1

The Services Provided by Marine Ecosystems: Economic Assessments and Their Usages

1.1. Marine ecosystem services

1.1.1. *Ecosystem services*

According to the *Global Footprint Network*, humanity is, metaphorically speaking, contracting a considerable "debt" to the environment because our consumption is not sustainable in the long term. This results in an erosion of the natural capital on which we depend to feed, warm, hydrate and house ourselves, and to engage in leisure activities. To render this understandable, this organization has established, based on the use of the ecological footprint indicator, that humanity has consumed a year's worth of natural capital by a point in the year situated around the middle of August. Between this date and the end of the year, humanity lives on with a debt. To make this idea of ecological debt even more coherent, a large number of scientists and also stakeholders in civil society have turned to the notion of "ecosystem service".

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Ehrlich and Mooney [EHR 83] seem to have been the first to mention the notion of ecosystem service explicitly in an article entitled “Extinction, substitution and ecosystem services”. But it would be necessary to wait 14 more years to see this concept benefit from intense publicity through two widely-circulated publications: “Nature’s services: Societal dependence on natural ecosystems” [DAI 97] and “The value of the world’s ecosystem services and natural capital” [COS 97].

“The services that ecosystems offer are the benefits that people take from the ecosystems” (*Millennium Ecosystem Assessment*, [MEA 05, p. 9]). Ecosystem services contribute to human well-being from access to the essential goods that they provide (food, drinking water, etc.), the security that they offer (security against hazardous events, mitigation of the effects of climate warming, etc.) or simply the pleasure that they provide (observation of natural countryside, recreational activities in the open air, etc.).

The *Millennium Ecosystem Assessment* [MEA 05] carried out between 2001 and 2005 under the auspices of the UN and involving 1,360 scientists aimed to describe these ecosystem services precisely. The MEA is distinguished into the following four categories of ecosystem services:

– provisioning services equate schematically to the natural resources that are used through a process of extraction for mankind’s direct consumption;

– regulating services, which represent ecological functions enabling the productivity and resilience of ecosystems to be guaranteed;

– cultural services, which are both recreational (activities in the open air) and subjective in nature (spirituality, identity, etc.);

– supporting services, in conjunction with ecological processes, enable the renewal of life on Earth.

Through these categories, a new approach of the ecological and economic dynamics is available to us. The approach of using the idea of ecosystem services effectively allows us to put forward an unprecedented discourse on the conservation of biodiversity by underlining the trade-offs that are necessary to make between the different types of services furnished by biodiversity and means that the process of economic development and biodiversity conservation objectives are no longer systemically opposed. The notion of ecosystem service also provides a common semantic and theoretical base for different disciplines to work on the problem of interaction between the question of conservation and the question of development, and also a unit for assessment that allows interaction with decision-making bodies [DAI 08, RUF 09].

The MEA focused on ecosystem services but also on the pressures that are exerted on them. In effect, it underlines which human activities today cause the greatest threats to these services through their consumption of space, their exploitation of resources, the emission of greenhouse gas or the introduction of invasive species. Through their activities, people destroy a significant quantity of ecosystem services and thus, finally, their collective well-being (Figure 1.1).

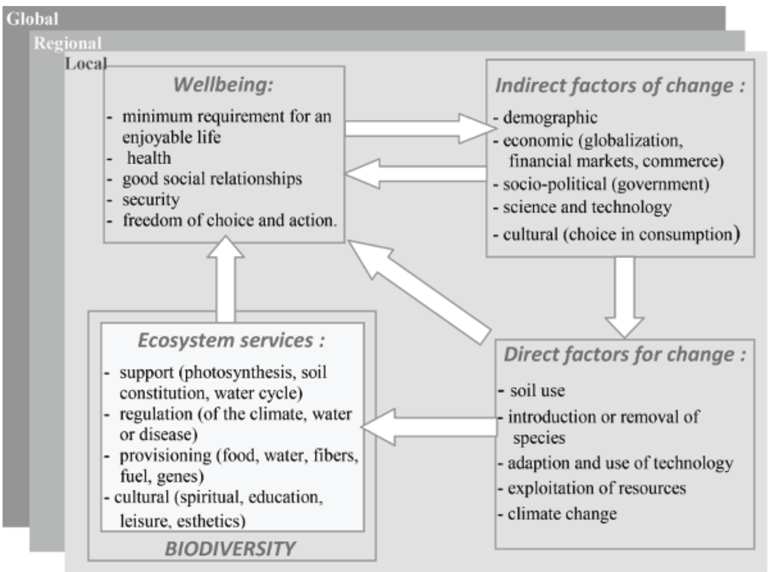

Figure 1.1. *The Millennium Ecosystem Assessment*

Category of services	Services	Evolutions
Services for provisioning or supply	Agriculture	+
	Farming	+
	Fishing	–
	Aquaculture	+
	Wild food materials	–
	Wood for construction	±
	Cotton, hemp, silk	±
	Firewood	–
	Genetic resources	–
	Biochemical products, natural medicines, pharmaceutical products	–
	Freshwater	–
Regulating services	Regulation of air quality	–
	Regulation of global climate	+
	Regulation of regional and local climate	–
	Regulation of the water cycle	±
	Regulation of erosion	–
	Purification of water and treatment of waste	–
	Regulation of diseases	±
	Regulation of parasites	–
	Pollinization	–
	Regulation of natural risks	–
Cultural services	Spiritual and religious values	–
	Esthetic values	–
	Recreation and ecotourism	±

"+" stands for an increase, "–" stands for a reduction and "±" stands for an increase in certain regions of the world and a drop in others. The support services are not mentioned here, as it is difficult to evaluate their evolution.

Table 1.1. *Evolution of ecosystem services between 1950 and 2005 [MAE 05, p. 46]*

1.1.2. *A historic balance leading to an inefficient exploitation of ecosystem services*

At the present time, man only uses a very small part of the services furnished by ecosystems. In effect, mankind has focused for the past 10,000 years on a single category of ecosystem services: the "provisioning services". The regulating and cultural services have always been neglected in favor of provisioning services. Thus, Table 1.1, which succinctly summarizes the evolution of the main ecosystem services over the course of the second half of the 20th Century, allows us to highlight that regulating services and cultural services have, for the most part, been neglected in comparison with provisioning services. Even if this tendency is easily justified by the need to keep up with the dramatic demographic increase that the world has known in the course of this period, the productivist model that is at its origin is today being pushed to its limits, and one of the main indicators that allows us to note this is the erosion of regulating services, which are also, indirectly, absolutely necessary for the human species.

This focus on ecosystem provisioning services has led to great inefficiency in the exploitation of biodiversity. Thus, most of the time, the strategy for biodiversity exploitation is based on the desire to maximize the production of particular provisioning services and neglect to take into account other categories of ecosystem service.

The marine ecosystem is a perfect example of this. A marine ecosystem will, in effect, be most often used to provide a single ecosystem service – fish for food – although this ecosystem is fundamental for a large number of ecosystem services for man – climate regulation, providing a habitat for species, a place for recreational activities, molecules or genes for the development of medication, etc.

The inefficient use of biodiversity and the services that it provides is one of the first factors that explains why our mode of development is not sustainable. The MEAs conclusions are indisputable. They emphasize that 60% of ecosystem services have decreased during the last 50 years. Among them, the renewal of fishing stocks and the production of freshwater seem to be most threatened. This degradation has been more significant over the course of the last 50 years than over the entire course of the rest of human history, and it will be even more significant in the 50 years to come. The ecosystem services that are disappearing are those of a collective or public nature and those that are not sold on the markets (recycling of waste, reproduction habitats for animals or countryside for mankind, etc.). Conversely, those that have been developed over the last 50 years are services of a private nature that can be sold on the markets and which today form the basis of the forestry, agriculture and aquaculture sectors.

This is why our systems for exploiting nature need to undergo radical change and take into account the ensemble of ecosystem services and most particularly communal or public cultural and regulating ecosystem services.

1.1.3. *Marine ecosystem services*

Ecosystem services with coastal habitats as their origin are so numerous that they could account for 43% of the ensemble of services furnished by the biosphere, although coastal ecosystems only represent 6.3% of the globe's surface [COS 97].

For France, the relative importance of ecosystem services associated with the sea and the seashore for the national economy can be evaluated as an initial approximation via the source revenue generated by these areas. This initial approximation is particularly simple for provisioning and recreational services. Thus, the sea product industry generated an added value of 2.363 billion euros in 2007, whereas the coastal tourism industry generated 9.220 billion euros for a total added value of activities depending on marine ecosystems state 27.6 billion euros (*Données économiques maritimes 2009*). The maritime economy is moreover the source of 486,000 jobs, including 242,558 linked to the tourism sector. An important part of this wealth is linked to the provision of services by marine biodiversity.

