THE ECONOMICS OF LAND DEGRADATION

ELD CAMPUS
Module:
Identification and selection of ecosystem services

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Main authors / compiled by:
Julia Hebbrecht, Hannes Etter, Silke Schwedes

Reviewed and edited by:
Richard Thomas

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Layout: kippconcept gmbh, Bonn
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For further information and feedback please contact:
ELD Secretariat
Mark Schauer
c/o Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Friedrich-Ebert-Allee 36
53113 Bonn, Germany
E info@eld-initiative.org
I www.eld-initative.org

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Abbreviations

ARIES	ARtificial Intelligence for Ecosystem Services
CICES	Common International Classification of Ecosystem Services
CGIAR	Consultative Group on International Agricultural Research
CO_2	Carbon dioxyde
DNA	Deoxyribonucleic acid
ELD	Economics of Land Degradation
ES	Ecosystem services
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
GBIF	Global Biodiversity Information Facility
GIS	Geographic Information System
GtC	Gigatonnes of carbon
InVEST	Integrated Valuation of Environmental Services and Tradeoffs
ITPS	Intergovernmental Technical Panel on Soils
MA	Millennium Ecosystem Assessment
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Cooperation and Development
SLM	Sustainable land management
SOC	Soil organic carbon
TEEB	The Economics of Ecosystems and Biodiversity
USPED	Unit Stream Power Erosion Deposition
WOCAT	World Overview of Conservation Approaches and Technologies

Table of contents

01 Ecosystem services. The theory behind it

Ecosystem services (ES) refer to all benefits that people obtain from ecosystems. They are not the same as most other goods and services, since they tend to be **much more complex** in their functioning, interactions and effects. ES are however beginning to be **given progressively more attention** in current conservation and development discourse, especially **ecosystem values** and their relationship to the economy (Emerton et al. 2018).

What is an ecosystem?

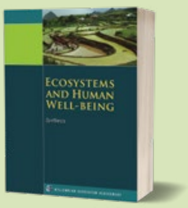
A dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit (MA 2005).

What is an ecosystem service?

The direct and indirect contributions of ecosystems to human well-being (TEEB 2010).

ES have been for the first time assessed worldwide by the Millennium Ecosystem Assessment (MA). The report also led to a common classification of ecosystem categories. According to the MA report about 60% of ecosystems services are being degraded or used unsustainably. Moreover, human activities during the last 50 years have impacted ecosystems more severely than ever before in human history. For instance, more land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850. As a result, one quarter of the earth's surface is covered by cultivated systems for agricultural activities (MA 2005).

Land provides many different multi-functional services that interact and contribute to human well-being. Each of these services has a (socio-)economic benefit that is of value to society as a whole and goes beyond market values. For example, terrestrial plants are a source of food, building mate-



The Millennium Ecosystem Assessment (MA) was called for by the United Nations Secretary-General Kofi Annan in 2000. The MA was carried out between 2001 and 2005 to assess the consequence of ecosystem change for human well-being, by attempting to bring the best available information and on ecosystem services to bear on policy and management decisions. According to the MA, near 60% of ecosystems are degraded. The MA established the scientific basis for action needed to enhance the conservation and sustainable use of ecosystems and their contribution to human well-being. The MA was in part a global assessment, but to facilitate better decision making at all scales, 34 regional, national and local scale assessments (or sub-global assessments) were included as core project components. Since the release of the MA, further sub-global assessments have started. The report is divided in: 1) conditions and trends; 2) scenarios; 3) recommendations for changes in policy. Among the outstanding problems identified by this assessment are the dire state of many of the world's fish stocks, the intense vulnerability of the 2 billion people living in dry regions due to the loss of ecosystem services, including water supply, and the growing threat to ecosystems from climate change and nutrient pollution (adapted from Emerton et al. 2018).

For more information regarding the MA go to:
http://www.millenniumassessment.org/en/About.html
and *http://www.millenniumassessment.org/en/History.html*

rials and fibre, while also providing other key services such as regulating the quality of soil, water, and air. Estimating the total economic benefit of land is not easy or straightforward. The **ecosystem service framework** can facilitate comprehensive ecosystem assessment by dis-aggregating land into broad independent categories (ecosystem services) that can be valued separately (i.e., provisioning, supporting, regulating, and cultural services, see figures 1 and 2) (ELD 2015, 1).

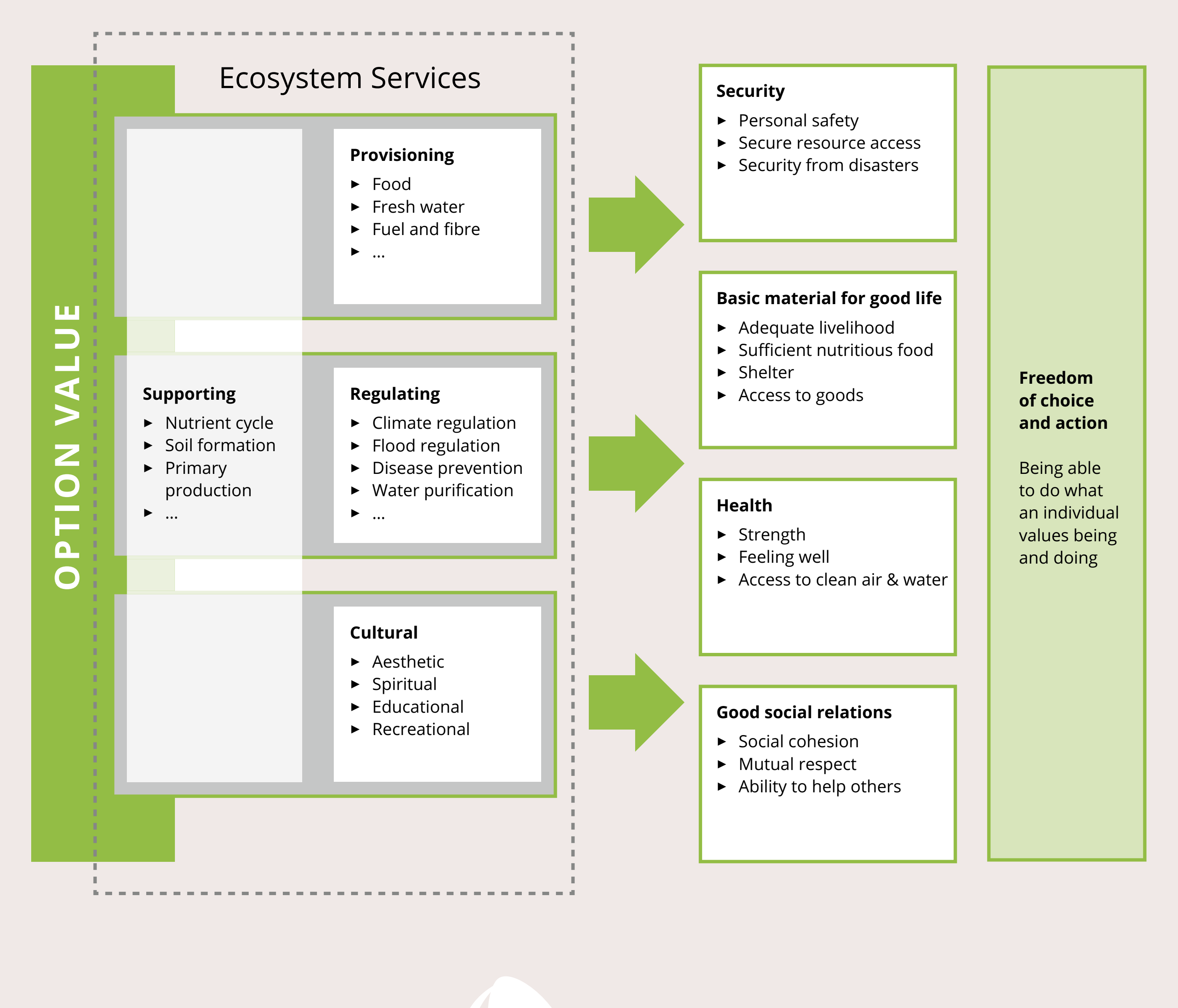
The ecosystem service framework has several classifications of ecosystem services for a range of purposes. These classifications have been established as guides for comprehensive ecosystem assessments rather than 'blueprints'. The categorisation used by the MA is one of the most popular.

Figure 1 shows the link between the four categories of ecosystem services and human well-being, which is based on the MA 2005.

FIGURE 1

The provision of ecosystem services from natural capital: linkages between ecosystem services and human well-being

Source: The Value of Land Report (ELD 2005, 1) adapted from MA 2005



Classification of ecosystem services

MA categorisation of ecosystem services

Figure 2 shows the four categories of ES according to the MA. These can be defined as follows (ELD 2015, 1):

Provisioning services – natural capital combines with built, human, and social capital to produce food, timber, fibre, water, fuel, minerals, building materials and shelter, biodiversity and genetic resources, or other 'provisioning' benefits. For example, grains delivered to people as food requires tools (built capital), farmers (human capital), and farming communities (social capital) to be produced. In simple terms: goods that people can obtain from the ecosystem;

Regulating services – natural capital combines with built, human, and social capital to regulate processes such as climatic events with water flow regulation (e.g., for increased flood or drought control, storm protection), pollution control, decrease in soil erosion, nutrient cycling, human disease regulation, water purification, air quality maintenance, pollination, pest control, and climate control with carbon storage and sequestration. For example, storm protection by coastal wetlands requires built infrastructure, people, and communities to be protected. These services are generally not marketed but have clear value to society;

Cultural services – natural capital combines with built, human, and social capital to produce more material benefits linked to recreation (tourism) and hunting as well as non-material benefits such as spiritual or aesthetic, education, cultural identity, sense of place, or other 'cultural' benefits. For example, production of a recreational benefit requires an attractive natural asset (a mountain), in combination with built infrastructure (road, trail, etc.), human capital (people able to appreciate the mountain experience), and social capital (family, friends, and institutions that make the mountain accessible and safe). Such cultural services would tend to be mostly experienced through tourism or religious practices; and

Supporting services – these maintain basic ecosystem processes and functions such as soil formation, primary productivity, biogeochemistry, soil formation, and nutrient cycling. They affect human well-being indirectly by maintaining processes necessary for provisioning, regulating, and cultural services. For example, net primary production is an ecosystem function that supports climate control through carbon sequestration and removal from the atmosphere, which combines with built, human, and social capital to provide climate regulation benefits. Some argue that these supporting 'services' should be defined as ecosystem 'functions', since they have not yet clearly interacted with the other three forms of capital to create benefits in terms of increased human well-being, but rather support or underlie such benefits. Supporting ecosystem services can sometimes be used as proxies for benefits when such benefits cannot be easily measured directly.

