those of the Galápagos Islands. The Galápagos archipelago receives cold nutrient-rich waters from the Humboldt Current in the south and the Cromwell Current upwelling in the west, which extends to the western coasts of the islands (Feldman 1985). However, the Galápagos waters are not productive year-round; the warm, nutrient-poor Panama Current affects the islands from January to April each year. Additionally, El Niño events occur within a range of every 3–7 years, increasing the sea surface temperature, deepening the thermocline, and causing dramatic responses in primary production (Chavez et al. 1999), and, thereby, limiting access to food for many marine organisms at higher trophic levels (Glynn 1988). El Niño events severely affect sea lions and fur seals (*Arctocephalus galapagoensis*), creating high pup and adult mortality rates in both species (Trillmich and Limberger 1985; Trillmich and Dellinger 1991; Salazar 1999; Alava and Salazar 2006). After the last strong El Niño event in 1998, an increasing number of sea lions settled in Puerto Baquerizo Moreno, forming what is now one of the largest colonies in the archipelago (Páez 2008). According to Aurioles and Trillmich (2008), total population numbers have decreased over the past few decades. Presently, approximately 18,000 individuals inhabit the islands, representing a 50 % decrease in the population since the last major El Niño event (Alava and Salazar 2006; Aurioles and Trillmich 2008). The colonies in Puerto Baquerizo Moreno have an estimated total of 1,500 individuals (Denkinger et al. unpublished data).

It is likely that El Niño events may increase in strength and frequency (Timmermann et al. 1999), posing serious threats for the sea lion population in the long term (Salazar and Denkinger 2010). The dynamic environment of the Galápagos, with alternating favorable and poor feeding conditions, leads to smaller sea lion and fur seal colonies compared to other pinniped species (Trillmich 1984; Riedmann 1990). To increase pup survival, Galápagos sea lions have long nursing periods of up to 2 years and may nurse a yearling and newborn at the same time (Trillmich 1984), though competition within siblings is often fatal for newborns (Trillmich and Wolf 2008). Rookeries of several females and one alpha male prefer flat sandy beaches where they are resting and nursing, whereas nonbreeding males and subadults tend to reside in less favorable habitats such as rocky shores (Wolf et al. 2005). Therefore, beaches are key habitats and require special management, especially considering the highly complex, social, and playful nature of sea lions. Alpha males of Galápagos sea lions are extremely busy guarding their harem and taking care of curious pups and juveniles that would otherwise venture out in the sea. While on land, pinnipeds need to rest to conserve energy for their biological needs (Costa and Gales 2003). Overall, Galápagos sea lions are an especially curious species and frequently approach humans. In fact, they seem more habituated to humans than any other sea lion species (Riedmann 1990). Pups and juveniles hone their skills with extensive play periods. They enjoy playful interactions with tourists, accompanying snorkeling biologists on their scientific projects, stealing research gear and biting scuba fins and quadrates, or simply following along.

Study Area and Social Background of San Cristobal and Galápagos

The study took place in the capital city of the Galápagos Province, Puerto Baquerizo Moreno (0°54′07.12″/89°36′40.34″), where some of the major sea lion colonies are located. Puerto Baquerizo Moreno is situated at Wreck Bay on the southern tip of San Cristobal Island (Fig. 13.1). The bay is also the main harbor for fishing vessels and the second most important for tour boats. San Cristobal is located in the southeast of the archipelago in a mixing zone (Edgar et al. 2004), where it receives warmer waters at the northern tip of the island and colder waters with strong winds and upwelling in the south of the island.

Annexed by the Ecuadorian government in 1832 and declared a National Park in 1959, the Galápagos Islands are still considered one of the best-preserved archipelagos in the world. The archipelago was designated a UNESCO World Heritage Site in 1978, placed on the list of World Heritage at risk in 2007 for its mounting problems associated with the rapid growth of tourism, escalating human population, and increased introduction of nonnative and invasive species (Watkins and Cruz 2007). Afterwards, various conservation organizations opposed its removal from the endangered list in August 2010.

In 1988, the passing of the Organic Law for the Special Regimen for the Conservation and Sustainable Development of Galapagos (LOREG) funded the Galápagos Marine Reserve (GMR) as it exists today. According to this law, only artisanal fishers registered with the National Park have permission to fish in the GMR (Hearn 2008a).

The number of fishermen registered in the Galápagos has increased from 752 in 1999 to 1,023 in 2008 though to date with the reduction of resources, the actual number of active fishers decreased from 628 to 400 (http://www.Galapagospark.

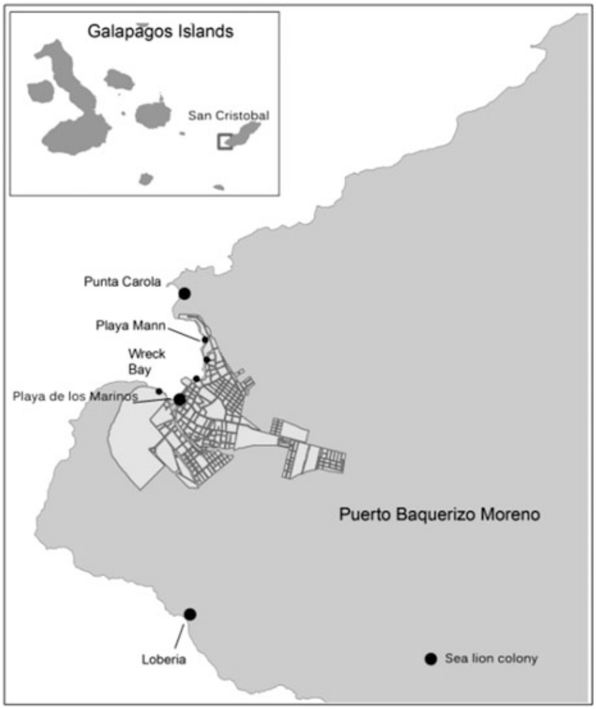

Fig. 13.1 Geographical situation of San Cristobal Island in the Galapagos Archipelago and study site at Wreck Bay

