Chapter 12
When Coviability Meets Ecosystem Services: The Case of Reunion Island's Coral Reefs

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Contents

12.1 Introduction

At the end of the 1960s and the early 1970s, the awareness of people about the impacts anthropogenic activities on the state of the natural environment has grown (Willson and Matthews 1970). In 1972, The United Nations Conference on the Human Environment, known as the *Stockholm Conference,* has highlighted this change. Its final declaration was clear. "*Man is both creature and moulder of his environment*"[1] … "*The protection and improvement of the human environment is a major issue which affects the well-being of peoples and economic development throughout the world*". On this basis, new paradigms[2] have been developed around the term "ecosystem". Following a multidisciplinary approach, they aim to offer a better understanding of the nature-society relationship. Six close concepts have thus

[1] Report of the United Nations Conference on the Human Environment, Stockholm, June 1972.

[2] We will define the paradigm as a way of understanding the world.

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O. Barrière et al. (eds.), *Coviability of Social and Ecological Systems: Reconnecting Mankind to the Biosphere in an Era of Global Change*,
https://doi.org/10.1007/978-3-319-78497-7_12

emerged: the socioecosystem, the social-ecological system, the eco-socio-system, the anthroposystem, the coupled human and natural system (Liu et al. 2007) and even the geo-eco-sociosystem (Mirault and David 2009) in reference to the geo-system, introduced as a geographic "substitute" for ecosystem concept (Bertrand 1968).

Integrated in space, the geo-system includes both: (a) ecological support (geological substrate, relief, climate, etc); (b) plant and animal communities; and (c) human beings who use and affect these two subsystems. C and G. Bertrand (1992, 2002) highlights that these various abiotic, biotic and anthropogenic elements react to each other and drive the evolution of the geosystem as a holistic entity. Corlay (1993, 1995) has applied the concept of a geo-system to the coast shown as "*an entity combining ecological and socio-economic system and the induced spatial structure*". The term eco-socio-system is only used by a small number of French speaking researchers. Having emerged from urban ecology and environmental education (Sauvé 1994), the term was then used by geographers (Corla 1995, 1998) then by ecologists (Hénocque et al. 1997). Some researchers understand it as a simple association of an ecosystem and a sociosystem (Mirault 2006). Others stress on the interactions between ecology, economy and society and highlight the homogeneity of the space in which these interactions take place.[3] Unlike the socio-eco-system, the anthroposystem and social-ecological system involve a co-evolution of the ecosystem and the sociosystem. Lévêque and Muxard (2004) and Lévêque et al. (2003) define the anthroposystem as… "*a structural and functional entity that takes into account society-environment interactions, and integrating in the same space one or numerous natural subsystems and one or numerous social subsystems, all of them are co-evolving in the long term*".[4] The concept of *social-ecological system* (also called socio-ecological system) is widespread. Its diffusion is especially boosted by the Journal *Ecology and Society* and the *Resilience Alliance*, a network of researchers which aims to promote resilience as a key concept of ecological and socio-economic dynamics. These dynamics are perceived in a non-linear interactive form, in accordance with the pioneering work of Holling, popularized in the book "Panarchy" (Gunderson and Holling 2002). The concept of social-ecological system is closely linked to the concept of ecosystem service (Fig. 12.1).

The concept of ecosystem services emerged in the 1970s and 1980s (Ehrly and Mooney 1983; Méral 2012). At the end of the 1990s and the beginning of the 2000s, their first worldwide monetary valuation published in Nature (Costanza et al. 1997) and the Millennium Ecosystem Assessment led by United Nations (MEA 2005) introduced ecosystem services to the forefront of the international stage. Bridging the scientific community and the decision-makers community, they are now a dominant paradigm in the management and conservation of the environment. They give a new interpretation of the nature/society relationships and are a way in which to internalize biodiversity into the market economy. In an interview with the

[3] http://www.eco-socio-systems.fr/eco-socio-system.html

[4] http://www.hypergeo.eu/spip.php?article270

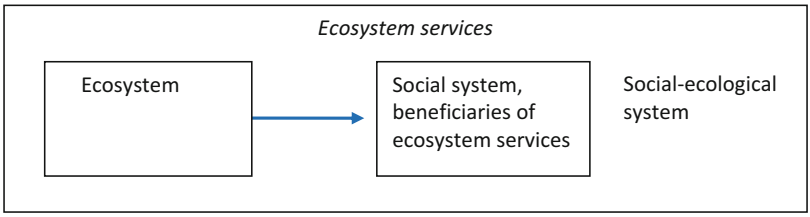


Fig. 12.1 Ecosystem services in a social-ecological system

daily newspaper, La Croix, October 12, 2010, C. Jouanno, a former Secretary of State for Ecology in France pointed out, "we need economic evaluations in order to be seen as serious people" in biodiversity management and conservation. A request of this kind is quite new. Until then, ecosystems were only perceived with a single focus: the protection of biodiversity. Protected areas are the main tool to achieve this goal. The strategic plan of the Convention on Biological Biodiversity has target that by 2020 17% of land areas and 10% of marine areas become protected areas on a world scale.

However, reducing the protection of biodiversity to create protected areas leads to a major risk: a division of planetary space into two entities: protected areas and highly 'anthropized' areas in which the protection of biodiversity would not take place. This spatial division dedicates a total absence of coviability between men and nature. In protected areas, the viability of nature is little or hardly inversely proportional to its use by men. The most effective protected areas to preserve biodiversity are those in which men are excluded. Symmetrically, the viability of human groups in anthropized areas is partly based on the intensive exploitation of nature. Such a difference between the supposed viability of nature and the supposed viability of human societies may lead to an economic and ecological dead end. A solution to this problem could be found with the principle of coviability between men and nature. The promoters of the Millennium Ecosystem Assessment (MEA) consider ecosystem services a central element of this coviability since, as mentioned above, they bridge the ecosystems and the individuals and human groups who benefit from it (Fig. 12.1) and form a socio-system (Lapierre 1992). Defining reference values and valuing them in a monetary way seems a good approach for integrating the ecosystem services in the decision-making mechanisms of territorial planning and stewardship. It is currently the main objective of the TEEB initiative (The Economics of Ecosystems and Biodiversity), widely supported by the European Union[5] (TEEB 2010). Following this rationale, bringing to the

