CHAPTER 5

Changes in ecosystem services

Leon Braat, Chris Klok, Matt Walpole, Marianne Kettunen, Niele Peralta-Bezerra and Patrick ten Brink

Summary

Ecosystem services constitute the physical link between ecological systems and human economies. With conversions of natural ecosystems to other forms of land use, such as cropland, pasture land or urban land, or by unsustainable fishing the oceans, or converting coastal mangrove to shrimp farms, the total flow of services in a region is altered. The changes often bring short-term economic benefits but longer-term costs. Maximization of provisioning services such as food, fish and timber has caused the loss of area with intact ecosystems and biodiversity and thus with the capability of these systems to provide regulating services such as climate and flood control, and air and water purification. With the loss of biodiversity at gene, species and system levels of 30 - 50% in the last few centuries, much potentially relevant information for future human welfare has already been lost.

Losses of services are related to biodiversity loss either proportionally (regulating and information services) or have a maximum at low to medium use intensities (provisioning and recreation services). It is essential to take account of the *net change* in services, as some benefits may increase while others get lost. Increasing one particular local service with private benefits generally leads to losses of the regional or global services with public benefits. It is also important to assess the *net benefits* of changes, as many human interventions require additional energy subsidies.

Losses of ecosystem services have social and economic consequences. It is estimated that *1 billion people* worldwide are dependent on fish as their sole or main source of animal protein, while fish provided more than *2.6 billion people* with at least *20 percent of their average per capita animal protein intake*. The expected demise of ocean fisheries will therefore have severe consequences. Water scarcity is a globally significant and accelerating condition for *1–2 billion people* worldwide, leading to problems with food production, human health, and economic development. The impacts of invasive alien species on are global and of headline importance affecting the flow of ecosystem services to several beneficiaries.

5.1 Introduction

The COPI analysis is aimed at an estimate of the economic consequences of biodiversity loss. In this chapter we present a qualitative and quantitative assessment of the expected future changes in ecosystems services of the world. The assessment is based on two types of sources: (1) the projected changes in land use and biodiversity, together with projections regarding the future demand for ecosystem services based on the OECD Baseline demographic and economic data and the expected influence of international conservation and sustainable use policies , and (2) a wide variety of case studies, many already reviewed in the Millennium Ecosystem Assessment (MA), and selectively summarised here, and a number of more recent cases (see *figure 5.1*). The assessment provides an essential input to the analysis of subsequent changes in economic value to society (see the next chapters).

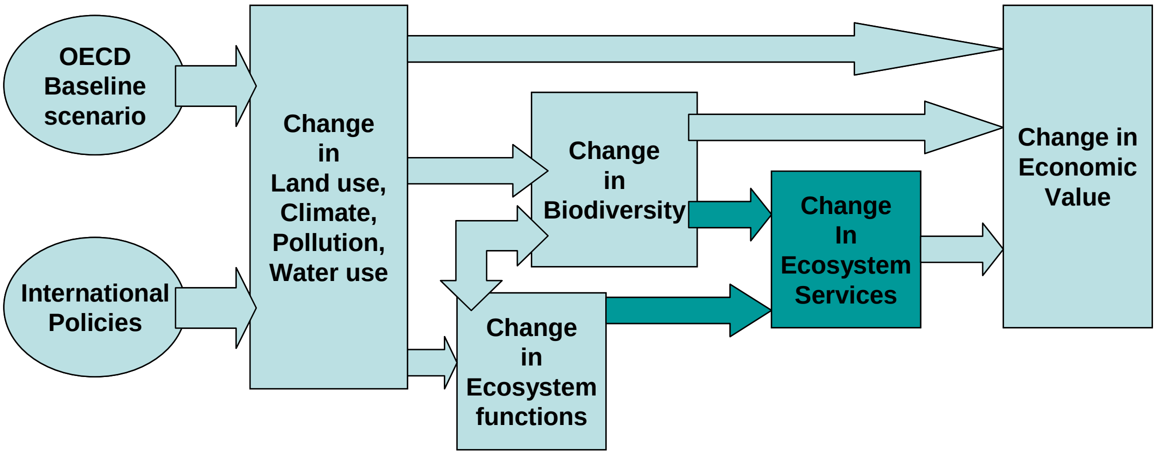


Figure 5.1   Chapter 5 in the conceptual model of the COPI analysis

The concept of ecosystem services in its modern form has been extensively discussed in the various reports of the Millennium Ecosystem Assessment. Earlier studies referred to the flow of goods and services from ecosystems to human systems as functions of nature (Braat, 1979, 1992; De Groot, 1992). An overview is presented in *figure 5.2* and *table 5.1*, taken from the MA (2005a). The MA has provided the basis for the analysis of ecosystem services work within the COPI study. There are of course different classifications possible of goods and services. A critical review and alternative classification is presented in Rodrigues et al. (2008), which is part of the Review of the Economics of the loss of Biodiversity.

Definitions (MA, 2005a; p.3) and conceptual implications

"Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits.

Human well-being has multiple constituents, including basis material for a good life, freedom of choice and action, health, good social relations, and security. Well-being is at the opposite end of a continuum from poverty, which has been defined as a "pronounced deprivation in well-being". The constituents of well-being, as experienced and perceived by people, are situation-dependent, reflecting local geography, culture, and ecological circumstances."

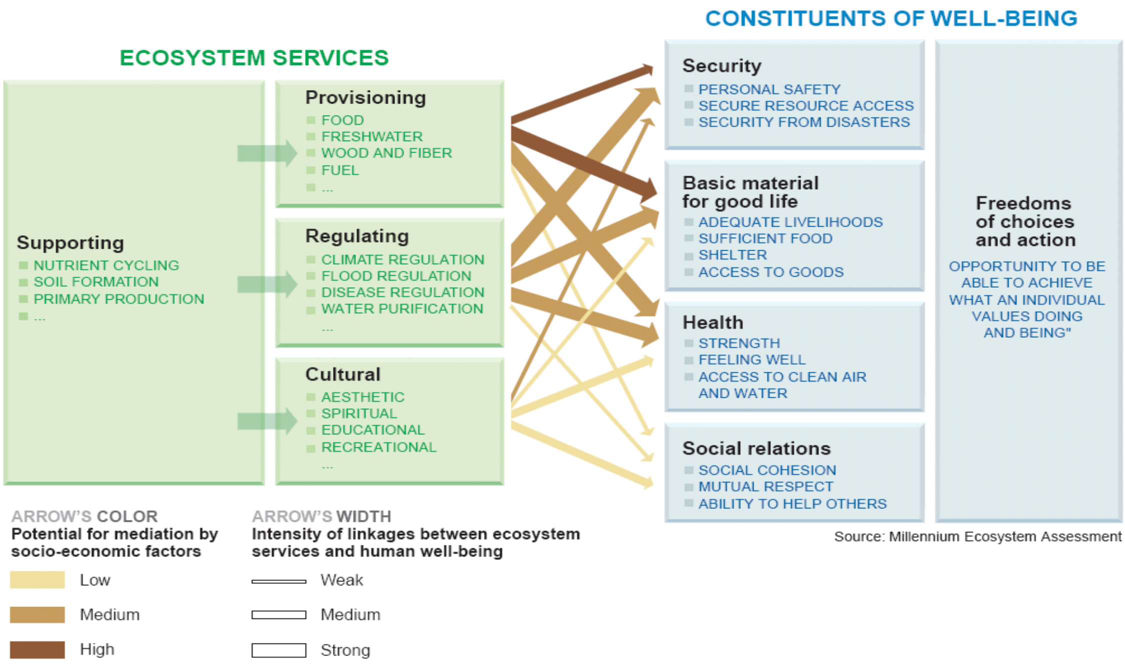


Figure 5.2 The Millennium Ecosystem Assessment Framework

The categories "human use" and "enhanced / degraded" in *table 5.1* do not apply for "supporting services" since, by definition, these services are not directly used by people (MA, 2005, p.25). A clear and useful distinction has been introduced between the internal dynamics within ecosystems (ecosystem functioning or supporting services), and the useable (potential) and used (actual) goods and services of ecosystems (provisioning, regulating, and cultural services). The potential and actual levels of ecosystems services are affected with the changes in ecosystem processes within ecosystems, as a consequence of, for example:

- climate change – e.g. a temperature change can lead to coral bleaching (see Chapter 4);
- the extraction of plant and animal specimens – e.g. loss of a keystone species will change the species dynamics of the ecosystem;
- change of nutrients flows – e.g. increase of nitrogen in soils from air pollution changes the balance among plant species on a given piece of land;
- change in water availability- e.g. rainfall patterns change or water abstraction, diversion of salination have major impacts on provision of agricultural produce or primary productivity of wetland habitats
- the input of toxic substances – e.g. heavy metal poisoning with effects on reproduction.

With conversions of original (pristine) ecosystems (called Natural Land Cover in the land use classification of the GLOBIO model), to other forms of land use (cropland, pasture land, urban land) or marine system use (e.g. mangrove to shrimp farming), the total flow of services in a region is altered. With the MA framework the possibility has been launched to have a common measure of loss of contributions to human well-being from ecosystems around the world. However, traditional ways of measuring and mapping productivity of different land use types need now to be amended, to include the contribution of ecosystems in terms of materials made available and work done, as compared to the input of materials and work from human sources.

Table 5.1 Ecosystems services (MA, 2005a) and dynamics

MA, 2005, P.21-25	ECOSYSTEM SERVICE	HUMAN USE		ENHANCED OR DEGRADED
PROVISIONING SERVICES				
1.1	FOOD-CROPS	↑		↑
1.2	FOOD-LIVESTOCK	↑		↑
1.3	FOOD-CAPTURE FISHERIES	↓		↓
1.4	FOOD-AQUACULTURE	↑		↑
1.5	FOOD-WILD PLANT / ANIMAL PRODUCTS	**NA**		↓
2.1	FIBER-TIMBER	↑		↑↓
2.2	FIBER-COTTON, HEMP, SILK	↑↓		↑↓
2.3	FIBER-WOOD FUEL	↑↓		↓
3	GENETIC RESOURCES	↑		↓
4	BIOCHEM'S, NATUR. MEDICINES & PHARMA' S	↑		↓
5	FRESH WATER	↑		↓
REGULATING SERVICES				
6	AIR QUALITY REGULATION	↑		↓
7.1	CLIMATE REGULATION -GLOBAL	↑		↑
7.2	CLIMATE REGULATION-REGIONAL & LOCAL	↑		↓
8	WATER REGULATION	↑		↑↓
9	EROSION REGULATION	↑		↓
10	WATER PURIFICATION & WASTE TREATMENT	↑		↓
11	DISEASE REGULATION	↑		↑↓
12	PEST REGULATION	↑		↓
13	POLLINATION	↑		↓
14	NATURAL HAZARD REGULATION	↑		↓
CULTURAL SERVICES				
15	CULTURAL DIVERSITY	**NA**		**NA**
16	SPIRITUAL & RELIGIOUS VALUES	↑		↑
17	KNOWLEDGE SYSTEMS	**NA**		**NA**
18	EDUCATIONAL VALUES	**NA**		**NA**
19	INSPIRATION	**NA**		**NA**
20	AESTHETIC VALUES	↑		↓
21	SOCIAL RELATIONS	**NA**		**NA**
22	SENSE OF PLACE	**NA**		**NA**
23	CULTURAL HERITAGE VALUES	**NA**		**NA**
24	RECREATION & TOURISM	↑		↑↓
SUPPORTING SERVICES				
25	SOIL FORMATION	**NI**		**NI**
26	PHOTOSYNTHESIS	**NI**		**NI**
27	PRIMARY PRODUCTION	**NI**		**NI**
28	NUTRIENT CYCLING	**NI**		**NI**
29	WATER CYCLING	**NI**		**NI**

↑	Increasing (human use) or Enhanced (Enhanced/Degraded)
↓	Decreasing (human use) or Degraded (Enhanced/Degraded)
↑↓	Mixed (trend 50 years up and down, regional differences)
NA	Not Assessed
NI	Not Included in analysis; not directly used by humans

This would seem quite possible, but requires a convergence of methodologies which has only just started. In the COPI study we therefore have used a number of assumptions, which necessarily simplify the complexities in producing the ecosystem services, but nonetheless produce a logical and traceable set of data as an intermediate step in the assessment of the economics of biodiversity loss.

