Title

Analysis and management of multiple ecosystem services within a social-ecological context

Abstract

The assessment of ecosystem services (ESS) requires approaches that are capable to deal with the complexity of social-ecological systems (SES). A new viewpoint is proposed, in which the social-ecological perspective of Ostrom's SES framework is used to describe the flow of ESS, through the identification of the social and ecological elements involved. Two types of ESS flow emerge from this analysis, depending on the way in which the elements of ESS supply (resource system and resource units) and demand (actors) interact: (i) a "direct flow type" in which the resource units deliver the ESS through some specific ecological functions (e.g. wetlands providing carbon sequestration), and (ii) a "mediated flow type" in which the resource units become themselves the ESS when "used" by means of human activities (e.g. fish harvested through fishing activities). The identification of activities is crucial to understand the interactions between ESS, because of the feedbacks they produce on the ecosystem functioning and thus on the provision of the same or other ESS. In addition, these feedbacks can depend on temporal aspects of ESS provision. On these regards, a hypothesis is proposed according to which a time lag can exist between the ESS supply-side and flow in human-modified SES. Altogether, this social-ecological analysis of ESS can contribute to focus the management strategies on the control of impacting activities and on the maintenance of those processes which underpin ESS' provision, thus contributing to the implementation of an ecosystem-based management of SES. These aspects are discussed in the light of the Venice lagoon example.

Keywords: ecosystem services; social-ecological systems; ecosystem-based management; time lag; Venice lagoon.

Highlights

- A social-ecological viewpoint to analyze ecosystem services (ESS) is proposed.
- Two types of ESS flow, direct and mediated, are defined.
- A time lag can be identified in the generation of some ESS.
- The viewpoint proposed can contribute to the management of social-ecological systems.

1. Introduction

Ecosystem services (ESS) have gained an increasing importance in the field of sustainability science and environmental management in the past decades (Burkhard et al., 2012; de Groot et al., 2010a, 2002; Millennium Ecosystem Assessment, 2005; Seppelt et al., 2011). ESS, being defined as the contributions of ecosystem structure and function – in combination with other inputs – to human well-being (Burkhard et al., 2012), result from the interactions between the ecological and social components of integrated social-ecological systems (SES) (Reyers et al., 2013), and thus their assessment requires an approach that takes into account the complexity of the SES by which they are generated.

The elements that make up the link between ecosystems and human well-being are often described by means of the “service cascade”, a sort of production chain in which the biophysical structures and processes of the ecosystem are linked to the benefits (and values) they provide through a series of intermediate steps (Haines-Young and Potschin, 2010; Potschin and Haines-Young, 2011). A key role here is played by the anthropocentrically defined concept of ecosystem function, that is, the capacity of the ecosystem to do something that is potentially useful to people (de Groot et al., 2010b; Haines-Young and Potschin, 2010; Potschin and Haines-Young, 2011). This function is considered an ESS only if a human beneficiary exists (Potschin and Haines-Young, 2011). The cascade thus stresses the role of society as the beneficiary of ESS, but on the other hand it does not provide a way to represent the active involvement of humans in ESS generation. The intervention of some anthropogenic factors in ESS delivery is an aspect that has been highlighted by several authors (Andersson et al., 2007; Bohnke-Henrichs et al., 2013; Burkhard et al., 2014; Fischer and Eastwood, 2016; Fisher et al., 2009; Jones et al., 2016; Queiroz et al., 2015). For instance, Fisher et al. (2009) specify that forms of capital other than natural can be required to realize benefits from ESS. These “additional inputs” (*sensu* Burkhard et al., 2014) refer to the anthropogenic contributions to ESS, which are recognized to be hardly separable from the ecosystem-based contributions in many human-influenced systems. The presence of additional inputs increases the complexity of ESS assessments (Burkhard et al., 2014), and a clear way to handle these inputs, both conceptually and in ESS assessments, is lacking.

A possible way forward is offered by the SES framework (McGinnis and Ostrom, 2014; Ostrom, 2009, 2007), aimed at providing a common language to organize findings and analyze outcomes at the SES level. According to this framework, *users* (later renamed as *actors*) extract *resource units* from a *resource system*, and this use is regulated by a *governance system* (McGinnis and Ostrom, 2014; Ostrom, 2009). The *outcomes* at the SES level are thus the result of the *interactions* among the four core variables of the SES (resource systems, resource units, governance system and actors). In a later revision of the framework, McGinnis and Ostrom (2014) open the way for its application to a broader set of situations, such as the cases in which the resources considered are ESS and public goods in general.

