The Animal Forest and Its Socio-ecological Connections to Land and Coastal Ecosystems

Jesús Ernesto Arias-González, Andrea Rivera-Sosa, Jaime Zaldívar-Rae, Christian Alva-Basurto, and Camilo Cortés-Useche

Contents

1 Introduction ................................................................................... 2
  1.1 Connectivity in Tropical Seascapes ..................................................... 3
  1.2 Global Climate Change Impacts on Animal Forests .................................. 5
2 Linkages and Complexities of Social and Ecological Systems ...................... 7
  2.1 Transformations of the Yucatan Peninsula ............................................. 8
3 Human-Derived Fluxes and Animal Forest Habitat Change .......................... 11
  3.1 Chemical Fluxes ........................................................................ 12
  3.2 Biological Fluxes ......................................................................... 14
  3.3 Physical Fluxes ........................................................................ 18
4 Management and Conservation of the Animal Forest and Tropical Seascapes .... 20
  4.1 Social Inclusion in the Management of Marine Protected Areas ................ 21
  4.2 Current and Future Management Tools .............................................. 22
  4.3 Governance to Improve the Management of Seascape Connectivity .......... 24
5 Conclusions ................................................................................... 26
6 Cross-References ............................................................................. 27
References .......................................................................................... 27

J.E. Arias-González (✉) • A. Rivera-Sosa • C. Cortés-Useche
Laboratorio de Ecología de Ecosistemas de Arrecifes Coralinos, Departamento de Recursos del Mar, Centro de Investigación y Estudios Avanzados del I.P.N-Unidad Mérida, Mérida, Yucatán, Mexico
e-mail: earias@cinvestav.mx; andrea.rivera@cinvestav.mx; camilo.cortes@cinvestav.mx

J. Zaldívar-Rae
Coordinación de Investigación, Vicerrectoría Académica, Universidad Anáhuac Mayab, Mérida, Yucatán, Mexico
e-mail: jaime.zaldivar@anahuac.mx

C. Alva-Basurto
Parque Nacional Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc. Comisión Nacional de Áreas Naturales Protegidas, Cancún, Quintana Roo, Mexico
e-mail: chr.alva@yahoo.com.mx

© Springer International Publishing Switzerland 2016
S. Rossi (ed.), Marine Animal Forests,
DOI 10.1007/978-3-319-17001-5_33-1
Abstract

Tropical landscape and seascape systems are intimately linked by complex ecological relationships that provide environmental services to human societies located in coastal areas and beyond. Paradoxically, nonsustainable activities from these human societies are threatening the functions and benefits of these systems. Anthropogenic processes that damage tropical seascapes are rapidly increasing as a result of coastal and tourism development, increasing human population, unsustainable economic growth, and extensive transformations of natural landscapes. In addition to this overwhelming trend, tropical coastal seascapes are threatened by global climate change. Thus, to address this problem, it is essential to understand the complex ecological relationships between the components of coastal seascape systems and their links to land ecosystems, including the positive and negative effects of humans. The physical and ecological relationships between tropical landscapes and seascapes often define the energy and matter fluxes through which human activities exert their influence on coastal ecosystems. We illustrate these relationships by presenting a case study and conceptual model of coastal and tourism development in the Yucatan Peninsula, Mexico. Scientific knowledge and proposals for better governance practices are available to guide management actions and to protect the connectivity of seascapes systems. Nonetheless, political will, coupled with the implementation of local and regional integrated management schemes of coastal zones, is urgent. More examples are needed of inland and coastal human societies that successfully integrate scientific knowledge of the links among ecosystems and their decision-making processes in order to achieve sustainable development based on the services provided by their surrounding seascapes.

Keywords

Tropical seascapes • Connectivity • Mangroves • Seagrass • Coral reefs • Yucatán Peninsula

1 Introduction

In tropical waters, seascapes, or interlinked patches of marine ecosystems ranging from mangroves to seagrass beds to coral reefs constitute a major feature of the coastal zone and are often located adjacent to each other (Ogden 1997). The tropical seascape is a spatially heterogeneous area of coastal environment that can be perceived as a mosaic of patches, a spatial gradient, or some other kind of geometric pattern found in either benthic or pelagic environments (Böstrom et al. 2011). A seascape encompasses meta-ecosystems, i.e., sets of ecosystems connected by spatial flows of energy, materials, and organisms across ecosystem boundaries (Loreau et al. 2003). This concept represents an expansion of the notion of meta-communities through the integration of mass and energy transfers among these ecosystems. It provides a theoretical framework for the understanding of interlinked
processes among different ecosystems, such as dissolved and particulate matter fluxes, the exchange of living material, the export and import of matter and energy, and diversity-production patterns, among others (Loreau et al. 2003).

The capacity for the development of each particular ecosystem within a tropical seascape can be enhanced by its interaction with other ecosystems. This may be one of the reasons why tropical seascapes are major providers of natural resources and ecosystem services for millions of human beings (Moberg and Rönnbäk 2003). The structural and functional values of the different mosaics of ecosystems that constitute these tropical seascapes and their interactions with humans are highly relevant. Interactions between seascape components (including the human societies living in these areas) can largely be subdivided into chemical, biological, and physical fluxes (Ogden 1997). Examples of some of the interactions among ecosystems include exchanges of larvae, juvenile and adult fauna, plankton and nutrients (Lowe and Falter 2015), detritus, water, sediments (Nagelkerken 2009a), and sewage pollution from terrestrial runoff (Wear and Vega-Thurber 2015).

1.1 Connectivity in Tropical Seascapes

The coastal tropical seascape is a continuum that spans inland ecosystems, coastal ecosystems, and the ocean. Although rivers represent only a quarter of the coastal area of the world, the vast majority of water and sediment is discharged through this land-sea connection, so the flow and exchange of dissolved and particulate materials from land to sea are substantial. Also, groundwater is an important source of nutrients such as dissolved inorganic nitrogen (DIN) for coastal ecosystems and coral reefs, particularly in areas with high coastal development. Submarine groundwater discharge (SGD) brings an estimated range of 3–800 mmol h\(^{-1}\) of nitrogen per meter of shoreline (Paytan et al. 2005). In areas with permeable and porous carbonate geology, such as Yucatan, Mexico, the water quality is regulated by groundwater discharges and may be similar in magnitude to that of rivers; these inputs are linked to agro-industries, atmospheric deposition, urban-public activities, and industrial activities, with an estimated nitrogen to phosphorus (N:P) discharge ratio of 194.9:1 (Aranda-Cirerol et al. 2006).

Bouillon and Connolly (2009) consider that tropical rivers in coastal margins deliver most of the carbon and nutrients supplied from land to sea. According to Alongi et al. (2014), global water discharge from tropical rivers is higher in America than in other continents, while the highest global sediment discharge is in Asia. Tropical rivers channel up to 55–64 % of the total global flux of riverine dissolved inorganic carbon (DIC), with the highest yields taking place in Asia, where carbonate rock is most abundant. Approximately 30 % of the global particulate inorganic carbon (PIC) flux is discharged from the tropics. Equatorial rivers have lower DIC but higher dissolved organic carbon (DOC) concentrations than those at other latitudes. This can be attributed to the carbon-rich African soils, and the prevalence of peat and black-water rivers in tropical Asia and the Americas. The total DOC discharge accounts for 63–66 % of the total global flux. Moreover, most of the
tropical particulate organic carbon (POC) discharge occurs in the Americas and Asia, with the total POC discharge from the tropics estimated at 64–70% of the global flux.