It is in effect the more or less direct origin of numerous ecosystem services such as:

– bioturbation, primary production or the water cycle (supporting services);

– the renewal of fisheries, the production of aragose (derived from algae) or renewable energy (provisioning services);

– the control of erosion and silting, the recycling of waste and the control of pollution (regulating services);

– visual tourism, recreational fishing or simply bathing (cultural services).

By relying on a review of the literature, it is possible to identify 74 services directly linked to marine and coastal biodiversity, including seven for support services, 20 for provisioning services, 27 for regulating services and 18 for cultural services ([COS 97, DUA 00, HOL 99, JAC 01, KAI 11, KRE 05, MEA 05 (Chapters 18 and 19), RON 07, SOL 04, WOR 06]; Tables 1.2–1.5).

Support services	Source of service's production (structure or function)
Bioturbation	Benthic invertebrate species biodiversity and fish that carry out activities in the substrate (spawning, searching for food, sheltering)
Primary productivity	Genetic and species biodiversity through a complementarity effect of redundance and selection
Secondary productivity	Genetic and species biodiversity through a complementarity effect of redundance and selection
Cycle of nutrients and mineralization	Gas fixing and decomposition of organic matter by species biodiversity, fundamental to the nitrogen production necessary for primary production
Water cycle	Oceans as an essential base of the water cycle
Creation of habitats for animals and vegetables (formation of soils)	Biodiversity of soil invertebrates, microorganisms in the soil, nitrogen fixing plants, plants and animals that produce organic waste
Oxygen and carbon cycle	Oceans as an essential base of the oxygen and carbon cycles

Table 1.2. *Marine ecosystem support services and their sources (n = 7)*

Provisioning services	The service's source of production (structure or function)
Renewable energy	Marsh, swell, current, oil from microalgae
Fish for food	Genetic and species biodiversity helps limit the risks of extinction for fisheries as well as the variability of takings and facilitates the renewal of fisheries in crisis
Crustaceans for food	Abundance and diversity of crustaceans
Molluscs for food	Abundance and diversity of mollusks
Algae and derivatives (agarose) for food	Abundance and diversity of algae
Materials for construction	Abundance and diversity of primary materials necessary for construction (marine sediments, sand and stones, nodules)
Materials for clothing	Abundance and diversity of primary materials necessary for clothing (skins, viscera, etc.)
Non-renewable energy	Abundance and diversity of petrol and gas deposits
Spat (for farmed shellfish)	Spat biodiversity
Fish meal for animal food	Fish biodiversity
Fish oil for animal food	Fish biodiversity
Fertilizer	Biodiversity enabling organic fertilizers to be produced (algae, kelp, fish bone, etc.)
Molecules for pharmaceutical products	Molecular diversity of renewable and non-renewable resources in coastal and marine zones
Chemical models	Biodiversity possessing the necessary characteristics to provide organisms with tests
Genetic resources	Marine and coastal genetic biodiversity
Materials for artistic productions (pearls, mother of pearl, etc.)	Biodiversity that gives rise to the production of materials useful for artistic productions
Support for the transport of merchandise and passengers	Oceans and seas as supports for marine routes
Organisms with tests	Biodiversity of organisms possessing the necessary characteristics to provide organisms with tests
Molecules for industrial and cosmetic products (glues and creams)	Molecular diversity of renewable and non-renewable resources from marine and coastal zones
Freshwater storage (estuaries)	Estuaries in good ecological state

Table 1.3. *Marine ecosystem provisioning services and their sources (n = 20)*

Regulating services	The service's source of production (structure or function)
Dynamic of soil fertility	Biodiversity of soil invertebrates, soil microorganisms, nitrogen-fixing plants, plants and animals that produce organic waste
Control of the phytoplankton dynamic	Diversity and abundance of zooplankton
Control of the zooplankton dynamic	Diversity and abundance of zooplanktivores
Control of the dynamic of fish populations	Diversity and abundance of piscivores
Maintenance of hydrological equilibrium	Water cycle assured by the oceans and coastal habitats
Spawning grounds for species	Biodiversity of seagrass, wetlands, salt marshes and oyster beds
Refuge zone for species	Diversity of marine and coastal habitats
Resilience in the face of natural or human disturbances	Genetic and species biodiversity through the effect of complementarity, redundance and selection
Control of pathogens and harmful materials	Species biodiversity via the role of populations of predators and filtering organisms
Regulation of herbivores	Species biodiversity via the role of populations of predators
Mitigation of the eutrophization effects	Species biodiversity via the role of filtering organisms
Control of pollution and detoxification	Species biodiversity via the role of filtering organisms
Transfer of energy from the substrate to higher trophic levels	Species biodiversity that makes up the food chain
Control of waves and energy currents	Diversity of marine and coastal habitats that act as buffer zones (seagrass, dunes, etc.)
Control of erosion and silting	Seagrass biodiversity
Mitigation of the effects of rising sea level and floods	Species biodiversity in vegetation (mangroves)
Protection against ultraviolet	Oceans and seas have an important role in the biogeochemical cycles and shelter microorganisms useful for protection against UV

Air purification	Oceans and seas have an important role in the oxygen and carbon cycles
Regulation of the global climate	Oceans stabilize the quantity of CO_2 in the atmosphere and regulate the temperature of the global atmosphere
Regulation of local climates	Oceans stabilize the quantity of CO_2 in the atmosphere and regulate the temperature of the local atmosphere
Retention of soils	Root species biodiversity
Control of water turbidity	Species biodiversity via the role of filtering organisms
Regulation of water quality	Species biodiversity via the role of filtering organisms
Control of human diseases	Microbiological diversity
Transport of species	Currents and tides
Recycling of waste	Species biodiversity of soil invertebrates and aquatic microorganisms
Regulation of salinity	The salinity levels of coastal zones are dependant on fluxes of freshwater from land
Carbon stocking	Biodiversity of phytoplankton, macroalgae and seagrass

Table 1.4. *The marine ecosystem regulating services and their sources (n = 27)*

Cultural services	Source of the service (structure or function)
Feelings of well-being	Marine and coastal ecosystems
Support for "traditional" jobs for coastal populations	Abundance of resources on which local communities depend
Cultural identity of coastal populations	Natural coastal countryside in connection with traditional practices
Views (coastal countryside)	Countryside biodiversity
Ecotourism	Countryside biodiversity
Visual tourism (whales, dolphins)	Animal biodiversity
Bathing	Biodiversity of filtering species
Walking	Countryside biodiversity

Recreational fishing	Biodiversity in species valued for recreational fishing
Pleasure sailing	Seas and oceans devoid of very large floating objects (invasive species, macrowaste, other boats) and without excessive eutrophization
Deep-sea diving	Marine biodiversity
Surfing and windsurfing	Waves and wind
A source of inspiration	Countryside biodiversity
Support for religious beliefs	Sacred natural places and objects
Preservation of marine and coastal biodiversity for ethical reasons	Marine and coastal biodiversity
Source of knowledge	Marine and coastal biodiversity
Scientific usage (a marine model for basic research)	Marine and coastal biodiversity
School excursions	Marine and coastal biodiversity
Monitoring of global changes affecting the natural environment	Monitoring of phenological characteristics and species distribution

Table 1.5. *Marine cultural ecosystem services and their sources (n = 18)*

1.2. The monetary evaluation of ecosystem services

1.2.1. *The factors that motivate demands for monetary evaluation*

1.2.1.1. *The demands for monetary evaluation of ecosystem services in an institutional framework*

From the 1990s, the evaluation of ecosystem services has been recommended as a tool to aid decision making on the question of biodiversity, and this applies within a variety of governing bodies.

Different international organizations therefore promote the use of economic evaluations of ecosystem services. In its IV/10 decision, the Conference of the Parties (COPs) at the Convention on Biological Diversity (CBD) considers that "the economic evaluation of biological diversity and biological resources constitute an important tool for well-targeted and well-distributed economic incentives" [CON 98]. In its principle 4, the COPs decision VII/11 calls again for "the incorporation of the ecosystem and social aspects of goods and services resulting from ecosystems in decisions relating to national compatibility, politics, planning, education and the management of resources" [CON 04, p. 217].

In 2007, a report on biodiversity from the Parliamentary Office for the assessment of scientific decisions [LAF 07] underlined that "the sustainable development of biodiversity is a necessity and an opportunity. Two axes are profiled in this domain: the remuneration of services provided by ecosystems and the exploration of a reservoir of goods that could be a key tool for the fourth industrial revolution …: it is necessary to evaluate ecosystem services monetarily and to provide economic sanctions for their destruction for private ends".

More recently, the OECD (Organization for Economic Co-operation and Development) has recalled that "appropriate economic evaluations of biodiversity and its loss will result in better, more efficient decisions, and can prevent inappropriate compromises" [OEC 12, p. 191].