org), representing roughly 2 % of the total population. By the year 2006, fishing made up less than 4 % of local income (Watkins and Cruz 2007).

Artisanal fishers see tourism as a less strenuous and dangerous economic activity and many have already transitioned, at least partially, to the tourism sector. In San Cristobal, they pilot tour boats and work as guides. Still, they continue to struggle to reap the benefits that the Galápagos brings to those in tourism and conservation. Some fishers have proposed several projects including *pesca vivencial* (fishing with tourists and sport fishing) and catch and release sport fishing (see Chap. 10).

Tourism, on the other hand, is the most important source of income and comprises approximately half of the island income (Watkins and Cruz 2007). The local population, especially fishermen as boat operators, first became involved in tourism in the 1960s (Quiroga 2009; Watkins and Cruz 2007). With increasing numbers of tourists arriving in the 1970s, the National Park began training tour guides. In 1974, the Charles Darwin Research Foundation recommended limiting the maximum number of tourists to 8,800 per year. The islands quickly exceeded this limit in 1979 with a total of 11,765 tourists, the majority of which stayed on live-aboard cruise boats, mostly owned by foreign companies. In the 1990s, more tourists came for local, land-based tourism. By 2008, annual visitation had risen to 184,000, and despite a temporary decrease in 2009, due mostly to the global economic crisis, the numbers continued to increase in 2010 and 2011 with an expected increase to 150 % by 2020 (Watkins and Cruz 2007).

There has been an important increase in the availability of employment in the tourism sector. Since the 1970s, the human population has grown exponentially from a few thousands in the 1950s to the current official number of 25,124 people (Villacis and Carrillo 2013), thus intensifying the demand on local food supplies and transport of goods from the continent to the Galápagos. Consequently, pressure on pristine areas and the risk of species introduction have grown (Kerr and Cardenas 2004; Bremner and Perez 2002). This ongoing phenomenon occurring in the Galápagos has been defined as "continentalization" (Grenier 2010).

Human residents on San Cristobal regularly interact with sea lions. The Galápagos sea lion (*Z. wollebaeki*) is endemic to the islands and found throughout the archipelago. Some of the largest sea lion colonies are at Playa de los Marinos, in the center of San Cristobal, and La Lobería and Punta Carola, recreational beaches close to town (Fig. 13.1).

Methods

The study explores three areas (1) human perception and implications, (2) sea lion behavior, and (3) human impact and conservation issues.

Human Perception of Sea Lions

Residents of Puerto Baquerizo Moreno were divided into different categories according to their primary economic activities. The categories include fishers, tourists, and others, such as merchants, public employees, and general public (referred to as "the community"). Surveys were conducted to examine two themes: how residents' daily activities are affected by sea lions and people's perception of sea lion conservation. Categorical variables were used to understand people's perceptions, being related to the objectives of each open-ended or closed-ended question (Patton 2005; Table 13.1) and the sector of the population surveyed, while the discrete variables state the number of responses in each sector. Chi-square tests and contingency tables were used to analyze the statistical power (1-beta = 0.90) of the results. With the aim to determine the sample size ($N = 194$), the statistical software, G-Power, was utilized.

We conducted 70 surveys in each sector to reach the required sample size of $N = 194$ with a total of 210 interviews. Temporary residents make up only 10 % of the 210 people surveyed. The Galápagos special law regulates residency and only permanent residents can live and work unlimitedly on the islands; in contrast, temporal residents live and work intermittently according to their work contracts. Responses were classified into positive and negative (see Table 13.1).

Table 13.1 Categorical variables positive and negative responses used in interviews (open-ended and closed-ended questions) with local inhabitants of San Cristobal Island on their perspective to Galápagos sea lions

Value	Are sea lions attractive and likeable?	Would your life be better if sea lions disappeared?	Have you ever been attacked by a sea lion?	Do sea lions interfere with your daily activities?	Is it important to protect sea lions?
1	They are attractive	My life would be better	Yes	Yes	Yes
−1	They are not attractive	My life would be worse	No	No	No