So, ecosystem services are considered to stem from ecosystem functions within the natural environment, recognising that these are still provided in varying amounts when the original land cover in a biome is modified by humans (see *figure 5.1*). Furthermore, outputs from converted land or marine systems will likely have an economic value that includes more energy, matter and information than provided by the remaining parts of the original ecosystem, because these values also include human input(s), e.g. labour, fertiliser (see *figure 5.3*). So, if food or timber are provided by introduced or domesticated species but otherwise depend on the same processes as in natural (i.e. non-converted) ecosystems, they need to be considered, e.g. replacing deer with cattle may generate similar services in similar ways. To consider the loss of deer meat and ignore the gain in cattle meat would not make sense. Note that ecosystem services can be mimicked to a large extent and be provided **artificially** (e.g. water purification by water purification technologies, rather than via ecosystems), usually with some kind of fossil fuel-based technology.

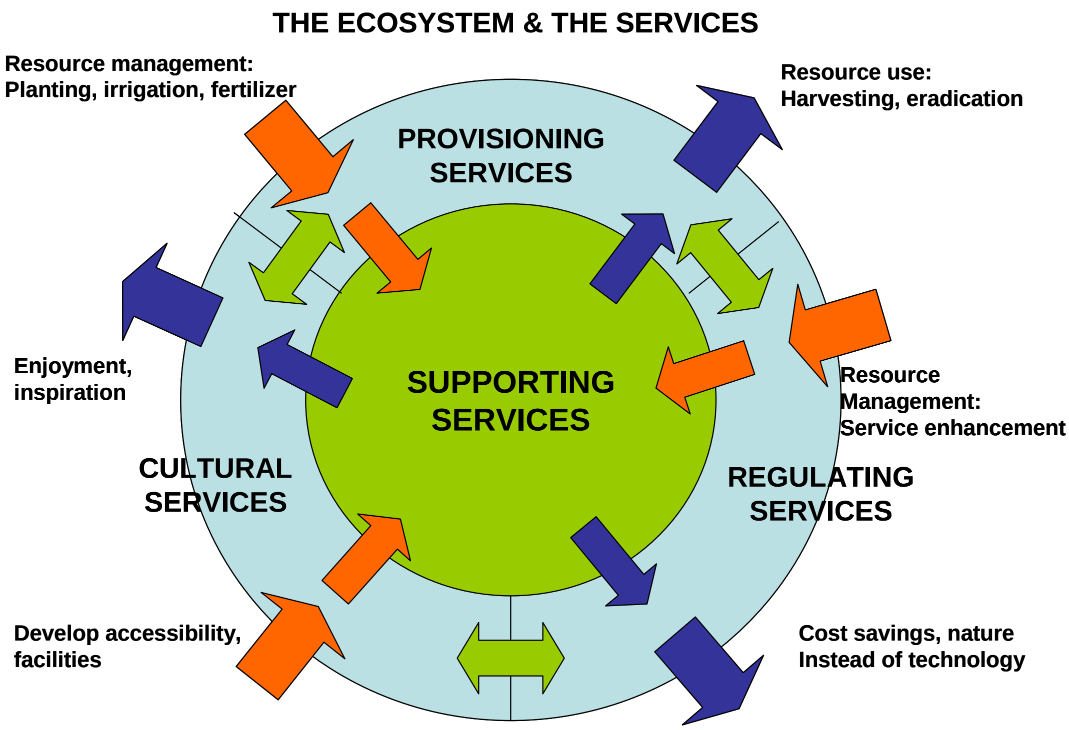


Figure 5.3 ***The ecosystem services relationships, including investments (red arrows), competition (green arrows) and benefits (blue arrows)***

When estimating the change in services, a COPI assessment needs to take account of the ***net change.*** One would need to look at the ecosystem service contribution to e.g. cattle meat, and ensure net of other inputs – else the picture of the benefit will be skewed. Similarly one needs to look at the ecosystem services over the long term, as this helps provide a clearer picture of true changes in benefits and losses of services (short term economic gains at the cost of long term ecological degradation). If net values cannot be obtained yet, then the gross values should be used only with a clear warning about aforementioned issues. In the current COPI assessment the so called "leverage" effect - i.e. the existence of one Ecosystem Service to allow a series of other non-ecosystem service related values to be created – is not included. Also, services should in principle be valued whether they are commercialised or not. Where they are commercialised they are easier to value, where not there is a need to estimate non-market values. It is important to avoid an imbalance by having many data on the commercialised and few or none on non-commercialised services as this might lead to misleading messages.

5.2 The mechanisms behind changes in ecosystem services.

5.2.1 Provisioning services

When natural ecosystems are converted to produce food, timber, fresh water or other material contributions to human well-being, the essential changes are:

- When only components of the ecosystems are removed, like in a hunter – gatherer economy, functioning is not noticeably affected. This is probably still only occurring in remote areas such as Eskimo territory and some Tropical rainforest and Savannah native tribes in Africa, South-America, South-East Asia and Australia.
- Where over-exploitation has been the common pattern, in hunting and fishing it has lead to local or regional extinctions of e.g. predator species (wolf, bear in Europe) and game species (many large mammals in North-America), and the total eradication of virgin forests in many areas around the world. Capture fisheries and conversion of tropical rainforest to Palm oil plantations are the present day examples.
- In early agriculture, the structure of the ecosystem is altered. Wild species are replaced by domesticated species (plants and animals), in early societies in Europe and some areas in developing countries still at a limited scale, compared to the surrounding wild ecosystems. The remaining ecosystem services contributing to the production are: biomass production through contributions from the local soils and hydrological systems. The original biodiversity has disappeared to a large extent, a different set of species appears and in extensive agriculture some kind of sustainability may be achieved, with susceptibility to environmental fluctuations. In intensive agriculture and plantation forestry, biodiversity drops to very low levels, and the ecosystem only contributes some basic soil functions and may become the habitat of some human-adapted species.
- When most of the productive processes of the original system have been replaced by "artificial" processes, the last contribution of the original ecosystem is the provision of the basic genetic program to produce biomass (a range from greenhouse vegetables, and bio-industry to water cultures). Biodiversity is only relevant at the genetic level.

5.2.2 Regulating services

Mankind has been quite successful in manipulating ecosystem productive processes to provide consumers with food and fiber etc., but it has been much less so in manipulating and mimicking the regulating processes of the world's ecosystems. A major reason is that *all of these services are the result of complex large scale interactions between physical forces and the biological processes driven by them, but mitigating, modulating and abating them, when intact.* The generic relationships between ecosystem functioning, biodiversity and ecosystem service levels in this group are:

(1) alteration of ecosystem composition and structure (simplification, removal of key species) leads to rapid decline of regulatory capacities, as many of these depend directly on the availability of ecosystem structure and biological activity which captures, stores and releases water, nutrients, and soil structure. Services such as pollination, pest and disease regulation depend on the presence of particular "controlling" species, which often have very narrow niches. Decline of biodiversity, as measured in the MSA (see chapter 3), is assumed to lead to a proportional decline of the service.

(2) Decreasing the extent of natural ecosystems, aside from per hectare changes in structure and composition leads also to serious losses of the "abiotic" regulating services, at least proportional, and most likely also for the biotic services.

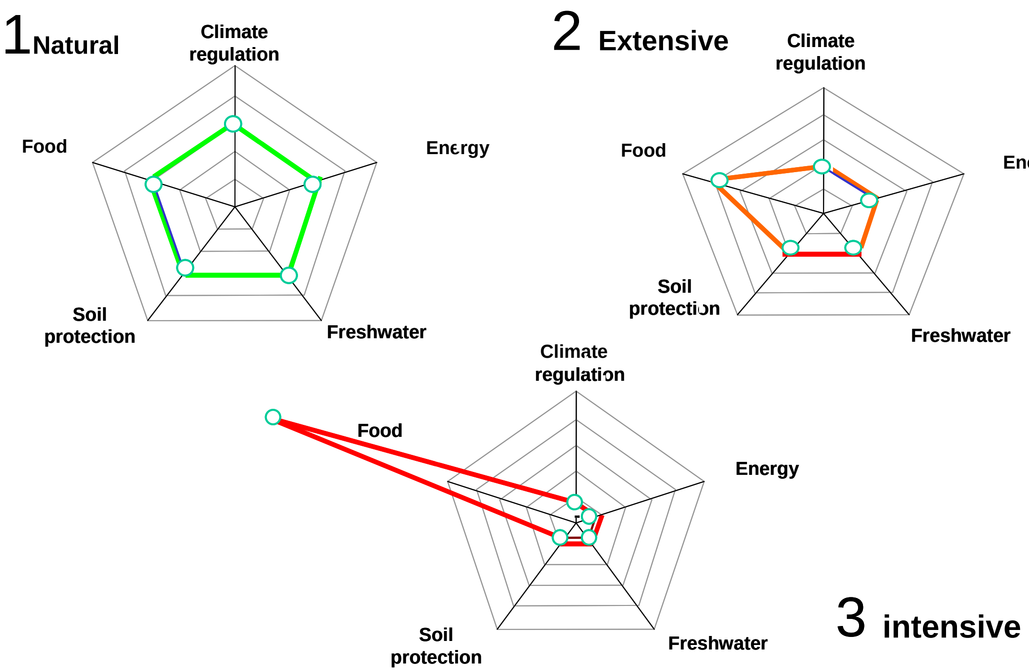
5.2.3 Cultural services

Two categories are distinguished based on the way ecosystems contribute:

(1) The recreation and tourism service is defined in terms of physically enjoying the ecosystem, its structure and its components (animal, plant species, streams) with or without extracting parts of the system. However, to accommodate people to consume the service, access has to be created, so a percentage of the area is converted to urban land use. A range of types of recreation can be distinguished based on dependency on "high, intact species richness" or "total system naturalness". At the high end for example scuba diving & snorkling on coral reefs, at the low end, a picnic in a city park. Service levels are therefore considered to decrease proportionally faster than biodiversity at the high end of the range and proportionally slower at the low end.

(2) Other cultural services are less attached to particular quantities, but sometime very much to particular qualities of ecosystems. Their service levels are, for lack of better knowledge currently assumed to respond proportionally to changes in biodiversity (MSA, including area and quality aspects).

Figure 5.4 illustrates the relationships between different ecosystem services in a different way than *figures 5.2 and 5.3*. In diagram 1, the service levels in a natural ecosystem are depicted to be in some kind of balance, fitting the capability of the particular ecosystem. In the second diagram, the system has been converted to extensive use for *food* production, thereby decreasing the potential and actual service levels of the other provisioning (energy, freshwater), regulating (climate) and supporting services (soil protection). In Diagram3, representing an intensive food production system, the other services have been reduced to very low levels.



*Source: Ben ten Brink (MNP **2008**).*

Figure 5.4 The consequences for ecosystem service levels of maximising food production

Next to these generalised characterizations of the functional relationships between biodiversity, ecosystem processes and ecosystem services a great amount of information is available in specific case studies. Before introducing a simple model, a few of these cases are reviewed. Very little work has been done so far on the quantification of the functional relationships between biodiversity features such as mean species abundance, species richness, extinction risks etc and specific ecosystem services.