From the point of view of many political decision makers, the monetary evaluation of biodiversity seems to have become a tool that could better help protection of biodiversity, and this point of view is not unique to economists. Conservation biologists, and more broadly environmental non-governmental organizations, defend this approach to show that biodiversity "is worth" something. Public administrative bodies in charge of environmental policies highlight this approach to allow using new financial methods or for optimizing their projects for public development. Economists seek to place monetary units on ecosystem services to promote work on the question of biodiversity and to put in place tools for market regulation. For most institutional bodies, it ultimately involves the most used standard of measurement in a society with a market economy and we cannot avoid it when discussing the conservation of biodiversity.

To resume, the key argument to justify granting a monetary value to biodiversity is that if an ecosystem service has no monetary value, it will at best remain unused and at worst will be wasted. And it is evident that public representations are strongly influenced by the monetary standard, which is the most used indicator for transactions in our market society. Thus, the monetary evaluation of ecological phenomena would offer a strong tool for argument in societies with market economies.

Then, from a very pragmatic point of view, the question of the monetization of biodiversity and the services that it provides seem essential in many cases.

First, for insurance, because the monetary value enables the economic risks associated with the destruction of biodiversity to be taken into account, monetization should in particular enable us to evaluate the indemnity linked to external factors (e.g. pollution by hydrocarbons or increased risk of flooding), but also, possibly, premiums for good practice.

Then, for fiscal policies, monetization seems necessary for putting in place systems for taxation and subsidies that should ideally reflect the societal costs and benefits associated with the evolution of ecosystem services, with a view for creating the necessary incentives and leading to changes in behavior.

Finally, for the choice between public or private investments, including the question of biodiversity in investment, decisions require the ability to carry out cost-benefit evaluations for the different projects in order to be able to compare and prioritize them.

For the “market” finally, since biodiversity has a economic value, it can give rise to commercial exchanges, can be valued and can inspire investment in its preservation and restoration.

1.2.1.2. *The regulatory effect of the monetary evaluation of ecosystem services*

There are two opposing theories concerning the regulatory effect of establishing a price for biodiversity. According to Timothy Swanson’s analysis [SWA 94], a high price would be an incitement to conserve a natural renewable resource since it is imperative not to “kill the goose that lays the golden eggs”. On the other hand, according to Clark’s analysis [CLA 73], the placing of a higher price on renewable natural resources would trigger a rapid and unsustainable use of the latter. In particular, practices on the luxury market can be observed, which do not necessarily respond to conventional economic rules. So, the increasing rarity of a consumed species (for food, collection, etc.) will cause the costs of sourcing it, and therefore the market cost, to increase this without causing a drop in demand. There is an anthropogenic "allee effect" with which we can underline the value that mankind attributes to rare species and which accounts for their exploitation down to the last individual Franck Courchamp *et al.* [COU 06]. Gault *et al.* [GAU 08] emphasize, moreover, that this behavior is based above all on the perception of rarity and not on real biophysical rarity.

In this respect, the two theories are exactly the same. In effect, high or low prices can have inverse effects depending on the contexts in which they occur. The important element in this context is access regulation. So, in cases where a natural renewable resource has a strong monetary value, the consumers who benefit from this exclusive access will tend to seek a management method that assures the effective renewal of this source of revenue. On the other hand, if access is not secure, or indeed free, then it is rational to use it down to the last unit of resource so long as there is a solvent demand for this resource.

1.2.2. *Monetary evaluation methods and their limits*

1.2.2.1. *The values of ecosystem services*

To respond to institutional demands concerning the monetary value of biodiversity, the *The Economics of Ecosystem and Biodiversity* (TEEB) was launched in 2007 (www.teebweb.org) through the initiative of the G8 and five developing countries. The goal of this work was to achieve a better understanding of the economic benefits resulting from biodiversity. The TEEB "promotes the integration of economic values for biodiversity and the services provided by ecosystems in the decision-making process" [TEE 10, p. 27].

But the economic evaluation of ecosystem services began much earlier than the TEEB, which was instead an opportunity to take stock of what already existed. Thus, Laurans *et al*. find 5,028 references issued from 1,419 sources corresponding to the following key words: "evaluation" and "ecosystem services", "natural capital", "environment" and "evaluation", "biodiversity" and "evaluation" and "total economic value"[1] [LAU 13, p. 210].

For marine ecosystems, a quick search on ScienceDirect using the key words "ecosystem services", "evaluation" and "marine" returns around 1,026 references[2].

The creation of economic evaluations of marine ecosystems is not only found in the academic literature. So, governments and governmental agencies, non-governmental organizations and *think tanks* also produce economic evaluations. In order to collect these evaluations, the database *Marine Ecosystem Services Partnership* (www.marineecosystemservices.org/explore) aims to collect existing economic evaluations on marine ecosystems, including the gray literature.

The idea of putting a price on ecosystem services to take account of the consequences of environmental degradation on social well-being is based on a utilitarian principle [BON 07]. This approach depends on the notion of sustainability, which enables us to derive an economic value reflecting individuals' attachment to the different goods and services to which they have access. Thus, according to a economic value, it implies that environmental breakdown has an impact on the utility functions of individuals. It is this impact that is important to measure in monetary terms in order to offer adapted price signals.

To do this, a classification of the different forms of value that biodiversity can take is required [BON 07]:

– the use value equates to a direct and current use of the asset;

1 Results on 31/01/2012, the three databases ISI (access via *Web of Science*) and Elsevier's Scopus have been consulted, key words in English.
2 Results on 13/12/2013, carried out on ScienceDirect Elsevier, key words in English.

– the non-use value equates to a direct, future use of the asset by the present generation (option value) or for future generations (legacy values);

– the existence value equates to the value of the asset for its own sake, regardless of usage.

The sum of these three types of value corresponds to the total economic value of biodiversity (Figure 1.2).

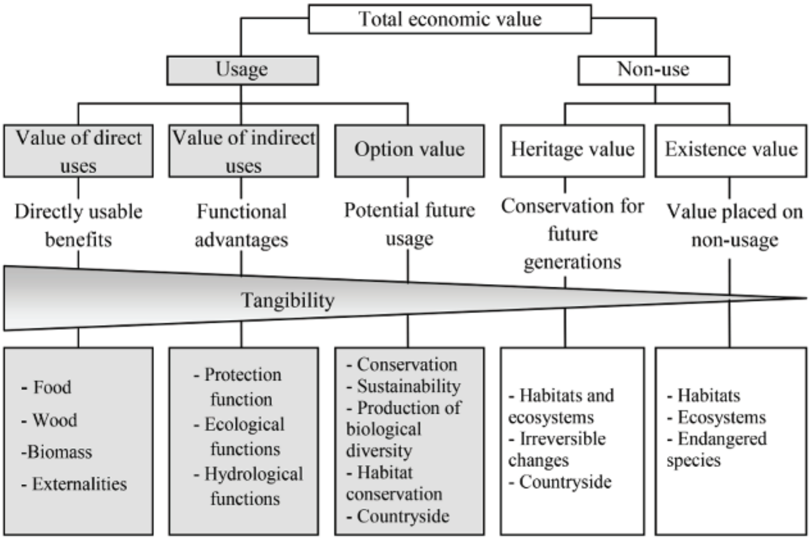

Figure 1.2. *The total economic value of biodiversity and ecosystem services (source: Centre d'analyse stratégique, 2009)*

It is evidently considered possible to evaluate monetarily the benefits provided by ecosystem services and the biodiversity that generates them – hence the desire to give them a monetary value. However, to carry out the monetization of ecosystem services is very much complex.

If provisioning services are associated with exploited resources for which there is a market price, the three other categories of services provided by the ecosystems are not, for much of the time, the object of any commercial transaction and for this reason cannot be measured in monetary terms using a market price. Also, different methods have been developed by environmental economists to try, in spite of everything, to attribute a monetary value more or less directly to these ecosystem services.

1.2.2.2. *Assessment methods for regulating services and cultural, recreational services*

Where regulating services are concerned, methods often rely on real market processes: by estimating the contribution of regulating services to the creation of products and services sold on the markets (for example the contribution of breeding habitats for the fish that make up fishing stock); by estimating the cost of restoration or damage prevention to regulating services important for society (for example the cost of putting in place a dyke to replace the protecting function furnished by destroyed coral ecosystems). It is a question, above all, of creating a link between natural habitats and the production of ecosystem services, directly or indirectly useful to mankind.