FIGURE 2

The four categories of ecosystem services with examples
Source: TEEB 2010

Provisioning Services are ecosystem services that describe the material outputs from ecosystems. They include food, water and other resources.

Food: Ecosystems provide the conditions for growing food – in wild habitats and in managed agro-ecosystems.
Raw materials: Ecosystems provide a great diversity of materials for construction and fuel.
Fresh water: Ecosystems provide surface and groundwater.
Medicinal resources: Many plants are used as traditional medicines and as input for the pharmaceutical industry.

Regulating Services are the services that ecosystems provide by acting as regulators eg regulating the quality of air and soil or by providing flood and disease control.

Local climate and air quality regulation: Trees provide shade and remove pollutants from the atmosphere. Forests influence rainfall.
Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
Moderation of extreme events: Ecosystems and living organisms create buffers against natural hazards such as floods, storms, and landslides.
Waste-water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as many pollutants.
Erosion prevention and maintenance of soil fertility: Soil erosion is a key factor in the process of land degradation and desertification.
Pollination: Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.
Biological control: Ecosystems are important for regulating pests and vector borne diseases.

Habitat or Supporting Services underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals.

Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migrating routes.
Maintenance of genetic diversity: Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock.

Cultural Services include the non-material benefits people obtain from contact with ecosystems. They´include aesthetic, spiritual and psychological benefits.

Recreation and mental and physical health: The role of natural landscapes and urban green space for maintaining mental and physical health is increasingly being recognized.
Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for many countries.
Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Icons designed by Jan Sasse for TEEB. They are available for download at www.teebweb.org

CICES classification of ecosystem services

Besides the above mentioned MA framework, the Common International Classification of Ecosystem Services (CICES) framework is also used. The CICES was developed by the European Environment Agency in order to provide a systematic description of the contribution of biodiversity to human well-being. CICES is not a new classification of ES that seeks to replace previously developed classifications such as MA or TEEB. It is rather conceived as a tool that creates equivalences between classification systems. The first CICES version 4.3 was published in 2013, a reviewed version – CICES 5.1 – taking into account user experience was then launched in 2017. Since its first publication, CICES has built a strong user base in Europe. It was notably used to map and assess ecosystems and their services under action 5 of the EU Biodiversity Strategy to 2020 (CICES 2019).

As in MA, CICES also uses provisioning, regulation and cultural as main categories of ES. Only supporting services are not included in CICES, because these do not provide biotic outputs and are thus considered to have an indirect impact on human well-being. CICES services are 'final' in the sense that the ecosystem outputs or characteristics that contribute to well being are still connected to or dependent upon the ecological structures, processes and functions that underpin them (CICES 2019).

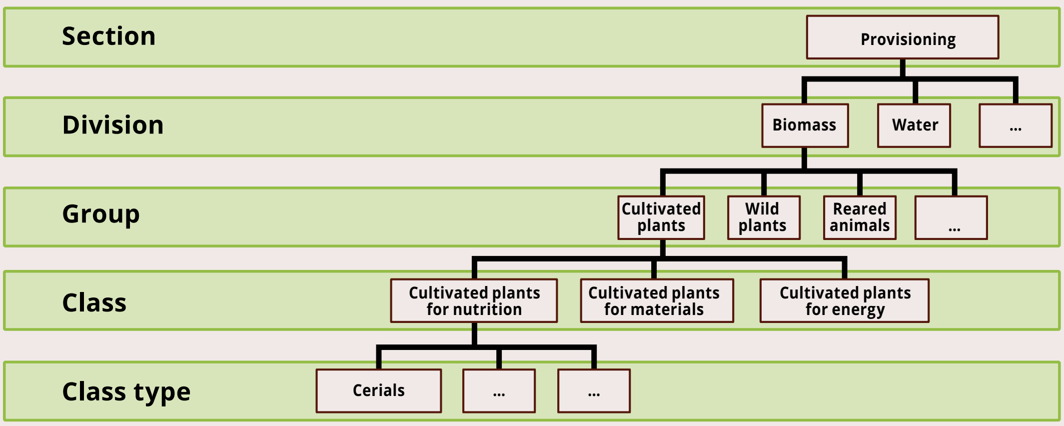
CICES uses a five-level structure in order to identify 'final ecosystem services'. Figure 3 illustrates this five-level approach with the example of cereals provisioning as final ecosystem output. To start with, the section level refers to one of the main ES categories, in this case provisioning. Then the "division" level corresponds to biomass production. The following three levels levels are used to further specify the classification from the group "cultivated terrestrial plants" to the class "cultivated terrestrial plants for nutrition" and then the class type "cereals" (CICES 2019).

The hierarchical structure is also designed to address issues of scale and accommodate geographical differences in what kinds of ecosystem output are recognised as a service. Thus, the more aggregated groups and division categories may be used for reporting at broader spatial scales, where a number of more specific classes are combined. At finer geographical scales, these broader categories of service might be represented by the specific classes that make sense at the local level (CICES website).

FIGURE 3

Illustration of the CICES five-level structure in the case of cereal production

Source: CICES 2019



Ecosystem services enhanced by sustainable land management practices

In the module on land degradation versus sustainable land management (SLM), we already introduced the concept of ecosystem services related to land. Unsustainable land use practices lead to processes of land degradation. Remember the six categories of land degradation defined by WOCAT being:

- **Soil erosion by water**, e.g. gully erosion, coastal erosion, mass movements/landslides;
- **Soil erosion by wind**, e.g. loss of topsoil, off-site degradation effects;
- **Chemical soil deterioration**, e.g. fertility decline and reduced soil organic matter content, salinisation;
- **Physical soil deterioration**, e.g. compaction, soil sealing;
- **Biological deterioration**, e.g. reduction of vegetation cover, increase of pests; and
- **Water degradation**, e.g. change in quantity of surface water, and change in aquifer level.

Depending on the extent of the phenomena, these processes lead to a decline or loss of different ES:

- Soil fertility decline, and consequently a decline in provisioning ES like crops, fruits, fibre, timber, fuelwood and medicines;
- Loss of topsoil, soil erosion eventually causes damages further upstream (increased sedimentation in rivers, etc.);
- Reduced flood regulation functions;
- Soil and/or (ground-)water contamination;
- Reduced water storing capacities, sinking groundwater levels;
- Reduced carbon sequestration and climate regulation functions;
- Reduced biodiversity (soil microorganisms as well as flora, fauna, habitats above-ground).

SLM practices on the contrary **enhance the ecological support functions of land**. Remember the four categories of SLM measures being agronomic, vegetative, and structural or management measures. These measures maintain ecological resilience and the stability of ecosystem services and have therefore proven positive socio-economic, ecological, economic and institutional benefits (compare module on land degradation versus SLM, section benefits and long-term impacts of SLM measures).

Amongst others, they help to:

- **increase the organic matter content** and therefore maintain or improve soil fertility; consequently they maintain or increase the availability of provisioning ES like crops, fruits, fibre, timber, fuelwood and medicines;
- **enrich and stabilise the topsoil and reduce soil erosion**, thereby preventing sedimentation in rivers and reducing risks for flooding;
- **keep and/or enhance soil health and water purification mechanisms**;
- **maintain or enhance water storing capacities** and thereby to maintain or increase groundwater levels which can lead to an improved access to water;
- **foster carbon sequestration** and climate regulation functions;
- **maintain or increase biodiversity** (soil microorganisms as well as flora, fauna, habitats above-ground); and
- **improve the resilience** of production towards climate change and extreme weather events.

02 Understanding regulating and supporting services: water, nutrient and soil organic cycles

While provisioning services are relatively easy to identify, quantify and assess, and cultural services play a minor role in the context of agricultural systems (which ELD usually focusses on), the regulating and supporting services are of specific relevance in order to be able to compare different agricultural and/or land use systems. This is why the main underlying natural cycles will be briefly recalled in this chapter – the water, the nutrients and the soil organic carbon cycles.

The water cycle

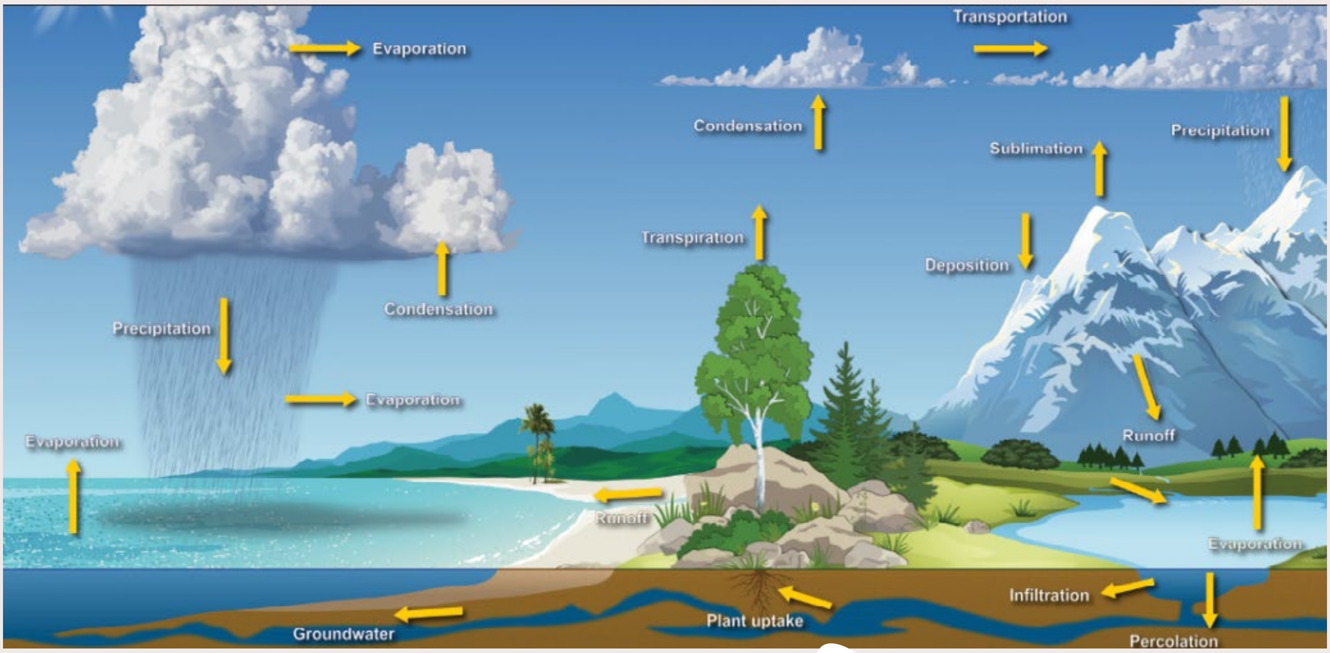
Water is an essential element for life on earth. Along the water cycle, water goes through different processes and changes inbetween three phases – solid, liquid and gas. It transits between different reservoirs – the air, clouds, the ocean, lakes, vegetation, snowpack, glaciers, and thus plays a role in the earth's climate system (NOAA 2019).