Box 5.1 Biodiversity and ecosystem services (MA, 2005b)

- **Species composition is often more important than the number of species in affecting ecosystem processes**. Conserving or restoring the composition of communities, rather than simply maximizing species numbers, is critical to maintaining ecosystem services.
- **The properties of species are more important than species number in influencing climate regulation.** Climate regulation is influenced by species properties via ecosystem level effects on sequestration of carbon, fire regime, and water and energy exchange. The traits of dominant plant species, such as size and leaf area, and the spatial arrangement of landscape units are a key element in determining the success of mitigation practices such as afforestation, reforestation, slowed-down deforestation, and biofuels plantations.
- **The nominal or functional extinction of local populations can have dramatic consequences in terms of regulating and supporting ecosystem services.** Before becoming extinct, species become rare and their ranges contract. Therefore their influence on ecosystem processes decreases, even if local populations persist for a long time, well before the species becomes globally extinct.
- **Preserving interactions among species is critical for maintaining long term production of food and fiber on land and in the sea.** The production of food and fiber depends on the ability of the organisms involved to successfully complete their life cycles. For most plant species, this requires interactions with pollinators, seed disseminators, herbivores, or symbionts. Therefore, land use practices that disrupt these interactions will have a negative impact on these ecosystem services.
- **The diversity of landscape units also influences ecosystem services.** The spatial arrangement of habitat loss, in addition to its amount, determines the effects of habitat loss on ecosystem services. Fragmentation of habitat has disproportionately large effects on ecosystem services.

The above characterisations are based on the ecological textbooks and the mass of qualitative case material published through the MA (2005b). Together with the cases inserted in Boxes in this chapter *a set of simplified functional relationships for groups of ecosystem services have been developed* in the COPI project to allow a bridge between the calculated future changes in areas (per type of land use) with associated changes in total biodiversity (because of the different biodiversity levels per land use type), and the wide variety of monetization case studies and estimates of economic benefits of the use of ecosystems (see *figure 5.5*). Summarising the literature and example discussed above, the following reasoning underlies the shape of the curves. Obviously, these are generalised curves. Specific situation will have specific versions of these generalised curves.

Provisioning (P): There is no provisioning service, by definition, in a pristine ecosystem. With increasing intensity of use and conversion of the structure, species composition and thus functioning of the original natural area, MSA decreases (from 1 to 0) and the benefit flow (EV; ecosystem service value) increases. Adding labour, fertiliser, irrigation, pest control etc. will raise the gross benefits, and possibly the net. At some point, the remaining ecosystem will be reduced to a substrate for production of biomass. The final state is defined as approaching zero value, having been built on and covered by concrete or asphalt.

Regulating (R): Most of the information from case studies on the regulating services distinguished in the MA points at a complex relationship between the “intact” ecosystem and the service levels. As systems are converted, their regulating service potential, and actual performance drops more or less proportionally with the decrease of MSA along the range of land use types.

Cultural – recreation (Cr): A crucial feature in the valuation of the recreational services of ecosystems is accessibility. The graph therefore displays an increase from low value at inaccessible pristine systems to high values in accessible light use systems and a subsequent drop to degrade systems. This is of course very much generalised, as the biodiversity aspect counts, not the openness of landscapes, the cultural-historical value or amenities.

Cultural – Information (Ci): Most of the other cultural ecosystem services and their values are a function of the information content which is considered to decrease with the degree of conversion.

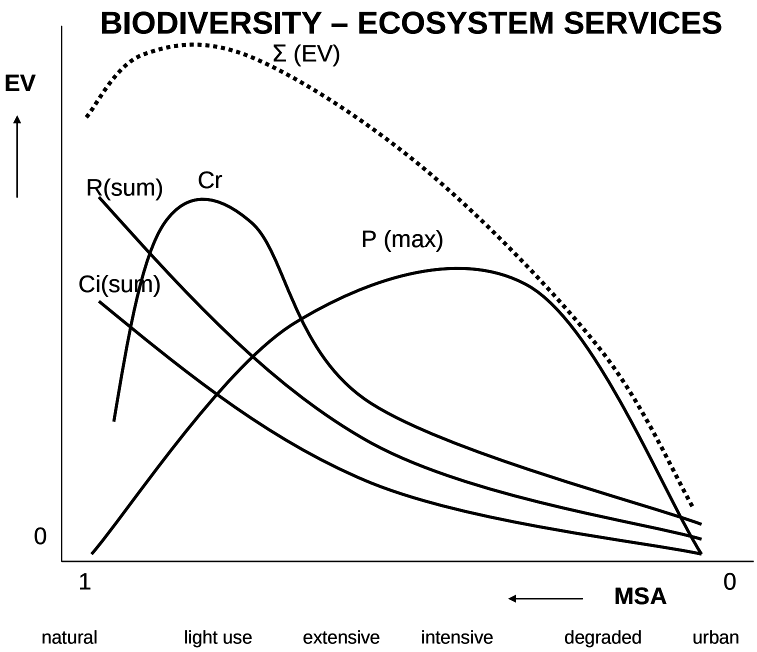


Figure 5.5 Generalised functional relationships between ecosystem service level and degree of land use intensity (decreasing MSA values)

The graphs have been used to develop multiplication factors (index) to be combined with the MSA factors (remaining biodiversity per land use type). These indices are presented in *Table 5.2*. These ecosystem service indices are used in the COPI spreadsheet to support benefit transfers from case studies with monetized ecosystem services. All areas in the world are classified to be in a particular biome and land use type (see Chapter 4 and the x-axis in figure 5.5). A particular type of land use is characterised with the set of indices. The biome-land use type(s) in the case studies analysed is determined and the monetary values are transferred to the areas with the same or similar type. Of course, this procedure has a considerable margin of uncertainty, but within the scope of the study, a reasonable estimate can thus be produced.

The relationships between ecosystem service levels, for the 4 groups of services, and changes in land area, within biome-land use units, have been assumed to be more or less linearly proportional. This is well documented for most land-based provisioning services. For services based on intact ecosystems with natural populations of plant and animal species, there is a so called species-area relationship, which implies a slow decrease of service level for with decreasing area, until some threshold is approached (minimum area). The species populations then collapse. However, as the COPI study does not deal with regional or local changes, these effects have been ignored, although we are aware of their existence at the smaller geographical scales.

Table 5.2 Table of value –factors of ecosystem services (clusters) per land use type

COPI Category		natural areas			Bare natural	forest managed	Cultivated and managed areas				Artificial surfaces
		Pristine (historic)	Natural	Light forest			grazing area	woody biofuels	Extensive Ag	Intensive Ag	
General*	MSA	1	0.9	0.7	0.9	0.5	0.7	0.5	0.3	0.1	0.05
P*: Provisioning	Importance (gross)	-	*	**	*	***	**	***	****	*****	-
	Index	0	0.2	0.5	0.05	0.7	0.5	0.7	0.8	1	0
R*: Regulating	Importance	*****	*****	****	*	***	****	***	***	*	*
	Index= F*(msa)	1	0.9	0.7	0.05	0.5	0.7	0.5	0.3	0.1	0.05
C1*: Recreation	Importance	-	*****	*****	**	***	****	*	***	*	* (- to ***)
	Index	0	1	1	0.5	0.6	0.8	0.15	0.5	0.1	0.1
C2*: Info (spiritual, education)	Importance	*****	*****	****	*	***	****	**	***	*	*
	Index= F*(msa)	1	0.9	0.7	0.5	0.5	0.7	0.2	0.3	0.1	0.05

* These are broad relationships; for COPI valuation, where data exists that is more precise (eg for carbon storage), this will be used. The numbers here are back-up ratios to help fill gaps

The indices have been valuable in helping address the gaps, and future testing and fine tuning would be valuable to help clarify the relationships between Land use types and MSA levels of ecosystem services.

5.3 Ecosystem services, land cover and land use

5.3.1 Introduction

In this section the state and trends of ecosystem services as described in the MA report State and Trends (MA, 2005b) are summarised. With overview tables indicating the relative importance of a particular land cover – land use type for the ecosystem service types distinguished by the MA and a summary of qualitative and quantitative descriptions of trends per ecosystem service a basis for economic value assessment is presented. In later sections, the expected changes in service levels will be introduced as the basis for the assessment of economic loss of biodiversity. The selection of services is based on the original MA list, shown in *table 5.1*. The "X" es indicate the importance of the land use type, relative to other types, for the provision of each of the services distinguished.

5.3.2 State and trends in the levels of Provisioning Services

Food

- Global food production has increased by *168%* over the past 42 years. The production of cereals has increased by about *130%*, but is now growing more slowly. Nevertheless, an estimated *852 million people* were undernourished in 2000–02, up *37 million* from the period 1997–99. Of this total, nearly *96%* live in developing countries. Sub-Saharan Africa is the region with the largest share of undernourished people.

- Total fish consumption has declined somewhat in industrial countries, while it has increased to *200%* in the developing world since 1973. For the world as a whole, increases in the volume of fish consumed are made possible by aquaculture, which in 2002 is estimated to have contributed *27%* of all fish harvested and *40%* of the total amount of fish products consumed as food.
- In addition to fish, wild plants and animals are important sources of nutrition in some diets, and some wild foods have significant economic value. In most cases, however, wild foods are excluded from economic analysis of natural resource systems as well as official statistics, so the full extent of their importance is improperly understood.

Table 5.3 Overview of relative importance of Provisioning ecosystem services in the GLOBIO land use classes and water systems

Biome types and land co	Provisioning services									
Biome types and land cover types	1.1 Food-crops	1.2 Food-livestock	1.3 Food-capture fisheries	1.4 Food-aquaculture	1.5 Food-wild plant /animal products	2.1/2.3 Fiber-timber/wood fuel	2.2 Fiber-cotton, hemp, silk	3. Genetic Resources	4. Biochemicals, natural medicines, pharmaceuticals	5. Fresh water
natural areas		X	X		XXX	XX	X	XXX	XXX	XXX
bare natural										
forest managed		XX			XX	XXX		XX	XX	XX
extensive agriculture	XX	X					XX	XX	XX	X
intensive agriculture	XXX						XXX	X		
woody biofuels						XXX				
grazing area		XXX			X			X	X	
Artificial surfaces										
Ice										XXX
Hot desert					X			X	X	
Inland Waters			XX	X	XX			XXX	XXX	XXX
Coastal areas			XXX	XX	XXX			XXX	XXX	
Marine			XXX		XX			XXX	XXX	

Timber

- Global timber harvest has increased by *60%* in the last four decades and will continue to grow in the near future, but at a slower rate. In 2000, plantations were *5%* of the global forest cover, but they provided some *35%* of harvested roundwood, an amount anticipated to increase to *44%* by 2020. The most rapid expansion will occur in the mid-latitudes, where yields are higher and production costs lower.
- The global value of timber harvested in 2000 was around $400,000 million, and around *25%* of that entered into world trade, representing some *3%* of total merchandise trade. In constant dollar terms, global exports increased by a *factor of 25* between 1961 and 2000.
- Five countries—the United States, Germany, Japan, the United Kingdom, and Italy—imported more than *50%* of world imports in 2000, while Canada, the United States, Sweden, Finland, and Germany accounted for more than half of exports. During the past decade, China has increased its imports of logs and wood products by more than *50%*.
- Up to *15%* of global timber trade involves illegal activities, and the annual economic toll is around *$10,000 million*.

- The global forestry sector annually provides subsistence and wage employment of *60 million work years*, with *80%* taking place in the developing world.

Renewable Energy

- Fuel wood is the primary source of energy for heating and cooking for some *2.6 billion people*, and *55%* of global wood consumption is for fuel wood. An estimated *1.6 million deaths* and *39 million disability-adjusted life years* are attributed to indoor smoke pollution, with women and children most affected.
- Renewable energy technologies are being rapidly developed throughout the world, but examples of full commercial exploitation are still fairly modest.