Oceans also shape the structure and function of tropical seascapes. For example, currents carry out an enormous amount of larvae to tropical seascapes, where they can further develop. Oceans are the main regional connection drivers among meta-ecosystems, through waves, streams, coastal upwelling, and cyclones (Lowe and Falter 2015). These physical processes transport key materials, nutrients, and plankton, supporting life in the tropical seascapes. As Lowe and Falter (2015) mention, although oceans play a fundamental role in shaping the distribution of species, a modern understanding of the complex interactions between oceans and coral reefs is emerging. Nevertheless, oceans play a critical role within the patterns of biodiversity distribution through the dynamics of currents at different scales and the interaction of nutrients among ecosystems. Oceans not only have an enormous influence on the growth, metabolism, and community structure (Hammer and Wolansky 1988) of the different assemblages and ecosystems that compose a tropical seascapes but also on the hydrodynamic processes related to heat dissipation, transport and mass transfers (nutrients and carbon), heat, temperature, and momentum (drag and dissipation) (Lowe and Falter 2015).

Several tropical seascapes features can contribute to the stability of local ecosystems. These features include tropical forests, mangroves, seagrass, fringing reefs, barrier reefs, the generation of continental margins, reef lagoons, and the control of coastal erosion through the mitigation of energy from waves. Different aspects of the tropical seascapes structure and functioning depend on the geomorphology of the coastal zone and continental shelf, which are connected through the movement of inorganic matter, detritus, and living material (Loreau et al. 2003). In these seascapes, mangroves and seagrass beds promote the development of offshore coral reefs by interfering with discharges of freshwater and acting as sinks for pollutants and organic materials, filtering the runoff water that may eventually reach coral reefs (Harborne et al. 2006; Berkström et al. 2012; Gillis et al. 2014). These coastal vegetation systems control the concentration of nutrients such as nitrogen and phosphorus as well as suspended sediment in the water column. Nevertheless, these ecosystems can also naturally be net exporters of nutrients to coral reefs (Bouillon and Connolly 2009). In turn, coral reefs create a protective environment for seagrass beds and mangroves by buffering the energy from oceanic waves and currents (Harborne et al. 2006; Berkström et al. 2012) and by protecting the coast from pounding waves, storms, and hurricanes (Gillis et al. 2014).

There are also movements of floating living material, such as macroalgae (for instance, the brown alga Sargassum) and seagrass, which can strongly influence populations, consumer-resources, food availability, and community structure (Polis et al. 1997). Biological interactions through the biological transfer of material among different ecosystems due to ontogenetic migration or trophic relay (Bouillon and Connolly 2009), as well as the transport of larvae from one ecosystem to another may influence the shape of the coral reef community, as in the case of fish assemblages (Mumby et al. 2004). It is known, for example, that both mangroves and
seagrasses act as nursery grounds for fish recruits, decapods, and many other organisms (Nagelkerken 2009a) or fish, which subsequently integrate into or interact with coral reef communities (Nagelkerken 2009b; Mumby et al. 2004).

1.2 Global Climate Change Impacts on Animal Forests

The coastal tropical seascape is crucial for global climate change, particularly for the circulation of heat, salinity, and water vapor (Alongi et al. 2013). While some ecosystems are likely to benefit from climate variations, coral reefs are extremely vulnerable. For instance, coral bleaching can be caused by a gradual increase in water temperature (1–2 °C above the maximum temperature recorded), causing stress and the expulsion of the endosymbiotic zooxanthellae that provide its main energy source, as this bleaching causes their death (Munday et al. 2008). It is estimated that over 16 % of coral reefs worldwide have suffered serious damage from massive bleaching events (Wilson et al. 2006). Projections of temperature models indicate that bleaching may become a recurring phenomenon worldwide in the course of this century, threatening the ecological balance of seascape systems (Buddemeier et al. 2011) (Fig. 1). In addition, 33–50 % of coral reefs have been largely or completely degraded by a combination of local factors and global climate change (Wilkinson 2008).

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) provides high certainty that anthropogenic emissions have caused
measurable changes in the physico-chymical aspects of ocean environments, including warming and associated phenomena such as sea-level rise, hypoxia, and acidification (Howes et al. 2015). These changes imply direct effects on ocean biological processes. In the ocean, key biological processes such as the dispersal and replenishment of larvae may undergo changes in association with the high sea surface temperatures of the sea (Ayre and Hughes 2004). Increased ocean temperatures are expected to affect larval development in corals, which, in turn, may lead to declines in adult stocks and change temporary patterns of dispersal and gene flow. This may eventually cause spatial and latitudinal constrictions or expansions (Ayre and Hughes 2004) in populations. In fact, it has recently been suggested that high temperature may lead to increases in the local retention of coral reef larvae (Figueiredo et al. 2014).

Species population and their connectivity could also be compromised by the increased fragmentation of reef habitats resulting from ocean acidification and bleaching of coral reefs (Munday et al. 2008). Ocean acidification will cause deficiencies in calcification rates and a reduction of recruitment by disrupting coral larval settlement and algal interactions, among other effects (Doropoulos et al. 2012). It is estimated that drops in pH values by the formation of bicarbonate ions (HCO₃⁻) in seawater due to surplus atmospheric carbon dioxide (CO₂) may reduce the availability of carbonate ions in seawater by up to 50 % by the year 2065 (Cao and Caldeira 2008). Carbonate ions are essential for organisms that produce shells or exoskeletons based on calcium carbonate (CaCO₃), such as corals, mollusks, echinoderms, foraminifera, and crustaceans (Doropoulos et al. 2012).

Another impact associated with temperature is the concentration of dissolved oxygen: water warming causes a decrease in the availability of oxygen (O₂) in the ocean (hypoxia) (Vaquer-Sunyer and Duarte 2008). Future scenarios of the concentration of dissolved oxygen are not encouraging, as it has been predicted to decline by 1–7 % worldwide in the next 100 years (Keeling et al. 2010). Most affected are aquatic fish and invertebrates because their physiological mechanisms are determined by the concentration of dissolved oxygen in the water. The sensitivity and susceptibility to hypoxia vary considerably among taxa (Vaquer-Sunyer and Duarte 2008). Thus, the biological and ecological impacts of hypoxia are extremely complex and difficult to estimate (Pörtner and Knust 2007).

Sea-level rise is perhaps the most pervasive threat to the integrity of seascapes that encompass coastal lagoons, mangroves, and coral reefs. Higher sea levels may result in a larger influence of seawater in coastal systems where the balance between salt and fresh water is critical to many ecological processes. Among these systems are coastal lagoons, seagrass communities, and mangrove forests whose suitability as nurseries for pelagic and reef species may be compromised by imbalances in salinity (Harborne 2013). Indeed, Gilman et al. (2008) suggest that sea-level rise may cause large-scale loss of mangrove habitat, coastal dunes, and lagoon ecosystems. Sea-level rises may also result in increased wave energy and modifications of wave regimes that can fundamentally alter the morphodynamics of coasts. In the case of reefs, the loss of coral crests due to bleaching and other processes may be exacerbated by projected increases in annual mean wave heights and changes in
wave direction (Hemer et al. 2013). The loss of this wave mitigation effect may, in turn, affect other physical and biological elements of reefs themselves and, in the case of barrier reefs, even those of ecosystems located on the adjacent coast. However, it has also been suggested that under sea-level rise scenarios, coral cover, and reef growth may significantly increase (Hopley 2011).