[5]The following text is particularly clear about the assumptions made by EU on ecosystem services and their monetary assessment: "*Human well-being is dependent upon 'ecosystem services' provided by nature for free. Such services include water supply, air purification, fisheries, timber production and nutrient cycling to name a few. These are predominantly public goods with no markets and no prices, so their loss often is not detected by our current economic incentive system and can thus continue unabated. A variety of pressures resulting from population growth, changing*

attention of decision-makers and the public the monetary value of services (Fisher et al. 2009) provided by ecosystems is a necessary and sufficient condition to generate virtuous practices among users of these ecosystems and thus limit their degradation. In a previous article (David et al. 2012), it has been shown that the application of this proposal to a coral ecosystem suffered from many conceptual and methodological inaccuracies that made it hardly operational. This may be extended to whole ecosystems if we refer to a recent study by economists and political scientists showing that among the 313 articles devoted to ecosystem services in the journal *Ecological Economics*, only eight of them mentioned the use of this concept in environmental management (Laurans et al. 2013). In this chapter, we assume that men/nature coviability is based on the existence of feedback loops between ecosystem services and sociosystems services. To test this hypothesis, we will take the ecosystem services provided by the coral reefs of the Reunion Island as an example.

Our chapter is structured in four parts. Firstly, we briefly present our methods. Secondly, we revisit the concept of ecosystem services and the rationale behind the classification of services operated by the MEA (2005) then we tackle the main criticisms made on this work (Fisher et al. 2009; Fisher and Turner 2008; Boyd and Banzhaf 2007; Wallace 2007). Thirdly, we will stress upon the identification and the classification of ecosystem services attached to the reef environment of Reunion Island. Previous studies about these reef uses, mainly (Mirault 2006), offer a quantitative and qualitative framework that allows to revisit ecosystem services in a spatial unit identified as the resource area. Fourthly, we will tackle the concept of sociosystem service, and conclude with the feedback loop between ecosystem services and sociosystems services as a main vector of coviability between nature and human societies.

12.2 Methodology

This work is part of the OREMSE project (Ontology, Coral Reefs, Mangroves, Environmental Services), included in GEOSUD, one of the projects selected as part of the call for proposals "Equipment of Excellence" in the Programme d'Investissements d'Avenir (large national bond issued in 2011). GEOSUD aims to develop a national satellite imagery infrastructure to serve research on the environment and territories and its applications in the management of public

diets, urbanization, climate change and many other factors is causing biodiversity to decline. As a result, ecosystems are continuously being degraded. The world's poor are most at risk from the continuing loss of biodiversity, as they are the ones that are most linking it the ecosystem services that are being degraded... The TEEB study evaluates the costs of the loss of biodiversity and the associated decline in ecosystem services worldwide, and compares them with the costs of effective conservation and sustainable use. "It intends to raise awareness of the value of biodiversity and ecosystem services and to facilitate the development of cost-effective policy responses and better informed decisions". http://ec.europa.eu/environment/nature/biodiversity/economics/index_en.htm

policies. In this framework, OREMSE focuses on coral reefs and mangroves, the two most emblematic coastal ecosystems of the intertropical zone. It aims to first analyze the services provided by coral reefs and mangroves to neighbouring populations and second the way to map them. The final goal is to provide knowledge to improve the use in satellite imagery for a better management and conservation of these two ecosystems. Two working papers were produced in this field (Cillaurren and David 2014a, b).

Our methodological approach is based on a simple observation. Ecosystem services provided by coral reefs have been little studied. As Hicks (2011) pointed out, most of studies are devoted to a reduced number of services. In fact, coral reefs provide a large number of services as many studies on the coral reef uses have shown. This discrepancy between the observed reality and the content of articles can be easily summed up: does the problem come from coral reefs or from the concept of ecosystem services? This question can be divided into two symmetric parts:

- Is the coral ecosystem so specific from a functional point of view that it makes it difficult to apply the concept of ecosystem services to it?
- Is the concept of ecosystem services sufficiently structured and rich to apply to coral reefs?

Responding to this last question led us to critically review the concept of ecosystem services, based on the scientific literature published in international journals. To answer the first, we have selected the coral reefs of Reunion Island as a pilot site. Our knowledge of this coast allowed us to follow a four-step method:

- Delimitation of the sociosystem, composed of beneficiaries of ecosystem services provided by coral reefs;
- Study of services linking the coral ecosystem to this sociosystem;
- Identification of sociosystem services provided by the coastal sociosystem to coral reefs;
- Analysis of the relationships between coral ecosystems, ecosystem services, coastal sociosystems and sociosystem services.

Located on a volcanic hotspot in the South Indian Ocean (55 ° 29 East and 21 ° 53 South), the Reunion Island is young. Coral reefs are poorly developed. They only cover 10% of the island's coastline (25 km) on its leeward side (Fig. 12.2). Despite its small size, the coral reef works as an "attractor" to human activities and urbanization. It can be seen as a social ecological system with many resource areas. Each resource area is a spatial entity that associates an area and the resources it houses as an object of use or representation. It can be distinguished from others by:

- two spatial components: geomorphology, bathymetry,
- two resource components: habitat, animal or algal populations,
- the ecosystem services it generates,
- the type and quantity of human uses.

Fig. 12.2 The reef coast of Reunion Island from space (Pléiades 2013 in https://spatial.ign.fr); Licence Pléiades : Contains informations © CNES 2013, Distribution Airbus DS, all right reserved. Prohibited commercial use

12.3 From Viability to Ecosystem Services, When a Sociosystem Meets an Ecosystem

Viability is a prior concept to ecosystem services. In the 1980s, Aubin (1991) founded the basis of a mathematical theory of viability. At the same time, UNCTAD (the United Nations Trade and Development Conference) used the viability concept for planning the future of small island territories. The viability of a territory was seen as the combination of a static state, "*the meeting of necessary and sufficient conditions to exist and last*", and a dynamic state comparable to "*the conditions required to sustain island development, including the most comprehensive use of*

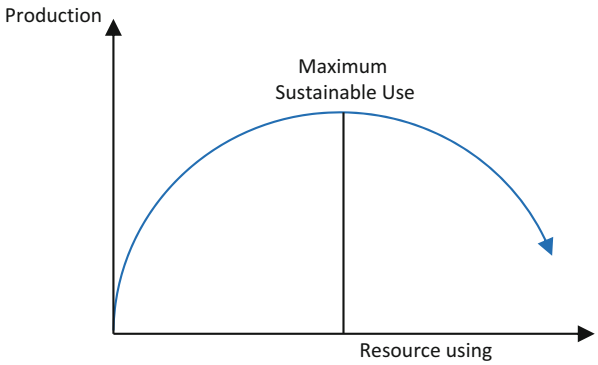


Fig. 12.3 The Graham-Shaefer model (Graham 1935) and (Schaefer 1954, 1957) applied to any resource

natural resources and the progress of social and economic living standards of populations" (Doumenge 1983, 1985).