Fibre

- Global cotton production has doubled and silk production has *tripled* since 1961, accompanied by major regional shifts in production areas. Production of other agricultural fibres such as wool, flax, hemp, jute, and sisal has declined.
- There are still instances where species are threatened with extinction due to the trade in hides, fur, or wool, in spite of international efforts to halt poaching and trade.

Fresh water

- Forest and mountain ecosystems serve as source areas for the largest amounts of renewable freshwater supply—*57% and 28%* of total runoff, respectively. These ecosystems each provide renewable water supplies to at least 4 billion people, or two thirds of the global population. Cultivated and urban ecosystems generate only *16% and 0.2%,* respectively, of global runoff, but because of their close proximity to human settlements, they serve *4–5 billion people*.
- Between *5%* and possibly *25%* of global freshwater use exceeds long-term accessible supply. Much of this water is used for irrigation with irretrievable losses in water-scarce regions. All continents record overuse. In the relatively dry Middle East and North Africa, non-sustainable use is exacerbated, with current rates of freshwater use equivalent to *115%* of total renewable runoff. In addition, possibly *1/3* of all withdrawals come from non-renewable sources, a condition driven mainly by irrigation demand.
- Global freshwater use is estimated to expand *10%* from 2000 to 2010, down from a per decade rate of about *20%* between 1960 and 2000. Contemporary water withdrawal is approximately *3,600 cubic kilometres* per year globally or *25%* of the continental runoff to which the majority of the population has access during the year. If dedicated instream uses for navigation, waste processing, and habitat management are considered, humans then use and regulate over 40% of renewable accessible supplies.
- Because the distribution of fresh water is uneven in space and time, more than *1 billion people* live under hydrologic conditions that generate no appreciable supply of renewable fresh water. An additional *4 billion (65% of world population*) is served by only *50%* of total annual renewable runoff in dry to only moderately wet conditions, with concomitant pressure on that resource base. Only about *15%* live with relative water abundance.
- Water scarcity is a globally significant and accelerating condition for *1–2 billion people* worldwide, leading to problems with food production, human health, and economic development. Rates of increase in water use relative to accessible supply—from 1960 to present averaged nearly *20% per decade* globally. The annual burden of disease from inadequate water, sanitation, and hygiene totals *1.7 million deaths* and the loss of at least *50 million healthy life years*.

Bio-prospecting

- Bio-prospecting is the exploration of biodiversity for new biological resources of social and economic value. There are between 5 million and 30 million species on Earth, each one containing many thousands of genes. However, fewer than 2 million species have been described, and knowledge of the global distribution of species is limited. History reveals that less than *1%* of species have provided the basic resources for the development of all civilizations thus far, so it is reasonable to expect that the application of new technologies to the exploration of the currently unidentified and overwhelming majority of species will yield many more benefits for humanity.

5.3.3 State and trends in Regulating services

Nutrient cycling

- In pre-industrial times, the annual flux of nitrogen from the atmosphere to the land and aquatic ecosystems was *90–130 teragrams (million tons) per year*. This was more or less balanced by a reverse ‘‘denitrification’’ flux. Production and use of synthetic nitrogen fertilizer, expanded planting of nitrogen- fixing crops, and the deposition of nitrogen-containing air pollutants have together created an additional flux of about *200 teragrams a year*, only part of which is denitrified.
- Phosphorus is also accumulating in ecosystems at a rate of *10.5–15.5 teragrams per year*, which compares with the preindustrial rate of *1–6 teragrams* of phosphorus a year, mainly as a result of the use of mined P in agriculture.
- Sulphur emissions have been progressively reduced in Europe and North America but not yet in the emerging industrial areas of the world: China, India, South Africa, and the southern parts of South America.

In contrast to the issues associated with nutrient oversupply, there remain large parts of Earth, notably in Africa and Latin America, where harvesting without nutrient replacement has led to a depletion of soil fertility, with serious consequences for human nutrition and the environment.

Table 5.4 Overview of relative importance of Regulating ecosystem services in the GLOBIO land use classes and water systems

Biome types and land co	Regulating services								
Biome types and land cover types	6. Air quality maintenance	7.1/2 Climate regulation global /regional	8. Water regulation	9.Erosion regulation	10. Water purification & waste treatment	11. Disease regulation	12. Pest regulation	13. Pollination	14. Natural hazards regulation
natural areas	XXX	XXX	XXX	XXX	X	XXX	XXX	XXX	XXX
bare natural									
forest managed	XXX	XX	XX	XX	X	X	X	XX	XX
extensive agriculture	X	XX	X	X		X	X	XX	XX
intensive agriculture									
woody biofuels	XX	XXX	X	XX					X
grazing area	X	X	X	X	X	X	X	XX	XX
Artificial surfaces									
Ice	X	XXX	XX						
Hot desert									
Inland Waters	XXX	XXX	XXX		XXX	X	XXX		
Coastal areas	XXX	XXX	XXX		XXX	X	XXX		
Marine	XXX	XXX	XXX		XXX	X	XXX		

Climate and air quality

Ecosystems provides atmospheric 'services': warming, cooling, water recycling and regional rainfall patterns, atmospheric cleansing, pollution sources and nutrient redistribution. Ecosystems are currently a net sink for carbon dioxide and tropospheric ozone, while they remain a net source of methane and nitrous oxide. Ecosystems influence the main anthropogenic greenhouse gases in several ways:

- Carbon dioxide—Pre-industrial concentration, *280 ppm*; concentration in 2000, *370 ppm*. About *40%* of the emissions over the last two centuries and about 20% of the CO2 emissions during the 1990s originated from changes in land use and land management, primarily deforestation. Terrestrial ecosystems have been a sink for about a third of cumulative historical emissions and a third of the 1990s total (energy plus land use) emissions. Ecosystems were on average a net source of CO2 during the nineteenth and early twentieth century and became a net sink sometime around the middle of the last century.
- Methane—Preindustrial concentration, *700 ppb*; concentration in late 1990s, *1750 ppb*. Natural processes in wetland ecosystems account for *25–30%* of current CH4 emissions, and about *30%* of emissions are due to agriculture (ruminant animals and rice paddies).
- Nitrous oxide—Preindustrial concentration, *270 ppb*; concentration in late 1990s, *314 ppb*. Ecosystem sources account for about *90%* of current N2O emissions, with *35%* of emissions from agricultural systems, primarily driven by fertilizer use.
- Tropospheric ozone—Preindustrial, *25 Dobson Units*; late 1990s, *34 DU*. Several gases emitted by ecosystems, primarily due to biomass burning, act as precursors for tropospheric ozone. Dry deposition in ecosystems accounts for about half the tropospheric ozone sink. The net global effect of ecosystems is a sink for tropospheric ozone.

Land cover changes between 1750 and the present have increased the reflectivity of solar radiation (albedo) of the land surface, partially offsetting the warming effect of associated CO2 emissions:

- Deforestation and desertification in the tropics and sub-tropics leads to a reduction in regional rainfall. The biophysical effects of ecosystem changes on climate depend on geographical location and season.
- Deforestation in seasonally snow-covered regions leads to regional cooling during the snow season due to an increase in surface albedo and leads to warming during summer due to reduction in evapotranspiration. Large-scale tropical deforestation (hundreds of kilometres) reduces regional rainfall, primarily due to decreased evapotranspiration.
- Desertification in tropical and sub-tropical drylands leads to decrease in regional rainfall due to reduced evapotranspiration and increased surface albedo.

The self-cleansing ability of the atmosphere is fundamental to the removal of many pollutants and is affected by ecosystem sources and sinks of various gases. Removal of pollutants involves chemical reactions with the hydroxyl radical. OH concentration and hence atmospheric cleansing capacity has declined since preindustrial times but probably not by more than *10%*. The net contribution of ecosystem changes to this decline is currently unknown. The reactions are complex, but generally emissions of NOx and hydrocarbons from biomass burning increase tropospheric ozone and OH concentrations, and emissions of CH4 and carbon monoxide from wetlands, agricultural practices, and biomass burning decrease OH concentration.

Disease control

Intact ecosystems play an important role in regulating the transmission of infectious diseases.

- Natural systems with intact structure and characteristics generally resist the introduction of invasive human and animal pathogens brought by human migration and settlement. This seems to be the case for cholera, kala-azar, and schistosomiasis, which have not become established in the Amazonian forest ecosystem.

- Dams and irrigation canals provide ideal habitat for snails that serve as the intermediate reservoir host species for schistosomiasis; irrigated rice fields increase the extent of mosquito breeding areas, leading to greater transmission of mosquito-borne malaria, lymphatic filariasis, Japanese encephalitis, and Rift Valley fever.
- Deforestation alters malaria risk and uncontrolled urbanization of forest areas has been associated with mosquito borne viruses (arboviruses) in the Amazon, and lymphatic filariasis in Africa.
- Habitat fragmentation, with subsequent biodiversity loss, increases the prevalence of the bacteria that causes Lyme disease in North America in ticks.
- Overcrowded and mixed livestock practices, as well as trade in bush meat, can facilitate interspecies host transfer of disease agents, leading to dangerous novel pathogens, such as SARS and new strains of influenza.

Extreme events

Quantification is rare but available studies on extreme events, their impacts on human well-being, and the roles of ecosystem services do in mitigation and alleviation of the impacts allow several qualitative assertions to be made (see also sections on coastal systems):

- Many measures of human vulnerability show a general increase, due to growing poverty, mainly in developing countries.
- Impacts of natural hazards are increasing in many regions around the world. Annual economic losses from extreme events increased tenfold from the 1950s to 1990s. From 1992 to 2001, floods were the most frequent natural disaster (*43% of the 2,257 disasters*), and floods killed *96,507 people* and affected more than *1.2 billion people* over the decade. A large number of damaging river floods occurred in Europe in the last decade. Material flood damage recorded in Europe in 2002 was higher than in any previous year.
- Interactions of modern human activities with ecosystems have contributed to increasing human vulnerability and to the impact of extreme events on human well-being.

5.3.4 State and trends in Cultural services

Human cultures, knowledge systems, religions, heritage values, social interactions, and the linked amenity services (such as aesthetic enjoyment, recreation, artistic and spiritual fulfilment, and intellectual development) have always been influenced and shaped by the nature of the ecosystem and ecosystem conditions in which culture is based.

At the same time, humankind has always influenced and shaped its environment. Rapid loss of culturally valued ecosystems and landscapes lead to social disruptions and societal marginalization, now occurring in many parts of the world.

Our understanding of the tangible benefits derived from traditional ecological knowledge, such as medicinal plants and local species of food, is relatively well developed. However, our knowledge of the linkages between ecological processes and social processes, and their tangible and intangible benefits (such as spiritual and religious values), and of the influence on sustainable natural resource management at the landscape level needs to be strengthened

Table 5.5 ***Overview of relative importance of Cultural ecosystem services in the GLOBIO land use classes and water systems***

	Cultural s.		Supporting	
BIOME TYPES AND LAND COVER	15-23 Cultural & Nature Information values	24. Recreation and ecotourism	25/28/29. Soil formation/ nutrient & water cycling	26/27. Photsynthesis & Primary Production
natural areas	XXX	XXX	XXX	XX
bare natural				
forest managed	XX	XX	XX	XXX
extensive agriculture	XXX	X	XX	XX
intensive agriculture	X		X	XXX
woody biofuels			X	XXX
grazing area	XXX	X	X	XX
Artificial surfaces				
Ice	X	X		
Hot desert	X	X	X	X
Inland Waters	XXX	XXX	XXX	XX
Coastal areas	XXX	XXX	XXX	XXX
Marine	XXX	XXX	XX	XXX

5.4 Trends in services in terrestrial biomes and landscapes

5.4.1 Introduction

The data in this overview of developments in the levels of various ecosystem services are from the MA (2005b) report on State and Trends and a number of other sources. The focus is on quantitative data.