Coastal cities and small island nations are the most vulnerable to sea-level rise. Social-ecological ecosystems are currently under threat and will further face severe challenges due to global climate change. This may have unprecedented effects on local communities that live on the coast and depend on fishing and marine resource extraction. It can impact nearly all fisheries, coastal societies, and economies worldwide because it may affect the biodiversity of seascapes as a whole.

2 Linkages and Complexities of Social and Ecological Systems

Coastal ecosystems are transformed by humans and are facing a great variety of local and global stressors that produce important changes for marine animal forests (Burke et al. 2011). Within seascapes, coral reefs are among the world’s most diverse ecosystems. A recent estimation establishes that coral reefs offer food and shelter to 830,000 species (95 % confidence interval: 550,000–1,330,000 species) (Fisher et al. 2015). Associated with this high diversity, coral reefs provide many valuable services for humans, including shoreline protection, livelihoods from ecotourism, fishery production, and a living factory of compounds for biomedical use with a global value of over US$ 31 billion (estimated for 2014) for all reefs combined (Wear and Vega-Thurber 2015). Nevertheless, 75 % of coral reefs are currently at risk from local stressors and thermal stress. It is envisaged that by 2030, over 90 % of reefs might be at risk, along with the benefits they provide (Jackson et al. 2014).

The great majority of global coral reefs are close to coastal zones. Globally, human influences are producing dramatic shifts from coral to algae cover and are disrupting biodiversity (Acosta-González et al. 2013) and ecosystem functioning and services (Morberg and Folke 1999). A small disruption in biodiversity can cause the collapse of key services that coral reefs provide, such as habitat for the recruitment of commercial species. In turn, the loss of coral reef services may negatively affect the resilience of the socio-ecological system as an imbalance develops between human demand for such services and the actual capacity of ecosystems to supply them.

Linking social and ecological systems is necessary to better understand the complex interactions between humans and coral reefs. There is growing interest in the dynamics and sustainability of the natural environment and human interactions (Diaz et al. 2011) and the conceptualization of social-ecological systems (Biggs et al. 2015). The socio-economic system can be characterized by the human activities that have been developed, such as tourism, urban development, or fishing. These drivers can impact tropical seascapes (seagrass, mangroves, and dunes) and therefore lead to negative feedback loops in the ecosystems services. Nevertheless,
the management of seascape connectivity—for instance, through the establishment of marine protected areas or the protection of habitats—may involve direct actions and solutions to environmental problems and may include economic, political, and cultural decisions that create positive feedback loops between the ecological and socio-economic systems. Overall, the ecological system may be characterized by the state of ecosystem services, such as herbivorous fish biomass that can control macroalgae, the condition and architecture of coral reefs, commercial fish stocks, fish biodiversity, and fish feeders that can control lionfish.

2.1 Transformations of the Yucatan Peninsula

2.1.1 Conceptual Model of the Yucatán Peninsula

In this section, we define a conceptual model of the cross-interactions and connectivity within seascapes, with a focus on the Yucatán Peninsula as a case study (Fig. 2). In the model, the orange arrows show the negative feedbacks and the
impacts of the destruction of habitats such as mangrove vegetation, dunes, beaches, and seagrass ecosystems and their influences on the loss of coral cover and increased macroalgae, leading to phase shifts in coral reefs due to increased nutrient inputs and sedimentation. All these feedbacks result in a decrease of ecosystem services and functional diversity, which may entail socio-economic changes for coastal populations.

The main ecosystem functions provided by the connectivity of ecosystems are also represented by colored arrows and are further described. The land (brown arrows) influences other habitats through sediments, nutrients, and freshwater discharge, but also through pollutants carried through groundwater. Mangrove ecosystems are the first buffers to receive land inputs, which then help slow down the freshwater flow; and along with sea grasses, both assist in the binding of sediment loads and in the absorption of inorganic nutrients.

These nutrients catalyze primary production within the system and result in an export of organic material for near shore and offshore webs. It is important to note that the state of these interactions is related to the amount of nutrients in the system, biogeochemical cycles, the balance/unbalance of the food web in each of the ecosystems, and the overall functional diversity of species in the tropical seascape. Overall, the seascape shares key services, such as storm buffering and the net export of fish invertebrates in all life cycles (larval, juvenile, adults), areas of reproduction, and habitat zones.

One example is the rapid transformation of the Caribbean coastal zone of the northern Yucatán Peninsula (State of Quintana Roo, Mexico). The development of Cancún and the Mayan Riviera from the 1970s to 1990s has caused profound changes in the coastal seascape and the socio-ecological system (Torres and Monsen 2005) (Fig. 3). Cancún is by far one of the most dramatic cases of coastal transformation from a natural habitat to an urbanized tourism destination and is a picture-perfect case for demonstrating how the alterations of a coastal ecosystem have occurred over a short timescale (20 years) and continue to progress.

Cancún is the main beach tourism in Mexico, with visitors from all over the world (4,013,032/year) and significant revenues of $4,135 million dollars (USD) per year (as of November 2014) (McCoy 2015). Despite the substantial economic benefits (jobs, income generation, international tourism destination) of this activity, Cancún is far from being sustainable and is considered to have reached its environmental capacity, with complex deteriorations in its social and cultural capital (McCoy 2015).

Moreover, multiple stressors act on the transformation of coastal seascapes on the Caribbean coast of the Peninsula, including direct clearing of tropical forests and mangroves, and the construction of housing developments for low-income families, and the construction of hotels and other infrastructure on coastal dunes. Due to this development, this area suffers severe problems with coastal erosion (González-Leija et al. 2013). Moreover, thousands of hotel rooms have been built, and many of the low-income housing developments dispose of their sewage through septic tanks that are connected to absorption wells (Torres and Monsen 2005). Even when sewage is treated, only a fraction of it goes through water treatment plants. Hence, wastewater
and its pollutants eventually reach the groundwater and make their way into coastal lagoons and reef areas (Hernández-Terrones et al. 2015).

2.1.2 Geological Formations Influence the Tropical Seascape

The vulnerability of tropical seascapes in the Yucatán Peninsula is intimately related to the geological dynamics of the region. The peninsula is a partially emergent calcium carbonate platform extending to the north and northwest into a massive continental shelf (Perry et al. 2003). There is almost no surface runoff on most of the peninsula, and the aquifer system has developed within a nearly horizontal permeable limestone and dolostone karst whose oldest rocks are from the Tertiary period (Perry et al. 2003). Thus, a fresh groundwater lens flows through this karstic plain above a saline intrusion layer. The depth of the nearly flat water table (gradient = 2 cm/km) is determined by elevation above mean sea level, the depth of the interface between fresh and seawater, and, to a lesser extent, by the recharge of the aquifer from annual precipitation, which increases from 500 to 1,500 mm along a northwest-southeast axis. The water table is frequently exposed in places where the ceiling of underground cavities has collapsed, forming sinkholes, or cenotes (from dzonot, the Mayan word for well) as they are locally known, while in coastal areas, groundwater usually forms springs (especially on the West and North coasts of the peninsula). Other interactions include the flows of fresh ground water from karstic cave systems into the sea, which are more often on the Caribbean coast. Overall, the balance of fresh and seawater has been a major determinant of coastal geomorphology, influencing the formation of coastal lagoons and even coral reefs.