Transcribed according to a simple mathematical formulation, this definition could be expressed as follow:

VT = f (MSUnr, GLS) where:
VT: viability of the territory,
MSUnr: maximum sustainable use of natural resources
GLS: growth in the social and economic living standards of populations

The concept of maximum sustainable use of natural resources is the maximum production extracted from a natural resource without altering its reproductive capabilities, in such a way that the resource quantity used remains sustainable over time and at its maximum level (Fig. 12.3). Coming from the Graham-Schaefer model for fisheries resources (Laurec and Leguen 1981), this concept leads to considering the used resources as a natural heritage, since their sustainable use allows their transmission to future generations.

In this sense, territorial viability works as true nature-society coviability. It requires both a viability of nature, i.e. an optimal functioning of the ecosystems making it up which results in maximum and sustainable productivity of these ecosystems, and a viability of the social or sociosystem, corresponding to optimal functioning of the society and the economy. Dependent on the ecosystems' production, this social system viability leads to optimum growth in the social and economic living standard of human populations. Beyond this optimum growth, the use of natural resources from is too great and breaks the balance between nature and society.

The concepts of maximum sustainable use of natural resources and viability as conceived by UNCTAD in the 1980s (Doumenge 1985) falls under the resources economy. The ecosystem services concept is part of the ecological economics, driven by the International Society for Ecological Economics created in 1989

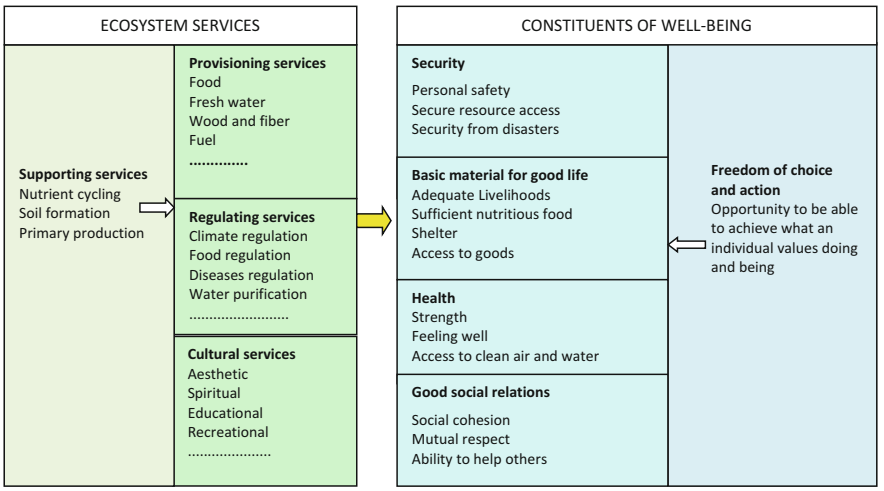
(Gomez Baggethum et al. 2010). Ecosystem services structure an essential relationship of dependency between an ecosystem and a socio-system. This relationship is still considered to be unidirectional (Fig. 12.1). Daily (1997, p.3) has defined ecosystem services as "the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfill human life". For Costanza et al. (1997), ecosystem services are the benefits that human populations derive directly or indirectly from the functioning of ecosystems. They come in four types:

- supporting services as the cycles of nutritive elements within the biotopes which are the origin of the production of the other three services;
- provisioning services, such as fresh water, food, soil, breathable air, genetic resources, which allow life on Earth;
- regulating services, such as the reduction of wave energy and thus coastal erosion by the reef barriers;
- cultural services.

This typology was taken by the MEA (2005) which extended the concept of benefits to a set of material goods and services, intangible, present and future. Thus, the MEA defined ecosystem services in a very broad way, "the benefits people obtain from ecosystems" and shown as an essential component of the well-being of human societies (Fig. 12.4).

Two main criticisms were made of this definition by Boyd and Banzhaf (2007) and Wallace (2007). Firstly, it mixes ends and means. Thus, the two first authors have introduced the concept of final ecosystem services, which put in direct relationship the ecosystem which transmits services and the socio-system which receives them, in opposition to the concept of basic or intermediate ecosystem services. Supporting services are intermediate or services. Provisioning, regulating and cultural services are direct services. "*Final ecosystem services are components of nature, directly enjoyed, consumed or used to yield human well-being*". Being an integral part of nature means that "*ecosystem services should be isolated from non-ecological contributions to final goods and services. Once ecosystem services are combined with other inputs, such as labor and capital, they cease to be identifiably 'ecological'*" (Boyd and Banzhaf 2007). Secondly, the MEA puts services and benefits in a same set. For Boyd and Banzhaf and Wallace, it is clear that services are different from benefits (Table 12.1) Scuba diving is not a cultural service produced by the reef ecosystem but rather a benefit that divers obtain from the reef. The underwater landscape is the ecosystem service which provides this benefit.

Wallace's analysis is particularly interesting because it inserts the ecosystem services in an identifying framework named "human values" (Table 12.1), defined as "*... the preferred end-states of existence, including those required for human survival and reproductive success, which taken together circumscribe human well-being*" (Wallace 2007, p. 237). The sociocultural development is a key element of human well-being. This definition is close to the definition of viability given by Doumenge (1983), but applied at the individual scale. In this context, all ecosystem services are the material expression of ecosystem processes on a natural asset



Intensity of linkages between ecosystem services and well-being: *strong*, *medium*, *weak*

		Constituents of Well-Being			
		Security	Basic materiel for good life	Health	Good social relations
Ecosystem Services	Provisioning services				
	Regulating services				
	Cultural services				

Fig. 12.4 Classification of ecosystem services according to the MEA (2005) and intensity of relationships between ecosystem services and human well-being

(Table 12.1). The author defines ecosystem processes as "*complex interactions (events, reactions or operations) among biotic and abiotic elements of ecosystems that lead to a definite result*". These processes work as transfers of energy and matter in natural assets, considered as resources and part of a natural capital.