Figure 4 presents the main processes within the water cycle being (NOAA 2019):

- Evaporation: the process where liquid water changes into water vapour (gas);
- Condensation: the process where water vapour (gas) changes into water droplets (liquid);
- Plant uptake: Water taken from the groundwater flow and soil moisture;
- Transpiration: evaporation of liquid water from plants and trees into the atmosphere;

FIGURE 4

The global water cycle: main water fluxes
Source: NOAA 2019



- Transportation: the movement of solid, liquid and gaseous water through the atmosphere;
- Runoff: river, lake and stream transport of water and transport of ice in glaciers;
- Precipitation: water that falls to the earth. Most precipitation falls as rain but includes snow, sleet, drizzle and hail;
- Groundwater: Underground water flow (aquifers);
- Deposition: Water vapour (gas) changes into ice (solid) without going through the liquid phase;
- Sublimation: Ice and snow (solid) changes into water vapour (gas) without moving through the liquid phase;
- Infiltration: Movement of water into the ground from the surface;
- Percolation: Movement of water past the soil going deep into the groundwater.

Water is a vital element for human livelihood. It is used for drinking, industrial applications, irrigating agriculture, hydropower, waste disposal, and recreation. The following box shows some major threats placed on water through human use. Some drivers are climate change and related extreme wheather events, but also the steadily growing world population. The depletion of water supplies is an important issue to be addressed since it is likely to affect human livelihoods in the future (NOAA 2019).

Threats for global water supply

- Between 1960 and 2000, water withdrawals from rivers and lakes for irrigation or for urban or industrial doubled;
- Worldwide, 70% of water use is for agriculture;
- Globally, humans use slightly more than 10% of the available renewable freshwater supply through household, agricultural, and industrial activities;
- In some regions such as the Middle East and North Africa, humans use 120% of renewable supplies (MA 2005).

The water cycle is an essential part of many ecosystems and provides humans with diverse ES. It is difficult to assign the water cycle to strictly to either supporting, regulating or provisioning services (MA 2005, 2). For instance, **precipitation** is the main source of water which falls under **supporting services**. Then, ecosystems partition precipitation into **evaporative, recharge and runoff processes** which corresponds to **regulating services**. **Freshwater** is also essential to human consumption, which represents a **provisioning service** (Falkenmark and Folke 2003).

Here are some examples of some major ecosystem services provided by the water cycle (Coates et al. 2013):

- **Wetlands** play a major role in the regulation of surface and ground water flows;
- In **soils**, water retention is fundamental to provide enough water for plant growth. For instance, desertification is essentially due to water loss from soils;
- **Vegetation**, and more generally **land cover**, are major components of the water cycle;
- Ecosystems can be considered as “natural water infrastructure”, which has a similar fuctionning human-built infrastructure and thus plays a key role in water management.

Figure 5 illustrates the large variety of ecosystem services that the water cycle provides to humans at the scale of a landscape. Figure 6 shows the water cycle at the scale of an agroecosystem.

FIGURE 5

A conceptual framework illustrating the water cycle and ecosystem services in a simplified landscape setting
Source: Coates et al. 2013

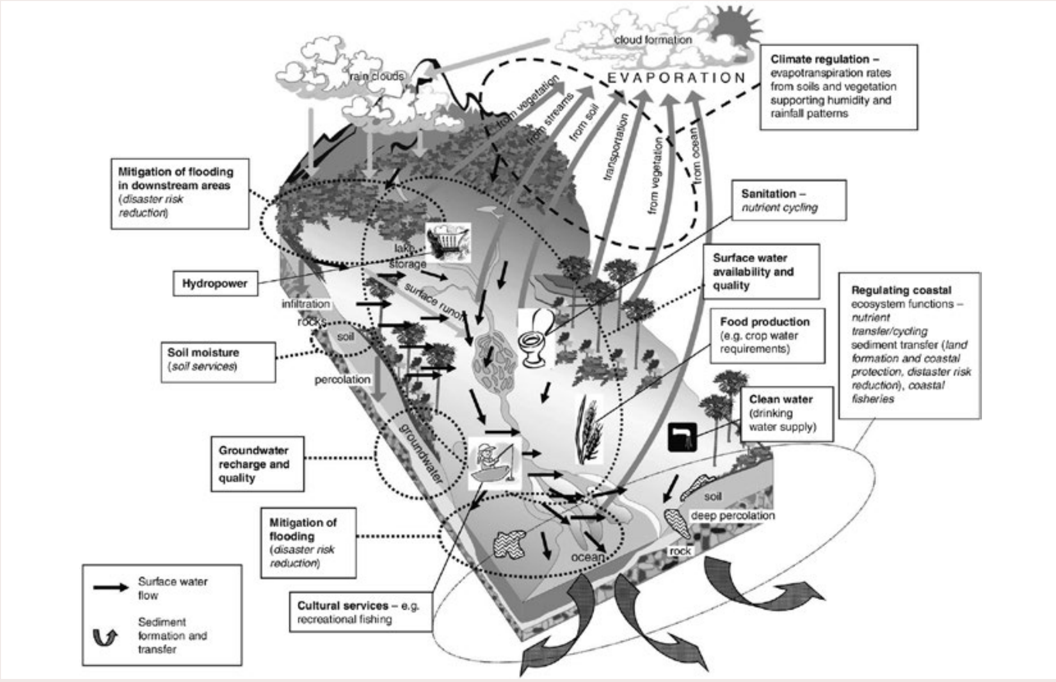
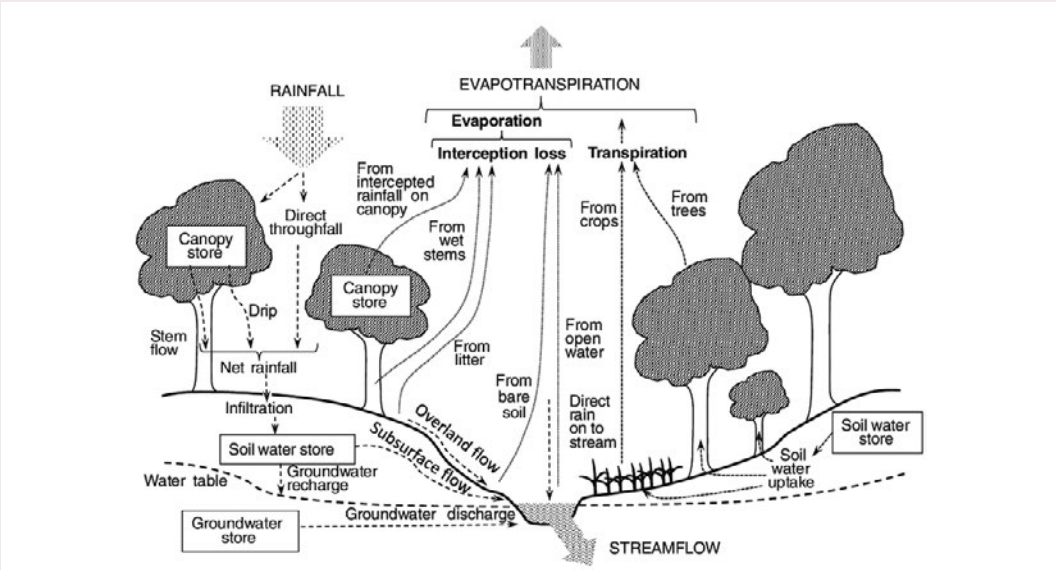


FIGURE 6

The water cycle in an agroecosystem
Source: Coates et al. 2013



The nutrient cycles

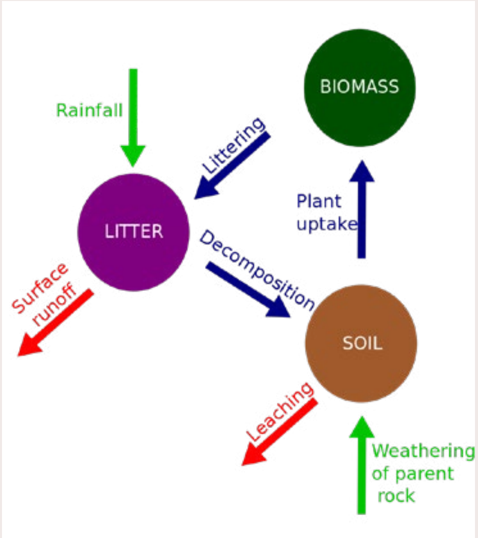
Plant growth relies on numerous nutrients from soils, among which are carbon, nitrogen (N) and phosphorus (P) (MA 2005, 3). The carbon cycle will be studied in more detail in the following paragraph. As for N and P, they transition across different pools (soils, biomass, atmosphere, inland water and ocean) along their cycles changing their molecular form during these processes. Figure 7 shows the general pattern of nutrient cycles between soils and biomass. It is to be noted that a balance between organic and inorganic elements in soils is needed as to ensure that plants can absorb inorganic nutrients.

In the following box, some key facts about the problems regarding increasing accumulation of N and P in ecosystems due to fertilisation and pollution are provided.

FIGURE 7

The nutrient cycle of a typical terrestrial ecosystem

Source: Wikipedia 2019



Key facts about the nitrogen (N) cycle

- In preindustrial times, the annual flux of N from the atmosphere to the land and aquatic ecosystems was 90–130 million tons per year. This was more or less balanced by a reverse "denitrification" flux;
- Production and use of synthetic N fertiliser, expanded planting of nitrogen fixing crops, and the deposition of N-containing air pollutants have together created an additional flux of about 200 million tons a year, only part of which is denitrified;
- The resultant N accumulation on land and in waters has permitted a large increase in food production, but at the cost of increased emissions of greenhouse gases and a frequent deterioration in freshwater and coastal ecosystem services, including water quality, fisheries, and amenity value – less than half of the applied N fertilisers find its way into the crop plant. The remainder leaches into water bodies or returns to the atmosphere.