Sea Lion Behavior

Sea lion behavior was monitored at two sea lion colonies on Puerto Baquerizo Moreno (see Fig. 13.1): Playa de los Marinos, a beach with strong human impact due to regular boat crossing and reparation, and La Loberia, a recreational beach southwest of the Island (3 km from the town center) with moderate to low human impact. As fewer interactions between humans and sea lions occurred at La Loberia, the observations of interactions were mainly focused at Playa de los Marinos. Behavioral surveys of Galápagos sea lions were carried out in March 2009 for a total of 18.5 h at both sites. Each survey lasted from 2 to 3 h in the late afternoon. Playa de los Marinos was surveyed from March 4 to March 15 and La Loberia from March 16 to March 26. The biggest colony at Playa de los Marinos consisted of an average of 230 individuals (SD = 41), while the colony at La Loberia had an average of 40 individuals (SD = 7). At both sites, we selected a focal harem consisting of an alpha male, females and their pups, and juveniles, and subgroups of bachelor males without harems. We recorded behavior for different age and sex classes such as adult males, adult females, females with pups, and pups (newborns until first mould). Next, we continuously observed the colony recording reactions (e.g., fleeing, barking) or duration of each behavior, including resting. Human interactions with sea lions are considered events and were classified as passive or aggressive. We recorded the interactions each time a person was present at the sea lion colony and calculated the percentage of aggressive and passive interactions of individuals relative to total actions at a distance of 10–20 m so that the observers' presence would not influence the behavior of humans or sea lions. To analyze the reactions of sea lions to human presence, we identified different situations: (a) aggressive approach (i.e., scaring the sea lions away, throwing sand or stones), (b) nonaggressive approach at a distance >4 m, and (c) nonaggressive approach at a distance <4 m. We calculated the frequency of each situation involving humans over total observation time. For each situation, the percentage behavior for each size class was calculated as a proportion of behavior to total observation time and compared within the different situations using chi-square tests.

Human Impact and Sea Lion Conservation

To assess human impact on sea lions, we used data of the sea lion colonies at Puerto Baquerizo Moreno from an ongoing monitoring program of the Galápagos National Park (GNP) and the Galápagos Academic Institute for the Arts and Sciences (GAIAS) and Galapagos Science Center (GSC) from February 2008 to December 2012 and from occasional reports to the GNP office. All cases were divided into the following impact categories according to the cause of death or injury: shark attacks (i.e., round bite wounds), dog bites (i.e., clear patterns of dog teeth), human related (i.e., entanglement in rubbish or other items, propeller cuts, boat or car accidents, impact of knives or other objects), fishery related (entanglements in fishing gear), diseases (skin diseases, ulcers, eye infections, pup mortality), and starvation (hip bones and rips clearly visible). Dead sea lions were externally examined and in some cases autopsies of sea lion carcasses were performed to study the cause of death. All impact categories were listed over the years as total numbers of all reports. In the same way, the health condition of the animals was recorded as *dead* animals, including juveniles and adults; *pup mortality*, when dead or aborted pups were observed; *injured*, when animals showed blows, cuts, or amputated limps clearly not caused by sharks; *entangled*, when animals were entangled either in debris or fishing gear; *sick*, if animals had extreme mucus secretion, eye infections, skin diseases, parasites; or *starved* (see above).

Results

Human Perceptions of Sea Lions

Consistent with our hypothesis, the results of 210 surveys with fishers, people working in the tourism sector, and the remaining community revealed that only the responses of the fishing sector tended to differ: fishermen expressed more negative perceptions of sea lions than the other two groups.

Both the tourism sector (66 %) and the rest of the community (69 %) perceive *sea lions as an attractive and amusing species*, while only 28 % of the fishing sector responded positively. Thirty-five percent of fishers stated that sea lions were neither attractive nor amusing and the remaining 38 % stated that they were indifferent to this species.

Personal experiences of *direct threats from sea lions such as attacks or other aggressive behavior* differed greatly (x^2: $p < 0.001$) among sectors; 3 % of the tourist sector, 17 % of the rest of the community, and 33 % of fishermen reported attacks or aggressive behavior from sea lions.

In response to "*whether or not sea lions interfere with their work activities*," 70 % and 86 % of the tourism sector and the rest of the community, respectively, answered that sea lions do not interfere with their daily activities. Meanwhile, 64 %

of the fisheries sector indicated that sea lions disrupt their work activities. Of those that answered positively, many commented that sea lions are noisy and unhygienic due to the fact that they defecate in public places. Among fisherman, 33 % responded that sea lions interfere with their daily activities by eating their bait and catch and by resting aboard their boats, dirtying, and at times sinking them.

Most people in all three sectors agreed, "*their lives would remain the same without the presence of sea lions*." However, 33 % of fishermen responded that their lives would improve while 30 % of the rest of the community and 39 % of the tourism sector indicated that their lives would be worse without sea lions (Fig. 13.2).

With regard to sea lion conservation, the responses of all three sectors converged for the first time: 93 % of the community, 91 % of tourism, and 89 % of fishermen indicated it was *critical to protect this species*. Concerning *sea lion population numbers*, most respondents in all sectors incorrectly stated that there are more sea lions now than 10 years ago. Few people (6 % of the rest of the community and 9 % of the tourism sector) and none of the fishermen interviewed were aware of the *endangered status of the Galápagos sea lion* (Fig. 13.3).

Sea Lion and Human Interactions

All sea lions tended to escape and pups appeared to be especially frightened when approached aggressively by humans (2–4 escapes/h). We found human behavior with respect to sea lions significantly more aggressive at Playa de los Marinos, where people perform various daily and work-related activities in the presence of sea lions, than at La Lobería, where people primarily go to relax (t-test, $p < 0.005$; Fig. 13.4). Though the GNP recommends that people must maintain a 2-m distance from wildlife, sea lions already react strongly at a 4 m distance. We observed that most people approached sea lions at a distance of less than 4 m (Fig. 13.4).