For recreational cultural services, environmental economists have adopted the reconstitution method for market price. The reconstitution of market price is based either on the travel costs method or on the hedonic pricing method. The travel costs method consists of evaluating the time that some individuals and groups are prepared to "spend" to benefit from the services offered by a particular ecosystem [APP 04]. The hedonic pricing method is based on the hypothesis that some goods – notably housing – have a value that does not depend only on the characteristics of the object itself, but also on the natural environment in which the latter is situated [TRA 08].

Although these assessment methods carried out using preferences revealed by the market are relatively robust, they are hampered by two limitations.

The first is the cost of developing them, since they require information to be collected on site and since they use a large quantity of very precise data and require the use of relatively sophisticated econometric models to be able to put forward a robust assessment.

The second limit of these methods is that they do not enable us to take account of values for the non-use of biodiversity, nor the option values, and only give a very vague suggestion of the values for indirect use. Indeed, the values of the ecosystem services associated with biodiversity seem to be linked largely to non-uses or indirect uses (Figure 1.2; [ENV 09, HEA 00, NAE 09]). This is why environmental economists have suggested creating hypothetical markets on which agents can express preferences that will not necessarily be linked to the uses of biodiversity, but to the value accorded to them for their own sake.

1.2.2.3. *The methods for assessing values for the non-use of biodiversity*

Today, the most used method for assessing the non-use values of biodiversity in monetary terms is the contingent valuation method (CVM) [BON 07]. The CVM is based on preferences concerning the conservation of biodiversity declared in the context of a hypothetical market. To make this hypothetical market more coherent, interviewees were asked how much they would be willing to receive in return for one or several units of particular components of biodiversity destroyed or, conversely, how much they would be willing to pay to improve the restoration of one or several units of these same components. Thus, through the means of statistical analyses enabling a large number of variables to be taken into account relative to the context in which these preferences are expressed, as well as the personal parameters of the respondent, it is possible to accord values to the biodiversity components concerned. The advantage is evidently that individuals can express preferences for the biodiversity components that do not arise from any direct use but simply to the fact that they attribute a value to biodiversity for its own sake.

These methods are however the source of significant controversies on the subject of their capacity to estimate non-use values [OCO 99, HEA 00]. Milanesi [MIL 11] has published an article that summarizes these limits. His article emphasizes a publication by Diamond and Hausman dating from 1994 [DIA 94]; these authors suggest testing the coherence of the CVM by evaluating its precision, credibility and reliability using experimental methods. If the precision of the method is debatable, since it leads to considerable variability in the estimations, the authors do not consider this point to be a prohibitive problem for this method, since it is possible to increase the size of the sample up to the point where the confidence level is good (even if that has a considerable cost). Similarly, if the CVM generates important biases that can limit its reliability, it is technically possible to control these biases using a strict protocol for the enquiry and statistical corrections *ex post*. The credibility of the CVM seems, however, to pose a fundamental problem for the authors, who believe that the individuals surveyed are not responding to the question put to them since they do not understand, in the majority of cases, a trade-off based on a logic of substitution between the environmental good considered and their revenue. The responses reflect (1) an attitude that relates to a public good and not really to the question [KAH 94], (2) a feeling of moral satisfaction [KAH 92], (3) a personal cost–benefit calculation concerning the project or the regulations in question [PAY 93], or indeed (4) a reaction that seeks, for example, to “punish the polluter” [MIL 11, p. 13].

1.2.2.4. *The monetization frontier*

The factors outlined above explain why it is today accepted that if the values of the direct and indirect uses of the numerous ecosystem services provided by biodiversity are approached in a reliable manner, where these data exist, the values of non-uses (cultural and spiritual services) or those associated with the elementary processes of the reproduction of living organisms (supporting services) are, however, difficult to estimate for technical (a less tangible and familiar value in the eyes of individuals) and ethical (can one give a value to the elements that make up life on Earth [NOR 98]?) reasons.

There is therefore a limit beyond which the monetization of biodiversity and the services that it provides makes little sense [OCO 99]. The opportunities for monetary valuation concerning the non-commercial environmental functions become weaker; the broader the scales on which these evaluations should be carried out, the larger the complexity of the phenomenon to be evaluated and the greater the diversity of the values that can be attached to them (notably the non-use values). This limit to monetization should enable us "to distinguish clearly on principle what arises from deliberation (from social and political debate) and what can be handled by economic analyses" [VAN 02, pp. 439–440].

It therefore seems fairly logical to discard the non-use values in the assessments and simply seek to provide information on the value of ecosystem services reflecting specific uses, benefiting specific economic actors, on a defined/restricted spatial and temporal scale [HEA 00]. The gain thus obtained from the point of view of the reliability of the assessments allows us, however, to abandon the goal of aggregating the values and obtain a total economic value for biodiversity and the ecosystem services that it provides, without which the latter will mechanically underestimate the real value of the ecosystem services associated with the conservation of biodiversity.

A multi-criteria approach to the value of biodiversity and ecosystem services seems from this point best adapted to provide a broad range of indicators for ecosystem services based on ecological, economic or social information, which makes sense to a wide variety of actors. This tool can be used in collective decision-making processes and does not reduce this process to a cost–benefit analysis, enabling an optimal choice to be made in which all forms of value would be reduced to a single monetary standard.

1.3. The monetary evaluation of ecosystem services: some results for marine ecosystems

As mentioned above, the program entitled *Marine Ecosystem Services Partnership* (www.marineecosystemservices.org/, 11 December, 2013) has the objective of structuring reflections on an international scale around the evaluation of marine ecosystem services. On 11 December, 2013, it had collected 1,940 evaluations of marine ecosystem services corresponding to 893 studies.

Our analysis is based on a sample of 114 studies (containing 355) issued from this database reveals a considerable amount [MAR 13]. One-third of the studies evaluate food provisioning services (56 assessments, being 15.78% of the total) and services linked to tourism, recreational activities as well as esthetic values (63 assessments, being 17.75%, of which the vast majority focus only on tourism). The control of erosion and the protection of the shore represent 10.99% of the values produced by these studies; 5.64% of the assessments focus on soil formation (2.82%) and genetic resources (2.82%). Other ecosystem services form the object of 11–27 economic evaluations (Figure 1.3).

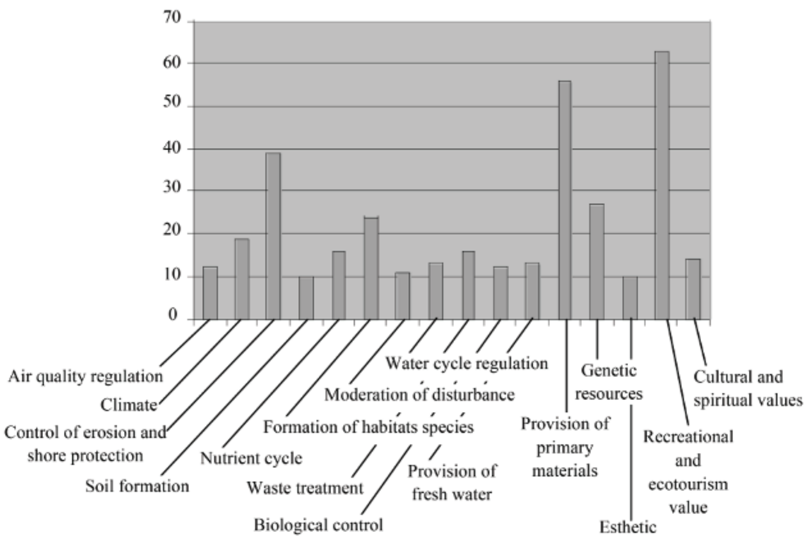

Figure 1.3. *Types of ecosystem services evaluated monetarily [MAR 13]*

The over-representation of provisioning services (food and construction materials) and cultural and recreational services can be explained by the existence of market prices or tangible indicators concerning the economic impact of these activities (visits, jobs, net benefits, etc.) making an economic evaluation easy to carry out. We can also underline the presence of a regulating service that stands out: the service of controlling erosion. This service is well represented since it is rather easy to measure the cost of coastal erosion, in monetary terms, in comparison with the lost real-estate value. Two other regulating services are frequently evaluated: refuge habitats and climate regulation. The former is necessary for the renewal of exploited fishing stocks. The second is in line with carbon storage, which can be translated into a monetary value due to the existence of a market for "carbon tons".

These results can be put into perspective using a literature review carried out by de Groot *et al.* [DE 12] in which the authors analyze 665 monetary values calculated for 22 ecosystem services furnished by 10 biomes. The results are presented in Table 1.6.

Within the 10 biomes presented, the marine and coastal biomes (coral reefs, coastal systems and wetlands) have higher total economic values. The highest values are those of regulating services. The regulation of erosion is the service that reaches the highest monetary value for coral reefs and coastal systems. In the case of coastal wetlands, it is the waste treatment service that has the greatest economic value. Conversely, the total economic value of the marine biome *stricto sensu* is the least significant of the 10 biomes. It should be noted that only 14 estimations (out of 665) were carried out for this biome, which concerns only five ecosystem services (for the other biomes, 10–17 ecosystem services are evaluated). This can be explained by the difficulties inherent in the monetization exercise on an area that is still little known.