5.4.2 The land biomes

Forests

Forests annually provide over *3300 million cubic meters* of wood (including *1800 million cubic meters* of fuel wood and charcoal), as well as numerous non-wood forest products that play a significant role in the economic life of *100s of millions of people*; contain about *50%* of the world's terrestrial organic carbon stocks, and forest biomass constitutes about *80%* of terrestrial biomass. They contribute over *2/3* of global terrestrial net primary production. Slowing forest loss and restoring forest cover in deforested areas could thus help mitigate climate change. Forests provide more than *75%* of the world's accessible freshwater through forested catchments and prevent or mitigate natural hazards such as floods, landslides, and soil erosion. They play an important role in cultural and spiritual traditions and, in some cases, are integral to the very definition and survival of distinct cultures and peoples. Forests continue to play an important role in providing recreation and spiritual solace in more modernized, secular societies, and are essential for the subsistence and survival of more than *300 million people*, most of them very poor. The *60 million indigenous people* who live in forest areas are especially dependent on forest resources and the health of forest ecosystems.

The dry-land biomes

Dry land ecosystems support tourism through a high species diversity of large mammals, they provide nutrient cycling by processing most arid primary production through a high functional diversity of invertebrate decomposers and they also contribute to rainfall water regulation and soil conservation, and produce a diversity of wild and cultivated plants.

The Mountain landscapes

For many societies, mountains have spiritual significance. Scenic landscapes and clean air make mountains target regions for recreation and tourism. In many mountain areas, tourism is a special form of highland-lowland interaction and forms the backbone of regional as well as national economies. Mountains are particularly important for the provision of clean water, and their ecological integrity is key to the safety of settlements and transport routes. As ‘‘water towers,’’ mountains supply water to nearly half the human population, including some regions far from mountains, and mountain agriculture provides subsistence for about half a billion people. Services further include water for hydroelectricity, flood control, mineral resources, timber, and medicinal plants.

5.4.3 Inland waters

The disruption of natural flooding regimes has devastated many riverine habitats and led to decreased sediment transport and a loss of flood buffering and nutrient retention. Flooding can cause severe hardship to humans, with the *1998 floods in China* causing an estimated *$20,000 million* worth of damage, but it is also essential for maintaining sediment-based fertility of floodplains and supporting fish stocks in large rivers. Inland waters have significant aesthetic, artistic, educational, cultural, and spiritual values, and they provide invaluable opportunities for recreation by many communities and, increasingly, for tourism.

Box 5.2 Freshwater habitats and biodiversity

Freshwater ecosystems, including rivers, lakes, swamps and deltas provide numerous benefits to people beyond fresh water. Rice is perhaps the major cultivated wetland plant, providing staple food to around half of the world’s population. Moreover freshwater systems yield millions of tons of fish each year. In West Africa, and in parts of East Africa, Asia and the Amazon basin, inland capture fisheries comprise a major dietary input. This is particularly so for land-locked countries, e.g. Zambia (over *50% of animal protein consumed by people*), and Malawi (*75%*). These resources may be critical in times of food stress. Some *20 of the 30 countries* with the highest per capita consumption of inland fish are classified as low income and food deficient (Groombridge & Jenkins, 1998).

Freshwater systems are in decline, in part because they are perceived to be of little value compared with other uses of the land, and because the benefits they do provide are public goods, the use of which is unregulated. Since 1900 over half of wetlands worldwide have disappeared. Freshwater resources in the Mediterranean are under pressure from a growing population of ca *450 million people*, and as one of the principal global tourism destinations. However, many of these services are undervalued, and half of the region’s wetlands have been lost. As a result, *56%* of Mediterranean endemic freshwater fish species are threatened (Smith & Darwall, 2006).

Of Kenya’s wetlands, between 1970 and 2003, the area of swampland declined by *40%* whilst flow rates in most rivers declined by more than *30%*. Lakes experienced dramatic fluctuations in water levels, with frequent periods of drying out. The reasons for these declines include reduced vegetation cover in catchment basins, invasive species and pollution from surrounding land use intensification (Koyo *et al*., 2005). For rural people, however, wetlands are critical livelihoods resources. Communities around Yala Swamp in Western Kenya are *100%* dependent upon the wetland for water, whilst *86%* of the population rely on building materials from the area. The costs of wetland degradation on local people is considerable due to the high price of substitute goods – iron roofing sheets cost six times more than papyrus from the swamp, whilst bricks are 14 times the cost of wood and clay (Schuyt, 2005).

5.4.4 Man-made landscapes

Box 5.3 Biodiversity decolonises the country side

The Dutch have a saying that "God created the world, but the Dutch created Holland." About half of the land area in The Netherlands lies below sea level. Much of this land has been reclaimed from the sea. The Dutch built dikes around swampy or flooded land and then pumped the water out, originally with windmills. This resulted in a small scale diversity of rural landscapes based on agriculture, which was traditionally multifunctional, based on labour intensive mixed farming, where animals produced "fertilizer". After World War II, Dutch agriculture changed into a highly specialized intensive farming system, in which the production system is characterized by high inputs of capital and labour. This type of agriculture had a strong negative impact on biodiversity. Further intensification and lower market prices of agricultural products in the last few decades resulted in a large number of farmers seeking diversification of income by applying for as agri-environmental subsidies. Currently one farmer out of seven delivers "agri-environmental services".

Farming for Nature (www.boerenvoornatuur) is an initiative to stimulate diversification in the rural area with the aim to preserve and enhance its natural and cultural values. The rural area can provide many provisioning, regulating, cultural and supporting services such as food for livestock, water, climate, erosion and pest regulation, cultural heritage values, and primary production. The Rural European Platform (www.rurep.org) has similar objectives at the European level. This Platform seeks new ways of financing rural development by cooperation with public and private stakeholders at the local level, as well as CAP payments and other European and/or national funds allocated to rural areas.

5.5 Trends in ecosystem services in marine systems

5.5.1 Provisioning services

Capture fisheries
Fish are consumed in virtually all societies, but the levels of consumption differ markedly. Marine fisheries are a globally important source of food: it is estimated that *1 billion people* worldwide are dependent on fish as their sole or main source of animal protein, while fish provided more than *2.6 billion people* with at least *20 percent of their average per capita animal protein intake* (FAO 2006). Per capita consumption is generally higher in Oceania, Europe, and Asia than in the Americas and Africa. Small island countries have high rates of consumption; land-locked countries often low levels. Reliance on fish is particularly high in some developing countries, accounting for example for up to *70% of animal protein* for China, Thailand and Bangladesh. During the past century, the production and consumption of fish (including crustaceans and molluscs) has changed in important ways. Average per capita consumption has increased steadily: during the last four decades, the *per capita consumption of fish* increased *from 9 to 16 kilograms per year*.

Demand for fish is increasing with population growth, rising wealth and changing food preferences as a result of the marketing of fish in developed countries as part of a healthy diet. Between 1974 and 1999, the number of stocks that had been overexploited had increased steadily and by 1999 stood at 28% of the world’s stocks for which information is available. The most recent information suggests that just over half of the wild marine fish stocks for which information is available are moderately to fully exploited, and the remaining quarter is either overexploited or significantly depleted.

Box 5.4 Loss of the North Sea provisioning services

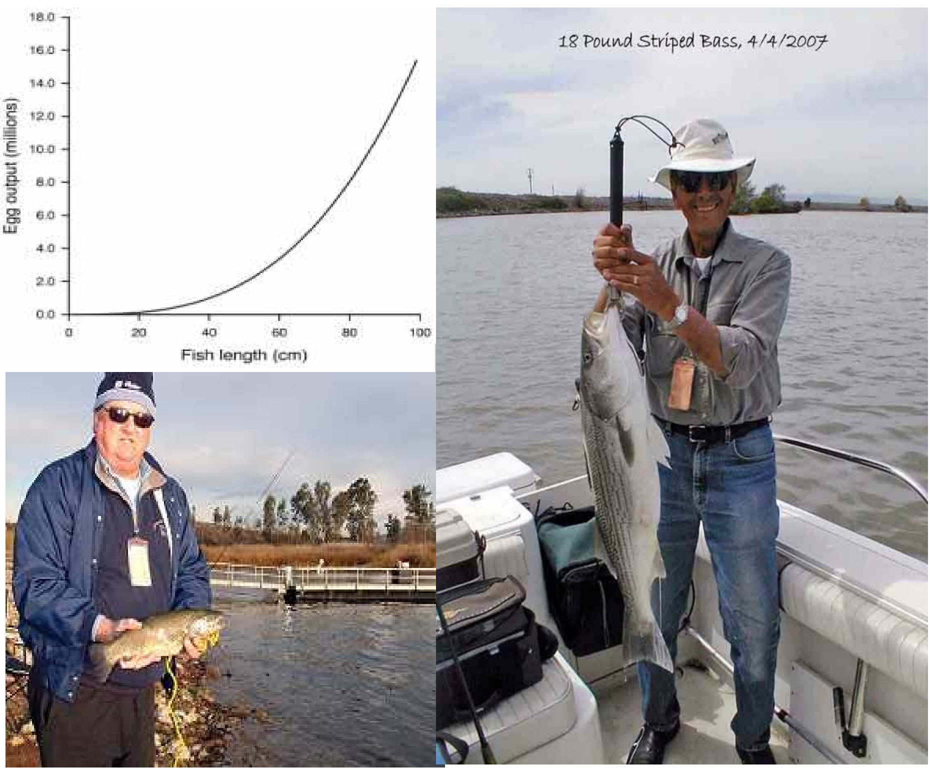
The North Sea is one of the most productive areas in the world with a range of plankton, fish, seabirds and benthic communities and is one of the world’s most important fishing grounds. It accounts for some *2.5 million metric tonnes* of fish and shellfish catches annually and a fishing industry with significant jobs including catching, processing, transportation and shipbuilding. Overexploitation of North Sea fisheries is now a major threat to biodiversity and ecosystem health. Most of the stocks of commercial fish species in the North Sea are in seriously endangered condition with *30 to 40 % of the biomass* of these species being caught each year. In addition, *70%* of young cod, for example, die before sexual maturity. Furthermore, heavy fishing pressure has resulted in *80%* mortality in young fish. The levels of by-catch of particularly harbour porpoises (ca *7000*), pose a particular risk to overall populations. About *2.5 million* pairs of seabirds breed around the coasts of the North Sea. In 2004, seabirds on the North Sea coast of Britain suffered a large-scale breeding failure. There were strong indications that this breeding failure was linked to a food shortage caused by high levels of fishing for sandeels. The beam trawling in the southern and central North Sea reduces total benthic biomass by *39%* and benthic production by *15%* relative to the un-fished state. It is also estimated that for *1 kilogram* of North Sea sole caught by beam trawl on the seabed, *14 kilograms* of other animals are killed. The spawning stock biomass of Cod had declined from a peak of *250,000 tonnes* in the early 1970s to less than *40,000 tons* in 2001. The biomass of top predators has decreased with *65%* in 50 years. Other services affected by biodiversity loss include marine tourism and recreational services that include bird watching, whale watching and sea angling. The value of the whole production chain from fishing, aquaculture, processing to marketing is estimated to be approximately *0.28 %* of the EU gross domestic product. In Europe, the number of fishermen has been declining in recent years, with the loss of *66,000 jobs* in the harvesting sector.

Aquaculture
Although aquaculture is an ancient activity, it is only during the past 50 years that it has become a globally significant source of food. In 2002 it contributed about *27%* of fish harvested and *40% (by weight)* of all fish consumed as food. However, the variety of supply from aquaculture is well below that of capture fisheries: only *5* different Asian carp species account for about *35%* of world aquaculture production, and inland waters currently provide about *60%* of global aquaculture outputs. Farmed species such as salmon and tuna, which use fishmeal, contribute to the problem since much of the fishmeal and oil currently used in the aquaculture industry is derived from wild-caught small pelagic fish. In some countries, such as Chile, small pelagic fish that were once a source of cheap protein for people are now largely diverted for fishmeal.