Approaches at distances of less than 4 m caused stronger reactions at Playa de los Marinos than at La Lobería. At the former, females moved away, whereas pups, males, and females with pups tended to defend themselves. Mothers with pups focused primarily on nursing, ignoring aggressive approaches on some occasions. At distances greater than 4 m, sea lions in all age classes simply observed or did not react to human presence (Fig. 13.5).

Human Impact and Conservation Issues of Sea Lions at San Cristobal

From February 2008 to December 2012, the GNP and the Galapagos Science Center received a total of 648 reports of dead, injured, or sick sea lions, with an

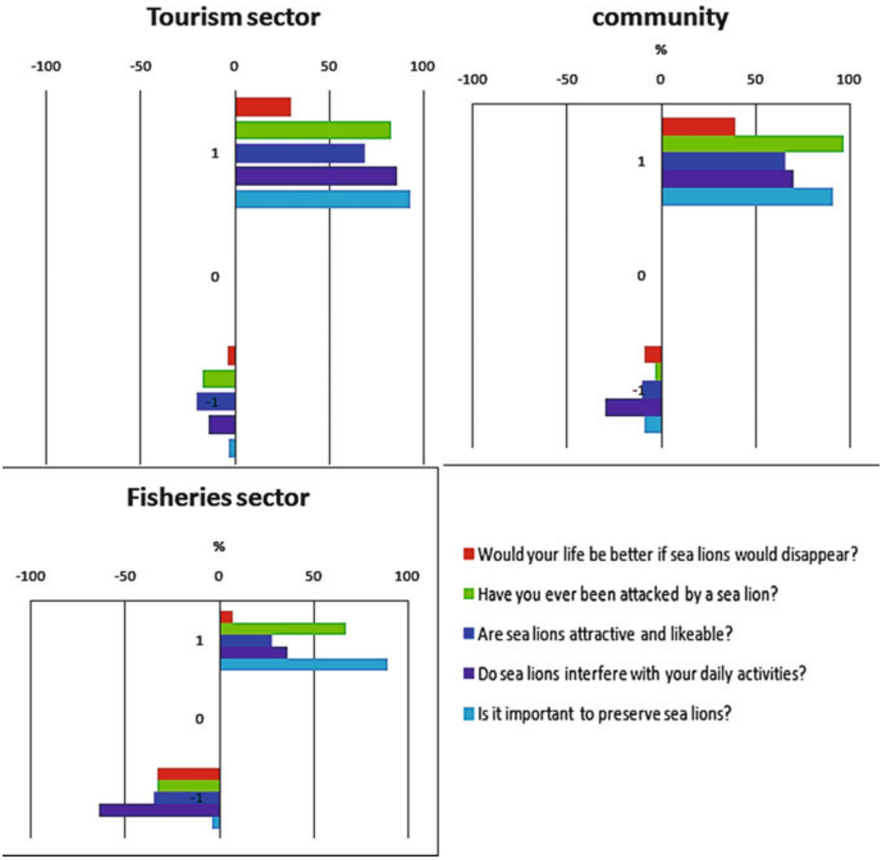

Fig. 13.2 Human perception of different social sectors on Galápagos sea lions based on interviews using a set of five open-ended and closed-ended questions (see Table 13.1)

increasing number of incidents occurring in the latter half of this 4-year period. As shown in Fig. 13.6, adult and juvenile mortality peaked in 2010 and 2012 with 20 animals reported in both years, while pup mortality increased from 35 dead pups in 2009 to 96 pups in 2011, reflecting a 64 % increase in mortality. Even though pup mortality decreased slightly in 2012 to 68 pups, animals observed with disease symptoms continuously increased to 98 animals in 2012. Similarly, the amount of injured animals rose dramatically from 4 animals reported in 2008 to 96 animals by November 2012 (Fig. 13.6).

Threats were mostly related to diseases (51 %) followed by death or injuries associated with direct anthropogenic impacts accounting for 20 %, whereas interaction with fishing gear only affected 2 % of the sea lions observed. Only 4 % of sea lions suffered shark attacks, while dogs caused 3 % of the problems reported.

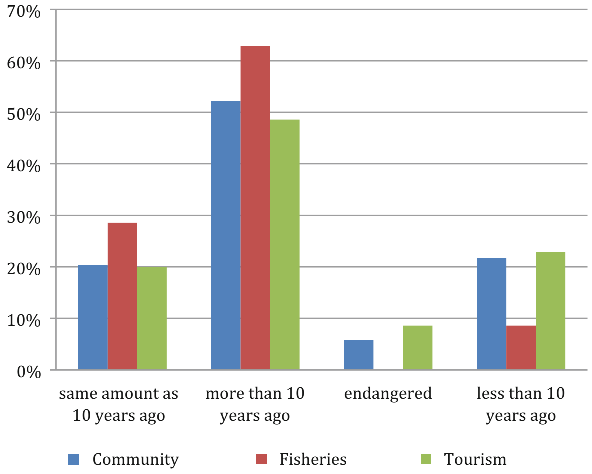

Fig. 13.3 Human perception of different social sectors on the status of Galápagos sea lion conservation