Fig. 3 Urban transformation and growth in Cancún, northern Yucatán Peninsula, Mexico, due to tourism expansion promoted by the Mexican Government, along with national and foreign investors. Satellite images taken on February 5, 1979(left) and January 24, 2009 (right). (Image source: United Nations Environment Programme (UNEP), from Latin America and the Caribbean Atlas of our Changing Environment, 2010)
Another element that shapes coasts on the Yucatán Peninsula is the transport, removal, and deposition of fine biogenic sand by currents and winds. This is the predominant geomorphological process along the Northeast, North, and West coasts of the peninsula. This constant transport of sand makes for a more turbid water column than on the Caribbean coast of the Peninsula, and its clearest effect is the formation of sand barrier islands on the Northeast, North, and West coasts, as currents and waves coming inshore from the northeast transport and deposit sands in an east-to-west direction. Thus, “cul-de-sac” lagoon systems eventually form, in which the windward edge of the barrier island joins the continent by sand deposition, while the leeward edge remains open. As a result, areas near the mouth of these lagoons are under direct influence of the sea, while conditions at the closed end are more influenced by evaporation, rainfall, and groundwater sources. This creates salinity and nutrient gradients that result in a wide variety of terrestrial and aquatic habitats. As the geomorphological development of these lagoons progresses, the leeward mouth is finally blocked by sand, and they turn into enclosed lagoons and wetland systems, where the balance among evaporation, rainfall, and groundwater input becomes critical in defining ecological conditions.

The Caribbean coast of the Peninsula is substantially different from the others in that karstic rock often reaches the sea, creating long extensions of rocky coast interspersed with stretches of sandy beaches. Another major difference is the absence of a vast continental shelf and the presence of the Mesoamerican Reef (MAR), the world’s second-largest barrier coral reef, running parallel to the coast. The absence of an extended continental shelf and the fact that sands are usually confined to certain areas of the coast result in much clearer waters than on the North and West coasts of the Peninsula. Groundwater usually reaches the coast and the sea more directly than on the other coasts through karstic cave systems that were above sea level during the last glacial period but have been flooded by seawater to different degrees ever since that period ended.

3 Human-Derived Fluxes and Animal Forest Habitat Change

In addition to the complex impacts of global stressors, coastal ecosystems are exposed to a number of problems associated with changes in the local environments. Overall, these changes derive from alterations of chemical, biological, or physical fluxes, which are caused by the growth of human settlements and infrastructure, habitat loss, resource overexploitation, and land reclamation activities that can completely destroy whole components of tropical seascapes (Fabricius 2005).

As a complement to the conceptual model of a socio-economic and ecological system, Figure 4 shows real case images of the complex direct and indirect interactions. It also demonstrates the linkages of human-derived fluxes (drivers, impacts, and ecosystem state) that result in the loss of ecosystem services. The main drivers of the socio-economic system (red) are related to tourism and urban development, increases in migration and low-income housing, and overfishing. The loss of key habitats in the tropical seascape is shown in light brown. Such losses may cause
coastal transformations to the ecological system (light blue). As mentioned before, the ecosystem state (light blue) may be in distress due to phase shifts and decreased resilience, whereas coral reefs may be exposed and prone to further impacts of bleaching and disease outbreaks.

3.1 Chemical Fluxes

3.1.1 Water Quality and Nutrient Inputs

Locally, one of the most pressing issues is the decline in water quality in coastal areas, which is associated with land transformations in order make way for agricultural expansion and urban development. These changes alter watershed runoff and chemical fluxes from land to sea. Water quality parameters such as dissolved inorganic nutrients (nitrogen and phosphorus) and suspended particulate organic matter concentrations may increase due to these land use conversions and affect coastal ecosystems by increasing turbidity, sedimentation, and pollution (Fabricius 2005).

Fig. 4 Interactions of complex drivers of change, impacts and ecosystem state within the socio-ecological system of a tropical seascape (Image sources: INEGI, 2015; DigitalGlobe, Google Earth. Elaboration: CINVESTAV-LEEAC, Mexico, and all other images: Andrea Rivera-Sosa)
Each of these parameters is associated with a medium to moderate negative impact on calcification, tissue thickness, zooxanthellae density, photosynthesis, and survival of adult colonies in reefs. In contrast, it has been documented that particulate organic matter in the water column may have positive effects on the ecological processes of coral reefs (Fabricius 2005). Corals can adapt to reduced light caused by high turbidity in the water column by increasing lipid reserves in polyps, thus ensuring energy levels necessary to survive low light conditions (Maynard et al. 2010; Fabricius 2005). However, despite their ability to adapt to high turbidity or sedimentation, corals are highly vulnerable to chemical toxins (heavy metals, insecticides, and fungicides) that can be deleterious at different life history stages, ranging from fertilization to larval development processes (Markey et al. 2007).

Sewage pollution is often identified as a problem for coral reefs, but it has not received the serious attention that is needed. As Wear and Vega-Thurber (2015) recently noted, even treated sewage can introduce a variety of substressors to coral reefs. These individual stressors chemically interact with one another, thus having more intense negative effects on corals (e.g., nutrient-enhanced pathogen growth). These synergistic interactions are poorly understood, and it is suspected that they may potentiate the impacts of other nonrelated stressors, such as bleaching or overfishing leading to phase shifts. Redding et al. (2013) also showed an important correlation between an increase in derived nitrogen from sewage pollution and disease severity in the coral genus of Porites in Guam. Similarly, Mora (2008) and Bozec et al. (2008) showed that in the Caribbean, the abundance of macroalgae and coral mortality was correlated with human density in areas neighboring coral reefs.

Studies in the Pacific and Atlantic oceans are showing that phase shifts involve not only transitions from coral to algal dominance but also from coral to sponge dominance (McMurray et al. 2015). In particular, Knapp et al. (2013) suggested that sponge dominance in the lagoon of the Palmyra Atoll, in the Central Pacific Ocean, was a result of a decrease in environmental quality: sponges thrived as sediments, turbidity, and food availability increased in an environment that was originally dominated by Acropora species, crustose coralline algae, turf algae, and the giant clam Tridacna maxima (Knapp et al. 2013). In another example, surveys conducted in Florida between 2000 and 2012 showed that the population and recruitment of the barrel sponge Xestospongia muta has been increasing over time, while scleractinian coral cover has been decreasing (McMurray et al. 2015). In the Caribbean, major phase shifts are causing changes in reef structure, as larger more structurally complex species, such as those in the Orbicella complex, are being replaced by less complex species, such as those in the genus Porites (Alvarez-Filip et al. 2013).

