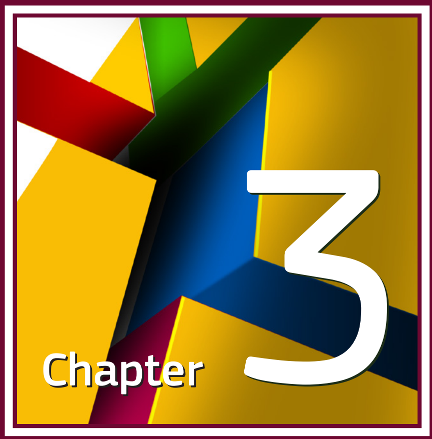

Assets at risk and potential impacts

3.5

Environment and ecosystem services

Online Version

3.5 Environment and ecosystem services

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3.5 Environment and ecosystem services

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1 Introduction to ecosystem services at risk

The impact of disaster on ecosystem services is dependent on the state of ecosystem degradation. There is a complex and often geographically specific relation between vulnerability to disasters and ecosystem services degradation.

According to the 2007, Potsdam G8 global initiative on The Economics of Ecosystems and< Biodiversity (TEEB), ecosystem services are defined as the contributions that ecosystems make to human well-being (Haines-Young and Potschin, 2018). They are important because they support, directly or indirectly, our survival and quality of life. Back in the 1990s, Costanza et al. (1997) valued the ecosystem services of the world at around USD 33 trillion. Interestingly, that value is about twice the gross domestic product of the world in the same period.

When we talk about impact on ecosystem services, the concept of measuring direct losses is not applicable. Direct losses are mostly monetary value (see subchapter 3.6), valid for human-made objects, whereas ecosystem services do not have market prices. Current efforts to calculate the impact of a disaster on the complex network of ecosystem services tend to underestimate the real cost. Some ecosystem services are interlinked; the degradation of one could trigger cascade effects, and the consequence of disasters, in some cases, will only appear over time. For the EU, accounts have been generated as pilot studies on specific ecosystem services such as water purification (La Notte et al., 2017); on crop pollination and outdoor recreation (Vallecillo et al., 2018); and on crop and timber provision, global climate regulation and flood control (Vallecillo et al., 2019) (Section 3.5.3)..

The earthquake and tsunami that struck southern Thailand in 2004 revealed the relation between vulnerability to disasters and ecosystem services. Well-preserved coastal ecosystems in Thailand functioned as a natural barrier to absorb the energy of the wave, whereas the effect was the opposite in areas where the coastal ecosystem was degraded (Wilkinson et al., 2005). It was only after 2007, with the establishment of the Global Network of Civil Society Organisations for Disaster Risk Reduction, that the relationship between the quality of ecosystems and the impact of natural hazards became evident. In 2015, the Sendai framework for disaster risk reduction emphasised the need to address underlying causes of disaster risk and to prevent the emergence of new risks. However, it fails to capture ecosystem services and the environment among the assets to protect.

It is increasingly recognised that conventional engineered ('grey') infrastructure measures such as dykes and sea walls have shortcomings, as they typically address protection needs without addressing the underlying drivers of risk. The scientific community has raised concerns about the necessity to move from reactive approaches to a proactive one, optimising all functions and ecosystem services (Sebesvari et al., 2019). Nature-based solutions or green infrastructures in combination with bioengineering in urban areas have proved a long-term success for specific regions in central Europe (Dushkova and Haase, 2020). Important differences from grey infrastructure are that green solutions may also attenuate the hazard itself and they can self-adjust.

In the European context, the RECONECT project ([1]) demonstrates the effectiveness of nature-based solutions for hydro-meteorological risk reduction in rural and natural areas. Nevertheless, these initiatives need to continue

([1]) http://www.reconect.eu/

upscaling to a regional level, which will require financiers and investment support. To that end, it is essential to have a business plan template from successful case studies, making it easier for financiers to step in and contribute to upscaling nature-based solutions (RECONECT, 2019). The NAIAD project ([2]) aims to operationalise natural assurance schemes, defined as a range of schemes to internalise the insurance value of river systems. Natural assurance schemes can reduce risk, especially of drought and flooding, and this risk reduction can be assessed and incorporated within insurance schemes.

In this subchapter, we discuss the need for investing in long-term assessment of impact on ecosystem services. We also think that governments should keep supporting national accounting of ecosystem services and that they should use the Common International Classification of Ecosystem Services (CICES) for that purpose. Mapping and assessment of the assets can also be employed for ecosystem accounting. Ecosystem services impact assessment, even though it is very important and necessary, cannot hide the facts that disaster risk management should move towards an ecosystem-based approach and that ecosystem degradation must be reversed. It is also important to highlight that impact on ecosystem services triggers a cascading effect that could be reflected in direct and indirect losses. These elements are discussed in detail, and we provide examples of and bibliographical references on how the ecosystem-based approach stands as a promising approach that can impact all elements of the disaster risk equation: mitigating hazards, reducing exposure, reducing vulnerabilities and increasing the resilience of exposed communities.

2 Classification of the Ecosystem Services; the CICES Subdivision

CICES uses a five-level hierarchical structure for ecosystem mapping and assessment. The first four levels can be employed for ecosystem accounting.