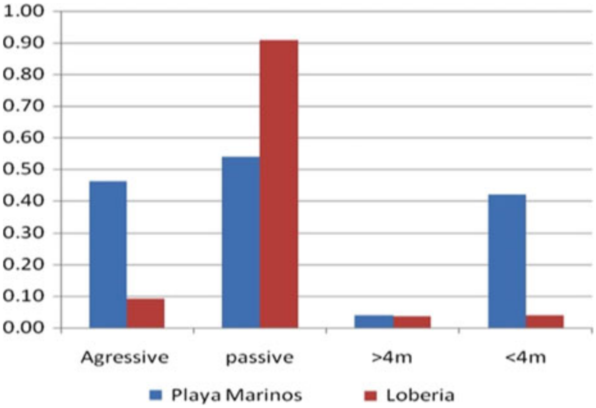

Fig. 13.4 Observed frequencies of human approach to sea lions at Playa de los Marinos and Loberia on San Cristobal Island

Possible natural causes, such as parasitic infections (2 %) or malnutrition (3 %), are minimal compared to human-inflicted injury and death or disease (Fig. 13.7).

Both disease (including pup mortality)- and human-related problems have drastically increased from 2008 to 2012. Fishery-related problems peaked in 2010 coinciding with the sport fisheries event organized by the municipalities of San Cristobal. Dog attacks peaked in 2011 with a total of six cases of injured or dead sea lions (Fig. 13.8).

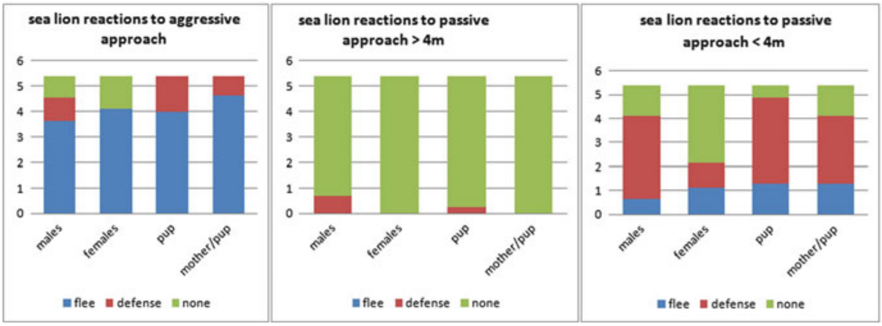

Fig. 13.5 Sea lion reactions to different distances of human approach

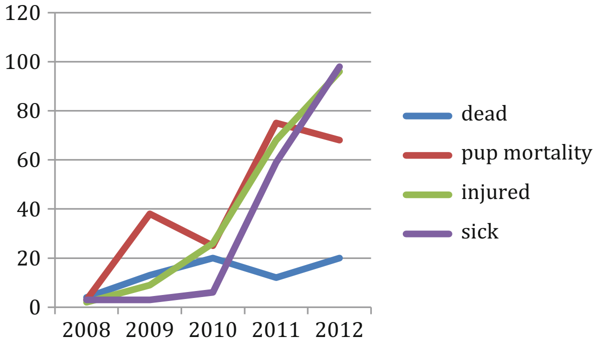

Fig. 13.6 Temporal trend of the condition of Galápagos sea lions reported to the Galápagos National Park Office at San Cristobal from 2008 to November 2012 ($N = 648$)

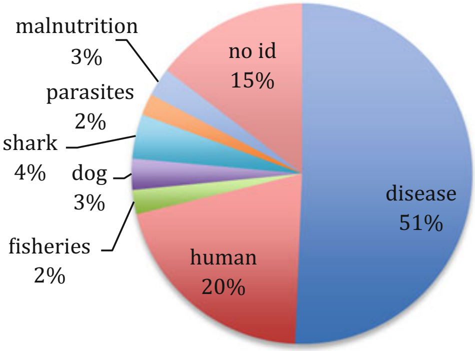

Fig. 13.7 Proportion of cumulative natural and anthropogenic threats reported for Galápagos sea lions on San Cristobal Island ($N = 780$)

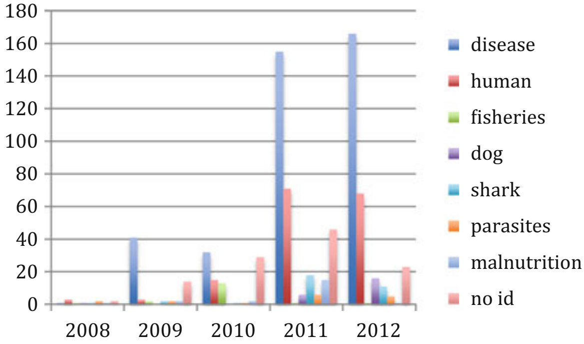

Fig. 13.8 Annual frequency of natural and anthropogenic threats reported to the Galápagos National Park Office on San Cristobal from February 2008 to November 2012

Discussion

Wildlife conflicts emerge when human and wildlife requirements overlap (Distefano 2008). The growing number of humans and expanding urban landscapes across the globe affects wildlife habitats and populations, thus creating conflicts, especially between large carnivores and humans (Beckmann and Lackey 2008; Thornton and Quinn 2009). The municipalities of Galápagos have experienced an accelerated increase in the number of residents with population growth driven to a large extent by tourism, averaging 5.2 % a year between 1950 and 2001 (INGALA 2012).