Fisher and Turner (2008), Fisher et al. (2009) also brought constructive criticism to the concept of ecosystem services defined by the MEA. They define ecosystem services as "the aspects of an ecosystem utilized (actively or passively) to produce human well-being. Contrary to Boyd and Banzhaf (2007) who see services as only "*the directly consumable end points*"; they argue that "services must be ecological phenomena. They do not have to be directly used" . . . "functions and processes become services if there are humans that benefit from them. Without beneficiaries they are not services" (Fisher et al. 2009, p.645) In this framework, these benefits are the outcome of services.

Table 12.1 Classification of the eco-system services suggested by Wallace (2007)

Category of human values	Ecosystem services experienced at the individual human level	Processes and assets that need to be managed to deliver ecosystem services	
		Ecosystem processes	Biotic/abiotic assets
Adequate resources	Food for organism energy, structure, key chemical reactions	Biological regulation	Biodiversity assets
	Oxygen	Climate regulation	Land (soil/geomorphology) assets
	Water (potable)	Disturbance regimes, including wildfires, cy-clones, flooding	Water assets
	Energy for cooking and warming component under physical and chemical environment	Gas regulation	Air assets
	Dispersal aid and transport	Management of "beauty" at landscape and local scales	Energy assets
Protection from predators/ disease/parasites	Protection from predation	Management of land recreation	
	Protection from disease and parasites	Nutrient regulation	
Benign physical and chemical environment	Benign environmental regimes of:	Pollination	
	Temperature and energy (includes use of fire for warning)	Production of raw materials for clothing, food, construction, etc.	
	Moisture	Production of raw materials for energy, such as firewood	
	Light to establish circadian rhythms	Production of medicines	
	Chemical	Social-cultural interactions	
Social-cultural fulfilment	Access to resources for:	Soil formation	
	Spiritual and philosophical contentment	Soil retention	
	a benign social group, including access to mates and being loved	Waste regulation and supply	
	Recreational and leisure pursuits	Economic processes	
	Meaningful occupation		
	Aesthetical purposes		
	Opportunities values, capacity for cultural and biological evolution (knowledge and education resources, genetic resources.)		

An underlying link between ecosystem services and their use is implicit in the various given definitions (Boyd and Banzhaf 2007; Wallace 2007; Fisher et al. 2009). It seems important to detail this link and to put to the front the contribution of ecosystem services to the viability of societies. It is the topic of this third part, devoted to the reef coastline of Reunion Island.

12.4 From the Ecosystem to Its Uses and Services, the Case of Coral Reefs in Reunion Island

The two first typologies of ecosystem services provided by coral reefs were published by Moberg and Folk (1999) then Moberg and Rohnback (2003). They are more complete that the MEA typology (Table 12.2)

In the mid-2000s, some extremely detailed work was carried out on the uses of the Reunion island reef environment (Mirault 2006; Mirault and David 2006) in the VALSECOR project (Socio – economic values of the Reunion Coral reefs).[6] The first works on ecosystem services of the reef were published a few years later

Table 12.2 Comparison of three topologies of ecosystem services provided by coral reefs

Typology of ecosystem services according to		
Moberg et Folk (1999)	Moberg et Rönnbäck (2003)	Millenium Ecosystem Assessment (2005)
Physical structure services	Storm and flood protection	Supporting services
Biotic services within and between ecosystems	Nursery, feeding and breeding group	Provisioning services
	Maintenance of biodiversity and genetic resources	Regulating services
Biogeochemical services	Remineralisation of organic and inorganic matter	Supporting services
		Regulating services
Biotic services between ecosystems	Export of organic matter	Regulating services
Information services	Climate, pollution record	Cultural services
	Educational and scientific information	Cultural services
Social and cultural services	Support recreation	Cultural services
	Sustaining the livelihood of coastal communities	Provisioning services
	Cultural, spiritual and artistic values	Cultural services

[6]This research was carried out with a focus on the perimeter of the marine natural reserve (Lemahieu et al. 2013; Lemahieu 2015).

(Revillion 2009). This timeline logically led us to establish a strong link between uses and ecosystem services. We assume that ecosystem services are part of the ecosystem but only in a potential way. They become real ecosystem services when they are revealed when used by people. Users do not target a service but a resource in a resource area, which could be seen as the habitat housing this resource. In this framework, the ecosystem is not a whole but a set divided into many resource areas which have the potential to provide ecosystem services.

All uses can be identified according to four parameters: (a) the user who is the use producer, (b) the beneficiary of this use who is a use consumer, (c) the nature of the use and (d) the resource area which emits it, which can be seen as the morphological compartment housing the resource used. Transcribed according to a simple mathematical formulation, this definition could be expressed as follow:

$$U = f\ (Pu, Cu, Nu, Ra)$$

where

Nu: nature of use,
Pu: producer of use.
CU: consumer of use
Ra: resource area

All services can be identified according to four parameters: (a) the nature of the service, (b) the way by which the use reveals the ecosystem service, (c) the resource area which emits the service, (d) the beneficiaries of the service. Transcribed according to a simple mathematical formulation, this definition could be expressed as follow:

$$ES = f\ (N, R, Ra, B)$$

where

N: nature of service
R: way of revelation
Ra: resource area
B: beneficiaries

The two first parameters can be used to classify ecosystem services. Usually, the nature is the only way for classification. The way by which the service is revealed provides another valuable dimension of ecosystem services.

On Reunion Island, the link between the uses and the ecosystem services can divide the coral reef ecosystem into eight main resource areas from the beach to the open sea (Tables 12.3 and 12.4). Each of them can receive three types of use. Direct uses such as fishing, scuba diving, glass bottom boat cruises are directly driven by the coral ecosystem's functioning and processes. Semi direct uses such as swimming, beach practices, coastal housing are driven by the physical features

Table 12.3 Identification of main resource areas in Reunion Island's reef ecosystem according to their bathymetry, geomorphology and ecosystem

Bathymetry	Environments	Morphological units	Ecosystems	Resource areas
Subtidal area	Open sea		Pelagic ecosystem	Offshore area
	Outer reef	Deep fore reef slope	Fish and benthic ecosystems	Outer reef slope
		Fore reef slope	Fish and benthic ecosystems	Fore reef
Intertidal area	Reef flat limit	Reef crest	Algal ridge ecosystem	Reef flat
	Reef flat	Back reef	Coral ecosystem	Reef flat
		Reef pass channels	Coral ecosystem	Reef pass channels
		Back reef channel	Sand ecosystem	Back reef channel
			Coral ecosystem (Pinacles)	
	Shore	Beach	Sand and sedimentary ecosystems	Beach
Supratidal coastal area	Backshore	Beach	Sand and sedimentary ecosystems	Beach
	Terrestrial baseline	Upland	Terrestrial ecosystems with salt tolerant vegetation	Terrestrial coastline

Based on Mirault and David (2009)

generated by the presence of coral reefs (waves, coastal drift for example). Indirect uses are not related to the presence of the reef ecosystem or to its functioning, but to several direct uses, semi direct uses and indirect uses made of the ecosystem (Mirault and David 2009). Thus, scientific research, implementation of scuba diving clubs or kitesurf schools are indirect uses of a coral reef ecosystem.