Excessive nutrient inputs not only cause phase shifts in coral reef ecosystems but may also affect seagrass ecosystems (Fig. 5). The nitrogen and phosphorus derived from filtration of septic tanks from coastal housing may cause the proliferation of algae and cause direct competition for light, space, and nutrients in seagrass. This problem may be exacerbated in lagoon systems where less nutrient dispersion occurs due to high resident times of seawater due to the protection of barrier reef systems.
3.2 Biological Fluxes

3.2.1 Phase Shifts

Stressors such as nutrients from sewage and groundwater pollution may be the main precursors of phase shifts from coral-dominated to algae-dominated reefs although they may act in conjunction with fishing pressures, bleaching, and hurricane events (Bozec et al. 2008). Contrary to what is generally proposed in the coral reef literature (Burke et al. 2011), groundwater pollution on the Caribbean coast seems to have resulted in a benthic phase-shift scenario that is thought to be independent of the distribution of herbivorous fish (Bozec et al. 2008). The nutrient-rich wastewater may itself cause the proliferation of macroalgae over a threshold where herbivores may not be able to control them, even if herbivore populations are not affected (Williams and Polunin 2001). This bottom-up process of the benthic phase shift has seldom been documented, but it constitutes an interesting explanatory alternative to the paradigm of fishing reducing the abundance of herbivorous fish (mainly parrot fish species) and allowing macroalgae to overgrow and outcompete corals (Russ et al. 2015).

Recent work (e.g., Bozec et al. 2008; Kramer et al. 2015; Russ et al. 2015; Wear and Vega-Thurber 2015) suggests that such a bottom-up control is relatively simpler than the top-down control, as it only implies a change in habitat consisting of increased nutrient availability (Russ et al. 2015). Thus, the underlying cause of habitat change could also be from different sources of local or regional coastal impacts and global climate change, such as dredging, sedimentation, sewage pollution, hurricanes, or coral bleaching. In contrast, top-down control may imply more processes (Russ et al. 2015): (1) fishing to reduce herbivore (i.e., parrot fish) abundance, (2) reducing grazing pressure, (3) increasing cover of macroalgae, and (4) decreasing coral cover (algae outcompetes adult corals for space or inhibits coral recruitment).
Particularly in the Mesoamerican reef region (MAR), different bottom-up processes may produce benthic phase shifts, both at the local (Bozec et al. 2008) and regional scales, even within marine protected areas where there has been an evident increase of herbivorous fish (Kramer et al. 2015). This pattern is consistent with those observed in coral reefs in the Philippines (Russ et al. 2015) and New Caledonia (Carassou et al. 2013).

Moreover, although there are no quantifications of the loss of species produced by changes at a large scale, there has been a recent phase shift from coral to algae in the Mahahual reef system, Quintana Roo, Mexico (Fig. 6). This area has shown that the establishment of a cruise ship pier and the loss of vegetation cover linked to tourism and housing expansion may have produced the loss of 40 fish species and 43 ha ($\sim10$ km$^2$) of coral cover (Acosta-González et al. 2013; Martínez-Rendis et al. 2015). This type of massive tourism development is seen in many locations in the Mesoamerican Region and may be another precursor of phase shifts.

3.2.2 Loss of Tropical Wetlands
Humans vastly benefit from the ecology of mangrove ecosystems via provisioning services (food and natural resources), regulating services (ecosystem processes), and cultural (nonmaterial) services. Mangroves play a critical ecological role in providing breeding and nursery habitats for valuable commercial species and fisheries (Davidson 2014). Mangrove wetlands and seagrass habitats make crucial contributions in terms of biogeochemical processes, serving as sinks for inorganic nutrients and sediments and as exporters of organic matter (Childers et al. 1999). However, changes in temperature, salinity, and extensive development are also leading to major decreases in seagrass ecosystems, which through ecological connections can negatively affect other components of the seascape.

Fig. 6  Phase shifts from a coral- to an algal-dominated coral reef in Mahahual reef, Mexico (Image source: Roberto Hernández-Landa, Date: 2010)
Despite their vast ecological services, tropical wetlands are among the most vulnerable ecosystems and are disappearing at an alarming rate. An estimated 54–57% of mangrove ecosystems have been lost over the last century (Davidson 2014). Wetland cover losses are linked to the overexploitation of natural resources, modification and/or reclamation of land for urban development, and aquaculture operations (Davidson 2014).

In Mexico, it is estimated that in the last 25 years, at least 10% of the mangrove ecosystems and cover have been lost or severely altered (Valderrama et al. 2014). Many of the tropical wetland ecosystems in the Cancún area and Riviera Maya have been vulnerable since the tourism expansion of the 1970s. Due to increased pressure to preserve important habitats, a series of Protected Areas were designated. Even though wetlands are under current protection, those located adjacent to or near the areas of the urban expansion of Cancún continue to be affected.

The government, through the National Fund for Tourism Development (Spanish acronym FONATUR) and other federal sectors, actively promotes tourism development through the purchasing of land with tourism potential and the reselling of it to interested investors (Saldivar 2016). In the years 2005, 2009, and 2011, the Mexican Secretariat of Natural Resources (Spanish acronym SEMARNAT) provided legal permission for the construction and expansion of new tourism developments for the Tajamar Esplanade (74.24 ha) (SEMARNAT 2016). However, The General Wildlife Law (Article 60-TER-1/02/2007) states, “no removal, filling, transplanting, pruning or any work or activity shall intervene in the integrity of the hydrologic flow of a mangrove ecosystem” (SEMARNAT 2016). Despite this, the federal government gave permission for the destruction of 49.10 ha (total area varies depending on the information source) of wetland ecosystem to expand the Tajamar Esplanade in Cancún, causing a major national and international uproar from the civil society and nonprofit organizations (Fig. 7).

Overall, there are many issues with the interpretation of laws for the formal protection of the wetlands and natural resources, yet political or economic interests may influence the decision-making processes. For instance, the FONATUR donated to SEMARNAT a total of 3,533 ha to be designated a Natural Protected area, namely, the Mangroves of Nichupté and Ecopark Cancún (107 ha-2013) (SEMARNAT 2016), but this donation may be used in strategic political decisions to allow the development of certain areas. Moreover, in response to the environmental destruction, the federal government issued a public statement that mentioned: “If permission had not been given to clear cut the area, the lawsuits of the investors who acquired the land with the permission of SERMANAT and FONATUR would have resulted in a potential financial loss to the Mexican government of more than three billion Mexican pesos, which is equivalent to more than half the budget of the Mexican Ministry of Tourism for 2016”. Currently, the project has been “temporarily suspended” (SEMARNAT 2016; Saldivar 2016).

The destruction of wetland and mangrove ecosystems is an eminent threat to coastal areas with high tourism demand. However, concerns and misconceptions
have arisen regarding the recovery and restoration of these ecosystems. Once the ecosystems have been lost, the trajectories of recovery are extremely costly, and their success can only be measured in the long term. The urgent need to recover essential wetland ecosystems has led to an emerging field of restoration, which includes the de-canalization of wetlands and rivers, rehabilitation of degraded floodplains, decommissioning of dams, replanting of vegetation and wildlife, and the implementation of conservation and management plans to protect wetland ecosystems. This has been partly due to the economic valuation of wetlands and the fact that more than half of the world’s diverse wetlands have disappeared (Davidson 2014).