During the middle of the twentieth century, many environmentalists promoted a western, postcolonial view of nature and conservation, called the Yellowstone model that emphasized charismatic animals and parks free of people. They encouraged an eco-centric discourse and elevated the conservation of nature above human needs and their societies, according to ideals adopted from the industrialized nations (Quiroga 2009). Likewise, with the foundation of the GNP in 1959, many Galápagos species, including sea lions, came to have multiple and contested symbolic meanings. Though people engaged in science, tourism, and conservation see emblematic species like the sea lion as an endemic and unique species in need of protection, many local people engaged in fisheries activities perceive them not only as a nuisance since they compete for the same resources but as a symbol of a repressive and exclusionary social, political, and economic system.

As expected, our survey responses revealed that people's productive activity shapes their perceptions, desires, and cognitions with respect to local fauna. Their practical and material concerns determine their belief systems, which depend on whether or not sea lions attract commerce in the form of tourism or constrain their livelihood activities, as in the case of Galápagos fishermen. The tourism sector and the community have a generally positive view of sea lions. Sixty-nine percent of the community and 66 % of people working in tourism stated that they found sea lions both attractive and amusing, and the majority of both sectors stated that lions do not disrupt their daily activities. For both groups, these marine mammals constitute one of the most attractive species, owing to their popularity among visitors. For divers and snorkelers, swimming and diving with sea lions is a unique experience. Part of the attraction that people find in sea lions lies in the way these creatures cross boundaries between humans and animals, water and land, and the domestic and the wild, among others (Mullin 1999). Animals like sea lions also share some level of personality making them attractive and inspiring for tourists (Mullin 1999). As tourism becomes a more important economic activity, many fishing households depend increasingly on tourism as a source of income. Currently, tourism makes up about 50 % of the total Galápagos income, and fishing constitutes less than 4 % (Watkins and Cruz 2007). In San Cristobal, local people who own hotels, restaurants, boats, and other properties operate and manage most of the industry.

Sixty-eight percent of the fishermen described sea lions as disruptive of their daily livelihood activities. They expressed a more negative view of sea lions than the tourism sector and the rest of the community; only less than one third of fishermen stated that they found the marine mammals attractive and amusing.

The fact that sea lions pose a threat to fishers' livelihoods has been given increasing attention on a global scale. Since World War II, global fisheries, especially in the Southern Ocean, have shifted to deeper fishing grounds (200–500 m in depth) as a result of the depletion of fish stocks in shallower waters (Pauly et al. 2005). As a consequence of overfishing in Alaska, for example, Steller sea lions (*Eumetopias jubatus*) suffer from nutritional stress associated to reduced stocks of Pacific herrings (*Clupea pallasi*) and other forage fish species and reliance in low-energy or low-quality fish (e.g., pollock, *Theragra chalcogramma*) (Rosen and Trites 2000; Trites and Donnelly 2003). Thus, sea lions have increasingly taken over to competing for marine resources with fishers, resulting, at times, in their injury or death (Alverson 1991).

In the Galápagos, some fisheries such as lobster (Murillo et al. 2004; Hearn et al. 2006) and the sea cucumber harvesting have all but collapsed (Shepherd et al. 2004; Toral-Granda 2005). The lack of monetary income, resulting in part from market fluctuations and the increasing number of restrictions on fishing activities, has forced fishers to dive deeper and risk their health, or life, to gather sea cucumber and lobster and also to navigate to distant areas such as sea mounts. Therefore, pelagic and demersal fisheries, located in shallower waters or seamounts, have become critical for fishers. As in other parts of the world, these conditions result in a conflict between fishers and marine mammals as they compete for the same increasingly scarcer resources. According to Galápagos fishers, sea lions tend to congregate close to their fishing grounds and follow fishing boats in order to take advantage of the catch while hauled on board. Studies show that in many places, sea lions do in fact benefit from feeding in close association with commercial fishery fleets (Hückstädt and Antezana 2003). In the Galápagos, as elsewhere, marine mammals are at times slaughtered in order to improve fish stocks or to protect the fish caught or aquaculture production (Lavigne 2006). In 2008, a massacre involving 53 male sea lions, 9 adult males, 6 adult females, 25 immature sea lions, and 13 pups occurred in Pinta Island, a remote island of the Galápagos

Archipelago, but no signs of dismemberments or the removal of organs were found (Hearn 2008b). Yet, this kind of assaults can cause the killing of mothers found in fishers' foraging grounds, therefore increasing the amount of starved juveniles and pups found in the colonies. Interestingly, a shifting baseline study with three generations of fishers on San Cristobal revealed that while the size of fish and amount of catch has decreased (Burbano 2011), sea lion populations have also decreased (Salazar and Bustamante 2003; Alava and Salazar 2006; Aurioles and Trillmich 2008).

On a worldwide scale, culling comprises 5 % of the human-induced threats facing small cetaceans in addition to bycatch (26.5 %) (Culik 2004). In the Galápagos, some fishers openly comment that they kill sea lions by stabbing them, clubbing them on the head, cutting them with a knife, or slaughtering them in their colonies. Several sea lions have been found dead with broken skulls or cuts on their throats on the beaches of San Cristobal and elsewhere in the Galápagos. This study included these records as human impact causes of injury and not as fishery interaction (Figs. 13.7 and 13.8).

The conflict between fishers and sea lions is not merely a question of competition for marine resources but at times represents a symbolic act of opposition to what some fishers see as a conventional, top-down style of local environmental management. Regulations, many of which recommended by foreign scientists and the Charles Darwin Foundation to GNP authorities, have resulted in severe tensions and conflicts with fishers and even in violent riots and protests (Stone 1995; Ferber 2000; Quiroga 2009).