These uses allow the related ecosystem services to be identified. Three major types of ecosystem services can be distinguished according to the way in which the services are revealed by uses.

(a) Matter or energy flows produced by a resource area become services only when they are put into use and/or revealed by the action of human beings. This can be labor which produces goods or a provisioning service. In the case of fishing, a resource, which is a stock of organic matter in the form of a fish population, is put into use when a fishing effort is carried out by fishermen (the resource users). As a result, this fish population becomes an exploited stock and then a fish production. The labor carried out on the ecosystem for providing ecosystem services returns to extract a resource from its resource area. So it can be described as an extractive use and the resulting service can be qualified as 'ecosystem service revealed by labor'. It provides identifiable and measurable well-being items (benefits according to the MEA) to the consumers of this resource, such as protein intake in the case of fishing. The resource area generating this can be called "a resource area supporting services revealed

Table 12.4 The reef ecosystem and resource uses in Reunion Island

Morpholo-gical units	Ecosystems	Resources	Uses	Use type
Deep reef slope	Fish and benthic ecosystem	Fish	Commercial fishing	Direct
			Recreational fishing	Direct
Fore reef slope	Fish ecosystem	Fish	Commercial fishing	Direct
			Recreational fishing	Direct
	Benthic ecosystem	Fish and benthic species	Recreational fishing	Direct
			Scuba diving (including illegal fishing)	Direct
	Reef ecosystem	Coral ecosystems	Spear-gun fishing	Direct
			Lobster fishing (including poaching)	Direct
			Filming and photo activities	Direct
			Glass bottom boat	Direct
Reef Crest and Back reef and Reef pass channels	Coral ecosystem	Coral environment	Foot fishing	Direct
			Spear-gun fishing	Direct
			Snorkeling	Direct
			Filming and photo activities	Direct
			Environment protection and nature conservation	Semi-direct

Backreef channel and Beach	Coral and sand ecosystem	Coral environment	Foot fishing	Direct
			Snorkeling	Direct
			Filming and photo activities	Direct
			Underwater trail	Direct
			Sliding sports	Semi-direct
			Canoeing, paddling	Semi-direct
			Swimming	Semi-direct
			Water sports school	Semi-direct
			Environment protection and nature conservation	Semi-direct
	Sand and sedimentary ecosystems	Beaches	Swimming	Semi-direct
			Sunbathing	Semi-direct
			Beach sports	Semi-direct
			Sport leagues or clubs	Semi-direct
			Nautical clubs	Semi-direct
			Walk	Semi-direct
Upland	Terrestrial ecosystems with salt tolerant plant species	Coast line	Walk	Semi-direct
			Picnic	Semi-direct
			Stores	Indirect
			Accommodation	Indirect
			Restaurant services	Indirect

Adapted from Mirault (2006)

by labor". The action of human beings can also be representational, which produces information. In this case, the service can be qualified as 'ecosystem service revealed by representation'.

(b) The services driven by the mere presence of a resource area require no human labor to be revealed and thus benefit human populations. The clearest example is the protection of the coast line against the energy of the waves breaking on the reef front. These services are referred to as 'non-revealed ecosystem services' and the resource area generating them are called "resource area emitting non-revealed services'. These services benefit the coastal population living near the emitting resource area (the sociosystem). They also play a role of induction towards economic stakeholders such as the CRPMEME (Regional Committee of Marine Fisheries and Aquaculture) and social stakeholders, such as traditional fishing associations, reef protection associations or the Group of Public Interest RNMR which manage the natural marine reserve in Reunion Island.

(c) In order to be revealed, some services require the presence of users on-site which means the use of the resource area by the simple attendance of people without any labor or representation to use the resource. They will be referred to as 'ecosystem services revealed by attendance'. The concerned resource areas will be called 'resource areas of attendance'. Non-extractive recreational activities, like swimming and surfing fall typically within such ecosystem services of attendance. It is also the case of the discovery of the environment, usually classified as cultural services (MEA 2005).

If uses reveal ecosystem services, there is no exclusive match between a use and a service. The same use can drive several services as shown in the case of fishing that can be classified as a supply service or as a recreational service. Table 12.5 connects resource areas, the ecosystem services they emit, the uses that reveal these services and the beneficiaries of these services, who are also the beneficiaries[7] or consumers of the uses that are made of the reef ecosystem resources areas. These beneficiaries are part of the reef socio-system. They are divided into four groups.

- public law stakeholders covering three groups of people: (a) local authorities, (b) State services and their civil servants (including researchers) and (c) the environmental managers studying, managing or promoting the reef ecosystem. All of them are involved in the management of the territory adjacent to the coral reef ecosystem and the maritime territory which hosts it;
- private law stakeholders who are users of the reef ecosystem and/or beneficiaries of its services. This group includes the islanders and the people not living in Reunion Island;

[7]All actors of the civil society can be seen as beneficiaries of ecosystem services whether they are (a) users of natural resources, (b) institutional or associative actors working on management, protection and information about the reef ecosystem, (c) resident population or tourist practicing recreation activities.

- private law stakeholders involved in a commercial activity based on direct, semi-direct and indirect use of the reef ecosystem resources areas;
- private law stakeholders involved in a public service mission (such as the CRPMEM) or in improving social well-being (such as environmental NGOs or NGOs of small traditional fisheries) concerned either directly or indirectly by the reef ecosystem.