The use of ESS in environmental management, especially in the context of an ecosystem-based management, is becoming increasingly important (Agardy et al., 2011; de Groot et al., 2010a; McLeod et al., 2005). Management of SES faces the challenge to harmonize the provision and use of multiple ESS in a way that they become sustainable. Management focused on single ESS fails to capture the complexity of the system and can produce undesirable effects due to trade-offs between ESS, that is, a situation in which increased provision of one ESS can inhibit the provision of another ESS (Bennett et al., 2009; Meacham et al., 2016). Therefore, a deeper understanding of social-ecological processes involved in ESS provision is required also from a management perspective, for the implementation of strategies aimed at maintaining these processes to a level that is capable to provide sustainable levels of multiple ESS.

In the present work, a new viewpoint for the analysis of multiple ESS, based on the SES framework, is suggested. This approach is used to: (1) describe the social-ecological elements involved in the generation/use of ESS, (2) to categorize ESS, and (3) to explore possible implications in terms of management of multiple ESS. Finally, an example of application in the Venice lagoon is presented and discussed.

2. Analyzing ecosystem services through the social-ecological systems framework

2.1. Direct and mediated flow types

According to the SES framework, a general chain of elements is proposed, in which (1) ESS depend on *resource units* that are generated by the processes of a *resource system*; (2) the ESS provide benefits to some *actors,* and (3) their management is determined by the rules set by a *governance system* (Figure 1). Here the resource units correspond to the elements of the system that actually provide the ESS, which, from a spatial perspective, represent the "service providing units" (*sensu* Syrbe and Walz, 2012).

The ESS flow (i.e. the *de facto* used ESS, Burkhard et al., 2014), results from the interaction between the ESS supply-side (*resource systems* and *resource units*) and the demand-side (*actors*). Here two types of interaction are distinguished, namely *ecosystem function* and *activity*, which generate two different types of ESS flow, which are named "direct" and "mediated", respectively (Figure 1A and 1B). In the "direct" flow type (Figure 1A), the resource units generate an ecological *function* that is potentially useful to actors. Here the term function is used *sensu* Potschin and Haines-Young (2011), i.e. the capacity of the ecosystem to do something that is potentially useful to people. For example, energy dissipation is a function provided by coastal vegetation (*resource unit*), that underpins the disturbance prevention ESS. This function then becomes an ESS when and where it is actually beneficial to some actors (e.g. residents in the coastal area), with no need of a specific human input in ESS's generation. In the "mediated" flow type (Figure 1B), the interaction instead occurs in the form of an *activity* through which the resource units are "used" by actors. This *activity* is what makes beneficiaries "meet" the resource. The generation and availability of the resource units is dependent on ecosystem processes and functioning, however, the ESS directly depends on resources' availability and use. Let us make the example of a forest (resource system), in which trees (resource units) provide two ESS, one is the raw material "timber" (mediated ESS) and the other one is erosion control (direct ESS). In both cases the presence of trees depends upon ecological processes occurring in the forest, such as soil processes, water and nutrient cycling, and plant growth. However, the timber ESS can be obtained only if trees are cut and timber is harvested, that is, if an activity turns the resource units into an ESS. It should be noted that this exploitation can be decoupled from ecological processes up to the point that the resource is depleted (e.g. cutting rate higher than growth rate). In this situation, this ESS is not sustainable, but it is still an ESS until there are resource units available. In order to be sustainable, the exploitation should balance the processes that generate the resource units, and this requires to move one step back in our "production and use chain" and identify the key processes and their trends. Therefore, ecological processes are crucial also for mediated ESS, but are "hidden" behind the availability of resource units. In the case of the erosion control ESS, the dependence upon an ecological function (soil retention) is straightforward, the provision of the ESS is directly proportional to the function and does not require any type of human input to turn the resource units into ESS.

The activities involved in the mediated flow type can produce feedbacks directly on the resource system (red arrows in Figure 1B), resulting in negative effects on both the ESS itself and/or the flow of other ESS (ESS trade-offs). The identification of activities and their feedbacks is thus an important aspect that should be taken into account when analyzing interactions among ESS. The net result of all these interactions is the pattern of multiple ESS provided by the SES, which can be understood as an *outcome* of the SES.