Conflicts have also arisen from fishers' dissatisfaction with the GMR's governance framework, i.e., the participatory management system. Established in 1999, this system of comanagement comprises two levels of decision-making: the Participatory Management Board (PMB) and the Inter-institutional Management Authority (IMA). The PMB is made up of representatives from the fishing sector, the Galápagos Chamber of Tourism, naturalist guides, the Charles Darwin Research Station, and the Galápagos National Park Service (GNPS). Decisions on activities and regulations within the GMR must be reached by consensus within the board; cases go to the IMA if consensus cannot be achieved. According to a 2007 evaluation of GMR governance, while the comanagement regime has been successful with respect to strategic vision and participation rates, it has been less successful in terms of social justice, equity, and credibility (Heylings and Bravo 2007). Fishers have expressed resentment and accused the system of being prejudicial to their sector, a perception resulting from the fact that the majority of meetings in the PMB have dealt with fishing issues and regulations while not dealing with issues of other sectors (Heylings and Bravo 2007). Some fishers complain that other economic actors and sectors, especially the tourism sector, have the capacity to dispute and resolve issues outside of the system by taking advantage of their economic lobby and political connections. Many of the fishers prefer to take issues to the streets than addressing them in participative management meetings and the IMA. Overall, the fishers perceive that the social and political system in the GNP favors the tourism and conservation sectors.

In the past, political struggles have used other emblematic species such as tortoises as a symbol. For example, fishers threatened to kill Lonesome George, the last member of the Pinta Island tortoise species (*Geochelone nigra abingdoni*) and a famous tourist attraction, as well as other tortoises from the tortoise-breeding center at the Charles Darwin Research Station (Ferber 2000). Fishermen have complained that local people often lack access to adequate medical attention, while military helicopters rescue tortoises during volcanic eruptions (Nichols 2006; Grenier 2007). Like the tortoise, sea lions are a popular species among tourists. Although sea lion conservation has received less attention than that of tortoises, their relatively recent classification as an endemic species (Wolf et al. 2007) has given them a special status among the marine mammals of the Galápagos. In some cases, therefore, fishers' attacks against sea lions may become part of a symbolic act against the growing political and economic power of the tourism and conservation discourses.

Local institutions, including the GNP, the Charles Darwin Foundation, and other environmental NGOs, increasingly endorse a conservation vision emphasizing the importance of maintaining balanced marine ecosystems and protecting their resilience against fisheries and climate change. These campaigns and educational programs have shaped local people's views on nature and conservation and have placed fishers in a complicated position vis-à-vis the Park's goals. Yet, fisheries' regulation cannot be seen merely as an oppressive act on the part of the Park as there are also practical benefits to protecting fisheries' resources. Maintaining healthy marine environments helps ensure the long-term sustainability of Galápagos fisheries and thus local fishing activities, an idea that at least many fishers agree on. The primary issue, then, lies in finding ways to reconcile local conservation objectives with the needs of the people most likely affected by those objectives.

Despite the conflicts between fishers and sea lions, 89 % of interviewed fishers expressed support for sea lion conservation, a figure comparable to the 91 % of tourism or 93 % of the rest of the community. Therefore, a view that places fishers strictly outside of the Park's conservation strategy is not only misleading but also fails to capture the ways in which local people negotiate their practical concerns with their support of environmental protection measures. The global view of nature and emblematic species has created a hybrid worldview among members of the local population, where acceptance and rejection of the conservationist discourse coexist in complex forms (Quiroga 2012). Discourse of the local authorities and leaders demonstrates an example of this hybrid mentality. In 2008, the municipality of San Cristobal declared the sea lion "*La cara de San Cristóbal*" (the face of San Cristobal) and fenced in the boardwalk to the central beach, with several signs indicating regulations for sea lion observation. The boardwalk has consequently become a major attraction, especially in the evenings, when most sea lions are present on the beach.

Some fishers have transitioned into the tourism sector, allowing them to take advantage of the practical benefits of protecting local fauna. As those in tourism witnessing interactions between tourists and sea lions, they increase their awareness of the importance of these animals for the local economy. Many fishers now offer land-based tourism packages, where tourists visit the inhabited islands on small speedboats and stay in hotels. The development of a kind of tourism that generates opportunities for the local population to start their own businesses and that emphasizes environmental sustainability adds an important component to local conservation strategies. There exist, however, various legal, economic, and political barriers that hinder the possibility for fishers to totally transition into the tourism sector. Furthermore, some fishers have no interest in switching to tourism, as they have dedicated their lives to the specialized skill of fishing and value their identities and ways of life as fishermen. Some also see the move toward tourism as an imposition by GNP authorities and other groups. Thus, in order to address the tensions between economic activities and ecological conservation in the Galápagos, one must revise the structural factors that allow the inclusion of some groups in the larger vision of the National Park while excluding and marginalizing others and recognize that some local actors have a greater voice in the design of this vision.

The complex local views about conservation and endemic animals reflect an economy in transition. For the past 10 years, local officials and authorities explicitly promoted a move away from extractive activities such as fishing. With the economy increasingly dependent on non-extractive activities, especially tourism, the population now appreciates and values native animals, including the sea lion. Tourists' expectations put pressure on local administrators to maintain what they construct as "natural" and "pristine" environments (Errington and Gewertz 2003; West and Carrier 2004). The vision of nature as a provider of goods thus increasingly replaces and in many cases hybridizes, one in which nature provides cultural and regulatory services.