Table 12.5 Matrix combining resource areas, ecosystem services, uses and service beneficiaries

a) Matrix of the services revealed by labor and non-revealed services

Ecosystem services	Resources areas	Uses	Services benificiaries
Provisioning	Back reef channel	Angle fishing	Recreational fishers
		Traditional net fishing	Commercial fishers
	Reef flat /	Net fishing	Self-subsistence fishers
	Fore reef / reef pass channels	Speargun fishing	Commercial, self-subsistence and recreational fishers
		Angle fishing	Self-subsistence and recreational fishers
	Outer reef slope	Drop line fishing	Commercial, Self-subsistence and recreational fishers
Regulation	Fore reef	Protection against erosion	Coastal population
Economic induction	All resource areas	Professional grouping (scuba diving, tourism, bottom glass boat)	Users of reef involved in commercial activities
Social induction	All resource areas	Customers associations	Association network and users
		Reef protection associations	Association network and users
		Traditional fishers associations	Association network and users
		Marine Natural Reserve	Reef users/Public institutions in charge of marine environment, coast inhabitants
Cultural services	Outer reef slope	Expertise and scientific research-	Research agencies and consultants
	Fore reef	Films and photo's production	Professional and hobbyist photographers and video-makers, School population and public
	Reef flat		
	Reef Pass channels		
	Back reef channel	Education activities	
	Beach		
	Terrestrial coastline		

NON-REVEALED SERVICES SERVICES REVEALED BY LABOR

(continued)

Table 12.5 (continued)

b) Matrix of the services revealed by attendance

Ecosystem services	Resource areas	Uses	Services beneficiaries
Cultural	Outer reef slope	Expertise and scientific research	Researchers and consultants
	Reef Pass channels	Expertise and scientific research	Researchers and consultants
	Reef flat	Expertise and scientific research	Researchers and consultants
	Back reef depression	Environment discovery	School population and public
		Expertise and scientific research	Researchers and consultants
	Beach	Environment discovery	School population and public
		Expertise and scientific research	Researchers and consultants
	Terrestrial coastline	Environment discovery	School population and public
		Expertise and scientific research	Researchers and consultants
Recreational	Outer reef slope	Recreational boating and fishing	Recreational sailors
		Scuba diving	Local customers and tourists
	Fore reef	Scuba diving	Local customers and tourists
		surf	Local customers and tourists
	Reef flat	Snorkeling	Local population and tourists
		Recreational fishing	Local population and tourists
	Reef Pass channels	Canoeing, paddle	Local customers and tourists
		Snorkeling	Local population and tourists
	Back reef depression	Canoeing, paddle	Local customers and tourists
		Snorkeling	Local customers and tourists
		Sliding sports (WindSf/Kyte Sf)	Local customers and tourists
		Canoeing, paddle	Local population and tourists
		Swimming	Local population and tourists
		Tanning	Local population and tourists
		Open air games	Local population and tourists
		Walking	Local population and tourists
	Beach	Picnic	Local population and tourists
		Walking	Local population and tourists
Economic Induction	Terrestrial coastline	Scuba diving clubs	Local population and tourists
		Surf clubs	Clubs employees and divers
	Outer reef slope	Sliding sport clubs	Clubs employees and surfers
		Canoeing and paddle clubs	Clubs employees and sliders
	Fore reef		Clubs employees and sport practicing people
	Back reef depression	Itinerant sale	Shop keepers beach customers
		Equipment rental	Coastline population
		Residential housing	Hotel owners
	Beach	Commercial accommodation	Restaurant owners/tourists /local population
	Terrestrial coastline	Restaurant services	Local population and tourists
		Car parking	Local population and tourists

In Table 12.5, the services have been classified according to the two we have mentioned above (a) the processes characterizing their action, a distinction is thus made between services revealed by labor, non-revealed services (Table 12.5 a) and services revealed by attendance (Table 12.5 b); their nature, defined according to the typology of the MEA: provisioning services, regulation services and cultural services. This typology highlights the strong specialization of the beneficiaries of the supply services (all fishermen) and the importance of cultural services. Three types of fishermen have been distinguished. The less numerous are the food fishermen. They are all unemployed but they benefit from social welfare payments. Thus, they could live without fishing but this use provides them with a free source of marine protein and occupies their free time. Even if some are engaged in speargun fishing, most of these food fishermen are involved in on-foot fishing. They fish all coral reef resource areas in shallow waters. Fifteen years ago, seven types of fishing techniques were used (David and Mirault 2006).

Since then, the diversity of fishing techniques and boats has decreased. This food fishing is tending to disappear in favor of recreational fishing. Recreational fishermen show various profiles including jobless fishermen who angle in the reef passes and on the reef front at low tide and primary and secondary school teachers who practice boat fishing on the outer reef slope or speargun fishing. These fishermen are called recreational fishers because they are not involved in professional fishing. In fact, several of them fish on a regular basis, sometimes on a daily basis and because they sell their catches, they can be seen as informal and illegal professional fishermen. They practice speargun fishing and netting in particular.

The name "professional fishermen" reflects here two different realities. A first group of fishermen is composed of fishermen with a professional diploma. They are registered by the administration of Marine Affairs. A second group of 800 people receive each year a card of traditional fishermen awarded by the same administration. This card allows them to fish (*Mulloidichthys flavolineatus*) in shallow reef waters with a net of 10 m long and 3 m in height from February 1 to April 30, on Wednesdays, Thursdays, Fridays, Saturdays and Sundays, except holidays, from 5 to 9 h.

In the typology established by the Millennium Ecosystem Assessment (2005), the less well-treated aspect deals with cultural services. As stressed by Boyd and Banzhaf (2007) 'the MEA cultural services, including spiritual and religious values, aesthetic values, and recreation and ecotourism are particularly unsatisfying'. In Table 12.5 and 12.6, these services have been divided into four categories based on direct, semi-direct or indirect uses: cultural services, recreational services, economic induction services and social induction services.

- The cultural services are linked to four main types of uses:
  - The discovery of the reef ecosystem using either the underwater trail in the Hermitage or glass bottom boats (visiobulle) in St Gilles, or scuba diving, are direct uses of the reef ecosystem. They reveal a landscape service which belongs to the category of the attendance service and provides aesthetic wellbeing driven by the aesthetic value of the coral reef landscape.

  - Scientific research is divided in three types: (a) visual observation during field trips, which means a direct use, the attendance of different resources areas in the reef ecosystem, (b) collecting samples in the field which means a direct extractive use of the reef, (c) data processing in the laboratory and then the writing of scientific articles about these results, which means an indirect use of the ecosystem.;
  - The education of the public and schools via documentation that deals with the reef ecosystem is an indirect use, driven both by two previous uses: the discovery of the reef ecosystem and scientific research.
  - The production of multiple photographs (including postcards) and videograms (Table 12.6a), which is a direct use of the reef revealing a cultural service.

