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

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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,

[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

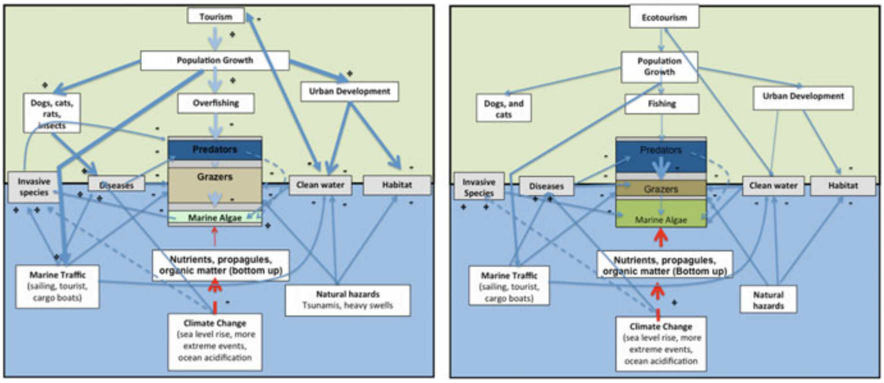

Fig. 5.1 The conceptual model illustrates the connections (with *arrows*) between ecosystem services and stressors (*boxes*) occurring on rocky shores of San Cristóbal Island. The strength of the connection or impact is illustrated by the width of the *arrow*, and the direction of the interaction (positive 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

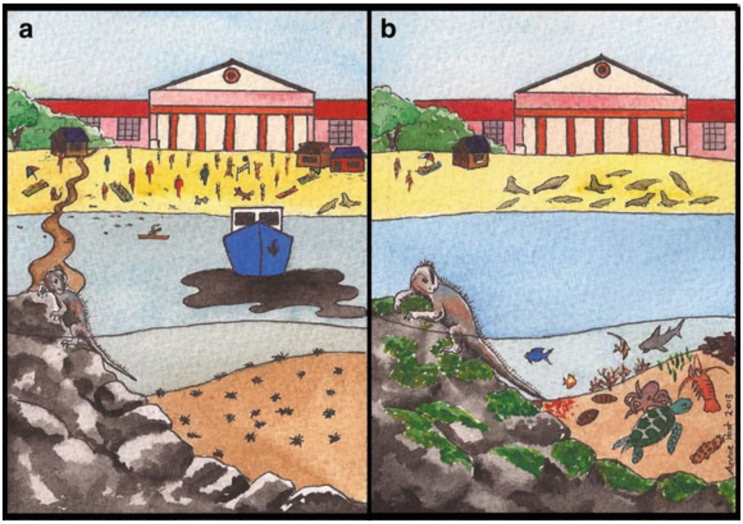

Fig. 5.2 Playa Mann viewed from La Predial, San Cristobal Islands, showing two alternative social–ecological stable states. (**a**) Playa Mann with more than three cumulative impacts overlapping at the same spatial and temporal scales; this results in less attractive locations with ecosystem benefits 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