Finally, this perspective allows to analyze the role of the governance system in the ESS delivery, which can be essentially of two types. In both flow types, the governance system should be responsible for the implementation of management measures aimed at the protection, maintenance or restoration of the resource system and units. In the case of mediated flow type, the governance system should come into play by setting rules that regulate the actors' activities, in a way that minimizes the negative effects.

The flow types that apply to the various ESS groups, according to the Common International Classification of Ecosystem Services (CICES) version 4.3 (Haines-Young and Potschin, 2013), are proposed in Table 1.

2.2. Temporal aspects in human-modified social-ecological systems

Let us consider a SES in which society and ecosystems have co-evolved over time: in such a system, ESS are provided by modified ecosystems and landscapes in which ecological and social elements are integrated. The elements of this SES are the result of processes at various temporal scales, which can influence the temporal aspects of the ESS provided. With a certain degree of simplification, we can make two hypotheses about the temporal aspects characterizing ESS in such systems:

- "short time scale" hypothesis (e.g. months, years), which represents the dependence of the current ESS provision on the "present" state and processes of the system;
- "long time scale" hypothesis (e.g. centuries), in which the current ESS provision is the direct result of "past" state and processes of the system, and this implies a sort of *time lag* between the ESS supply-side and flow.

These two hypothesis are not mutually exclusive, as ESS can depend upon multiple processes operating at different temporal scales. As a consequence, an ESS can be characterized by a mix of the two hypotheses. The long time scale hypothesis allows to handle those ESS, typically cultural ones, that are generated by a landscape in which both human and natural elements are integrated through a long-term co-evolution. Cultural ESS such as aesthetic information, recreation and tourism, and information for cognitive development, most likely depend on the characteristics of the whole landscape. The SES perspective and the inclusion of a "time lagged" component allow to broaden the analysis and to take into account the contribution of those human elements, e.g. tangible and intangible cultural heritage, that are the result of a long term interaction between society and the ecosystem and its resources. In Table 1, the temporal hypotheses that apply to the various ESS are proposed. In general, the short time scale hypothesis can be considered dominant in most regulating and provisioning ESS, being these ESS dependent on ecological processes and functions that are roughly contemporary to the ESS flow, e.g. primary production and soil functions. On the other hand, the long time scale hypothesis can be applied to cultural ESS, in the cases in which these ESS depend on human-modified landscapes that result from a social-ecological co-evolution spanning over long time frames. Cultural ESS can be characterized by a mix of both temporal hypothesis, whose relative importance varies case by case, depending on the elements and processes that constitute the ESS supply-side.

The temporal hypotheses have some implications concerning the way in which ESS “respond” to present pressures and perturbations of the system, and to the feedbacks produced by the activities involved in mediated ESS. For what concerns the long time scale hypothesis, the supply side depends primarily on elements “inherited” from the past SES. Therefore, under this hypothesis, ESS provision is less sensitive to present pressures and feedbacks, which, instead, can affect the current ecological processes to which the short term hypothesis is referred. As a result, depending on the temporal hypotheses, the feedback between activity and ESS supply-side can be present or not (Figure 2). In the case of long time scale hypothesis, the feedback is absent, but the activities involved in these ESS can nevertheless impact the present SES, and thus the provision of other ESS. Looking into the future, on a longer time frame, the human-modified landscape, and the time lagged ESS based on it, are affected by the overall type of human-environment relationship, that is, they reflect the overall pattern of multiple resources’ and ESS’ use that shape the landscape in the long term.

This approach can contribute to improve the assessment of many cultural ESS, which are still understudied (Mocior and Kruse, 2016; Raudsepp-Hearne et al., 2010), and often require a greater integration of the role of human culture in ESS research (Raudsepp-Hearne et al., 2010).