- Recreational services are revealed by coral reef ecosystem attendance:(a) coastal and marine uses (sunbathing, swimming, snorkeling, picnicking), (b) board sports (surfing, parasailing, windsurfing) and learning how to do these through clubs and schools, (c) canoeing and 'paddle sports and learning how to these, (d) scuba diving and learning how to scuba dive[8];
- Economic induction services concern owners of main or secondary residences, restaurants, hotels and any other form of paid accommodation, stores specialized in beach activities, street peddlers selling cold drinks or swimsuits on beaches;
- Social induction services are so-called because the existence of the reef ecosystem and its uses, including conservation of habitats and biodiversity, generate the creation of association of users devoted to the promotion of small traditional fishermen or environmental protection. These services identified as social induction directly initiate socio-systems services (see below).

The economic and social induction services are non-worked services. They generate no extractive usage of the reef ecosystem (Tables 12.5 and 12.6).

Resource areas can emit several types of services and/or support several types of uses and categories of beneficiaries. The 7 resource areas listed in Table 12.6 have emitted a total of 116 services which means an average of 16 to 17 services per resource area. There is little disparity between the resource areas. The reef pass and channels are the least productive (14 services). The more productive (20 services) is the back reef channel. Its interface between, on the one hand, the beach (19 services) and the terrestrial coastline (15 services) and, on the other hand, the reef flat (15 services) and the deeper reef resource areas (total of 47 services) is probably favorable in terms of attendance. On the 116 services emitted by the reef ecosystem, 89% are cultural services, which is quite unusual in the literature (Hicks 2011; Failler et al. 2015; Schuhmann and Mahon 2015). A fifth of these cultural services are recreational services and economic induction services (Table 12.6a and 12.6b).

[8]Learning these sports are more socio-system services orientated than ecosystem services orientated, even if they are usually called cultural services.

Table 12.6 The ecosystem services according to their area-resource emission and their beneficiaries

a) Cultural and recreational services

Benificiaries	Resources Areas						
	Terrestrial Coastline	Beach	Back reef channel	Reef flat	Reef pass channel	Fore reef	Outer reef slope
Hobbyist and videomakers							
Professional photographers							
Researchers, consultants							
School population and public							
Recreational fishers							
Recreational sailors							
Surfers							
Snorkelers							
Board sport users							
Canoeing and paddle sports users							
Swimmers							
Beach goers							
Picnickers							
Walkers							

(continued)

Table 12.6 (continued)

b) Cultural services of economic and social induction

Benificiaries	Resources Areas						
	Terrestrial coastline	Beach	Back reef channel	Reef flat	Reef pass channels	Fore reef	Outer reef slope
Recreational fishers associations							
Scuba divers and spear guners associations							
Traditional fishers associa-ions							
La Réunion Natural Marine							
Reserve							
Reef protection associations							
Professional tourism groups							
Professional fishers groups							
Scuba diving clubs and divers							
Surf clubs and surfers							
Sliding sports clubs and sliders							
Canoeing and paddle sport clubs and users							
Beach clubs							
Shopkeepers							
Restaurant owners							
Hôtel and campings owners							
Coastline population							
Users associations							

Social induction services (n =24)

Economic induction services (n =21)

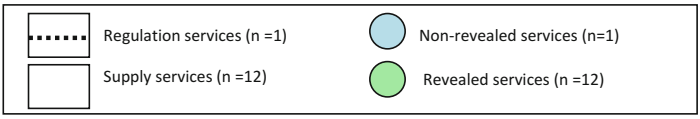
Nonrevealed services (n=32)

Attendance services(n =13)

(continued)

Table 12.6 (continued)

Benificiaries	Resources Areas						
	Terrestrial coastline	Beach	Back reef channel	Reef flat	Reef pass channels	Fore reef	Outer reef slope
Coastline							
population							
Drop line fishers							
Spearguners							
Anglers							
Net fishers							
Traditional net fishermen							



Most of the recreational services (16 out of 21) are services of attendance. They are revealed by the presence of users in the practice area. The economic induction services are either non-revealed services (8 out of 21) or services of attendance (13 out of 21). The first group deals mainly with the implementation of professional organizations whose aim is partly to support the exploitation of the reef ecosystem through fishing or tourism. The second group deals with the creation of two kinds of businesses. Some aim to promote the practice of a sport (scuba diving for example) completely devolved to the reef ecosystem. The others are located on the terrestrial coastal strip or on the upper parts of beaches. All their customers are reef users.

Unlike the economic and recreational induction services, the social induction services and the cultural services are linked to a large number of resource areas. Cultural services are mainly information (photography, field data, writing, videos) brought to the attention of the researchers and the school population) or photographs and films shot by professionals and hobby photographers. As indicated in Table 12.6a, the same resource area can emit both non-revealed and services of attendance. In the latter case, services deal with information collected either in the field by researchers or consultants, either during field trips by school children aiming at discovering nature. The creations of the 'Réserve Naturelle Marine' of the Reunion Island or of environmental NGOs which aim to protect the reef ecosystem are the

results of induction services which are both cultural services emitted by the reef ecosystem and socio-systems services aiming to protect this ecosystem. .

12.5 The Exploration of a New Concept: The Sociosystems Services

Sociosystem services are a set of services provided by human beings, as a social system, to ecosystems in order to secure and sustain ecosystem services. Under the frame of a social ecological system, the feedback loop between sociosystems services and ecosystem services is a necessary condition to nature/human society coviability (Fig. 12.5). For strengthening coviability between coral reef ecosystems and riparian human societies, four types of sociosystem services can be distinguished.