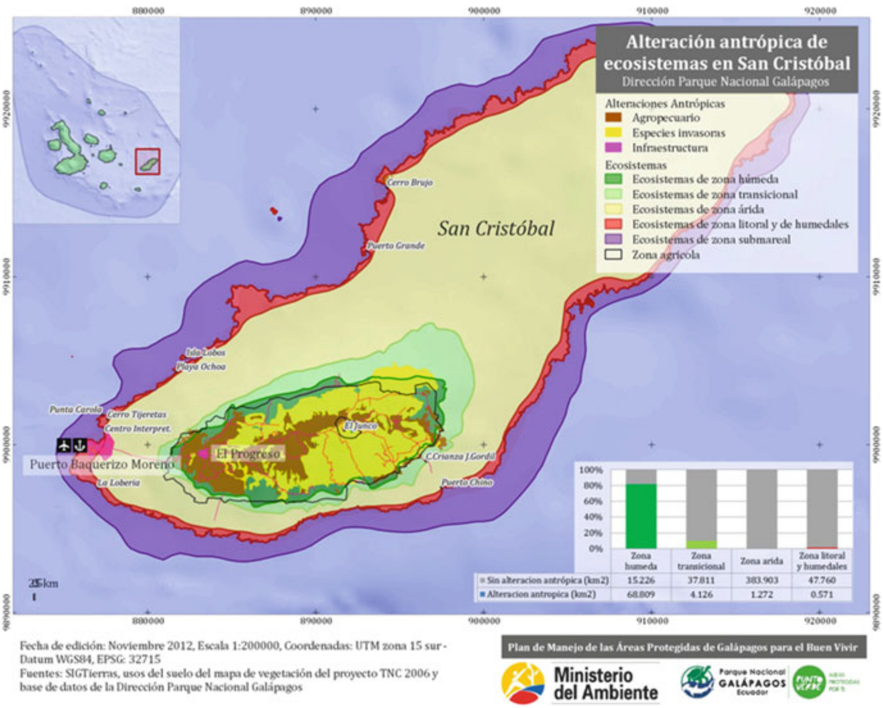

Fig. 5.3 Map of San Cristobal Island showing the different uses and impacts on different ecosystem types (modified with permission of WWF and Galapagos National Park. Map was last edited in November 2012)

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

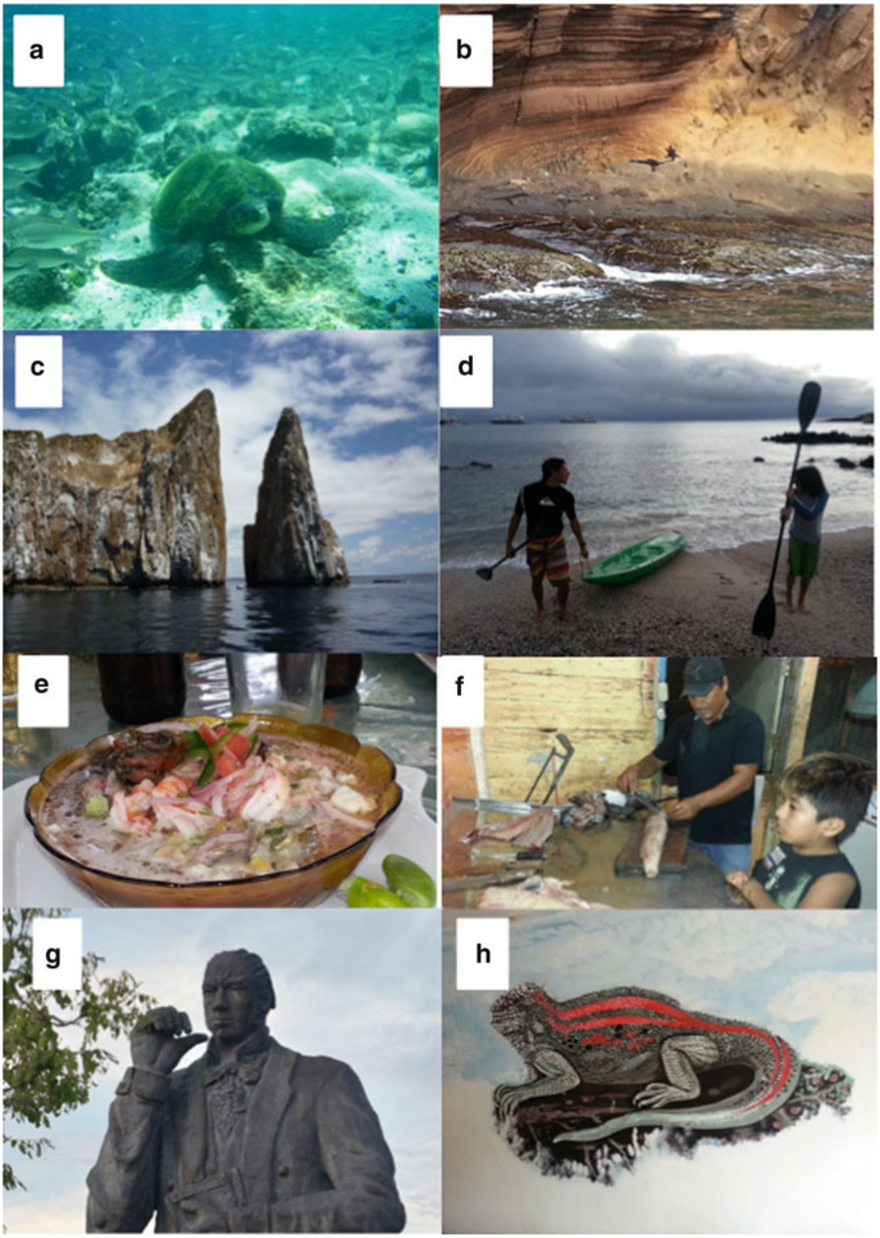

Fig. 5.4 Some important ecosystem goods and services provided by San Cristobal. These include healthy populations of charismatic species, good habitat representation to support different life stages, clean waters to provide safe seafood, and a satisfactory visit of tourist to the islands

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.

[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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