2.3. Management implications

According to the flow type and to the dominant temporal hypotheses, ESS can be grouped in direct, mediated with short time scale and mediated with long time scale. In relation to the presence/absence of feedbacks and the interactions between ESS (red arrows in Figure 1 and 2) some implications in terms of management of multiple ESS arise:

- the direct flow type ESS, not being dependent on human activities, are in principle able to self-sustain without any human involvement. Nevertheless, a decline of these ESS can occur due to the negative impacts of external drivers and other ESS’ activities, and thus some management measures can be necessary to maintain or enhance the flow of these ESS. This can be done either by acting on the causes of these impacts, or by protecting or restoring the elements of the supply side which are impacted.
- the mediated ESS with short time scale can be perceived at the same time as impacting and impacted elements. On the one hand their activities are potentially responsible for negative feedbacks and externalities, on the other, they can undergo other ESS’ side-effects. As a consequence, the management of these ESS should take into account the whole set of multiple interacting ESS, in order to identify and manage the activities that undermine the ecological functioning of the system.

- the mediated ESS with long time scale are peculiar due to the absence of feedbacks between the activity and the ESS supply-side. This implies that unsustainable levels of activities may not produce a visible impact on the ESS itself, but are instead likely to result in side-effects on other ESS. The management of these ESS is thus particularly challenging, because it requires an integrated perspective that focuses on minimizing their impacts on other ESS, and the benefits on the managed ESS may not be visible.

3. An example from the Venice lagoon

3.1. Ecosystem services analyzed by flow type and temporal hypothesis

The Venice lagoon is a transitional environment located along the north-western Adriatic coast (Italy). It constitutes a representative and complex example of SES, being the man-environment linkage one of the most relevant factors shaping the characteristics of this territory throughout its history (Munaretto and Huitema, 2012; Ravera, 2000; Solidoro et al., 2010). It represents, thus, a proper case study for applying the above described approach.

The ESS that are relevant for the Venetian lagoon context were selected based on Rova et al. (2015) and their classification in terms of flow type and dominant temporal hypothesis are shown in Table 2. The direct ESS flow type applies to regulating and habitat services, whereas the mediated ESS flow type applies to provisioning and cultural ones. Concerning the temporal aspects, regulating, habitat and provisioning ESS are characterized by the short time scale hypothesis, whereas, among the cultural ESS, some are dominated by the long time scale hypothesis and others by the short time scale one. In fact, some sub-categories of the recreation and leisure ESS, i.e. recreational fishing and hunting, are dominated by processes with short temporal scale, similarly to provisioning ESS. Some authors indeed classify these cultural ESS as provisioning, stressing the fact that they imply the "use" of tangible resources for human nutrition (Burkhard et al., 2014; Kandziora et al., 2013). All other cultural ESS are instead characterized by a long time scale, being based on the coevolution between the lagoon ecosystem and society. The "maritime transport" ESS, which in the Venice lagoon depends on the network of channels, was classified as "other services" in Table 2 because it is not unanimously considered an ESS (see for instance Atkins et al., (2011) vs. de Groot et al., (2010)).
The ESS "production and use chain" is reported in Tables 3-5.

The direct flow type ESS depend on a variety of ecological functions, and some of them depend on more than one function, indicating the variety of mechanisms through which the ecosystem contributes to these ESS (Table 3). Moving further "backwards" along the production chain, however, it is possible to group the underlying processes and resource systems essentially into three types, related to the lagoon's morphology, primary producers and interspecific interactions in the biological community. From this it clearly emerges the ESS' "co-production", that is, ESS resulting from common structures and processes of the system.

The ESS with mediated flow type and short time scale are generally mediated by some type of harvesting activity, and are based on the abundance of the target species, which in fact depends upon ecological processes with relatively short time scale; maritime transport is instead related to the lagoon's hydrodynamics and sediment transport processes (Table 4).

Time lagged mediated ESS depend completely or partially on long time scale processes, being the result of multiple processes at operating at different time scales (Dawson et al., 2010) (Table 5). This is the case for tourism, recreational navigation and information for cognitive development, which are characterized by a mix of short and long time scale hypotheses, meaning that both contemporary and time lagged components contribute to the ESS' flow. They are produced by three types of resource units, namely natural and cultural landscape (determining the sites' attractiveness), and navigable channels (determining the sites' accessibility). Natural landscape and navigable channels depend on relatively short time scale ecological processes, whereas cultural landscape is the time lagged component of these ESS, being the result of the coevolution between lagoon and society. The cultural landscape is in fact expression of cultural heritage and identity, to which the long time scale hypothesis can be applied as it consists of (1) man-made structures that reflect past uses of lagoon resources and ESS, and (2) local traditions related to the lagoon, such as venetian rowing regattas.