Key facts about the phosphorus (P) cycle

- P is also accumulating in ecosystems at a rate of 10.5–15.5 million tons per year, which compares with the preindustrial rate of 1–6 million tons of phosphorus a year, mainly as a result of the use of mined P in agriculture;
- Most of this accumulation is occurring in soils, which may then be eroded into freshwater systems, causing deterioration of ecosystem services;
- This tendency is likely to spread and worsen over the next decades, since large amounts of P have accumulated on land and their transport to water systems is slow and difficult to prevent.

Source: MA 2005, 3

The concept of planetary boundaries was initially introduced by Rockström et al (Rockström et al 2009a,b). A further study defined the nine planetary boundaries (Steffen et al. 2015), two of which are at high risk (see figure 8). Biogeochemical flows of nitrogen and phosphorus are concerned, with an important role of the current a global agricultural production system (Campbell et al. 2017).

Figure 9 illustrates a simplified form of the nitrogen cycle as a specific example. The nitrogen cycle consists of fluxes of nitrogen in different chemical forms between the atmosphere, the surface landmasses and oceans. In the atmosphere nitrogen is mainly present in gaseous form as dinitrogen along with other trace gases. Aquatic systems contain mainly soluble forms of nitrogen, such as nitrate and ammonia. Living systems mainly contain biological nitrogen in form of proteins and DNA (Erisman et al. 2007).

FIGURE 8

The status of nine planetary boundaries including the biogeochemical flows of phosphorous and nitrogen
Source: Campbell et al. 2017

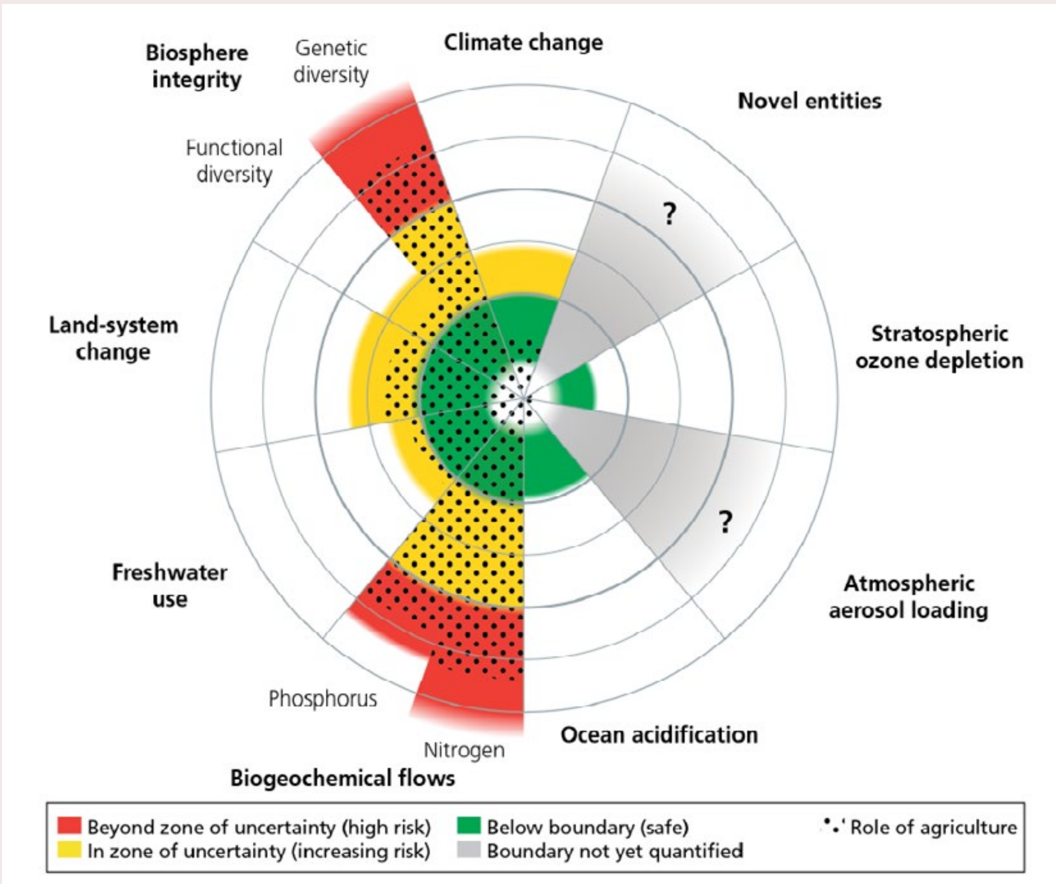
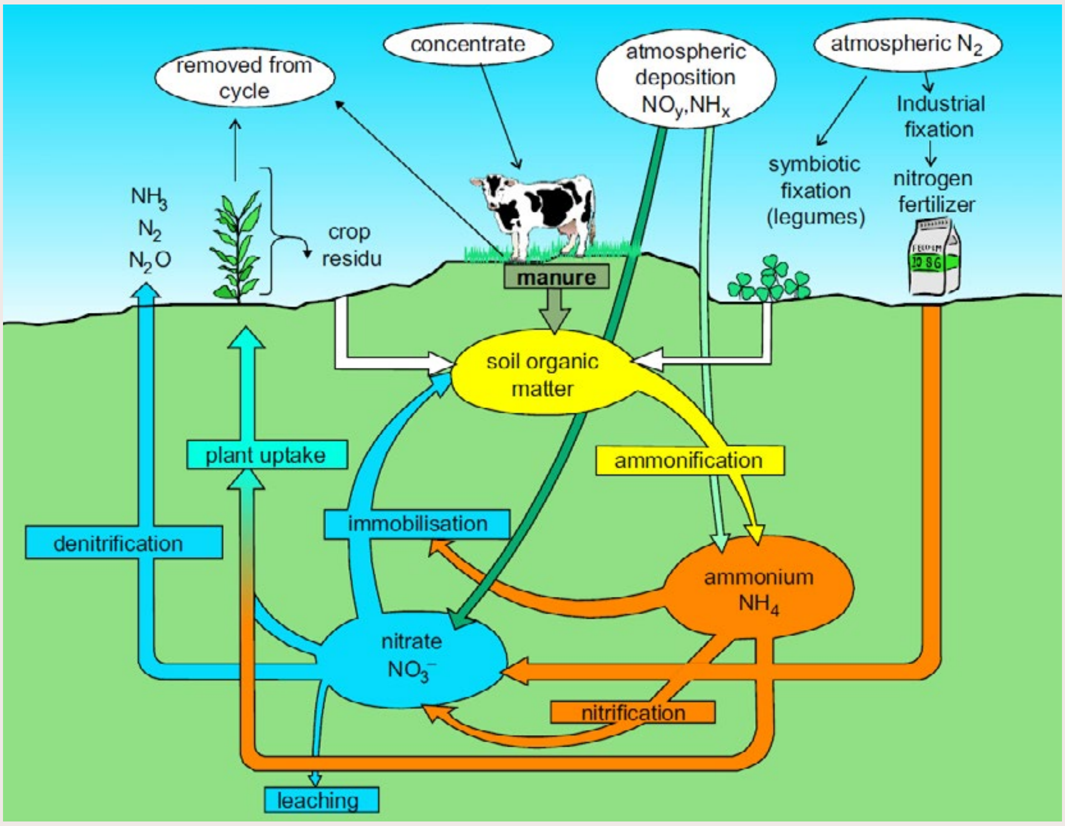


FIGURE 9

The most important elements of the nitrogen cycle
Source: Erisman et al. 2007



While a lack of nutrients in soils limits plant growth and reduces yields, excessive quantities of nutrients applied to agricultural fields have negative impacts on the environment (FAO 2017, 2):

- The loss of excess nutrients – especially N and P – leads to eutrophication and deterioration of water quality;
- An increased quantity of nitrous oxide – a greenhouse gas – is released from soils to the atmosphere;
- Mobile forms of N are leached to water used for human consumption, which can impact human health; and, in extreme cases, crop failure.

SLM measures are thus used to thwart these serious environmental issues. Here are some examples (FAO 2017, 2):

- Improvement of natural soil fertility and natural nutrient cycles through **soil conservation practices** such as the use of crop rotations with legumes, green- and animal manures, cover crops in combination with reduced- or no-tillage, limited herbicide use and agroforestry;
- Optimisation of nutrient use efficiency by applying **context-adapted soil amendements** such as compost or liming agents;
- Application of fertilisers should promote a **balanced crop nutrient uptake** and be based on soil and plant analyses.

For more details on SLM practices refer to module on land degradation versus SLM.

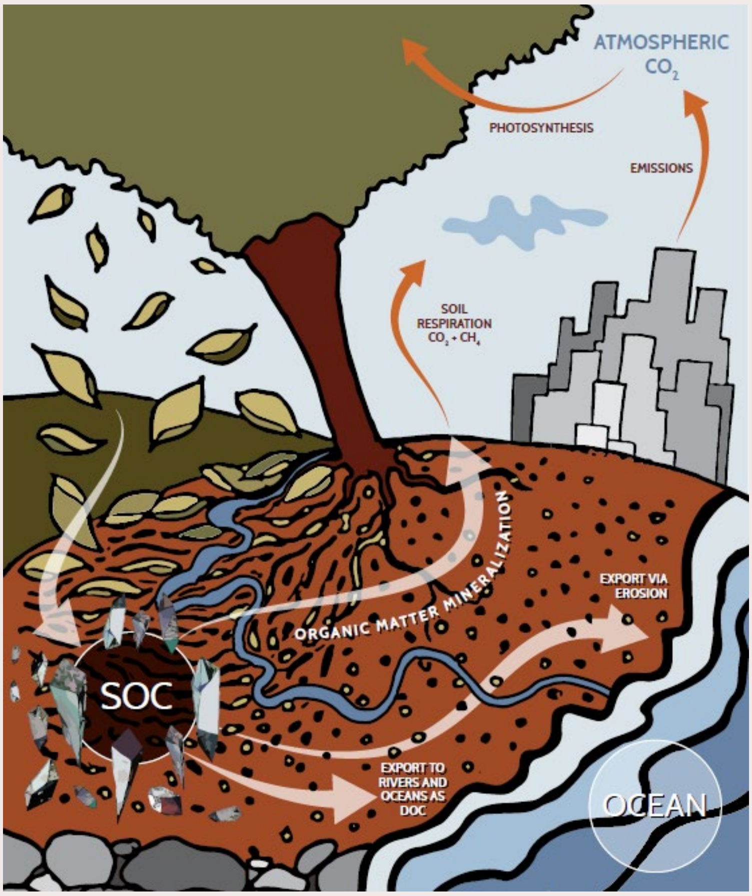
The carbon cycle

Soil organic carbon (SOC) is one part in the much larger global carbon cycle that involves the cycling of carbon through the soil, vegetation, ocean and the atmosphere (FAO 2017, 1). SOC represents a substantial carbon pool, storing 1500 PgC in the first meter of soil. In comparison, the other two major carbon pools, the atmosphere and terrestrial vegetation, contain 800 PgC and 500 PgC respectively (FAO and ITPS, 2015). The SOC pool is a dynamic reservoir, where carbon cycles between the different carbon pools (FAO 2017, 1).