The field of economic valuation of wetlands offers an opportunity to place a monetary value on a wetland that reflects its ecological and social importance in order to ensure its protection. For this reason, scientists are increasing their understanding of the major carbon stocks and fluxes in mangrove ecosystems as well as how they vary across species and zones to determine how much organic carbon can be stored (aboveground or at various layers underground). According to Herrera et al. (2016), many regions in Mexico, particularly those in the Gulf of Mexico, along with riverine type mangroves, contain species that can be considered high carbon sink facilitators. Also, mangroves in the Yucatan Peninsula were found to have the highest content of organic carbon (218.98 Mg C ha\(^{-1}\)) in the first layer of underground substrate (0–30 cm), followed by mangroves of the Gulf of Mexico Herrera et al. (2016). This important information allows for the estimation of total captured carbon, providing data to quantify the total value of an ecosystem and its loss when converted. This would enable the establishment of negotiating mechanisms for the conservation of wetland habitats to prevent and discourage the conversion of natural lands to filled lands for construction. In addition, this conversion of land releases the carbon stored in the soil, increasing the carbon dioxide and methane concentrations that contribute to climate change (Herrera et al. 2016).

**Fig. 7** Destruction of mangrove and wetland ecosystems of the controversial project Tajamar Esplanade, Mexico, due to tourism development and expansion (Image source: Christian Alva-Basurto, Date: 14/03/2016)
3.3 Physical Fluxes

3.3.1 Coastline Modifications
Tourism development continually demands a larger area of coastline, increasing the interface where natural processes interact with built-up areas and coastal dunes (Fig. 8). In general, there are certain natural and anthropogenic factors that influence coastal erosion on different timescales. The most important coastal processes affecting sediment transport and the building up of coastal dunes are hydrodynamic factors such as waves, currents, and tides, and wind (Masselink and Hughes 2003). Other short-term events such as storms may also influence coastal erosion and dune formation.

Naturally, coastal dunes develop in areas where there is sufficient wind to transport sediment (i.e., fine sand), after which vegetation growth stabilizes the sand. Thus, vegetation plays a very important role in securing the sand dunes and preventing wind erosion. Also, vegetation increases the fertility of the sand and favors the accumulation of debris, which then helps moisture to be retained. Over time, the dune increases in size, offering natural protection against beach erosion and serving as a sediment storage system (Masselink and Hughes 2003).

These dynamic processes vary in different areas, but it is indisputable that human settlements have a huge impact on beach recovery. Alteration of dune formation and vegetation for the construction of roads and other urban infrastructure considerably impacts the geomorphology of a coastal area (Fig. 9).

For instance, the roads not only have a direct impact on coastal dunes, but they also allow a continual flow of traffic and people, which continues to alter dunes. Sediment transport can also become unbalanced by modifications of the coastline, such as those caused by piers, groins, sea walls, boardwalks, and other human-made structures (Masselink and Hughes 2003). Moreover, the direct removal of sensitive components of ecosystems is widespread. As a result of coastal development, many hotels and resorts remove seagrass to make the beach more suitable for swimming.
Excessive and intensive tourism-related aquatic activities and attractions are concentrated for cruise ship visitors, further altering seagrass and coastal dunes (Fig. 10). Other impacts involve mechanical damage to corals or subaquatic vegetation due to recreational diving, anchoring, fishing (nets), and marine transportation.

There are even more extreme cases of coastal changes. This is the case of the Spratly Islands, south of China, where biodiverse atoll and seagrass ecosystems have been completely dredged and built over to create functional islands so that the government can gain control over territorial seas (Larson 2015). In addition, to complete habitat destruction, land reclamation, and dredging can produce sediment plumes and can reduce the availability of sediment, affecting the coastal morphology and processes in distant parts of the seascape (Masselink and Hughes 2003). In this process, the connectivity between populations of key species is also hampered (Larson 2015).
4 Management and Conservation of the Animal Forest and Tropical Seascapes

Worldwide, the main mechanism for the conservation and management of the tropical seascape is known as the Marine Protected Area (MPA). It is estimated that 27% of all coral reefs worldwide are currently within MPA schemes, but only 6% of these areas are considered effectively managed (Côté and Reynolds 2006; Burke et al. 2011). In Caribbean countries, there are more than 630 MPAs, encompassing 30% of the region’s coral reefs, and many locations still have to increase their areas of protection (Burke et al. 2011). For instance, Mexico, one of the largest countries in Latin America, has MPAs on 22.7% of its territorial sea, on 12% of its continental platform, and on 1.5% of its Exclusive Economic Zone (EEZ) (Bezaury-Creel et al. 2009).

MPAs are specifically delimited geographical areas that cover extensions of the continental platform and the seascape. MPAs can be internationally or nationally declared for the conservation of biodiversity, resources, environmental services, and cultural heritage (Kelleher 1999). Their main objective is the protection of habitats from destructive activities, the recovery, and productivity of fisheries, and the implementation of actions to increase resilience to impacts and maintain ecological processes across the seascape (Moberg and Folke 1999; Pandolfi et al. 2005; Mumby 2013). These areas may be established under a wide variety of criteria, standards, and levels of protection, which may include marine spatial planning, no-take reserves, regulation of fisheries, and accepted levels of resource exploitation (Aswani et al. 2015). Their design and operation might be federal and/or state-based, comanaged (NGO and state-based or private entities and the state), top-down (the most common), or bottom-up (community-based), run by indigenous organizations and/or include a mixture of involvement. The increasing number of different comanagement schemes is a result of the lack of direct funding from state and a lack of adequate management and implementation.

Efforts to preserve key marine ecosystems face major challenges due to a lack of funding, low capacity, and the absence of political will to enforce the environmental laws and regulations at the core of MPAs. This can effectively turn MPAs into “paper parks” (Mora et al. 2006), where conflicts with political interests (such as industrial fishing or tourism development), and problems with communities whose livelihoods depend directly on scarce natural resources cannot be managed. Moreover, when the capacities for management and effective intervention are lacking, scientific knowledge may actually become irrelevant as technical documents and recommendations are put forward but not implemented (Bearzi 2007).

Indeed, it is estimated that two-thirds of conservation assessments published in peer-reviewed scientific literature are not followed by conservation actions (Bearzi 2007). Another common problem between conservation science and the real world (Knight et al. 2008) is that few policy makers are willing to face the great challenge of inspiring people to protect the environment. Marine conservation requires a long-term commitment to pursue direct actions and a multidisciplinary approach to benefit marine ecosystems. In addition to solid science and well-conceived action plans,
what is desperately needed to promote MPAs is public pressure (Bearzi 2007). An effective MPA plan is one that links knowing and doing (Knight et al. 2008).

4.1 Social Inclusion in the Management of Marine Protected Areas

A complex issue in social-ecological systems is when people and/or indigenous communities have been part of a seascape and have depended on its productivity long before it is declared an ecologically sensitive area to be protected. Also, many settlements within MPAs continue to live in poverty under precarious and marginal conditions (Bezaury-Creel et al. 2009).

The establishment of MPAs and the inclusion of indigenous and local populations to ensure effective and rights-based access to resources has been a growing field of study, with controversial cases throughout the world that need to be constantly revisited. Case studies conducted globally have all argued the importance of the inclusion of local people in the establishment, management, and enforcement of MPAs (Christie et al. 2009). In many cases, livelihood alternatives are sought. Eco-tourism and community-based tourism (CBT) also seem to be proposed often.