While the majority of people interviewed in all three categories mentioned the importance of sea lion conservation, our observations of human–sea lion interactions revealed that many do not act accordingly. At Playa de los Marinos, nearly half of the interactions appeared aggressive. In reality, many people show little concern for sea lions in their daily lives or recreational activities. With the increasing proximity of humans and animals at Playa de los Marinos, sea lions now react more aggressively to humans, while sea lions at the more remote and less visited La Lobería are generally passive. Since rest on land remains crucial for sea lion survival, constant approaches and the presence of humans nearby present a stress factor that can alter resting and nursing patterns (Allen et al. 1984; Suryan and Harvey 1999), increase energy expenditure in females (Suryan and Harvey 1999), change social and mating behavior (Richardson et al. 1995), and, in the long term, result in a decrease in breeding success and population size (Johnson and Lavigne 1999), all of which reflected by the drastic increase of diseases and pup mortality.

On the whole, Galápagos sea lions tolerate human presence far more than sea lions in other areas of the world as they do not react when people approach to less than 4 m distances. Australian sea lions (*Neophoca cinerea*) on Carnac Island become aggressive when humans approach them at less than 15 m (Orsini 2004). California sea lions (*Zalophus californianus*) at Los Islotes in Mexico have reacted aggressively when tourist boats approached within 20 m of the colonies (Labrada-Martagon et al. 2005).

In recent years the number of dead or injured sea lions has increased as reported by the GNP. Numerous causes could contribute to this increase: despite regular monitoring efforts since 2008, people may report death and injury more consistently; an increase in fishing activities and recreational activities in sea lion colonies leads to more possibilities for negative human–sea lion encounters; or perhaps decreasing sources of food for sea lions versus increased predation of fishers' catch can result in more human–wildlife interactions. Reports of hooks attached to sea lions have increased in 2010 as well as cases of sea lions trapped in nets and other marine debris. The 20 % of human-related sea lion deaths, as opposed to 4 % by sharks (see Figs. 13.7 and 13.8), illustrates the need to raising awareness about human impact on sea lion populations. The past has seen mass killings of sea lions; similar to the Pinta Island massacre in 2008, 15 sea lions, including 11 males, but with their genitals removed, and 4 females, were found dead near La Lobería in San Cristobal Island in 2001 (Salazar 2001; Salazar and Edgar 2001). In addition, two more individuals were recently slaughtered, one in 2010 (Murillo, pers. obs.) and another in 2011. Sea lion genitals are sold as aphrodisiacs in the Asian black market and in traditional Chinese medicine stores (Malik et al. 1997). While Galápagos sea lions have lost a considerable amount of their populations during El Niño years (Trillmich and Limberger 1985; Trillmich and Dellinger 1991), growing anthropogenic interactions, increased competition by sea lions, and the resentment from fishers toward the conservationist pose new challenges to the resilience of the population and ultimately to its survival.

Survey results revealed that the local population in general, whatever their economic activity, could benefit from informational campaigns about sea lions. Sixty-three percent of fishers, 52 % of the community, and 49 % of the people in tourism stated that there are more sea lions today than a decade ago. Furthermore, fishermen constantly complain that the increase in the numbers of sea lions diminishes their catches. This perception held by all three sectors is partly true since sea lion populations reduced by 50 % in the 1997/1998 El Niño event (Salazar 1999; Salazar and Bustamante 2003). The current population size is less than 50 % of the population that existed before the 1982/1983 El Niño (Alava and Salazar 2006; Aurioles and Trillmich 2008). Future declines are very likely (see Salazar and Denkinger 2010) since El Niño events are estimated to become stronger and more frequent (Timmermann et al. 1999; Sachs and Ladd 2010). None of the fishermen surveyed and only 9 % of tourism and 6 % of the community correctly identified the Galápagos sea lion as an endangered species even though they were designated an endangered species by the IUCN in 2008 (Aurioles and Trillmich 2008). Thus, the local population lacks education about the state of the sea lion population and the threats they face. Furthermore, it is important to highlight the benefits of the sea lions as an ecological and economic resource. Sea lions are valuable for ecosystem services as top predators and keystone species, as well as for tourism. Globally, marine mammals remain important assets for tour operators; both whale watching

(Hoyt 2001) or pinniped watching (Kirkwood et al. 2003) are sources of income in many parts of the world.

Conclusions

As human development and activities expand into wildlife habitats in the Galápagos, including the sea lion colonies in the center of Puerto Baquerizo Moreno, conflicts between animal and human communities have become more prevalent. Benefit shapes the perception of wildlife since fishers share a more negative view on sea lions as they are directly affected by sea lions, dirtying or even sinking their boats and stealing their catch. On the contrary, people involved in tourism and other activities state that they do not feel bothered by the presence of sea lions in the town center of Puerto Baquerizo Moreno. Even though fishers just as the rest of the population support sea lion conservation, the nature of human behavior is not accordant when they approach sea lions in their daily lives. As the intensification of human impacts is a matter of concern for sea lion conservation, management strategies should focus on increasing the benefit of local people on their nature resources along with continuous education programs.

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