5.5.2 Cultural services

Recreational fishing
Some species are of considerable *cultural importance* (salmon are an important part of aboriginal culture in the Northeast Pacific, for instance), while others generate substantial income from tourism (especially dive tourism) and recreation. *Recreational fishing* was considered relatively benign until recently, mainly because information about its impact has been limited. Early estimates of global recreational catches were put at only *0.5 million tons*, but recent estimates of over *1 million tons* are probably more accurate. For some inshore fisheries, the catch from the recreational sector can exceed the commercial sector. Recreational fishing is an important economic activity in some countries; in the United States it is worth approximately *$21,000 million a year*; in Canada, *$5,200 million a year* and in Australia, *$1,300 million a year*.

Box 5.5 Loss of cultural ecosystem service due to overfishing



Graph: Egg output versus body size in tropical groupers (Serranidae). Large individuals produce more eggs than small ones (after Roberts & Hawkins 2000). Pictures: disappointed and happy recreational fishers.

Overfishing results not only in a decrease of the provisioning services reducing fish catch and in the long run in a collapse of fish stocks, but it changes the demography of fish too with more small individuals, leading to a decline in the cultural service of sports fishing. However, before populations collapse usually individuals start reproducing at a smaller size resulting in smaller fish, and therefore lower reproductive output. Development of fully-protected marine reserves can help to mitigate these loses of ecosystem services (Roberts & Hawkins, 2000). Evidence from the tropics indicates that costs of not setting up marine protected areas are much larger than acting now. In the temperate zone, countries with industrialized fisheries, however, have been slow to implement fully-protected reserves, believing (without evidence) that they will not work as well as in the tropics.

Marine tourism is a growing industry, principally in the marine wildlife tours sector. Similarly, coral reef tourism has increased in visitation levels and value, with a current net present value estimated at *$9,000 million*. The Great Barrier Reef attracts 1.6 million visitors each year and generates over *$1,000 million annually* in direct revenue. Marine fisheries are increasingly valuable for recreation, particularly in developed countries. In the US alone, in 2006 nearly *13 million anglers* made more than *89 million* marine recreational fishing trips on the Atlantic, Gulf and Pacific coasts, capturing almost *476 million fish*, of which *55%* were released alive In the European Union (EU 15), an estimated *8 million recreational sea anglers* spend an estimated *€25,000 million* a year, compared to a *€20,000 million* value for commercial landings in 1998.

Box 5.6 The benefits of clam fishing practices in lagoon of Venice, Italy

The clam fishing effort in the Lagoon of Venice has strongly increased since 1983, coinciding with the introduction of the Manila clam. It is now responsible for colonising large shallow areas and competing directly in the same ecological niche as the endemic clam species. Furthermore, the relatively high market price of this species, ranging from *€4.06 to 7.15* a kilogram, with a capacity to harvest *150 to 200 kg* of clams per day has contributed to its commercial profitability. Clam fishing activities have changed the morphology and marine life functions of the Lagoon. The consequence has been a reduction of the clam stock, destruction of nursery areas and feeding grounds of many marine species, including commercial fish stocks. Since the adoption of vibrating technologies has brought forward unavoidable negative environmental impacts on the Lagoon they are currently far from being a means for sustainable economical activity. Market data shows a diminishing supply of approximately *40%* in the catch between 2000 and 2001 due to a reduction in clam stocks. Increased pollution has also contributed to significant environmental damage to the marine ecosystem, including commercial fishes.

The community sees significant benefits in moving to a system of manual technology only, in spite of the loss in present earnings. A move towards full use of vibrating rakes only is one that would yield high economic benefits in the very short term but would then start to make net losses, given damage to the ecosystem service. There are different ways of looking at the '*accepted losses*'. On the one hand the losses can be considered as an estimate of part of the value of the ecosystem and its services (clam provision) in its normal, functional state, while clam fishing still occurs. On the other hand, these values can be seen as relating to stakeholder appreciation of the local economic value of the flow of ecosystem services (clams), where the local authority could see long term economic benefits as larger than those relating to the fisherman and be willing to pay to avoid rapid deterioration of the ecosystem and its services.

The authorities' perspective is represented by a lower discount rate (***3%***) than that of the fishermen (***7%*** private). There are three sets of potential 'benefits' from a move towards more sustainable clam fishing: (1) ensuring a more sustainable income stream for the fisherman; (2) establishing more sustainable economic activity related to clam fishing in the local economic context; and (3) broader ecosystem benefits and services (e.g. other fisheries, amenities, tourism).

5.5.3 Effects of changes in marine biodiversity

The removal or depletion below a certain level of populations of particular species or functional groups has been shown to have dramatic effects on some marine ecosystems and the associated fisheries. Predators in particular ('top-down control') seem to be very influential in shaping and maintaining various habitat states or population levels. In addition, experimental evidence suggests that a loss of species diversity increases vulnerability to the establishment of invasive species.

Marine fisheries are vulnerable to the decline in extent or quality of particular marine habitats that play important roles in the provisioning of key resources (e.g. food, shelter) for targeted species. These include, amongst others: fisheries based directly on coral reefs, seamounts, sea grass meadows and kelp forests. Marine fisheries are also vulnerable to the declines in the extent or quality of coastal habitats, including: mangroves, estuaries and coastal wetlands. Marine fisheries are furthermore affected by changes in inland ecosystems that affect the quality, volume and timing of water inputs as well as erosion regimes.

5.6 Trends in ecosystems services in coastal systems

5.6.1 Introduction

Coastal communities aggregate near the types of coastal systems that provide the most ecosystem services. Within the coastal population, *71%* live within 50 kilometres of estuaries; in tropical regions, settlements are concentrated near mangroves and coral reefs. These habitats provide protein to a large proportion of the human coastal populations in some countries; coastal capture fisheries yields are estimated to be worth a minimum of *$34000 million annually*.

Destruction of coastal wetlands has been implicated in crop failures due to decreased coastal buffering leading to freezing in inland areas. In general, the choice to exploit coastal resources results in a reduction of other services; in some cases, overexploitation leads to loss of most other services. Within the coastal system, choices that result in irreversible changes, such as conversion of coastal habitat for industrial use, urbanization, or other coastal development, often bring short-term economic benefits but exact longer-term costs, as regulating and provisioning services are permanently lost. Choices made outside coastal areas, such as the decision to divert water for agriculture and thus reduce the flow of fresh water to estuaries, are cause for particular concern because virtually none of the benefits accrue to the coastal sector.

5.6.2 Mangroves and coral reefs

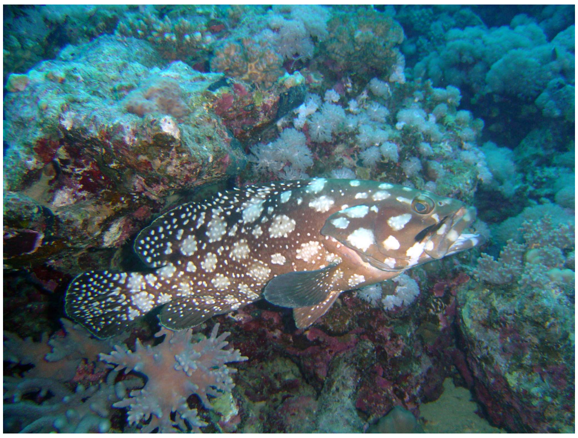
The importance of mangroves and coral reefs
The importance and quality of the various goods and services provided by mangroves varies among the various mangrove zones (Ewel et al. 1998). Fringe forests provide protection from typhoons, flooding, and soil erosion; they provide organic matter export, animal habitat and a nursery function. Riverine mangroves also provide protection from flooding and erosion, as well as sediment trapping, a nursery function, animal habitat, and the harvest of plant products (due to highest productivity). Basin forests provide a nutrient sink, improve water quality, and allow the harvest of plant products (due to accessibility).These forests thus buffer land from storms and provide safe havens for humans in the coastal countries in which they occur. Mangroves have a great capacity to absorb and adsorb heavy metals and other toxic substances in effluents. They can also exhibit high species diversity. Those in Southeast Asia, South Asia, and Africa are particularly species-rich, and those in association with coral reefs

provide food and temporary living space to a large number of reef species. In some places mangroves provide not only nursery areas for reef organisms but also a necessary nursery ground linking sea grass beds with associated coral reefs . Removal of mangrove can thus interrupt these linkages and cause biodiversity loss and lower productivity in reef and sea grass biomes (MA, 2005b).

Mangroves are highly valued by coastal communities, which use them for shelter, securing food and fuel wood, and even as sites for agricultural production, especially rice production. Due to their function as nurseries for many species, fisheries in waters adjacent to mangroves tend to have high yields; annual net values of $600 per hectare per year for this fishery benefit have been suggested. In addition, an annual net benefit of $15 per hectare was calculated for medicinal plants coming from mangrove forests, and up to $61 per hectare for medicinal values. Similarly large economic benefits are calculated for shoreline stabilization and erosion control functions of mangroves (MA, 2005b).

Reefs provide many of the services that other coastal ecosystems do, as well as additional services: they are a major source of fisheries products for coastal residents, tourists, and export markets; they support high diversity that in turn supports a thriving and valuable dive tourism industry; they contribute to the formation of beaches; they buffer land from waves and storms and prevent beach erosion; they provide pharmaceutical compounds and opportunities for bio-prospecting; they provide curios and ornamentals for the aquarium trade; and they provide coastal communities with materials for construction and so on (MA, 2005b).

Box 5.7 Ecosystem services of Philippine Coral Reefs



Brown-marbled grouper (*Epinepephelus fuscoguttatus*)

In the Philippines, coral reefs are important for fisheries and tourism. Fisheries is a small scale business where *more than 1 million fishers* contribute almost *1 billion US$ annually* to the countries economy. Also tourism has large possibilities for revenues, which can increase up to *US$ 300 000 annually* (estimate based on willingness to pay inventories). Fishing is considered unsustainable (over fishing, destructive fishing methods, sedimentation), and this pressure is expected to increase due to population growth. This pressure is already felt by local fishermen as a reduced catch. White et al. (2000) compared the costs and benefits of not acting versus implantation of marine reserves and showed that the benefits of setting up and maintaining reserves will exceed the costs. Inaction will have dramatic financial effects on both fisheries and tourism.

Quantitative changes in ecosystem services from mangroves and coral reefs
Coral reefs and mangroves are among the world's rarest ecosystems, and both are under serious threat. Some *30%* of reefs are already seriously damaged and *60%* could be lost by 2030 through fishing damage, pollution, disease and coral bleaching, which is becoming more common with climate change. Human activities currently threaten *88%* of reefs in South-east Asia, with *50%* considered to be at high or very high risk. Likewise, and estimated *35%* of mangroves have disappeared in the past two decades, with some countries having lost up to *80%* through conversion for aquaculture, overexploitation and storms. The annual rate of mangrove loss *(2.1%)* is higher than that of tropical rainforest *(0.8%)* (UNEP-WCMC, 2006).