However, it is important to mention that the establishment of an MPA and its management plan from a top-down approach may include programs for economic alternatives for the community that may not always be welcomed and perceived as a good initiative by local populations. Tensions, conflicts, and nonapproval can result from an improper process. Community-based tourism does not always work, and the mechanisms of its employment (or the politics of the MPA) may entail a variety of complex sociological and ecological factors that need to be taken into account.

For example, in Honduras, the first MPA in the country (the Natural Marine Archipelago Monument in Cayos Cochinós-1993) was promoted by national investors and a philanthropist, along with technical assistance from the Smithsonian Institution and financial support from international organizations. This area comprises 2 main islands and 13 cays with important seascape ecosystems, and it has a long history of resistance from indigenous fishing communities that benefit from the area (Brondo and Woods 2007). To foster acceptance among communities, the Honduran Coral Reef Foundation (HCRF) (a comanaging authority), local NGOs, and international organizations have promoted community-based tourism programs (in their management plans since 2004) as an alternative to fishing through training and confidence-building (Brondo and Woods 2007).

However, recent changes in the comanagement structure have provided a 10-year concession to the Mexican Azteca Foundation, which has resulted in other priorities related to tourism development (Kuch 2015). There are resource-based restrictions, and the majorities of the cays are privatized and have limited local communities use to one island and two cays. Moreover, the new concession actively promotes the filming of international reality shows (which are seeing increasing revenues abroad) in the sensitive habitats of the MPA (in cays designated for bird and turtle nesting habitats within the management plan) that have closed access to local indigenous
people. This type of tourism confers very little benefits upon the locals (750$ each per 4 communities/per filming), and the management is further creating social inequalities (Kuch 2015). This highlights the negative impacts of a nonsustainable type of tourism on the socio-ecological system. This case is interesting because it shows how neoliberalism can overrule the goals of sustainability included in the management plans of an MPA, which ends up further disrupting indigenous groups by creating double standards in favor of groups with higher capital (Brondo and Woods 2007; Kuch 2015).

4.2 Current and Future Management Tools

Optimistic scenarios have resulted from the implementation of MPAs, particularly fishery management tools, which have restored overharvested stocks and helped protect fish and invertebrate populations (MacNeil et al. 2015). Historically, the exploitation of fisheries (large vertebrates and shellfish) may have been the first large human disturbance of coastal ecosystems (Jackson et al. 2014). There is also adequate evidence that fishing affects food webs, population structures, and the distribution of species and that it contributes to the loss of biodiversity and ecosystem services. There is also evidence that the alteration of specific functional groups, such as herbivores, leads to the cascading deterioration of reef communities (Jackson et al. 2014).

For this reason, MPAs need a mixture of adaptive management schemes to work alongside land use planning across all sectors (tourism, urban development) and the implementation of marine spatial planning to enforce fishing areas and recreational areas (Fig. 11). Enforced zones that target no-take zones, closed seasons, and size and species restrictions have demonstrated proven results in the restoration of food webs from previously overfished conditions (Bellwood et al. 2004). Other actions in MPAs involve sustainable tourism practices and the establishment of educational centers to increase awareness.

In addition, a watershed- and ecosystem-based management approach is often needed for the employment of measures such as reducing fertilizer inputs, increasing forest cover, and installing sewage treatment plants to reduce sedimentation and nutrient pollution (Burke et al. 2011). The understanding that bottom-up processes may be just as important as top-down processes in bringing about phase shifts in coral reefs is extremely important for the management of seascape ecosystems. Preserving coral-dominated reefs may require regulating not only the fishing of herbivorous fish but also the growth of human settlements on the coast, in addition to requiring the treatment and disposal of wastewaters. Even if eutrophication and pollution threaten coral reefs as much as overfishing (Burke et al. 2011; Wear and Vega-Thurber 2015), eutrophication has received considerably more attention from conservation organizations, possibly because of the practical challenges of dealing with a large-scale threat. For instance, pollution sources are often multiple, geographically widespread or far from the reefs they affect. These factors, combined with the diversity of pollutants involved, the high cost of water treatment systems,
and the need to coordinate different government levels and jurisdictions, make management actions difficult to implement.

Conservation initiatives in the MAR region have recently focused on empowering MPA managers to understand elements of resilience and successfully ameliorate the impact of local and global stressors on the region’s reefs (Maynard et al. 2010). A new review by Aswani et al. (2015) provides an excellent summary and recommendations on how to move forward with emerging areas of science that may offer tools for the development and improvement of management actions regarding coral reefs. Overall, the main findings show that new technologies in molecular biology and marine biogeochemistry (stable isotopes) can be applied to isolate cause-and-effect relationships between stressors and biotic responses. They can also be used to determine the genotypic diversity within a population to further understand the levels of connectivity among tropical seascape populations. In addition, as global climate change continues to further impact ecosystems, scientists are studying genetic intervention strategies in the field of restoration by focusing on thermo-tolerant and disease-resistant corals from local source colonies and the translocation of these species to other areas. These actions must be followed to enable the effectiveness of mitigation and management efforts to be evaluated in order to provide insight into the potential resilience of particular coral reef species.

Fig. 11  Management of tropical coastal seascape connectivity demonstrating the importance of adaptive management schemes in Marine Protected Areas located adjacent to areas of high tourism development.

The Animal Forest and Its Socio-ecological Connections to Land and Coastal... 23
and genotypes to both local and global stressors (Aswani et al. 2015). In addition, the study promotes the shift in MPA designation and approach from the sole protection of “pristine locations” to areas under continual stress, where species with built resilience have been adapting over time and may offer genes tolerant to the tropical seascape.

4.3 Governance to Improve the Management of Seascape Connectivity

The creation of marine biological corridors (MBCs) has been widely encouraged as a response to the vulnerable condition of seascapes (McCook et al. 2010). The concept of MBCs was adapted from the Biological Corridor Program, a strategy to provide connectivity between protected areas that was implemented in the Mesoamerican region to enhance transcontinental biotic exchange, ensure gene flow, protect the migration routes, and widen the protection of habitats (Ankersen 1994). The same goals apply to MBCs, which consist of protected stretches of marine and coastal ecosystems linking national and international MPAs. In its simplest form, a protected corridor would be established to bridge a gap between two identical ecosystems encompassed by two neighboring MPAs. For instance, two MPAs covering two nonadjoining parts of a barrier reef could be linked by protecting the barrier reef areas between them. However, a more integrated view of corridors could protect areas linking landscapes and seascapes through places where crucial geochemical fluxes occur, currents flow, or migrations take place. The management of corridors would thus focus on protecting key links between MPAs, sometimes regulating and monitoring human activities that do not obviously or directly affect the MPAs. Although the effectiveness of implementing MBCs has faced criticism, the concept seems promising. Overall, the purposes of establishing conservation and management programs for marine and coastal corridors are to protect key ecosystem processes and strengthen the resilience of these ecosystems to disturbances and fluctuations (Maynard et al. 2010).