As shown on figure 10, the carbon cycle includes four main carbon pools, which are soils, oceans, the atmosphere and terrestrial vegetation. To start with, vegetation takes up carbon dioxide (CO_2) from the atmosphere and converts it into organic carbon through photosynthesis. Soils also take up carbon through the incorporation of dead organic material into the soils by heterotrophic microorganisms. Carbon can then be emitted back from soils into the atmosphere in the form of CO_2 through decomposition of soil organic matter by microorganisms. Carbon can also be exported to the ocean carbon pool as dissolved organic carbon or via erosion (FAO 2017, 1).

FIGURE 10

SOC in the global carbon cycle
Source: FAO 2017 (1)



Key facts about the carbon cycle

- Since 1750, atmospheric CO_2 increased by 34 %, with 60 % of that increase since 1959;
- Since 1950 terrestrial ecosystems have gained importance in their role as carbon sinks;
- Terrestrial ecosystems play a role in carbon sequestration through better forest management, changes in agriculture practices and the fertilising effects of N deposition, and increasing atmospheric CO_2.

Source: MA 2005 (1)

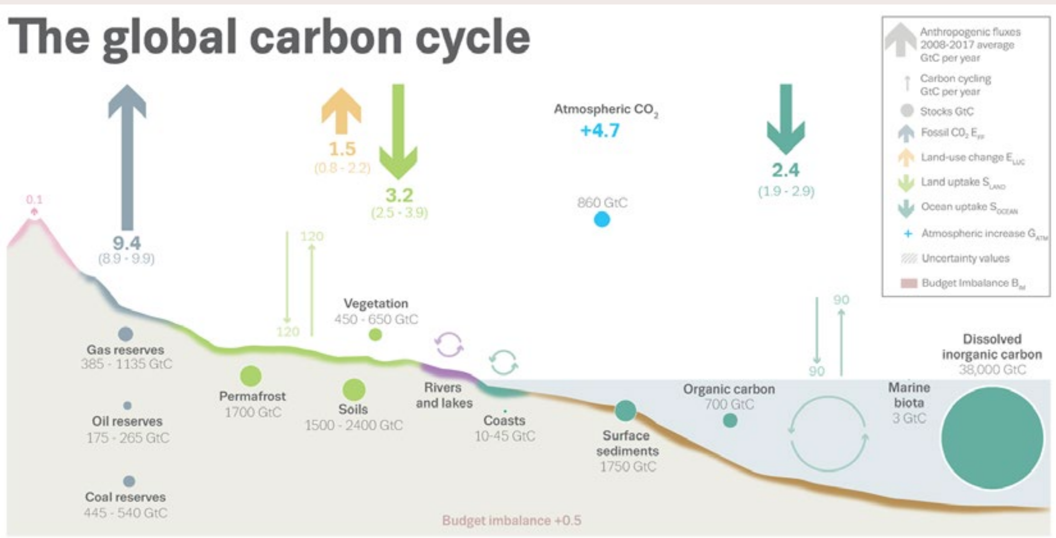
As for the nutrient cycles of nitrogen and phosphorus, soil organic carbon can be increased through SLM measures. For instance, natural soil fertility can be improved through soil conservation practices such as the use of crop rotations with legumes, green- and animal manures, cover crops in combination with reduced- or no-tillage, limited herbicide use and agroforestry (FAO 2017, 2).

Figure 11 illustrates the gobal carbon cycle – focussing on anthropogenic CO_2 emissions – over the period 2008-2017. During this period the average annual anthropogenic CO_2 emissions accounted for 9.4 GtC. From this quantity, around 4.7 GtC remained in the atmosphere every year, which corresponds to 50% of the total annual quantity. This emitted carbon then accumulated in the atmosphere (44%), in the ocean (22%) and on land (29%), with a budget imbalance of +0.5% (Global Carbon Project 2001–2018).

FIGURE 11

The global carbon cycle

Source: Global Carbon Project 2018



03 Special characteristics of ecosystem services

Ecosystem services are difficult to assess, to quantify and to valuate because of spatial and temporal dynamics, their connectivity and complexity as well as tradeoffs and synergies within ecosystem services (Emerton et al. 2018).

Spatial dynamics

There can be a difference between where an ecosystem service is produced and where the benefits are experienced (figure 12). In general, ES experience a change from a point of production to a point of use through three ways: a) biophysical processes change across the landscape, b) benefits and beneficiaries change across the landscape and c) costs of provision change across the landscape.

Temporal dynamics

Ecological conditions and processes can change in a dynamic way as societal preferences and needs can also change over time. Temporal dynamics might also matter for valuation since people tend to prefer to obtain benefits sooner rather than later.

FIGURE 12

Spatial dynamics in ecosystems
Source: Fisher et al. 2009

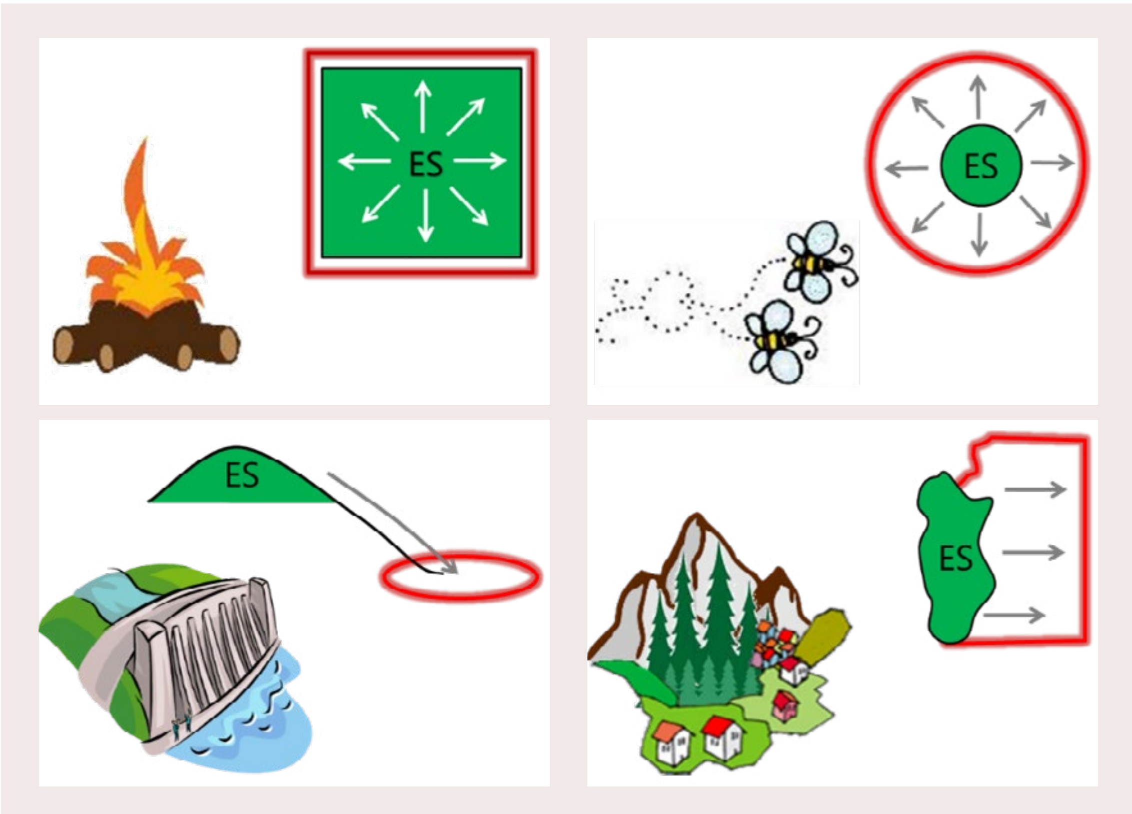
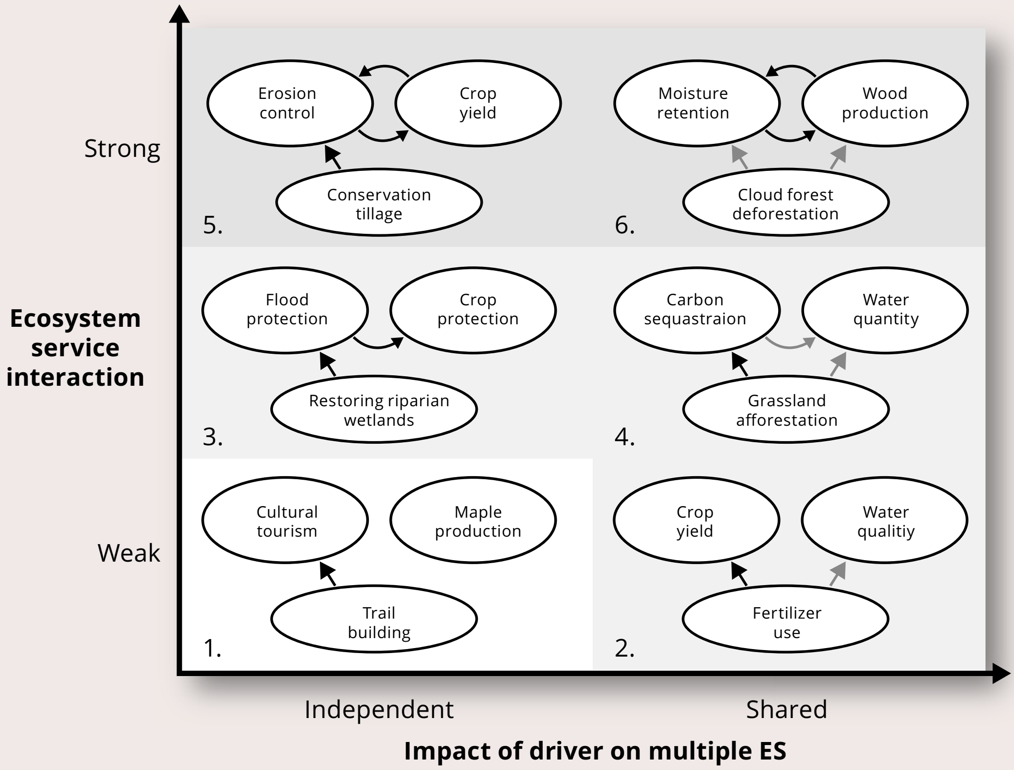


FIGURE 13

Ecosystem services interaction

Source: Bennett et al. 2009



Connectivity and complexity

Changes in the ecosystem can affect services differently. Changes or impacts on one component may also affect other services. This makes ecosystems be very complex to understand and to assess.