3.2. Management implications

The SES perspective and the identification of these different categories of ESS can be useful to focus the management needs of the Venetian system.

Direct ESS' flow occurs without the need of human interventions, but at the same time they are subject to the impacts of other ESS' activities and external pressures. A dramatic example is the evolution of the lagoon's morphology, that showed a marked decrease of salt marshes' surface (more than 50% between 1927 and 2002) and deepening of tidal flats (Sarretta et al., 2010). Human activities such as channel dredging, water extraction (and subsequent subsidence), and clam fishing activities (and associated sediment resuspension) seem to have played a key role in fostering these observed changes (Sarretta et al., 2010). The important role played by the lagoon's morphology for several ESS, such as coastal erosion prevention, climate regulation and lifecycle maintenance (Table 3) suggests that a negative trend of these ESS is likely to have occurred in association with these morphological changes. A SES management aimed at avoiding the decline of direct ESS requires, first, to understand which environmental pressures negatively affect the flow of these ESS, and second, to control these pressures in a way that they not produce a decline in direct ESS. It should be noted from the examples above that some of the activities involved in mediated ESS can be included among these pressures (e.g. clam fishing activities). Therefore, the provision of these mediated ESS should be balanced in a way that the effects produced by their activities on direct ESS are minimized.

All the activities listed in Tables 4 and 5 potentially contribute to the "pressure side" of mediated ESS. An advantage of the SES approach is that it allows to handle also ESS which have a clear role as pressures, such as clam, maritime transport and tourism, because it provides a way to identify both their dependence on the ecosystem and their negative feedbacks on it. Considering the short time scale ESS, clam harvesting and navigation on the one hand are necessary for the provision of seafood and maritime transport ESS, but on the other hand, they are also recognized to negatively affect the lagoon morphology and thus other direct ESS. Similarly, these activities produce negative feedbacks on "their own" ESS, namely overexploitation in the case of harvesting and sediment erosion (which leads to channels siltation) in the case of navigation. Therefore, in the case of short term mediated ESS, management actions need to have a double role: (1) to control the negative feedbacks aiming at maintaining the processes generating these ESS, and (2) to minimize their externalities in order to maintain the processes underpinning other ESS.

According to the long time scale hypothesis, time lagged ESS are generally less sensitive to negative feedbacks, although they reflect the overall pattern of human-environmental relationships in the long term. In case of ESS to which both temporal hypotheses apply, on the one hand, the short term component implies the possibility of a negative feedback between the activities and their own ESS, but on the other, the importance of this feedback is "attenuated" by the long term component of the ESS: a landscape with degraded ecological state (short term component), such as the water bodies in the immediate surroundings of Venice, might be nevertheless attractive because of its co-evolved character (long term component). This means that a control of the activities may not seem an urgent matter from the perspective of a single ESS, making the role of an integrated perspective even more crucial for the identification of management needs. This becomes clear if we look at tourism or recreational navigation: although they respond weakly to a change in state of the ecosystem or to an excessive number of visitors, some management is needed to control the negative effects of high tourist or navigation pressure on other ESS.

4. Conclusions

The approach proposed in this paper allows to identify the role played by social-ecological elements in the generation and use of multiple ESS. Overall, this integrated view suggests that ESS can play a role in the implementation of an ecosystem-based management of SES. First, the knowledge deriving from the analysis of multiple ESS leads to the identification of the ecological processes and functioning to be used as management targets, that is, those processes and functioning that underpin ESS provision. This means that ESS can help to set management targets that focus on ecosystem processes and functioning, rather than only on ecosystem structures. Second, the added value brought by a SES perspective is that it allows to integrate social elements (such as actors, activities and governance systems) in the ESS analysis. In particular, it helps to clarify their role both as elements involved in ESS generation and as pressures on the system. An analysis such as that sketched here for the Venice lagoon sets the basis for further research on multiple ESS interactions, aiming at supporting the implementation of ecosystem-based management.

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Captions

Figure 1. Ecosystem services production and use defined using the first-tier variables of the social-ecological systems framework, distinguishing between "direct" flow type (A) and "mediated" flow type (B). The background colors indicate the supply side (light grey on the left hand side), the demand side (dark grey on the right hand side) and the flow (no color). The bold red arrows in mediated flow type indicate the impacts of the activities. Abbreviations: ESS = ecosystem services; Gov. system = governance system.