To holistically manage the complex interactions of the tropical seascape, governments, key actors, and stakeholders require the implementation of Integrated Coastal Zone Management (ICZM) approaches. ICZM, together with watershed approaches, aims at creating sustainable coastal development initiatives in which policy makers can jointly protect resources while enhancing economic development. The ultimate goal is to devise development strategies based on local protection and management plans in order to reduce anthropogenic threats and propose overarching solutions. To achieve integrated management, the following minimum criteria need to be met: (1) a comprehensive vision of land use and planning policies; (2) implementation of water and sanitation regulations; (3) MPAS and zoning of areas for public use (including tourism); and, of course, (4) agreements and synergies among key actors and stakeholders to move forward. In addition, adapted approaches such as marine ecosystem-based management (EBM) in tropical regions accentuate the need to include social systems and governance at their core (Christie et al. 2009). Moreover,
the level of success of ICZM or EBM schemes will depend on how policy is implemented and adopted by all involved sectors and key actors. When smaller-scale management has been complex, management over large geographic scales such as the Caribbean region has proven to be extremely difficult.

In the Caribbean, the main industrial fisheries have targeted ecologically important species such as queen conch (*Lobatus gigas*), lobster, shrimp, groupers, and snappers, all of which are in decline (WECAFC 2011). More recently, commercial harvesting of sea cucumbers and historical catches of sharks, rays, and chimeras have been recorded (WECAFC 2011). Moreover, fishing pressures are simultaneously placed on coastal mangrove forests and coral reef systems, which enhance negative feedback loops between these components of the seascape. It has been observed that in many developing countries such as Honduras in Central America, the lack of regulations or the means to enforce them can result in the use of undersized nets that target juveniles in coastal lagoons and in large-scale fishing operations targeting spawning aggregation sites, further threatening sensitive and endangered species such as groupers and snappers.

Despite this complexity, there are several success stories in the MAR region. For example, the seven Central American countries enforced regional regulations for the Caribbean spiny lobster (*Panulirus argus*). These regulations include size limits, closed seasons, and export regulations (AECID/OSPESCA/SICA 2009).

Also, regional agreements and national and international environmental legislation have increased across all countries in the MAR. In particular, political interests in the conservation of trans-boundary tropical seascapes (such as the declaration of Tulum in 1997) (Kramer et al. 2015) have set an important path for the establishment of The Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region (WCR). The WCR includes very important technical agreements such as the Protocols on Oil Spills, Specially Protected Areas and Wildlife (SPAW), and Land-Based Sources of Marine Pollution (LBS). These agreements have served as governmental and international platforms to implement local strategies (Caribbean Environment Program 2015).

Leadership in organizations such as the Healthy Reefs Initiative, which coordinates and gathers information with over 60 key actors in Mexico, Belize, Guatemala, and Honduras, has been successful in promoting management actions based on science in the MAR region (Kramer et al. 2015). In particular, actions in Belize to establish moratoria on fisheries targeting herbivores, as well as banned petroleum exploration in MPAs and nearby zones, are a recent achievement of many institutions working together. The first shark sanctuary in the Americas has been established in Honduras, representing the implementation of key political decisions to preserve marine ecosystems. Moreover, in Quintana Roo, Mexico, there have been initiatives to manage one of its largest protected areas, known as the Sian Ka’an Biosphere Reserve (6,510 km²), using an ecological conceptual model that is driven by local and national societal needs and is implemented as an integrated resource management plan (Mazzotti et al. 2005).

For these reasons, new cross-sector political agendas and creative solutions need to be developed in order to ensure governance for the true management and
sustainability of the tropical coastal seascape. Aswani et al. (2015) recommend the establishment of five principles to ensure effective governance:

1. Develop leadership and raise awareness
2. Develop hybrid institutions or novel institutional collaborations (sustainable funding mechanisms)
3. Establish clear and fair rules with conflict resolution mechanisms
4. Experiment and adapt
5. Develop evaluation programs that monitor both social and ecological systems

Finally, Finkbeiner and Basurto (2015) recommend that societies rapidly adjust from regular comanagement schemes to seeking “multilevel” comanagement and peer-to-peer/governance networks. Doing so may require democratic participation in the creation of hybrid comanagement systems that can be tailored to historical, cultural, and ecological contexts.

5 Conclusions

Undoubtedly, achieving the much sought-after development of coastal human societies without compromising the animal forests and tropical seascapes of which they are a key component will require a deep understanding of the complex socio-ecological networks connecting the physical, chemical, biological, and human components of such seascapes. Accepting that human activities and the transformations they entail are an intrinsic aspect of most modern ecosystems is fundamental to establishing governance mechanisms and achieving sustainable interactions within socio-ecological systems.

It is also critical to realize that human settlements located inland, away from coastal areas, can have profound effects on the ecology of seascapes and the services they provide to other human populations. These complex inter-relations need to be documented, measured, and incorporated into models and management programs over considerably larger geographical scales than those considered so far. If we are to successfully tackle the challenge of sensibly using the resources and services that coastal seascapes offer, we will need creative solutions based on sound scientific and technical knowledge.

Scientists and coral reef managers now have the tools to understand the natural resources, ecological processes, and value of ecosystem services that allow better management decisions (Burke et al. 2011). Nevertheless, many of the actions needed are highly dependent on the power of political will and commitment. It is important to be aware that from a management point of view, knowledge alone can be of little use without the involvement of all those stakeholders whose actions most directly affect natural resources and services. The integrated management of social systems, seascapes, and animal forests will inevitably require changing some of our practices so that our negative impact on these natural systems is reduced and resilience mechanisms can absorb it. Perhaps among the most difficult practices to modify...
will be those derived from political and economic inertia among some of the most powerful stakeholders. Again, an adequate regulatory framework, availability of resources to enforce it, and political will are crucial. Both top-down (e.g., institutional support, enforcement, and legislation) and bottom-up (proactive inclusion of community governance systems) approaches need to be integrated (Aswani et al. 2015). Overall, the management of the connectivity of the tropical seascape needs to be adaptive, holistic, and efficient in order to decrease negative feedback loops.

The full protection of remnant sensitive areas will never be achievable if governments continue to overlook their own environmental legislation and actively promote the destruction of natural habitats to fulfill neoliberal agendas. Civil society has an important duty to hold governments accountable. This is not an easy task, and there still are many transnational obstacles to overcome, such as implementing political decisions to reduce carbon emissions worldwide. There are also more complex social factors that are likely to further influence coastal seascapes in the MAR region. For instance, in addition to traditional landscape transformations, large-scale forest destruction and land conversion to pasture, cattle ranching, and agriculture (oil palm) are now being financially propelled by organized crime (McSweeney et al. 2014). How such an increase in land use conversion will further impact tropical seascapes needs to be explored in the near future. As mentioned before, the overarching problems hindering the effective implementation of management, such as corruption, lack of governmental will, and economic interests that hinder conservation, need to be tackled.

Finally, the understanding of socio-ecological systems needs to be coupled with widespread involvement and commitment from society to realize a rapid increase in success stories, showing that sustainable development based on the wealth of animal forests is, in fact, possible.

6 Cross-References

- Complexity and Biodiversity in Caribbean Coral Reefs
- Conservation and Management of Vulnerable Marine Benthic Ecosystems
- Ecosystem-Based Management: Opportunities and Challenges for Application in the Ocean Forest
- Resilience of the Marine Animal Forest

References


Silvestri S, Kershaw F. Framing the flow: innovative approaches to understand, protect and value ecosystem services across linked habitats. Cambridge, UK: UNEP World Conservation Monitoring Centre; 2010.