Figure 13 illustrates some examples for this. Black arrows indicate a positive effect and grey a negative effect.

Tradeoffs and synergies

Ecosystem service tradeoffs arise from management choices made by humans, which can change the type, magnitude, and relative mix of services provided by ecosystems. Tradeoffs occur when the provision of one ES is reduced as a consequence of increased use of another ES. In some cases, a tradeoff may be an explicit choice; but in others, tradeoffs arise without premeditation or even awareness that they are taking place. These unintentional tradeoffs happen when we are ignorant of the interactions among ES (e.g., Tilman et al. 2002, Ricketts et al. 2004), when our knowledge of how they work is incorrect or incomplete, or when the ES involved have no explicit markets. But, even when a decision is the result of an explicit, informed choice, the decision may have negative implications. For example, adverse impacts may arise as a consequence of the scale mismatch between the intent of a particular management decision, the expected outcome, and the long-term or broad spatial scale of the decisions (van Jaarsveld et al. 2005). Ecosystem feedbacks and food web dynamics can also lead to unexpected consequences (Ostfeld and LoGiudice 2003).

Examples of tradeoffs between ecosystem services are illustrated hereafter. The first ones shows how the change from a natural ecosystem into an agricultural ecosystem or vice versa has implications on the relationship between provisioning, regulating and cultural ecosystem services (figure 14). The second one distinguished between an intensive crop cultivation system and a more extensive one, with restored ecosystem services (figure 15).

FIGURE 14

Comparison of ecosystems services provided by an agricultural and a natural ecosystem
Source: Gordon et al. 2010

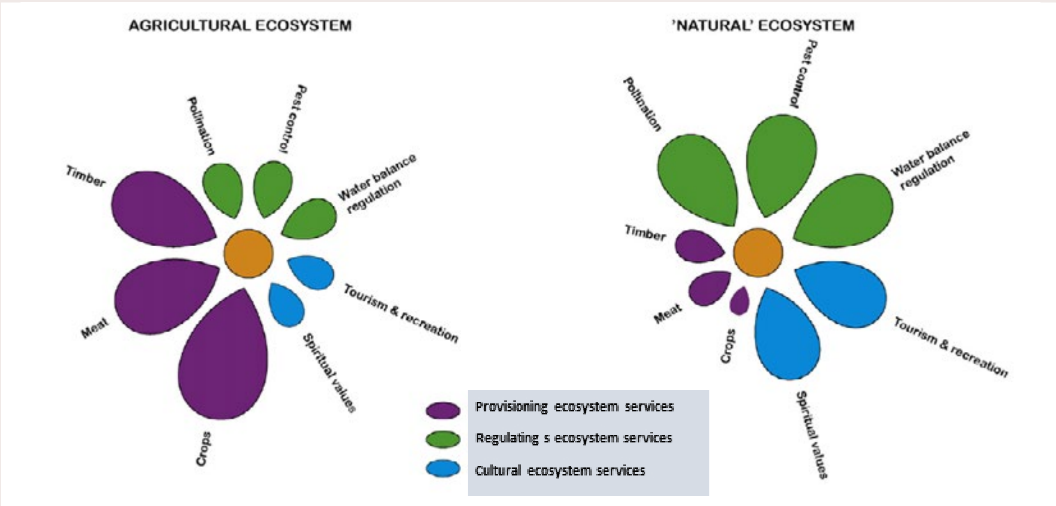
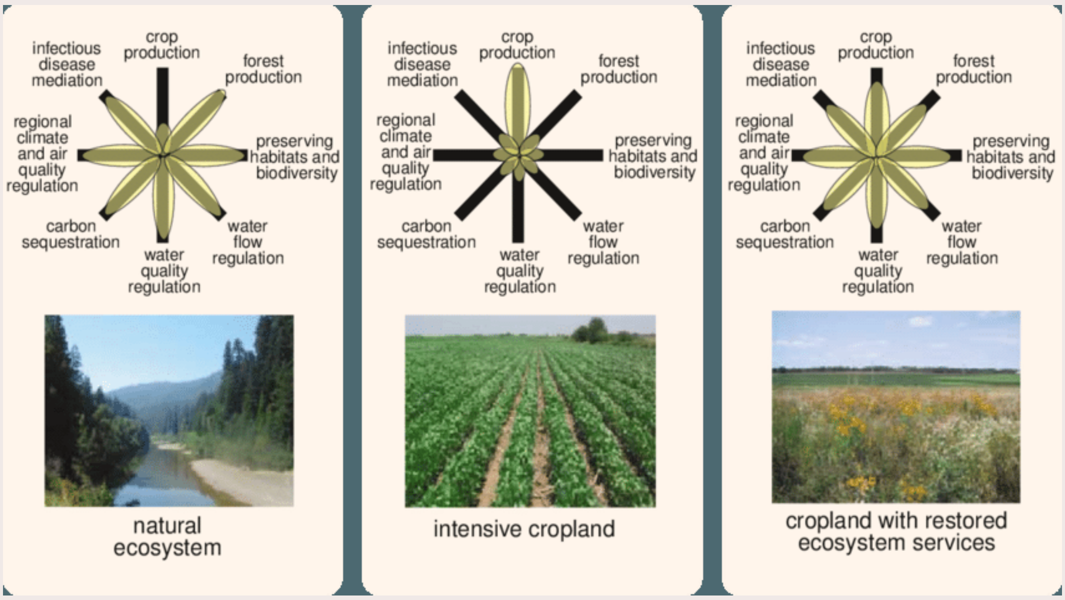


FIGURE 15

Comparison of ecosystem services provided by a natural ecosystem, an intensive cropland and a cropland with restored ecosystem services
From: Foley et al. 2005



It is important to note that **all these tradeoffs have implications for distribution, equity and the interests of different stakeholders**, including people downstream, future generations and/or wildlife. For instance, an intensive crop production system applying fertilisers and pesticides may reduce soil quality, biodiversity, biological control, air quality regulation as well as water regulation services and water quality, and might cause negative implications on health as well as usage constraints for future generations.

However, it is also possible to create synergies and thereby win-win situations, where more of one ecosystem service creates multiple other ecosystem services and benefits. An example for this can be an extensive crop production system, combining trees and crops, and using organic fertilisation only. This system helps to maintain the soil quality and may therefore promote primary production. In addition, it enhances carbon storage, helps to regulate water flows, improves most provisioning services (most notably food), and enhances biodiversity.

Tradeoffs have an impact on current and future provision of ES, and therefore, in development and well-being. Minimising and mitigating negative tradeoffs means decreasing environmental and social conflicts. Identifying tradeoffs provide information on which incentives and decisions need to change in order to decrease negative impacts on ES (ValuES 2018).

When identifying and analysis ecosystem services, it is important to distinguish ecosystem services regarding the beneficiaries. This will later on be a prerequisite for the cost-benefit analysis of a "business-as-usual" versus an "action"-scenario – *Who bears the costs? Who has the benefits?*

Rivalry and excludability in goods and services

It is important to not only understand the function of the ecosystem dynamics, but also the social systems that interface with the respective goods and services. Some services and their benefits will be private, some public. Governance systems, markets, informal land use and others are employed to utilise and benefit from ecological systems. These systems are complex and dynamic and will interact with the different categories of goods, requiring different social solutions for each type.

Some ecosystem services provide benefits that are **both rival and excludable** and can therefore also be traded in conventional markets (table1). They are **private goods**, for example food crops on a privately owned farm.

Other ecosystem services fall into a category often known as **toll or club goods**. This type of good is one that is **non-rival, but excludable**; for instance an entry fee is charged to enter a national park.

Another set of goods are those that are **rival, but non-excludable**. These are often called **open access or common pool resources**. Communal grazing areas would be an example here.

Finally, there are **pure-public goods**, which are **neither rival nor excludable**. For example, the ability of the atmosphere to protect people from harmful radiation is often considered an ecosystem service. Public goods are also open access parks in cities, forests and the like. The government most often manages these goods; it is difficult to identify who exactly should pay for the related services (adapted from Emerton et al. 2018).

TABLE 1

Rivalry and excludability in goods and services
Source: adapted from Emerton et al. 2018

		Is it possible to prevent consumers from having access to a good or service?	
		Excludable	**Non-Excludable**
Does the use of a good/ service by someone reduce its availability for someone else?	**Rival**	**Private goods:** – Food – Timber – Coal/ore/iron	**Common use goods:** – Climate stability – Water – Fish stocks
	Non-rival	**Club goods:** – National park – EU	**Public goods:** – Oxygen – Mountains/forests

Identification and assessment of ecosystem services

The ELD 6+1 step approach is a method that guides users through the process of establishing scientifically sound cost-benefit analyses to inform decision-making processes. The first three steps aim at identifying relevant ecosystem services in the predefined study area (ELD 2015, 2).

The first step is the inception phase where the scope, focus, spatial scale, and strategic purpose of the study are outlined and agreed upon with stakeholders who will be key in conceiving alternative scenarios in sustainable land management. This is done through a structured, participatory process of **stakeholder consultations** where the basic approach and rationale of the study is explained, and strategic issues are discussed (see module on communication, outreach and policy impact within the ELD campus). Further, to support the development and basis of the study, **background papers** on the policy, legislative, and institutional contexts and wider socioeconomic and ecological settings should be collated and prepared through desk research in this step (Noel and Soussan, 2010). It is crucial that the **scale of the study**, whether it is at the community, subnational (e.g., a province or watershed), or national level, and the specific geographical boundaries and land cover categories are clearly identified. Additionally, relevant **partner institution** that will support the research and subsequent implementation should be identified and included at this stage (ELD 2015, 2).