Figure 2. Short time scale (A) and long time scale ("time lagged") (B) hypotheses applied to ecosystem services with mediated flow type. In (B) the time lag occurs between the supply-side ("past SES") and the ecosystem services flow (present). The background colors indicate the supply side (light grey on the left hand side), the demand side (dark grey on the right hand side) and the flow (no color). The bold red arrows indicate the impacts of the activities. Abbreviations: ESS = ecosystem services; SES = social-ecological system.

Table 1. Ecosystem services' flow type and temporal hypothesis that apply to the ecosystem services groups of the Common International Classification of Ecosystem Services version 4.3 (Haines-Young and Potschin, 2013). The temporal hypotheses are referred to the specific case of human-modified social-ecological systems.

Table 2. Ecosystem services provided by the lagoon of Venice (adapted from Rova et al., 2015) classified according to Bohnke-Henrichs et al. (2013). The flow type and temporal hypothesis that apply to each ecosystem service are indicated.

Table 3. Elements of the social-ecological system involved in the production of ecosystem services with "direct" flow type in the lagoon of Venice. Abbreviations: ESS = ecosystem services; LV = lagoon of Venice.

Table 4. Elements of the social-ecological system involved in the production of ecosystem services with "mediated" flow type and short time scale hypothesis in the lagoon of Venice. The "governance systems" column includes the local authorities in charge of adopting and enforcing regulations; existing national and international regulations are not listed. Abbreviations: ESS: ecosystem services; R&L: recreation and leisure.

Table 5. Elements of the social-ecological system involved in the production of ecosystem services with "mediated" flow type and long time scale hypothesis in the lagoon of Venice. The grey background indicates the underlying processes with long time scale. Abbreviations: ESS: ecosystem services; R&L: recreation and leisure, SES: social-ecological system.

Table 1.

Section	Division	Group	Flow type		Temporal hypothesis	
			Direct	Mediated	Short time scale	Long time scale
Provisioning	Nutrition	Biomass		x	x	
		Water		x	x	
	Materials	Biomass, Fibre		x	x	
		Water		x	x	
	Energy	Biomass-based energy sources		x	x	
		Mechanical energy		x	x	
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	x		x	
		Mediation by ecosystems	x		x	
	Mediation of flows	Mass flows	x		x	
		Liquid flows	x		x	
		Gaseous / air flows	x		x	
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	x		x	
		Pest and disease control	x		x	
		Soil formation and composition	x		x	
		Water conditions	x		x	
		Atmospheric composition and climate regulation	x		x	
Cultural	Physical and intellectual interactions with ecosystems and land-/seascapes [environmental settings]	Physical and experiential interactions		x		x*
		Intellectual and representational interactions		x		x*
	Spiritual, symbolic and other interactions with ecosystems and land-/seascapes [environmental settings]	Spiritual and/or emblematic		x		x*
		Other cultural outputs		x		x*

* Cultural ESS can be characterized by a mix of both temporal hypotheses; the long time scale hypothesis can be dominant when these ESS depend upon human-modified landscapes with integrated human and natural elements.

Table 2.

Typology	Ecosystem services		Flow type		Temporal hypothesis	
			Direct	Mediated	Short time scale	Long time scale
Provisioning services						
	1. Sea food	1.1. Clam		x	x	
		1.2. Fish (artisanal)		x	x	
		1.3. Aquaculture		x	x	
Regulating and habitat services						
	2. Climate regulation		x		x	
	3. Disturbance prevention or moderation		x		x	
	4. Waste treatment		x		x	
	5. Coastal erosion prevention		x		x	
	6. Lifecycle maintenance		x		x	
Cultural services						
	7. Recreation and leisure	7.1. Tourism		x		x
		7.2. Recreational navigation		x		x
		7.3. Recreational fishing		x	x	
		7.4. Bird hunting		x	x	
	8. Cultural heritage and identity	8.1. Tangible cultural heritage		x		x
		8.2. Traditions		x		x
	9. Information for cognitive development			x		x
Other services						
	10. Maritime transport			x	x	

Table 3.