Healthy reefs and mangroves can absorb *70-90%* of the energy in wind-generated waves, thus protecting shorelines from storms and hurricanes. They also support a range of fisheries, and fish nursery habitats and, in the case of reefs, tourism and recreation (valued in some places at up to *$1 million per km^2* if the cost of maintaining sandy beaches is considered). Both ecosystems contribute significantly to national economies, particularly those of small island developing states, *90%* of which have reefs and *75%* of which have mangroves. Degradation of mangroves and coral reefs is already causing reduced fish catches and tourism revenues and increased coastal erosion, and may reduce food security and increase malnutrition in coastal communities. Most of the estimated *30 million* small-scale fishers in the developing world are dependent on coral reefs for food and livelihood. For example the productivity of the fisheries sector in Belize, Honduras and Mexico is directly dependent on the health of the adjacent barrier reef. Reef fisheries in the Caribbean generate some *US$310 million a year*, and in South-East Asia *US$2,400 million a year*. Some estimates suggest that reefs contribute up to *25%* of the total fish catch in developing countries, providing food for *1 billion* people (UNEP-WCMC, 2006).

The mean annual economic value of coral reefs and mangroves has been estimated at *US$100,000-600,000 per km^2* and *$200,000-900,000 per km^2* respectively. Yet the estimated annual operating costs for marine protected areas are only *US$775 per km^2*, a tiny proportion of the estimated benefits of reefs and mangroves. Currently marine protected areas are dramatically under-represented in the global protected area network, and significant efforts will be required to meet the 2012 CBD target of protecting 10% of total marine area globally (UNEP-WCMC, 2006).

Box 5.8 How to stay dry in the Netherlands: services of dunes and beaches

Dunes, beaches and dikes keep the North Sea from flooding The Netherlands with an almost 300-kilometre-long stretch along the coastline. Most of the area is part of the European network of nature reserves ‘Natura2000’. The nature values of this ecosystem are protected by European law. With *9 million people* living below sea level, coastal defence is a major economic issue in The Netherlands. Climate change, sea level rise, the tsunami in South East Asia in 2004 and the devastating effect of the hurricane Katrina in 2005 in the United States renewed the appraisal of this important ecosystem service of dunes beaches and dikes. In the coming years the Dutch government will invest *742 million euro* to increase the safety of this coastal defence. The dunes have also a long history in the supply of drinking water, e.g. to Amsterdam. Drinking water extraction started in 1853 and since 1957 water from the river Rhine is infiltrated in the dunes for purification and to mitigate desiccation of the dunes. This service has resulted in protection of the dune habitat against urban development. Dune and coastal habitat also have a high recreational value, especially for Germans tourists.

Box 5.9 Loss of ecosystem services in the Pearl River delta region

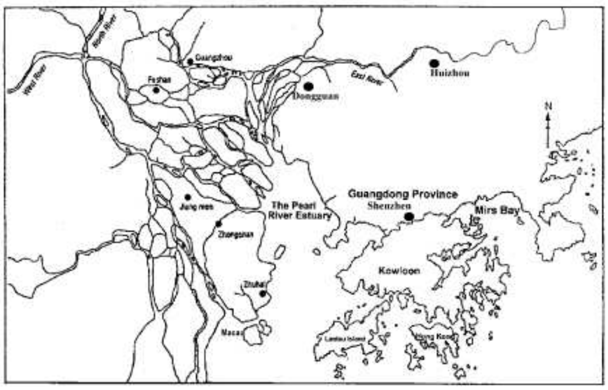


Fig. 1
The Pearl River estuary and eight major cities in the delta region

Industrialization and economic growth in the Pearl River delta region (China) resulted in large environmental degradation of the region. The delta changed in a relative short period from an area with high biodiversity and traditional farming into an industrialized area with low biodiversity. The area had many favourable physical characteristics, such as flat and fertile lands, abundant fresh water and easy access to the sea for agricultural and aquacultural development. Land restructuring resulted in a loss of arable land of over 20% in a single decade. The number of inhabitants increased from *9.6 million* in 1982 to *21.2 million* in 1996. Industrialization and the pressure inflicted by urban development resulted in a strong increase in water pollution; the estimated discharge of industrial effluent equalled *2000 million tons* and that of domestic waste *560 million* tons annually. Most of this discharge is not treated. The high load of effluents polluted the river resulting in frequent algal blooms up into the costal zone and contamination of water resources. Consequently ecosystem services such as provision of clean drinking water, fisheries and disease regulation are greatly reduced. The economic loss due to the environmental degradation was estimated to amount to *US$11,000 million* in the region.

Box 5.10 Loss of ecosystem services due to eutrophication

Many coastal marine ecosystems in the EU are subject to eutrophication caused by increased supply of nutrients of anthropogenic origin. Due to their wide distribution and their role in sustaining important ecological functions of the coastal marine zone, the shallow soft bottom systems are considered the key ecosystem in the Sweden archipelago. Loss of biodiversity has been detected at three different trophic levels. Along most sections of the coast both the upper and the lower depth distributions of sea grass have been reduced, resulting in a narrowing of meadows. In some areas sea grass meadows have disappeared *100%*. The number of species, and the density and biomass of benthic macro fauna is *40-50%* lower under mature algal mats than in normal situation. The number of fish species and the density and biomass of fish has been found to be significantly lower in areas where sea grass is missing. Similarly, *4 x* lower total density and *6 x* lower biomass of gobies has been observed in non-seagrass sites in comparison to seagrass beds.

The production of fish species of commercial and recreational value, will be significantly reduced as the reproduction of these species decreases and they are replaced by non-commercial fish species and crustaceans. In terms of ecosystem services, the loss of benthic fauna diminishes ecosystem's water purification capacity and its ability to manage organic waste. Additionally, decline in benthic fauna further disturbs the nutrient cycling within the system. Social and cultural ecosystem services are affected by algal mats/blooms through reduced aesthetic and recreational attraction.
The overall benefits of improved water quality in the Stockholm archipelago are estimated to be *€6 – €54 million per year*. In the last decade, the total catch in this fishery corresponds to a total gross income to fishermen of about *€19 million per year*. If the *30-40 %* reduction in the output of juveniles ultimately results in a corresponding decrease in total catch, total gross income to fishermen would be reduced by *€6 - €8 million per year*. As an estimate of the loss of recreation and tourism services, camping ground owners remove tons of dead red algae every year at *€8119 per km*. These effects of eutrophication are not unique to the Swedish west coast but they are also common in many coastal marine ecosystems in the EU.

5.7 Non-linearity and collapse in ecosystem response to pressures

5.7.1 Introduction

Most ecosystems are robust and can absorb many changes, but they can be pushed to a point beyond which they can no longer withstand external pressures. At this point, any further change in conditions can lead to non-linear change with a critical result – i.e. where there are major implications, often irreversible. This section is an adapted excerpt from P. ten Brink et al. (2008).

5.7.2 Critical thresholds

Thresholds have been discussed since the 'birth' of the sustainable development concept. The Brundtland report[1] mentioned thresholds in the context of sustainable development and survival. This speaks of natural critical thresholds, in other words points beyond which there is a change of state such that some function, service or value is compromised. The 'critical threshold' can be defined as a point between alternate regimes in natural systems. When a threshold in a certain variable in a system is passed, the system shifts in character. These natural 'thresholds' exist and are set by the biological, chemical and other physical laws of the ecosystem.

Examples of natural critical thresholds being exceeded, and their impacts, include:

- Acidification - soils are able to buffer acid deposition through natural release of cat-ions to varying extents depending upon the type of soil. When deposition exceeds this the soils acidify. This threshold concept was termed the 'critical load' and underpinned much of the policy debate on controlling acid emissions[2] – it also underlines that critical thresholds are

1 WCED (1987)

[2] See Farmer (1997) for a discussion on the buffering capacity of soils, acid deposition and the use of the critical loads concept.

often locality dependent and there could be different local/regional specifications of critical thresholds.

- Habitat size - below a certain size, areas of habitat (e.g. forest, woodland etc) will not sustain certain species. This relates to food availability, diversity and migration paths. Habitat may become fragmented through the construction of transport corridors.
- Population numbers or density – points exist below which a population will no longer be stable and risk of collapse occurs – e.g. cod spawning stock biomass in the North Sea declined from a peak of 250,000 tonnes in the early 1970s to less than 40,000 tons in 2001[3]. This was linked to over-fishing.

When critical thresholds are crossed, the provision of certain ecosystem services of benefit to society and its economic and social welfare may be lost[4]. Once a critical threshold has been crossed, it may be difficult (or even impossible) and generally costly to return the ecosystem to its original state. Note that in some cases crossing the threshold brings about a sudden, large and dramatic change in the eco-system and its functions, whilst in other cases the response is more gradual[5] and in others it is more probabilistic.

Fisheries yields of individual species are well-known to be subject to sudden collapse following overexploitation, often failing to recover to former levels of abundance particularly amongst slow-growing, slow-maturing species. There are many documented examples of recent sudden regime shifts in fresh water and marine systems, with implications for fisheries provisioning. Such shifts seem to be particularly likely in ecosystems that are or have been under intense fishing effort, and which have been simplified by the loss of one or more higher-trophic functional groups. While the collapse of entire fisheries has been observed across relatively large areas, more often the collapse of a particular species or set of species results in a shift in fishing effort towards other species (often further down in the food web) or towards other regions/ecosystems (e.g. towards increasing depths). These shifts mask the underlying sequential collapses from ocean-level or global fisheries statistics. Under current knowledge, it is therefore unlikely that a synchronised global collapse will be observed by 2025, but it is very likely that the slow decline that has been observed since the mid-1980s continues. Climate change and related ocean acidification are the greatest sources of uncertainty in predictions of marine fisheries, potentially responsible for sudden, large-scale, changes in the foreseeable future (MA, 2005b).

5.7.3 Critical trends

Recognition of ‘critical trends’ that will lead to breach of thresholds is also important. Critical trends are trends that, if not addressed, will lead to a critical threshold being breached. This can be a change in the value of a state variable (e.g. oxygen content in water) which, if continued (i.e. falling oxygen content through pollutant emissions which ‘demand’ oxygen[6]), would result in the critical threshold of a state being crossed (insufficient oxygen content to support life). The critical trend may refer to a pressure which is changing the state in such a way that it is threatening to cross a critical threshold (such as an increase in vehicle traffic, which in turn affects particulate levels). In many cases, where an actual threshold is not known, identifying a critical trend may serve as a proxy.

3 See Kettunen and ten Brink (2006)

4 For more see Kettunen and ten Brink (2006) and also ten Brink et al (2002) and also Millennium Ecosystem Assessment (2005)

5 See Walker and Meyers, 2004; Resilience Alliance and Santa Fe Institute 2004

6 E.g. BOD or COD – biological oxygen demand or chemical oxygen demand. The former can be household sewage whose decomposition takes up oxygen. COD can feature in pollutant emissions from certain industries.

5.7.4 Conclusions

The use of critical thresholds and trends should help make choices and the trade-offs and impacts of these choices explicit. It should help lead to more consistent decision-making. Their use can be instrumental in clarifying the range of winners and losers and hence help clarify responsibilities, ethical questions such as to unfair burdens and needs for compensation, or the need for different decisions. The explicit consideration of critical thresholds should give policy makers the ability better to inform and understand the decisions they are making, and to avoid decisions that lead to unsustainable outcomes. Linking critical thresholds to evaluation tools adds an extra dimension that simplifies the identification of unsustainable options. Through use of critical thresholds, there should be fewer cases of 'unacceptable' trade-offs arising from a lack of awareness and lack of visibility of the costs. In addition, it should be possible to identify more win-win-win (economy-environment-social/human) solutions, thus making a constructive contribution to sustainable development and moving towards an improved culture of sustainable development.

5.8 Invasive Alien Species and ecosystem services

The impacts of invasive alien species (IAS) affect a range of different ecosystem services. While a comprehensive survey has not yet been carried out, *table 5.6* shows examples of IAS impacts across the ecosystem service types, demonstrating that virtually all ecosystem services are affected by IAS.