BOX 1

Mapping land degradation (soil erosion) in Ethiopia

Source: ELD 2015 (2), Hurni et al. 2014

Hurni et al. (2014) performed a cost-benefit analysis of the existing and potential establishment of soil and water conservation structures in the highlands of Ethiopia. To identify the selected geographical characteristics for the study (in this case, land cover type, existing conservation structures, and soil erosion/deposition), the authors used a combination of Landsat imagery and expert opinion to determine land cover classes, in conjunction with the Unit Stream Power Erosion Deposition (USPED) model. This model predicts degradation patterns by estimating the spatial erosion and deposition patterns of soil matter, and was used in this study with the following parameters:

- Erodibility: Derived from datasets on spatial distribution of soil types, which calibrated erodibility parameters from the literature;
- Management type: From the high-resolution satellite imagery, physical conservation structures were identified using geospatial calculations;
- Soil cover: Using Landsat imagery, the cover of the soil was identified and fed into the USPED module in the GIS-software; and
- Elevation: A digital elevation model of the study area was used to obtain information on slopes (which needed to be considered here, as greater slopes increase the need for conservation structures) and the sediment transport capacity.

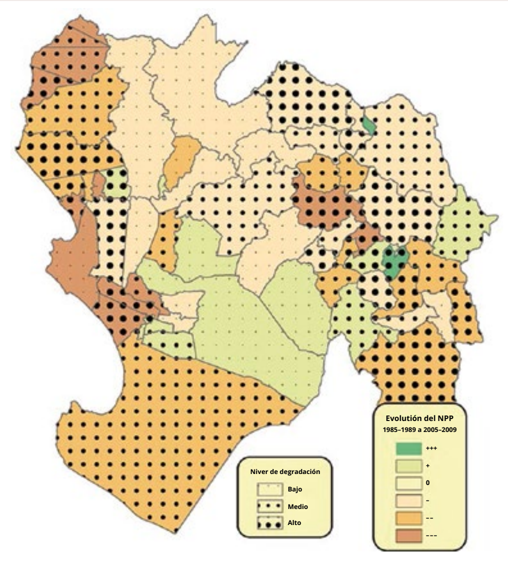
The resulting information was also ground-truthed with expert opinion, to ensure that the land cover identification as well as estimates of land degradation (soil erosion) and its impacts (deposition) were correct. On this basis, the authors had a firm foundation from which they could develop alternative land management scenarios and compare them against "business-as-usual" in a cost benefit analysis.

BOX 2

Assessing land degradation through GIS in Peru: Piura case study

Source: ELD 2015 (2)

The following map was developed by Morales et al. (2015) for the ELD Initiative, based in the Piura region of Peru. It highlights the net primary production trend, based on information obtained from the World Atlas of Desertification by the Joint Research Centre of the European Commission and Pirua Regional Government. Authors compared the trend between 1982 and 2009, and calculated an index by overlaying the different datasets in GIS with land degradation (erosion) that was associated with high slopes. Shaded areas represent levels of degradation within the different districts – information that was obtained from the regional government of Piura and adapted through local stakeholder workshops. Overlaying these various GIS datasets helped to validate and confirm the findings of participatory consultations on the ground.



The second step is the identification of geographical characteristics. It starts with a land cover assessment in order to categorise the study area into agro-ecological zones serve and to identify the geographic and ecological boundaries. Such assessments can be facilitated by the use of GIS programs (see boxes 1 and 2), which are widely available and have increasing accuracy of geographically referenced data on key variables such as **land cover, ecosystems characteristics, altitude, topography, precipitation, slope etc.**

Understanding land-delineating units

Ecosystem services and their benefits depend on biophysical conditions. **Mapping has high potential to support understanding complex ecological systems and interrelations.** The assessment of the type of ecosystem services (step 3 of an ELD study) will therefore base on the identification of the ecological characteristics of different land cover types (agro-ecological zoning), undertaken as step 2 of an ELD study (ELD 2015, 2).

Ecosystem services may also experience changes. Again, mapping – including the comparison with situations in the past – helps identify and visualise the **patterns of change of land cover and land use**, and therefore, support defining the exact scope of the study.

Important questions regarding the identification of ES are:

- Where are the ecosystems provided?
- Where are the benefits enjoyed?
- Where are administrative limits?
- What are barriers and boundaries?

With the help of maps, "bundles" of ecosystems can be identified in relationship to different land cover types. Mapping also helps to visualise and discuss the tradeoffs in terms of the use of ecosystems for different activities, so that environmental problems and conflicts are identified and solutions can be proposed (ValuES 2018).

Once the study area is mapped, possibly using an appropriate GIS program, different land cover categories are identified and grouped into standard **agro-ecological zones**. These zone classifications are already available in most countries, but can otherwise be derived from the global agro-ecological zonation produced by the FAO, from international sources found through desk research, or through an analysis of already available remotely sensed satellite data (e.g., Landsat). Agro-ecological ecosystem categorisation can be based on the ecosystem service framework of the Millennium Ecosystems Assessment (2005), i.e., provisioning, regulating, cultural, and supporting services (see figure 2). Several examples of data bases that can be used for the categorisation into agro-ecological zones are presented in the box below.

Participatory GIS can also be an effective tool for collecting information that can augment and qualify more conventional GIS data on land cover and use and ecosystems distribution, and can also validate or update outdated data (Etter 2013).

BOX 3

Data bases for use in assessing geographical characteristics and defining agro-ecological zones

World Bank's development data

The World Bank provides a platform for *energy data* as well as an *open data catalogue* at the global scale with a subdivision into seven regions. The energy data containts 594 different dataset for 164 countries worldwide. The open data catalogue covers all countries which are divided into seven global regions. There are three different types of datasets available: geospatial data; microdata; and times series. It provides several indicators such as water pollution in different industrial sectors and fresh water withdrawal according to the type of activity.

FAOSTAT

FAOSTAT provides free access to food and agriculture data from over 245 countries and territories and covers all FAO regional groupings from 1961 to the most recent year available. It provides several indicators such as the percentage of agricultural area, livestock per ha of agricultural area, average soil erosion.

Link: *http://faostat3.fao.org/faostat-gateway/go/to/home/E*

The Ecosystem Service Indicator Database

This database was created by the World Resources Institute to make ecosystem service metrics and indicators readily available for use in policy dialogues and decisions, in ecosystem assessments, and in natural resource management decisions.

Link: *https://www.sciencedirect.com/science/article/pii/S2212041617306630*

Global Biodiversity Information Facility

The Global Biodiversity Information Facility (GBIF) has been developed since 2000 after a OECD Science Ministers approval. In 2001, 28 countries and 11 international organisations participated in GBIF. Today GBIF includes 57 countries and 47 international organisations. The GBIF network currently has a data coverage of 320 million occurrence records from 8,500 datasets frm 360 publishers and spanning a wide range of geospatial, temporal and taxonomic coverages being shared through distributed network (GBIF 2012).

Link: *http://www.gbif.org/dataset*

Global Agro-Ecological Zoning

FAO's Agro-Ecological Zoning methodology is the primary tool used for land resources assessment. It is based on the FAO Framework for Land Evaluation which has been in use since 1978 for assessing agricultural production potential and production capacity, actual and potential yields and yield gaps. The Global Agro-Ecological Zoning based on the the above-mentioned methodology creates information products to assists with rational land-use planning on the basis of an inventory of land resources and evaluation of the biophysical limitations and production potentials of land (ELD 2015,2).

From: *http://www.fao.org/nr/gaez/programme/en/*

The step of assessing the types of ecosystem services also involves refining the analysis within agro-ecological zones and assessing the **type and state of ecosystems services stocks and flows for each land cover category** (Fisher & Turner, 2008) that has been identified for the study in the previous two steps (ES assessment).

Assessing types and state of ecosystem services

An ecosystem services assessment is an important step towards recognising the degree to which ecosystem services contribute to agriculture, livestock, forestry and/or fisheries (and vice versa) and, therefore, to local economies. It's thus a step towards ecosystem valuation.

What is the difference between an ecosystem services assessment and an ecosystem services valuation?

While an ecosystem services assessment provides a holistic view of ecosystem services, focusing primarily on the interplay of different processes and functions, an ecosystem valuation places values on those processes and functions, generating data to determine the relative social costs and benefits of services (ValuES 2018).

Ecosystem services assessments identify and measure the potential for the provision of ecosystem services in a specific political context and for specific beneficiaries. Ecosystem services assessments allow the identification of a balance of losses and gains of services and whether or not service provision is sustainable. Assessments also allow the identification ofthresholds and tipping points. ES assessments focus on the supply of ecosystem services, and their capacity to meet demands for ecosystem services. They provide biophysical information of ecosystems in terms of their geographic situation, their condition, trends, and underlying causes. ES assessments reflect the importance of the ES in terms of their availability and provision for beneficiaries, as well as the recognition of the underlying causes and drivers of conditions and trends, and their effects on stakeholders (adapted from ValuES 2018).

Steps of ecosystem services assessment

Important steps of an ES assessment are:

1. Analysis of key structures and processes of and within ecosystems
2. Understanding of ecosystem functions (based on studies, expert opinions, know-how)
3. Identification of service delivery
4. Potential supply of a service through an ecosystem (physical units)
5. Potential (social) demand for a service

Guiding questions during an ecosystem services assessment include:

- Which economic, social or cultural activities are relevant for people in the area?
- Which ecosystem services do these activities depend on or have an impact on?
- Which are the most relevant ecosystem services for the area and why?
- Which stakeholders carry out which activities and how are they dependent on the benefits of key ecosystem services?

Hence, as part of this step of the ecosystem service assessment, **detailed and extensive data on the provision and service flow of each service is collected**. That information is then systematised. Based on this approach, different criteria are then used to prioritise ecosystem services.

The main goal is to maintain the flow of ecosystem services (i.e. regulating services, see cycles above) to accomplish a constant provision of benefits, well-being and development. In order to do so, it is important to identify the capacity of ecosystems to maintain the flow of ecosystem functions. This information can also indicate the resilience capacity of the ecosystems to changes, and whether or not the state is nearing tipping points for the provision of ecosystem services. Parameters and indicators are useful when assessing ecosystems and ecosystem services (in case of ELD studies these are often related to soil analyses- of productivity, carbon stocks and soil erosion).

Note that whether a function, for instance a water retention function of a forest or an agroforestry production system, is considered as an ecosystem service or not, depends on whether this function provides a benefit for humans. In this case, the ecosystem service of water retention is an ecosystem service, as it decreases erosion and/or avoids flooding, both of which affect humans. Also, note that different people will value the ecosystem service differently. **The importance of some functions depends on the geographical space, as well as in the choices and values that society attributes to them.** It is therefore of great importance to identify the beneficiaries in order to acknowledge what is and what is not an ecosystem service (adapted from ValuES 2018).

The valuation of ES usually requires information on the biophysical characteristics (geographical situation, actual and potential supply, condition (quality and quantity) and trends).