ESS	Function	Resource units	Underlying processes	Resource system	Actors	Governance system
Climate regulation	Carbon sequestration	Seagrasses and salt marshes	Productivity	Primary producers	Global population	Comitatone[*]
			Accretion, sediment deposition	Lagoon morphology		
Disturbance prevention or moderation	Tide attenuation	Emerged and intertidal structures	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology	All actors in the LV	Ex Venice water Authority, Comitatone[*]
Waste treatment	Nutrient burial	Seagrasses and salt marshes	Productivity	Primary producers	All actors in the LV	Comitatone[*]
			Accretion, sediment deposition	Lagoon morphology		
	Dilution and export	Overall morphology, tidal exchange	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology		
	Nutrient cycling trough the food web	Consumers	Inter-specific interactions	Lagoon communities		
Coastal erosion prevention	Biostabilization	Bottom vegetation	Productivity	Primary producers	All actors in the LV	Ex Venice water Authority, Comitatone[*]
	Wind energy dissipation	Emerged and intertidal structures	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology		
Lifecycle maintenance	Larval transport	Overall morphology	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology	-	-
	Migration, reproduction	Reproductive, migratory and nursery habitat	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology		

[*] inter-institutional committee for the safeguard of Venice and its lagoon, created under the Special Law 789/1984 ("New Interventions for the Protection of Venice").

Table 4.

ESS	Activity	Resource units	Underlying processes	Resource system	Actors	Governance system
Seafood - Clam	Harvesting effort	Clam juveniles' and adults' abundance	Larval settlement, growth	Clam population	Fishermen, consumers	Municipality
Seafood - Fish (artisanal)	Fishing effort	Fish adults' abundance	Spawning, nursery, growth	Fish community	Fishermen, consumers	Municipality
Seafood - Aquaculture	Harvest, juveniles' fishing effort	Fish juveniles' abundance	Spawning, nursery, growth	Fish community	Fishermen, consumers	Municipality
	Ponds management	Fishing ponds	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology		
R&L - Recreational fishing	Fishing effort	Fish adults' abundance	Spawning, nursery, growth	Fish community	Residents	Municipality
		Navigable channels (accessibility)	Hydrodynamic processes, biostabilization	Lagoon morphology		
R&L - Bird hunting	Hunting activities	Birds abundance	Migration and reproduction	Bird community	Residents	Municipality
		Navigable channels (accessibility)	Hydrodynamic processes, biostabilization	Lagoon morphology		
	Ponds management	Fishing ponds	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology		
Maritime transport	Navigation, channel dredging	Navigable channels	Bio-morphodynamic and hydrodynamic processes	Lagoon morphology	Port business, tourist business, tourists	Port Authority, Comitatone*

* inter-institutional committee for the safeguard of Venice and its lagoon, created under the Special Law 789/1984 ("New Interventions for the Protection of Venice").

Table 5.

ESS	Activity	Resource units	Underlying processes	Resource system	Actors	Governance system
R&L - Tourism	Visiting	Natural landscape (attractiveness)	Ecological processes	Lagoon ecosystem	Tourists, residents, tourist business	Local municipalities
		Cultural landscape (attractiveness)	Coevolution between man and lagoon	Past elements of the SES		
		Navigable channels (accessibility)	Hydrodynamic processes, biostabilization	Lagoon morphology		
R&L - Recreational navigation	Navigation	Natural landscape (attractiveness)	Ecological processes	Lagoon ecosystem	Residents	Venice municipality, Veneto Region
		Cultural landscape (attractiveness)	Coevolution between man and lagoon	Past elements of the SES		
		Navigable channels (accessibility)	Hydrodynamic processes, biostabilization	Lagoon morphology		
Information for cognitive development	Environmental education activities, participation	Natural landscape (attractiveness)	Ecological processes	Lagoon ecosystem	Residents, tourists	Local municipalities
		Cultural landscape (attractiveness)	Coevolution between man and lagoon	Past elements of the SES		
		Navigable channels (accessibility)	Hydrodynamic processes, biostabilization	Lagoon morphology		
Cultural heritage and identity - Tangible cultural heritage	Conservation, appreciation	Elements of tangible cultural heritage related to the lagoon environment	Coevolution between man and lagoon	Past elements of the SES	Residents, visitors	Soprintendenza belle arti e paesaggio*
Cultural heritage and identity - Tradition	Involvement	Local knowledge	Coevolution between man and lagoon	Past elements of the SES	Residents	Local municipalities

* local authority for the safeguard of the cultural heritage.