Table 5.6: Impacts of IAS on Ecosystem Services - Examples

Type of Ecosystem Service Lost	Examples of the service being lost
Provisioning Services	
Food and fibre	• Agricultural losses – e.g. Colorado potato beetle (Finland) • Food: comb-jellyfish reduces anchovy catch (Black Sea) • Forestry losses - black locust (e.g. Cyprus) • Food security: destroy rice field: Golden apple snail (*Pomacea canaliculata*), Rats (*Rattus spp*.); invasive fish (e.g., *Oreochromis niloticus*, *Cyrpinus carpio*)
Ornamental resources	• *Rhododendron ponticum* displaces other plants in natural areas (e.g. Australia) • The common broom *Cytisus scoparius* has become a pest in production forest and nature reserves, destroying open land-scapes and threatening endangered plant species
Fresh water	• Algae blooms caused by alien phytoplankton such as Chattonella verruculosa and Alexandrium species can be toxic
Other	• Irrigation and drainage: Aquatic weeds (e.g., *Eichhornia crassipes*, S*alvinia molesta*, *Mimosa pigra*, *Pistia stratiotes*.)
Regulating services	
Climate regulation (eg temperature and precipitation, carbon storage)	• Carbon storage can be reduced by damage / death to trees in forests due to beetles (e.g Spruce bark beetle)
Water regulation (eg flood prevention, timing and magnitude of runoff, aquifer recharge)	• Decrease water levels (e.g. due to Japanese Knotweed or in South African native Fynbos ecosystem) • Hydroelectric: Aquatic weeds (e.g., *Eichhornia crassipes*, S*alvinia molesta*, *Mimosa pigra*,*Pistia stratiotes*.)
Erosion control	• Erosion of river banks and embankments by invasive weed

	(eg *Fallopia in* Germany) • The rabbit in Australia, causing soil erosion – impediment of the regeneration of forests and shrubs that prevent soil erosion
Water purification and waste management	• Depletes oxygen (water hyacinth)
Regulation of human diseases	• Invasive can bring in disease (influenza, small pox, dengue fever, malaria, bubonic plague)
Biological control (eg loss of natural predator of pests)	
Pollination	• Competing for pollinators such as bumblebees with the native riverbank species, and so reduces seed set in these other plants (*Impatiens glandulifera*)
Fire resistance (change of vegetation cover leading to increased fire susceptibility)	• Increased fire risk due to drying of land (eg South African fynbos ecosystem) or due to less species diversity and higher ratio of easily flammable trees (eg Portugal due to eucalyptus) • Increase fuel loads, leading to changes in fire regimes *Andropogon gayanus* (Gamba grass) e.g. Australia, Brazil
Other	• Cockroaches (50% exotic) causing asthma
Cultural services	
Cultural diversity, spiritual and religious values, educational values, inspiration, aesthetic values, social relations, sense of place and identity	• Change in landscape via invasive alien trees can lead to change of sense of place and identity – (e.g. alien trees covering originally treeless highland of Santa Cruz island, Galapagos)
Recreation and ecotourism	• Salmon parasite leads to reduction in value of recreational fishing (eg Norway) • *Chromolaena odorata*, affects the nesting sites of crocodiles (a focus of tourism in South Africa), directly placing these populations at risk • Toxic algae harming tourism (e.g. costs of US $ 75 million/ yr , in USA, incl. health, fishing closure, recreation ; NOAA news)) • Rabbit haemorrhagic disease harming rabbit hunting e.g. Australia
Supporting services	
Nutrient cycling	• When the shrub bush honeysuckle *(Lonicera maackii)* becomes dominant, tree seedlings and herbaceous plants become less abundant (e.g. USA), creating a near monoculture of honeysuckle

Scale of impacts

The impacts of IAS on ecosystems vary significantly depending upon the invading species, the extent of the invasion, and the vulnerability of the ecosystem being invaded. Some impacts are global and of headline importance (see Box 5.8 for some headline cases) whereas some effects take place at national, regional or local level. The latter are also often of fundamental importance to the areas and ecosystems in question, e.g. affecting the flow of ecosystem services to several beneficiaries. Additionally, some species may have invaded only a restricted region, but have a high probability of expanding and causing further great damage (e.g. see *Boiga irregularis*: the brown tree snake). Other species may already be globally widespread and causing cumulative but less visible damage (IUCN, 2005 and see also Van der Weijden et al., 2007).

Box 5.11 : Invasive alien species – some major health impacts *(McNeely et al, 2001)*

- An invasive species of rat, carrying a flea, was a vector for the bubonic plague that spread from central Asia through North Africa, Europe and China.
- Smallpox and measles were spread from Europe to the Americas, leading to major illness, mortalities and ultimately the fall of the Aztec and Inca empires.
- Infected cattle introduced into Africa carried the Rinderpest in the 1890s. This spread to domesticated and wild herds of bovids throughout the Savannah regions of Africa. Many cattle populations were decimated and it was estimates that 25% of the cattle-dependent pastoralists may have starved to death in the early 20th century due to this.
- The influenza virus, with its origins in birds, passed on to pigs, and then to humans

See Annex III on IAS for more details

5.9 Economic and social aspects

Marine capture fisheries are an important source of economic benefits, and important for income generation, with an estimated *38 million people* employed directly by fishing, and many more in the processing stages. *90%* of full-time fishers conduct low-intensive fishing (a *few tons per fisher per year*), often in species-rich tropical waters of developing countries. Overfishing affects human well-being through declining food availability in the long term, since fewer fish are available for consumption and the price of fish increases. Due to declines in coastal habitats, fishers are forced to go further offshore and for longer periods of time, resulting in *reduced food security*.

Nearly *40%* of global fish production is traded internationally. Most of this trade flows from the developing world to industrial countries. Many developing countries are thus trading a valuable source of protein for an important source of income from foreign revenue, and fisheries exports are extremely valuable compared with other agricultural commodities. Fish products are heavily traded, and exports from developing countries and the Southern Hemisphere presently offset much of the demand shortfall in European, North American, and Northeast Asian markets. Given the global extent of overfishing, however, it is likely that the global decline in marine fisheries landings, which already affects the poorer consumers in developing countries, will also catch up with consumers in industrial countries.

Many areas where overfishing is a concern are also low-income, food-deficit countries. For example, the exclusive economic zones of Mauritania, Senegal, Gambia, Guinea Bissau, and Sierra Leone in West Africa all accommodate large distant water fleets, which catch significant quantities of fish. Much of it is exported or shipped directly to Europe, while compensation for access is often low compared with the value of the product landed. These countries do not necessarily benefit through increased fish supplies or increased government revenue when foreign distant water fleets access their waters. In some countries, such as Côte d'Ivoire, the landings of distant water fleets can lower the price of fish, which affects local small-scale fishers. Although Ecuador, China, India, Indonesia, and the Philippines, for example, do not provide access to large distant water fleets, these low-income, food-deficit countries are major exporters of high-value fish products such as shrimp and demersal fish. As shown in the West African example, several countries in the region export high-value fish, which should provide a significant national economic gain so that cheaper forms of protein can be imported. In countries such as Ghana, however, the value of exports is often less than the value of imported fish, and the volume of imported fish does not meet the domestic demand for fish.

References

Braat L.C. (1979) *Functions of the Natural Environment*. Institute for Environmental Studies. Free University , Amsterdam.

Braat L.C. (1996) *Sustainable Multiple Use Management and Values of Dutch Forests.* In: J.C.J.M. van den Bergh (1996) Ecological economics and Sustainable development: theory, methods and applications. Edward Elgar, Cheltenham, UK, pp.199-216.

De Groot, R. (1992) *Functions of Nature: evaluation of nature in environmental planning, management and decision making.* Wolters-Noordhof BV, Groningen.

Ewel K.C., R.R. Twilley and J.E. Ong (1998) *Different kinds of mangrove forests provide different goods and services.* Global ecology and biogeography 7(1), 83-94.

Farmer, A.M. (1997). Managing Environmental Pollution. Routledge, London.

Groombridge, B. & Jenkins, M. (1998) Freshwater *Biodiversity: a preliminary global assessment.* WCMC – World Conservation Press, Cambridge, UK.

Kettunen, M. & ten Brink, P. (2006). Value of biodiversity- Documenting EU examples where biodiversity loss has led to the loss of ecosystem services. Final report for the European Commission. Institute for European Environmental Policy (IEEP), Brussels, Belgium. 131 pp.

Koyo, A., Ndetei, R., Odongo, R., Githaiga, J., Shivoga, W., Omengo, F., Manyala, J., Mwaura, F., Raburu, P., Wakwabi, E., Owiti, G., & Kinya, J., eds (2005) *Kenya National State of Wetland Ecosystem Report.* Kenya Wildlife Service, Nairobi, Kenya.

MA (2005a) *Millennium Ecosystem Assessment: Ecosystems and human well-being, Summary for decision makers*. Washington.

MA (2005b) *Millennium Ecosystem Assessment: Ecosystems and human well-being, Volume 1: Current state and trends*. Washington.

McNeely, J.A., H.A. Mooney, L.E. Neville, P. Schei, and J.K.Waage (eds.) 2001. *A Global Strategy on Invasive Alien Species.* IUCN Gland, Switzerland, and Cambridge, UK. x + 50 pp.

Meijer, M. L., and H. Hosper. (1997) Effects of Bio-manipulation in the Large and Shallow Lake Wolderwijd, the Netherlands. Hydrobiologia 342: 335-49.

Resilience Alliance and Santa Fe Institute. (2004) Thresholds and alternate states in ecological and social-ecological systems. Resilience Alliance. (Online.) URL: http://www.resalliance.org/index.php?id=183.

Roberts, C.M. and J.P. Hawkins. 2000. *Fully-protected marine reserves: a guide.* WWF Endangered Seas Campaign, 1250 24th Street, NW, Washington, DC 20037, USA and Environment Department, University of York, York, YO10 5DD, UK.

Rodrigues A., A. Balmford, M. Walpole, P. ten Brink, M. Kettunen, L. Braat, R. de Groot, R. Leemans, L. Scholten, E. Noirtin (2008) *Review on the economics of biodiversity loss: Scoping the Science*. Cambridge/ Brussels / Wageningen

Schuyt, K.D. (2005) *Economic consequences of wetland degradation for local populations in Africa.* Ecological Economics 53, 177-190.

Slim, P.A. & Loffler, M.A.M. 2007. *Kustveiligheid en natuur; een overzicht van kennis en kansen.* Alterra Wageningen UR/Bureau Landwijzer, Wageningen, 92p.

Smith, K.G. & Darwall, W.R.T., compilers (2006) *The Status and Distribution of Freshwater Fish Endemic to the Mediterranean Basin.* IUCN, Gland, Switzerland and Cambridge, UK.

ten Brink, P., Monkhouse, C. and Richartz, S. (2002) Background Report for European conference on 'Promoting the Socio-Economic Benefits of Natura 2000', Brussels, 28-29 Nov. 2002. Institute for European Environmental Policy (IEEP), Brussels, Belgium. 28 pp.

ten Brink, P., C. Miller, M. Kettunen, K. Ramsak, A. Farmer, P. Hjerp and J. Anderson (2008) *Critical thresholds, evaluation and regional development.* European Environment 18, 81-95 (2008).

Walker, B. and J. A. Meyers. (2004) Thresholds in ecological and social–ecological systems: a developing database. Ecology and Society 9(2): 3. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art3

WCED (1987). Our Common Future: Report of the World Commission on Environment and Development.

Weijden, W. van der, R. Leewis, P.Bol (2007) *Bio-invasions and their impacts on nature, the economy and public health.* KNNV Publishing, Utrecht.

White, A.T., Vogt, H.P., and Arin T. 2000. *Philippine coral reefs under threat: the economic losses caused by reef destruction.* Marine Pollution 40: 598-605.

Wong, A.W.M. and Wong, M.H. 2004. *Recent socio-economic changes in relation to environmental quality of the Pearl River delta*. Reg. Environ Change 4: 28-38.