To go further in the analysis, it is interesting to see how these values have evolved over time, by looking back at estimations conducted in 1997 by Costanza *et al.* and which were based on the same calculation methods described in the work of de Groot *et al.* ([MON 13]; Figure 1.4).

	Seas	Coral reefs	Coastal systems	Coastal wetlands	Inland waters	Fresh water (rivers, lakes…)	Tropical forests	Temperate forests	Wood	Grassland
Provisioning services	102	55724	2396	2998	1659	1914	1828	671	253	1305
1. Food	93	677	2384	1111	614	106	200	299	52	1192
2. Water				1217	405	1808	27	191		60
3. Primary materials,	8	21528	12	358	425		84	181	170	53
4. Genetic resources		33048		10			13			
5. Medical materials				301	114		1504		32	1
6. Ornamental materials		472								
Regulating services	65	171478	25847	171515	17364	187	2529	491	51	159
7. Regulation of water quality							12			
8. Climate regulation	65	1188	479	65	488		2044	152	7	40
9. Moderation of disturbance		16991		5351	2986		66			
10. Hydraulic regulation					5606		342			
11. Waste treatment		85		162125	3015	187	6	7		75
12. Control of erosion		153214	25368	3929	2607		15	5	13	44
13. Nutrient cycle				45	1713		3	93		
14. Pollinization							30		31	
15. Biological control					948		11	235		
Habitat services	5	16210	375	17138	2455	0	39	862	1277	1214
16. Plant nurseries		0	194	10648	1287		16		1273	
17. Genetic diversity	5	16210	180	6490	1168		23	862	3	1214
Cultural services	319	108837	300	2193	4203	2166	867	990	7	193
18. Esthetic value		11390			1292					167
19. Recreation	319	96302	256	2193	2211	2166	867	989	7	26
20. Inspiration		0			700					
21. Spiritual experiences			21							
22. Cognitive development		1145	22					1		
Total monetary value	**491**	**352249**	**28917**	**193845**	**25682**	**4267**	**5264**	**3013**	**1588**	**2871**

Table 1.6. *Summary of monetary values for each ecosystem service per biome (values in int.$/ha/year, 2007 price levels) [DE 12, p. 55]*

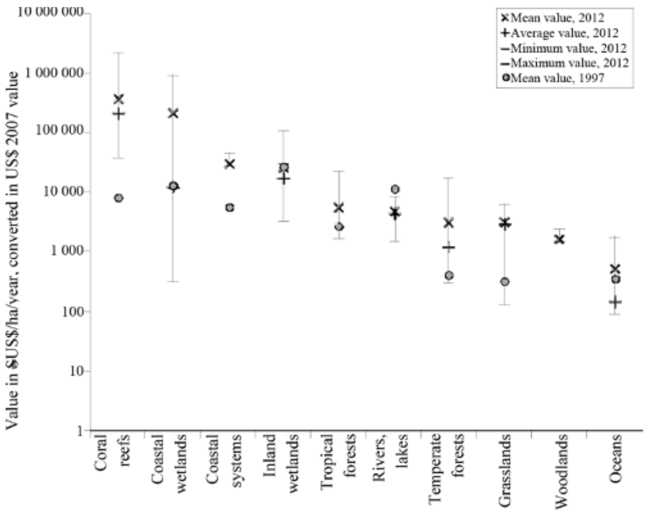

Figure 1.4. *Changes in monetary values observed between estimations by Costanza et al. in 1997 and those of de Groot et al. in 2012 (in US$ 2007)*

In Figure 1.4, it is shown that in 15 years, the changes in the values of ecosystem services provided by different types of natural habitat, representing the natural capital present on the Earth, have been very significant.

This variation seems to be the result of specific social and institutional factors. The article by de Groot *et al.* emphasizes, for instance, that the explosion in the value of ecosystem services associated with coral reefs (multiplied by a figure between 10 and 100 depending on the estimations) is mainly linked to increased recognition of the role played by this ecosystem in mitigating the phenomena of erosion. Thus, it is the growing perception of the risks associated with climate change and the consequences of the latter in terms of extreme events that has led to a much greater value to be attributed to all the habitats that can mitigate its effects. In the same way, the increase in the value of the climate regulating service seems to be a simple artifact of the creation of a carbon market (even if this value is dropping). The importance of this type of result is that it allows us to emphasize that the evolution of the value of ecosystem services is above all a question of perception and institutional changes, but not a consequence of the evolution of the ecosystem's dynamic as such.

A third and last level of analysis is the comparison of investment in the ecosystems and the return on the investment generated by the services whose creation they enable. This can be carried out by estimating ecological restoration costs and the benefits associated with ecosystem services thus produced. *In fine*, this should enable the calculation of internal rates of return (IRR) and benefit–cost ratios (BCR) for restoration projects for ecosystems.

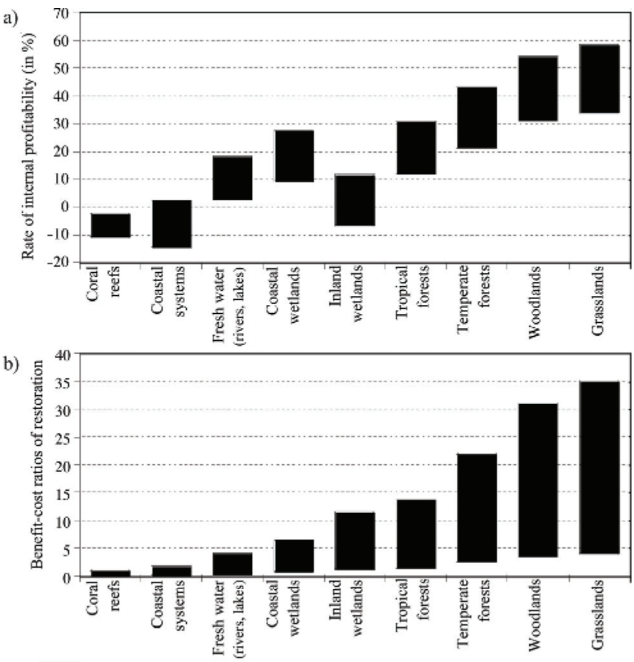

Figure 1.5. *a) Internal rate of return at 100% of the highest restoration costs reported and 30% of profits; the top of the bar represents the best case scenario (analysis conducted at 75% of the highest reported restoration costs and 75% of profits). b) Benefit–cost ratios of restoration (the bar represents the size of the values; the bottom of the bar, the worst case scenario [analysis conducted at 100% of the highest reported restoration costs, 30% of profits and a rate of social discount of 8%]; the top of the bar represents the best case scenario [analysis conducted at 75% of the highest reported restoration costs, 75% of profits and a rate of social discount of –2%]) in the nine main biomes based on 316 case studies over 20 years with management costs equivalent to 5% of capital [DE 13, p. 1290]*

Using 94 studies relating the restoration costs for ecosystems and 225 studies calculating the total economic values of the latter, de Groot *et al.* [DE 13] have calculated the IRR and BCR of restoration projects for nine biomes (Figure 1.5). The coral reefs and coastal systems have the weakest IRR and BCR, whereas their total economic values are most significant. This result is explained by the exceedingly high restoration costs.

Conversely, the grasslands have a relatively weak total economic value (Figure 1.4) but the restoration projects for these biomes offer significant returns on investment (Figure 1.5). The authors emphasize that "the restored ecosystems that offer the best return in absolute value [that is to say based on the current net value] are coastal wetlands and wetlands situated inland" [DE 13, p. 1289].

1.4. The effective use of the assessment of benefits associated with ecosystem services

1.4.1. *The expected uses of monetary evaluation*

1.4.1.1. *The different possible uses of monetary evaluation*

A recent study on the use of the monetary evaluation of ecosystem services lists three main types of possible use: decisive, technical or informative [LAU 13]:

– the economic evaluation of ecosystem services is decisive; when faced with different alternatives, it helps the decider to make a choice in an *ex ante* fashion. The authors distinguish three subcategories. Economic evaluation can help to make trade-offs, notably via a more effective inclusion of ecosystem services in economic analyses. The economic evaluation can also be used as a decision-making tool, promoting an open debate between the parties taking part in a project. Finally, economic evaluation can help to "prioritize conservation efforts" [LAU 13, p. 212];

– economic evaluation can also be used prior to a project or decision to calibrate the instruments that will be used in this framework. This technical use can serve to define compensation levels or to fix prices (e.g. entrance tickets for a park) or taxes on a destructive activity;

– finally, economic evaluation can have an informative end. It can help develop awareness campaigns and used to justify a position or demonstrate the validity of an option, even as a means of verification. Lastly, economic evaluation can serve as an indicator for monitoring.