(a) The 'sanctuary of the ecological habitats' service' deals with the creation and implementation of Marine Protected Areas, including 'No take' zones, in order to restore habitats when they are degraded and to keep their biodiversity in good health status.
(b) The "ecological engineering" service has five distinct types:

- The reintroduction of species whose natural numbers are too small to ensure their place in the ecosystem functioning, is the first one. Pacific Islands provide a good example with the reintroduction of both giant clams or mother of pearl shellfish such as 'trochus' (Teitelbaum and Freidman 2008). Planting mangroves for trapping sediments driven by the run off of eroded soils in watersheds is also an ecological engineering service. As it decreases the

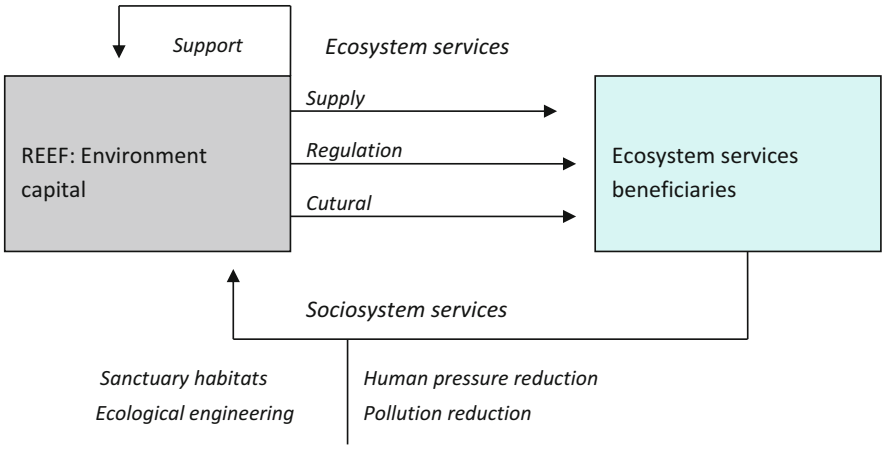


Fig. 12.5 The ecosystem and sociosystem services linked to the coral reefs

hyper sedimentation of coastal waters, it benefits indirectly to coral reefs. In any case, this engineering aims for the restoration of ecosystem services previously degraded by excessive anthropogenic pressure (Ronnback et al. 2007);

- The creation of artificial habitats is a second type of ecological engineering service. To put artificial reefs on shallow waters of reef lagoons is a good way to increase fish abundance on sand bottoms, where fish diversity is very low. Artificial reefs provide a new habitat to coral fish larvae where they can grow, sheltered from predators.
- The restoration of habitats so heavily degraded to be used as a sanctuary is a third type of service. The eroding dunes and the upper part of beaches offer a good example of this type of service. People plant herbaceous species such as the ipomoea family to reduce wind erosion and to slow down the wave's energy during high tides of major amplitude. Planting mangroves on seafronts where they naturally never or rarely grow is derived from such engineering. But here the result is often a failure.
- The fourth type of engineering service deals with the capture of larvae of reef species in the marine environment. Their breeding will produce juvenile and young adults for the reintroduction *in situ* or the aquarium fish sales. In nature, the life expectancy of these larvae is very low. Most of them will die, eaten by predators. So, their capture for breeding has negligible negative effects on the reef ecosystem. This service is upstream both to the 'reintroduction of species" service and to the "reduction of the anthropogenic pressure on ecosystems" service, to which it brings a quite valuable contribution, as it avoids to fish adults for sale to aquarium keepers.
- The fight against the proliferation of invasive species such as *Pterois volitans* in the Caribbean (Gonzales et al. 2009; Bouchon and Bouchon-Navarro 2010.) or the *Acanthaster planci*, a starfish that eats coral polyps[9] is the fifth type of ecological engineering service.

(c) The 'reduction of the anthropogenic pressure on ecosystems' service is one of the most common sociosystems services. It encompasses all of the regulations incorporated in the management of natural resources. This service takes three different forms:

- The regulation of the economic or social activities (including leisure) which have a direct impact on coastal or marine ecosystems.
- The regulation of economic activities that have an indirect impact on coastal or marine ecosystems.
- The integrated management of coastal areas, which requires regulation of all sectors of activities in this space.

[9]The coral reefs consist of animals, the polyps, which live in symbiosis with algae, the 'zooxanthellae', which provides much of the carbon they need via photosynthesis.

The regulation of economic or social activities can be carried out in two ways: first, the restrictions on the use of fishing boats and, second, the limitation of access to the resource areas. According to the geographical level of the decision-making process and the extent by which it is applied, two main types of limited access to areas can be distinguished: at both the local communities and the supra community scales, including national and the international levels. At the local scale, the limitation of access to the area is mainly carried out in the form of temporary closures of fishing and permanent closures on resource areas. At the supra community scale, an activity which is the subject to regulation is another parameter which can be used to classify socio-systems services.

For fishing, the three major limitations of access are respectively: (a) the permanent closure of fishing (fishing reserves), (b) the seasonal closure of fishing, for example in the spawning areas, in order to avoid the fishing of gravid females, (c) the fishing closures usually for a period of one to two or three years, under the context of rotating reserves.

For urbanization and tourism, regulation focuses on two points:

- The ban on construction in some areas. In the French Overseas Départements, the coastal Act (1986) governs urban planning and bans any new construction in a 80 m strip from the coast (except for exemptions) which corresponds to 50 geometric feet.
- The necessity for each coastal home or hotel to have an individual or collective sanitation system in order to reduce domestic effluents, sources of eutrophication of shallow coastal environments.

The regulation of economic activities that indirectly impact coastal or marine ecosystems deals mainly with activities which develop in watersheds, upstream the coral reefs, such as agriculture or urban development. This type of service is not yet common because few farmers, urban planners or public works contactors working on watersheds are aware of the potential impact of their activities on the coastal ecosystems. The example of chlordecone/kepone/in Martinique and Guadeloupe shows that chemicals used in watersheds for agricultural purposes can heavily impact the downstream reefs at range a of may kilometers away (Bertrand et al. 2010; Bodiguel et al. 2011). Coral is extremely vulnerable to pesticides and herbicides, hence the need to focus on sustainable agriculture that is more respectful of ecosystems in the islands, by minimizing the use of harmful inputs to the environment.

(d) The reduction of pollution in coastal ecosystems is a service provided mainly by water treatment plants. Their high cost is a huge constraint for the expansion of this service in poor islands. However, ecological engineering allows the implementation of biological plants using the remediation service provided by wetland vegetation, including mangroves.

12.6 Conclusion

Socio-system services aim mainly at sustaining the functioning of ecosystems when their health status is good or to restore them when they are degraded. Thus, they help sustain the quality of ecosystem services. Sociosystem services and ecosystem services are, therefore, linked by a feedback loop (Fig. 12.5). The preservation of such a loop to a high level of efficiency should be the top priority in the governance of coastal areas. It is the only way to ensure a sustainable and reasonable use of marine resources at both local and above local levels in order to promote nature/society coviability. In this perspective, the concept of a sociosystem service becomes central in the governance of coastal ecosystems. This relational interdependence between ecosystem and socio-system services leads to the combination of these two services under the name of environmental services. They are an essential key of nature/society coviability in coral reef areas as in any other coastal and marine environments.

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