A range of tools are available for assessing ecosystem services, such as the **Natural Capital Project's Integrated Valuation of Environmental Services and Tradeoffs (InVEST) tool** or the **ARtificial Intelligence for Ecosystem Services (ARIES) modelling** platform. These tools aim to help map ecosystem service provision and model their evolution over time, associate them to an economic value, identify scenarios, and help decision-makers assess tradeoffs between these scenarios for informed decision-making. Some of these assessment techniques are summarised in table 2, together with their features (e.g., scope and data demand) and resource requirements (i.e., skills, knowledge, time, manpower, and cost).

TABLE 2

Overview of ecosystem service assessment tools

Source: ELD 2015 (2)

Approach/tool	Description	Feature				Capacity/resources requirement				
		Scope	Data demand	Resolution	Valuation focus	Computing skill	Specialist technical knowledge	Time	Manpower	Cost
Toolkit for Ecosystem Service at Sitebased Assessment (TESSA)	A practical suite of tools for measuring and monitoring ecosystem services at a site scale	Land-scape	Low-High	Low-High	Low-High	Inter-mediate	Low	Low	Low	Low
Assessment Research Infrastructure for Ecosystem Services (ARIES)	A modelling approach for quantifying environmental services and faktors influencing their values, in a geographical area and according to needs and priorities set by its users	Land-scape-Global	Low-High	Low-High	Low	Inter-mediate-High	Low-High	Low	Low	Low
Corporate Ecosystem Services Review (ESR)	A series of questions for developing strategies to manage risks and opportunities arising from the company's dependadnce on natural resources	Land-scape-Global	Low	Low	Low	High	High	Low	Low	High
Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)	A computer-based platform for assessing how distinct scenarios might lead to different ecosystem service and human-wellbeing related outcomes in a geographical area	Land-scape-Global	Low-High	Low-High	High	High	High	Low	Low	High
Multi-scale Integrated Models of Ecosystem Services (MIMES)	A suite of models for assessing how distinct managemem scenarios might lead to different ecosystem service and human-wellbeing related outcomes	Land-scape-Global	Low-High	Low-High	High	High	High	Low	Low	High
Natura 2000	A tool for assessing the total overall socio-economic benefits and value of a site, and for determining more monetary vallues of individual benefits provided by the site.	Land-scape	Low	Low	High	Inter-mediate	Low	Low	Low	Low

05 Priorities matter – selecting ecosystem services for assessment

A popular concept when assessing and prioritising ecosystem services is **dependencies and impacts**. To apply this concept, key ecosystem services and activities that are carried out in an area need to be identified first. **Dependency** refers to the degree that an (economic or social) activity relies on a certain provided quantity or quality of a service, while impact means the degree to which an activity affects an ES negatively or positively or can cause a change in the provision of a given service. In the example below (see table 3), we see that timber exports depend on the existence of trees and also depend on soil fertility (which is important for plant and tree growth in general). We also see that timber exports influence the provision of timber, as trees are cut down and extracted from the ecosystem. However, while the export of timber does not depend on water regulation, it can still impact the service heavily, as the degradation of vegetation can cause a change in surface runoff and retention of water. Hence, activities can depend and impact ecosystem services differently (ValuES 2018).

By filling out the matrix for each activity and each identified ecosystem service, one can identify:

a) key services, and
b) activities that have a large influence on the provision of ecosystem services (or activities that heavily depend on services).

In table 3 we can see that the production of meat and diary products and the extraction of timber have the highest degree of impact on the identified key ecosystem services. These would, therefore, be logical targets for new policies or measures to better manage an ecosystem. Similarly, the

TABLE 3

Example of a dependency and impact matrix for a variety of ecosystem services and human activities
Source: ValuES 2018

Ecosystem Services	Development of (economic) activities in an area										Sum.
	Meat and Diary Production		Water Treatment Plant		Communal Tourism		Timber Export		Cotton Production		
	Dep*	Imp*	Dep	Imp	Dep	Imp	Dep	Imp	Dep	Imp	
Water Regulation	1*	2	2	0	1	1	0	2	2	1	12
Provision of Raw Materials	0	1	0	0	1	0	2	2	0	1	7
Recreation	0	1	0	1	2	1	0	1	0	1	7
Soil Fertility	2	2	0	0	1	1	1	1	2	2	12
Soil Flexation	2	1	1	0	1	1	0	2	2	1	11
Sum Impact & Dependencies	**5**	**7**	**3**	**1**	**6**	**4**	**3**	**8**	**6**	**5**	

** Dep = Dependence, Imp = Impact, 0 = no connection/relevancy, 1 = minor connection, 2 = major connection* ecosystem service of water regulation was rated highest when summing up the scores for dependence and impact. As such, this ecosystem service could be tentatively judged to be of key importance for the region.

It needs to be kept in mind that this is a qualitative approach, and as such the results should be treated with care. It is important to remember that the goal during screening and prioritising is NOT to assess the state and conditions of an ecosystem (which is undertaken in the next step), but rather to identify ecosystem services and to rank their importance according to dependencies and impacts of human activities on these ecosystem services (ValuES 2018).

Examples of other criteria to prioritise ecosystem services include:

- Biophysical change and levels of degradation
- Supply reliability
- Number of beneficiaries
- Difficulty of substitution
- Ease of reliable measurement
- Relevance to decision-makers
- Public concern

These are just a few examples of many different ways of ranking and prioritising ecosystems, for additional information and an overview of these types of methods refer to the ValuES website *http://www.aboutvalues.net/*.

To sum up, during screening and prioritising, key ecosystem services are identified and are linked to development, economic, social and cultural activities. They are then prioritised by either looking at impacts and dependencies between services and activities or by applying other criteria, such as the ones mentioned above. In addition, the main stakeholders that are involved in the activities are identified. This will then allow for focusing on a few key activities and services for the next step in the ES assessment and valuation and will thus provide a more focused approach (ValuES 2018).

The following table (table 4) shows ecosystem services typically taken into account in the framework of ELD studies. Pay attention to the fact that the classification could also be altered, for instance in case of carbon sequestration which could be classified as regulating service as well or in case of soil moisture conservation, which could also be classified as supporting service. Furthermore, some services appear twice, but in different contexts (e.g. crop farming and grazing), and can have different impacts. In the process of preparing for the quantification and valuation of ESS, it is of utmost importance to clearly identify those who should be taken into account for the cost-benefit analysis, and also to avoid double-counting!

TABLE 4

Typical ecosystem services taken into account in the context of ELD studies

Category	Ecosystem services	Biophysical impact
Provisioning	increased crop production	crop yield increase
	increased availability of forest products (non-timber forest products, firewood, medicinal plants)	fruits/timber/firewood produced
	increased edible biomass on rangelands	increased natural forage available
	availability of medicinal herbs (on grazing land)	improved animal nutrition and reduced animal diseases
	increased livestock product production	meat (or wool etc.) production increase
	increased honey production based on increased availability of nectar plants	honey production increase
Regulating	nitrogen fixation	increased crop yields
	soil moisture conservation	increased crop yields
	sediment stabilisation and reduction in soil erosion	positive impact on nitrogen and phosphorus, on erosion phenomena and/or on sedimentation down-stream
	increased infiltration and reduced runoff	increased infiltration to shallow aquifer/ groundwater recharge
	increased infiltration and soil moisture on grazing land	extended grazing areas and periods, enhanced stream flows and landscape value
	infiltration and recharge of shallow aquifer	increase in available groundwater
	reduced downstream sedimentation of reservoirs	sustained reservoir storage capacity
Supporting	carbon sequestration/ climate change mitigation	CO_2 - sequestered
Cultural	recreation, eco-tourism, spiritual inspiration	Increased biodiversity through nature conservation
	wildlife tourism – trophy hunting	
	improved human health	—

Further Reading Material

Videos

Ecosystem services in brief (OPERAs project 2015): *https://www.youtube.com/watch?v=Y2KdM9zoF8E*

Literature

Ecosystem services

TEEB Synthesis Report on the economic contribution of biodiversity and ecosystem services to human well-being
http://www.teebweb.org/our-publications/teeb-study-reports/synthesis-report/

ValuES (2019). Kosmus, M., Renner, I., Ullrich, S., von Bertrab, A. Integrating Ecosystem Services (IES) into Development Planning: Manual for trainers, GIZ Bonn and Eschborn, January 2019
http://www.aboutvalues.net/data/trainings/1_ies-manualtrainer.pdf

Ecosystem services assessment

Mapping and Assessment of Ecosystems and their Services (MAES 2018)
https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/5th%20MAES%20report.pdf

A guide to selecting ecosystem service models for decision-making: Lessons from Sub-Saharan Africa
https://www.espa.ac.uk/publications/guide-selecting-ecosystem-service-models-decision-making-lessons-sub-saharan-africa

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http://www.aboutvalues.net/data/trainings/3_manual_principlesesav_low.pdf

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http://www.aboutvalues.net/data/trainings/4_exercises_principles_of_esav_2018.pdf

Soil carbon / soil management / sustainable agriculture

FAO 2017. Voluntary Guidelines for Sustainable Soil Management Food and Agriculture Organization of the United Nations Rome, Italy
http://www.fao.org/3/a-bl813e.pdf

The „4 per 1000" initiative
https://www.4p1000.org/governance

UNCCD: Science-Policy Brief 01 "Pivotal Soil Carbon", November 2015
https://knowledge.unccd.int/sites/default/files/2018-09/2015_PolicyBrief_SPI_ENG_0_0.pdf

Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany
https://www.unccd.int/sites/default/files/documents/2017-09/UNCCD_Report_SLM_web_v2.pdf

Agriculture production as a major driver of the Earth system exceeding planetary boundaries (Campbell et al. 2017)
https://www.researchgate.net/publication/320356605_Agriculture_production_as_a_major_driver_of_the_Earth_system_exceeding_planetary_boundaries

Global conditions for the future of agriculture in the "Anthropocene"
http://regardssurlaterre.com/en/global-conditions-future-agriculture-anthropocene

Sustainability in global agriculture driven by organic farming (Eyhorn et al. Nature Sustainability)
https://static1.squarespace.com/static/5aa6a1a19d5abb87c61a1225/t/5cb87bbd24a694fbfcb60eae/1555594176681/NATSUSTAIN+Policy+Comment_OnlinePDF.pdf

Expanded algal cultivation can reverse key planetary boundary transgressions
https://www.sciencedirect.com/science/article/pii/S2405844017308514

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List of figures

List of tables

List of boxes

For further information and feedback please contact:

ELD Secretariat
Mark Schauer
c/o Deutsche Gesellschaft
für Internationale Zusammenarbeit (GIZ) GmbH
Friedrich-Ebert-Allee 36
53113 Bonn
Germany
E info@eld-initiative.org
I www.eld-initiative.org

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