Other authors focus on the question of how the information is used and on scientific knowledge in public decision making (see, for example, [BAU 12, HER 06, WEI 79]). A new category emerges from this literature, which refers to a strategic use of scientific information. In this case, scientific knowledge (such as, for example, the results of an economic evaluation of services provided by a marine ecosystem) is subject to a "process of perversion of information" [BAU 12, p. 40]. The scientific information can therefore be used to "confirm, or infirm, already acquired knowledge and to legitimate decisions in an *ex post* way" [BAU 12, p. 40]. The scientific information can be used symbolically, in order "to reassure stakeholders by demonstrating the particular importance attached to the objectivation of decisions" [BAU 12, p. 40]. Finally, the supply of new knowledge can be used tactically or procedurally to justify inaction or a delayed strategy.

1.4.1.2. *The use of economic evaluations of ecosystem services*

Despite a large number of applications of economic evaluation methods for ecosystem services, their use as an aid to decision making has had relatively little success.

Concerning the assessment of biodiversity, a study carried out by the OECD concluded that "so far [it] has not achieved the same level of popularity in policymaking as it enjoys in academic circles" [OEC 01, p. 25]. Other studies arrive at the same conclusions (see, for example, [PEA 98, PEA 00, TUR 07]). In 2007, Turner emphasized an "at best 'patchy' take up of CBA by policy makers" [TUR 07, p. 4].

In a study of the academic literature dealing with the economic evaluation of ecosystem services, Laurans *et al.* show that there is after all little information on their use [LAU 13]. Most of the academic papers only briefly referred to the question of use. Of the 313 publications analyzed, only eight relate precisely the role that assessment played in the decision-making process.

Concerning the assessment of marine ecosystem services specifically, a recent study reaches similar conclusions [MAR 13]. On the basis of both academic and gray literature, the authors show that the majority of studies refer to a potential use of economic evaluation in decision making. Only seven references (over 114 studies) report an effective use of the results of evaluation in a decision-making process.

These results, however, only give a partial account of what is at play. With decision-making processes being complex and difficult to study, it is possible that the question of how assessments are used is rarely considered in the literature focusing on monetization alone.

1.4.1.3. *Monetary evaluation: a tool for rationalizing policies or a strategic tool?*

Evaluations of the benefits associated with the restoration of some ecosystem services can also be used in a regulatory framework. As an example, the development of the Water Framework Directive led to the carrying out of cost–benefit analyses on projects for restoring "a good ecological state" (GEE) of land water with a view to knowing if the social costs associated with these projects were not too high in relation to the social benefits expected from these measures. If this was the case, then it could be concluded that there was a problem of a "disproportionate cost", which could trigger a demand for a dispensation[3] to reach the objective fixed by the directive (deferred

3 This dispensation could also be obtained for technical reasons (when no efficient technique is known, or when the preparation of the technique and the action required are too time consuming for the 2015 deadline) and natural reasons (when the reaction time of the milieu necessary for the measures to produce a favorable effect exceeds the 2015 deadline).

from 2021 to 2027 or less ambitious objectives). In France, 710 cost-advantage analyses have been carried out [FEU 14]. In three quarters of these analyses, the costs are higher than the benefits. The authors note that these assessments have above all served to justify decisions based “on other considerations” (politics, acceptability, compromise, etc.) [FEU 14, p. 15]. They underline moreover that the methods for carrying out these assessments are subject to numerous biases.

It therefore seems that the use of economic evaluation in taking decisions is still not clarified. Evaluation appears more as a means of *ex post* justification for decisions that were based on other considerations. This strategic use of assessments risks cause these methods to lose legitimacy. Stakeholder involvement through deliberative or co-constructed approaches for assessments can be a solution to open the debate. This could also enable a greater transparency in economic evaluations.

1.5. A complementary approach: assessing the cost of maintaining ecosystem services

1.5.1. *The principles of assessment*

Here, it is a question of evaluating the costs of environmental policies that aim to meet the objective to preserve the ecological potential that will at once benefit biodiversity for its own sake and also the direct and indirect users of the ecosystem services that it provides [LEV 12].

This method relies on two aspects that distinguish it from the approach above. The first is technical; the method does not have to take into account the uncertainties that exist around the sense-making values of biodiversity and ecosystem services, considering that the restoration of the ecosystems will eventually compensate all the lost well-being that follows a breakdown of the environment – on the condition that the populations that benefit from these restoration measures are the same as those have suffered the loss [ROA 06]. The second is ethical in nature; the method meet a strong sustainability criteria, which depends on the hypothesis that a proportion of the natural capital cannot be substituted by physical or human capital without running a risk of there being a collapse of the ecological system that supports it[4] [EKI 03]. From then on, it is no longer a question of evaluating monetarily the ecosystem services that could be interchangeable, but of assessing the costs of maintaining these ecosystem services.

If these costs can be thought of as the costs of the erosion of biodiversity and ecosystem services, it is because they concern the ensemble of costs that society is willing to pay to maintain a level of biodiversity, under a number of regulations [BAR 09].

1.5.2. *Evaluation of the cost of the degradation of the environment in the directive-framework "Strategy for the marine habitat"*

The directive-framework 2008/56 "Marine Strategy Framework Directive" considers, from its point (2), that "it is evident that the pressures exercised on natural marine resources and the demand for ecosystem marine services are very often too high and that the community should reduce its impact on marine waters" and emphasizes in article 1, line 3, that it is essential that "marine strategies apply an ecosystem-based approach to the management of human activities, enabling it to be guaranteed that the collective pressure resulting from these activities is maintained at levels compatible with the creation of a good ecological state (GES) and to ensure that marine ecosystems' capacity to react to changes caused by nature and by mankind are not compromised, while still permitting sustainable use of marine goods and services by current and future generations."

4 This approach is opposed on principle to weak sustainability, which postulates a perfect substitutability between the different forms of capital [PEA 93]. In effect, the only criteria that counts is that of the economic value furnished by the different form of capital, whatever the relative importance of the latter.

The costs of maintaining the GES of marine waters and services that are associated with it can be described in the following manner [LEV 14]:

– coordination costs correspond to the costs associated with monitoring and surveillance networks for ecosystem services and the sources of impact on these ecosystem services (including the construction of indicators); the running costs of establishments in charge of co-coordinating the protection of marine and coastal ecosystem services (*Agence des aires marines protégées* and *Conservatoire du littoral*); the costs of regulation and control, personnel training and costs for sanctioning the use of protected spaces in particular; and the costs of research, studies, of expertise and assessments of impacts relating to ecosystem marine services;

– costs of positive action correspond to the costs of awareness campaigns, local events and lobbying to limit usage injurious to marine ecosystem services; the costs of basic purchases and putting in place protected marine areas (PMA); and contractual procedures for developing sustainable practices;

– mitigation costs correspond to compensatory measures, ecological restoration programs, the installation of water treatment plants, the extraction of pollutants, etc.

In France, these costs have been estimated for nine themes corresponding to the pressures exercised on marine ecosystem services [LEV 14]. Using these themes, it has been possible to identify legal frameworks of an ecological nature corresponding to the levels of ecosystem services to be maintained (Table 1.7).

If we take the example of the biodiversity loss (Table 1.8), the costs of monitoring and information correspond to the costs associated with monitoring, research, the development of observatories, studies and expertise, coordination between stakeholders in conservation projects, and regulatory procedures. The costs of positive action are those that correspond with strategies for the protection of marine biodiversity. The mitigation costs correspond with the cost of strategies that are carried out after damage to marine biodiversity has occurred.

Themes	Links to GES descriptors	Current legal frameworks
Marine waste	D10 marine waste	OSPAR Convention and Barcelona Convention, legal framework for water treatment, EU Water Framework Directive
Micropollutants	D8 on contaminant concentration levels; D9 on the impacts on health	REACH Directive, legal framework for water treatment and for bathing waters, EU Water Framework Directive
Pathogenic microbial organisms	D9 on the impacts on health	Legal framework for water treatment, for bathing water and the rearing of animals for food, European Directive on water
Oil spills illegal waste/ hydrocarbons	D8 on the concentration levels of contaminants; D9 on the impacts on health	MARPOL, FIPOL, OSPAR Convention and Barcelona Convention
Eutrophisation	D5 on eutrophisation	Nitrate Directive
Impacts on invasive species	D2 on invasive species	Ramsar, CITES, Berne, Bonn, Biodiversity, Barcelona and OMI Conventions
Degradation of biological resources exploited	D3 on the state of exploited stocks	Common Fisheries Policy
Loss of biodiversity seabed integrity, trophic imbalances	D1 on biodiversity; D4 on trophic networks and D6 on seabed integrity	Convention on Biological Diversity, European and French Strategy on Biodiversity
Degradation caused by the introduction of energy into the habitat and by modification of the water regime	D11 on energy and hydrography	Environmental Impact Assessment Directive

Table 1.7. *The themes and ecological references from which the cost of maintaining ecosystem services has been evaluated*

Costs of monitoring and information	Costs of positive action	Costs of attenuation
Monitoring and surveillance network on biodiversity and the sources of impacts on biodiversity (including the construction of indicators)	Awareness campaigns, local events, lobbying to limit usages injurious to marine biodiversity	Compensatory measures
Establishment in charge of coordinating the protection of marine and coastal biodiversity (Agence des AMP and Conservatoire du littoral)	Basic acquisitions by the conservatoire	Restoration and adjustments
Control strategies, personnel training and sanctioning	Creation and management of PMA	
Study, expertise, assessment of impacts	Putting in place of Natura 2000 contracts to develop sustainable practices	
Research on biodiversity		

Table 1.8. *The types of costs measured for the degradation of biodiversity*

By focusing on a specific cost, it is possible to give estimations of costs in detail. These costs for the Channel-North Sea coast are thus detailed in Table 1.9.

Channel-North Sea		
Costs of monitoring and information		
Administration of guardianship and public establishments in charge of protecting the marine habitat	€ 6,147,000	24%
Studies on the impact of gravel extraction	€ 475,000	2%
Professional observatories	€ 2,555,000	10%
Voluntarily run observatories	€ 390,000	2%
Local non-governmental organizations (NGOs)	€ 768,000	3%
Research	€ 15,175,000	59%
Total	€ 25,510,000	100%

Costs of positive action		
Administration of guardianship and public establishments in charge of protecting marine habitat	€ 6,572,000	58%
Main national NGOs	€ 54,000	0%
Protected areas	€ 4,807,000	42%
Total	€ 11,433,000	100%
Costs of attenuation		
Administration of guardianship and public establishments in charge of protecting marine habitat	€ 5,667,000	35%
Protected areas	€ 782,000	5%
Mitigation and compensation for gravel extraction	€ 2,189,000	13%
Seaports	€ 7,763,000	47%
Total	€ 16,401,000	100%

Table 1.9. *Details of the distribution of costs of the degradation of biodiversity for the Channel–North Sea*

The assessment has enabled the calculation for the ensemble of themes and the ensemble of French coasts, an annual maintenance cost for ecosystem services of two billion euros per year [LEV 14].

1.6. Toward multifaceted evaluations of ecosystem services using a spatial approach

1.6.1. *The integrated spatial evaluation of marine and coastal ecosystem services*

The production of ecosystem services on land is today envisaged using a strong spatial specialization, including coastal and marine areas.

Certain coastal zones are specialized in the production of provisioning services with aquaculture and fishing. In these zones, natural variabilities are controlled using mechanization and the use of intensive practices, and this is detrimental to other categories of ecosystem services.

The production zones of cultural services have appeared more recently with increased appreciation of natural sites devoted to walking, recreational fishing, pleasure, diving and snorkeling. In these zones, it is the anthropogenic pressures associated with provisioning services that have been controlled because of regulating access and to a maximization of revenue coming from the tourist industry.

The production zones of regulating services, neglected for a number years, are beginning to be developed in the form, for example, of the restoration of coastal wetlands and protection for the coastline.

This vision, of local areas managed in differentiated ways depending on the category of ecosystem services to be to maximized, appears to be largely outdated. Today, it is expected that a coastal area should be able to maintain professional activities relating to the sea (above all when these activities have a local cultural dimension), this same area should offer the best conditions for the enjoyment of recreational activities relating to natural ecosystems and, finally, it should be managed in a way that guarantees the protection of nature and consequently a healthy environment for the local population. All categories of ecosystem services should thus be taken into account when the question of altering local areas is addressed. Most of the time, this idea of ecosystem service is not explicitly mentioned, but interest in this notion is rightly to be able to make explicit the stakes associated with these management projects from an integrated perspective.

Ecosystem management considers the intra- and interecosystem connections and aims to maintain their capacity to provide multiple services in the long term [MCL 09]. It puts forward a local approach that has political aspects and considers the different actions of management on diverse application scales [LES 10]. This approach can be combined with “marine spatial planning” (MSP) in an “ecosystem services framework” (ESF) to facilitate the sustainable management of marine ecosystems and the services that they provide [GUE 12] (Figure 1.6). MSP represents the decisional approaches that use geospatial information to evaluate how the ocean can be used by people while conserving ecosystem services [CEN 11]. This involves an explicit assessment of compromises in the development of ecosystem services by putting forward a quantitative approach for evaluating the value of the MSP in comparison with planning carried out at random [GUE 12].

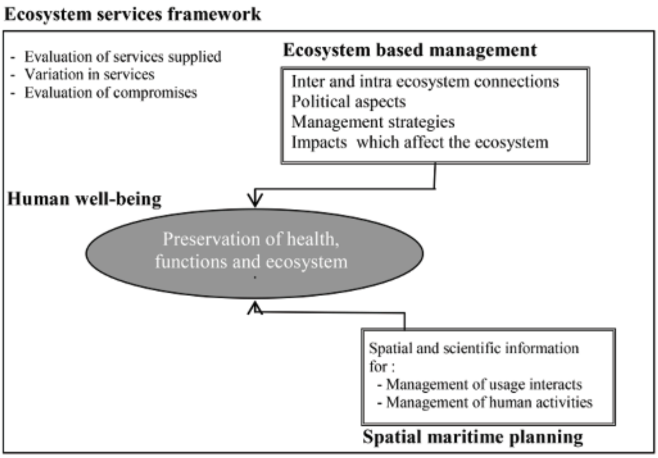

Figure 1.6. *The approach framework for marine and coastal ecosystem services*

An ESF approach is desirable from the point where monetization is no longer useful and therefore is useful in a deliberative context. It requires a good knowledge of the current state and evolution of ecosystem services using several measures, obtained using different models [LEH 13].

The geographical data enable several stakes to be clarified: the distribution and production of ecosystem services, the localization of biodiversity components enabling their production and taking into account of populations and areas benefiting from these services or on the contrary suffering from their reduction, and zones where different usages interact.

A large number of studies have mapped and quantified many ecosystem services and their variations for land habitats [BAI 12, BHA 12, CHA 06, EGO 08, GUL 13, MAE 12, NEL 09, SWE 11]. Nevertheless, studies in marine habitats are much rarer because of the difficulty in obtaining data [GUE 12].

1.6.2. *The spatial integrated assessment of ES and the compromises associated with their development*

The integrated assessment of ES and the compromises associated with their production are shown in Table 1.10. This is inspired by the approach developed by the *Natural Capital Project* [DAI 09].

<table>
<tr><th>Input</th><th>Models</th><th colspan="2">Output</th></tr>
<tr><th>Spatial data</th><th>Direct SE models</th><th>Ecosystem services</th><th>Monetary valorization</th></tr>
<tr><td rowspan="3">Land habitat:
– drainage basin, soil use
Marine habitat:
– habitats, bathymetry, professional and recreational usages

Socioeconomic:
- monitoring of visits and usages, exploitation costs, economic activities</td><td>Carbon
Wave energy
Coastal protection
Recreation
Fishing
Aquaculture
Esthetic quality</td><td rowspan="3">Sequestered carbon
Energy produced
Damages avoided
Number of visitors
Quantity of fishing stocks
Quantity gathered
Number of users per recreational activity</td><td rowspan="3">Value of sequestered carbon
Value of the energy produced
Value of damage avoided
Amount spent on recreational activities
Value of the quantity of fishing stocks
Value of the quantity gathered
Price of housing</td></tr>
<tr><td>Indirect ES models</td></tr>
<tr><td>Water quality
Risks for habitats</td></tr>
<tr><td colspan="4">Participative engagement by stakeholders (managers, users' groups, scientists, etc.) to identify objectives and construct scenarios</td></tr>
</table>

Table 1.10. *The integrated assessment of ES and their compromises [GUE 12]*

The choice of adjustments involving changes in the production of different ecosystem services should be based on trade-offs and compromises since it is impossible to maximize the production of each service simultaneously [BAR 08, HAL 07, TAL 06a]. The identification and representation of ecosystem services using a geographic information system (GIS) can help develop trade-offs. These should be made in collaboration with local stakeholders and be based on a participative and iterative approach [TAL 13b]. The ecosystem services can be mapped and quantified directly, by several models, either in biophysical units (for example the quantity of fish unloaded) or in economic units (for example the value of the quantity fished). Models of indirect ecosystem services, those related to the regulation of water quality or to the risks to habitats, can also be used to evaluate the intermediary effects of management in the flux of services [GUE 12]. Several methodologies among those described above can be used, if this is justified, to determine the services' economic value [LES 10].

After the spatial and quantitative identification of ecosystem services, the use of scenarios can be helpful for better apprehending the dynamics at play and facilitating the compromises to be made. These facilitate an assessment of the impacts on the level of the services provided by the ecosystems due to changes in uses. For example, we can evaluate the quantitative and distributive changes in ecosystem services triggered by an increase in the areas of shellfish exploitation, an increase in the number of fishing licenses or the adoption of more efficient management strategies for different pressures.

1.6.3. *Tools for spatial integrated assessment of ecosystem services*

Many tools are available for modeling marine and coastal ecosystem services. The choice of these tools should be guided by the project's objectives [VIG 11].

The "Multiscale Integrated Models of Ecosystem Services" tool provides models to aid decision making and can integrate maps of changes in soil use [MIM 13]. The models available quantify the effects of land and sea use and their impacts on the level of ecosystem services. These can be applied at global, regional and/or local level.

The tool "artificial intelligence for ecosystem services" [ART 13] takes account of existing information on the different categories of ecosystem services in order to put forward cartographic representations of them using agent-based modeling, GIS and probabilistic Bayesian networks enabling links between variables to be quantified [CHA 10, VIG 11].

The tool "integrated valuation of ecosystem services and trade-offs" (InVEST, [INV 13]) is one family of models for mapping and valuing goods and services furnished by marine and terrestrial areas. InVEST is based on ecological production functions and allows us to understand how changes in the structures, functions and processes of ecosystems impact ecosystem services [DAI 09]. The InVEST models are determinist and based on simplifications of models largely validated by the literature. The user can access the software code and modify it depending on the specific requirements of the project. The first versions of InVEST required the use of the software ArcGIS of ESRI (ArcGIS 2013). The most recent versions also function using open source tools such as Quantum GIS (Quantum GIS 2013) or gvSIG (gvSIG 2013).

An interesting case study on the use of the tool InVEST is one that was carried out for Lemmens Inlet, in British Colombia [GUE 12]. InVEST has been used to evaluate, in a participative context, the impact of different management options on the level of ecosystem services. All the scenarios proposed have explicit spatial (Figure 1.8) and quantitative components (Figure 1.9) enabling discussions with interested parties to be better planned, notably by underlining the necessary compromises, and the consequences of alternative management options.

The three scenarios are as follows:

– *status quo*: no change in the uses or limits of current zones (Figure 1.7(a));

– conservation: restriction of the number of floating homes and aquaculture in the zones close to eel grass. Four floating homes were removed from zones where they were infringing on eel habitats (X in black). Two new concessions of oyster farms in deep water were situated outside sensitive habitat zones (black squares). New kayak routes were proposed (dotted line). Fishing for clams (*Panopea abrupta*) has been forbidden (Figure 1.7(b));

– industrial: five new floating houses have been added (black circles), five new shellfish farming concessions have been added (black squares) and clam fishing is freely permitted (Figure 1.7(c)).

The results of these scenarios on ecosystem services are expressed using simple indicators:

– the risks for ecosystems, which represent the cumulative risk of human activities (floating houses, aquaculture, clam gathering) and coastal habitats (sea eels, soft and hard seabeds), in the light of three management scenarios (Figures 1.7(d)–(f));

– the concentration of fecal coliform bacteria compared to the concentration of floating homes [GUE 12] (Figure 1.7(g)–(i));

– evolutions relative to economic, ecological and social indicators (Figure 1.8).

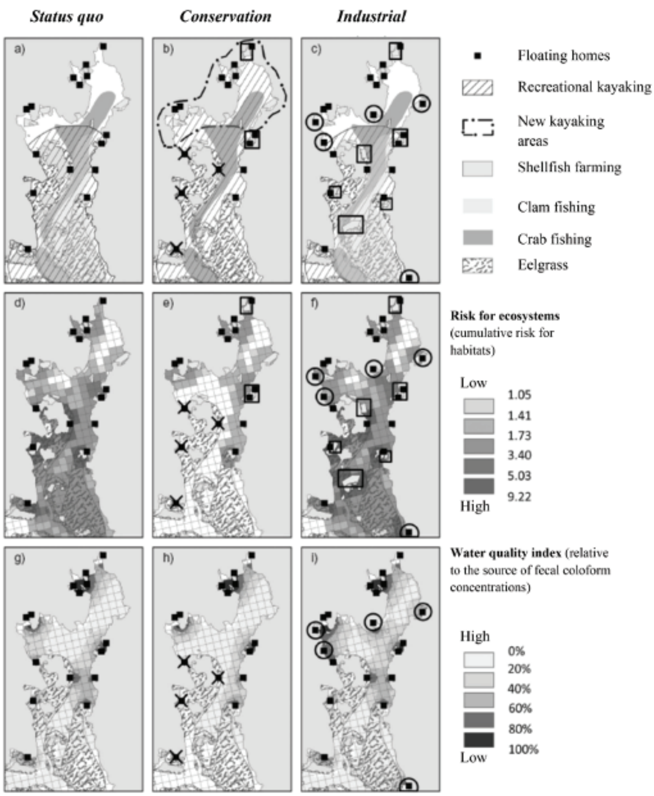

Figure 1.7. *Three management scenarios for Lemmens Inlet (a–c) and some InVEST (d–i) exit strategies [GUE 12] (see color section)*

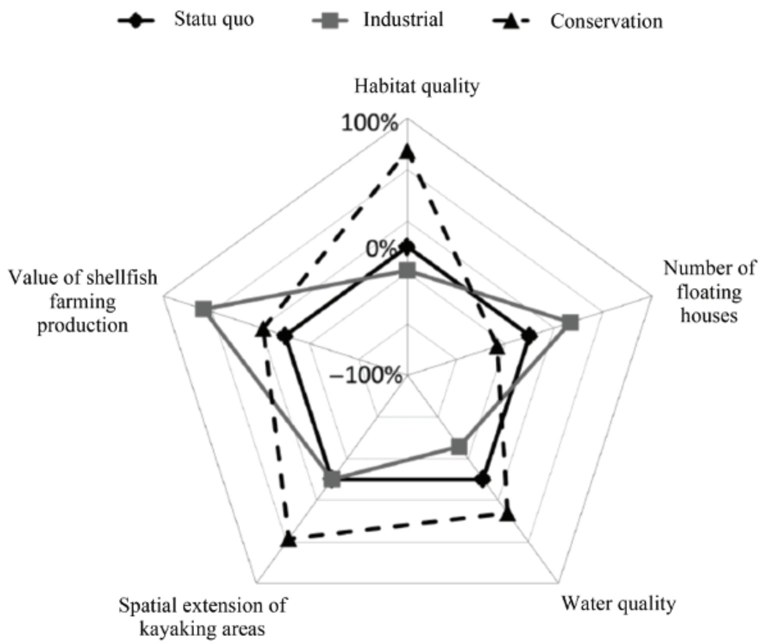

Figure 1.8. *Changes in the production of ecosystem services for three alternative scenarios. The initial levels of ecosystem services are represented by the diamond in continuous black lines. The outward extensions of the base form represent the relative gains and the contractions represent the losses. It is necessary to emphasize that the axis of the water quality is inverted (i.e. the points most removed from the origin have less fecal coliform bacteria and therefore the water quality is higher) [GUE 12]*

1.7. Conclusions

It appears that the notion of ecosystem service can help to improve the management of marine ecosystems by facilitating the trade-offs concerning choices relating to development projects or the conservation of sea shore and marine territory.

To do this, it is necessary to carry out assessments of these ecosystem services. It seems that the monetary approach can be useful when it facilitates an assessment of the costs and benefits associated with direct uses of these services. However, when these uses are too indirect, or indeed non-existent, it does not seem reasonable to seek to propose monetary evaluations of ecosystem services.

This point is reinforced by the report that the use of monetary assessments of marine ecosystem services still seems very limited or is envisaged strategically in the decision-making process.

A complementary assessment, based on multi-criteria approaches to the value of certain ecosystem services, which are difficult to estimate monetarily, can thus appear as a source of supplementary information to facilitate decision making on a local scale. The cartographic supports and use of example scenarios to represent these ecosystem services on different spatial, temporal, and also symbolic scales seem to offer entirely pertinent tools in this regard to accompany the decision-making process, aiming to articulate economic development and the conservation of biodiversity in coastal and marine territories. To this can be added indicators of the cost of the maintenance or restoration of ecosystem services in such a way to balance different levels of effort for different levels of production objectives for ecosystem services on a given local area.

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