There are several (international) classifications for ecosystem services. The Millennium Ecosystem Assessment (MA), TEEB and CICES have proposed commonly used classifications. In essence, they are closely related to each other; all three include provisioning, regulating and cultural services. CICES is commonly used in the EU, since it was also proposed as a typology for ecosystem services under the Mapping and Assessment of Ecosystems and Their Services initiative as part of the implementation of the EU biodiversity strategy to 2020.

CICES has a five-level hierarchical structure. The detailed class types make the classification user-friendly and clarify what ecosystem services are included within each class. Using a five-level hierarchical structure is in line with United Nations Statistical Division (UNSD) best practice guidance (Haines-Young et al., 2012), as it allows the five-level structure to be used for ecosystem mapping and assessment, while the first four levels can be employed for ecosystem accounting without reducing the utility of the classification for different users.

At the highest level are the three familiar sections of provisioning, regulating and maintenance, and cultural ecosystem services.

- Provisioning ecosystem services cover all nutritional, non-nutritional material and energetic outputs from ecosystems as well as abiotic outputs. Examples are crops for food, livestock feed and textiles, fish, timber, water, medicinal plants, genetic resources and biofuels.

(([2]) http://naiad2020.eu/

- Regulating and maintenance ecosystem services represent all the ways in which ecosystems can mediate or moderate the ambient environment that affects well-being. Examples are pollination, water retention and flood control, maintaining a liveable climate, and cleaning polluted air and water.

- Cultural ecosystem services are the non-material, and normally non-rivalrous and non-consumption resources, outputs of ecosystems that affect physical and mental states of people. Well-known examples are nature-based recreation and the aesthetic values of biodiversity and ecosystems.

Table 1 shows a shortened version of CICES at the level of groups (3). Subchapter 3.6 discusses additional methods to assess the value of cultural heritage in which monetising is further developed than with ecosystem services.

Ecosystem services have a dual role in the impact and mitigation of disasters. On the one hand, provisioning ecosystem services, such as crop provision, and cultural ecosystem services can be severely affected by disasters. Some ecosystems are particularly vulnerable to extreme events such as floods or droughts, or human-induced disasters such as chemical pollution. Depending on the extent of exposure to a disaster and on the resilience of an ecosystem to cope with disturbances, the capacity of a system to deliver its services will reduce.

On the other hand, ecosystems can also mitigate disasters. In this context, regulating ecosystem services are important, specifically when ecosystems act as transformers by changing the magnitude of flows of matter and energy (i.e. act as buffers; La Notte et al., 2019a). Wetlands, floodplains and riparian areas can store water and prevent downstream flooding in periods of extreme precipitation. Forest soils hold water and release it during droughts. Dunes and coastal wetlands are living barriers against seaborne storms, and protect people and infrastructure from damage. Wetlands and estuaries act as natural wastewater treatment plants and can process large amounts of chemical or nutrient pollution. Forests on steep slopes protect against rockfall or avalanches. Putting ecosystems to work for the benefit of people, including in the management of disaster risk, is currently operationalised in the framework of nature-based solutions (Maes and Jacobs, 2017) or ecosystem-based adaptation (Sebesvari et al., 2019).

A useful method to assess how ecosystems and their services are affected by disasters or contribute to disaster mitigation is to cross-tabulate disaster types against ecosystem services and score either the impact on or the mitigation capacity of each service for each disaster type. This methodology is commonly known as the matrix method and regularly applied in ecosystem services research to assess how ecosystems contribute to human well-being (see for instance Burkhard and Maes, 2017, for examples).

In addition, ecosystem service accounts (for which purpose CICES was developed) can provide key statistics to quantify the economic impact of disasters on ecosystems. Ecosystem service accounts quantify the physical and monetary flows from ecosystems into the economy. In the case of flood control (Vallecillo et al., 2019), it was possible to assess (1) which are the upstream areas providing the service flows and (2) who are their downstream beneficiaries; while a decrease is assessed for the former, a remarkable increase is reported for the latter that results in a critical amount of unmet demand, i.e. areas without protection by the ecosystems.

The outcome in physical terms is translated into monetary terms by using the avoided damage cost. Disaster risk reduction (DRR) by ecosystems is typically accounted for by using avoided damage costs as a valuation technique. The assumption is that damage costs of disasters would be higher in the absence of the mitigating functions of ecosystems, and this value is attributed to ecosystems. Vallecillo et al. (2019), thanks to the valuation of avoided damage costs based on the return period that is affected by the existing level of artificial defence measures, were able to separate those areas where artificial defence is enforced by ecosystem defence from those areas that are protected only by ecosystems.

(3) *The complete classification is available at* https://cices.eu/.

***Table 1**. A shortened version of CICES version 5 with relevant disaster impacts and mitigations*
***Source:** Authors, based on CICES.*

***I**=impacted, **M**=mitigated, **ES**=Ecosystem services, **ES** affected by disasters; **M**, **ES** can contribute to mitigating disaster*

SECTION	GROUP	HAZARDS	HAZARDS (that negatively affect ES)	HAZARDS (mitigated by ES)
Provisioning (biotic)	Cultivated terrestrial plants for nutrition, materials or energy	I, M	Floods, wind storms, forest fire, drought	Soil erosion, runoff, drought
	Cultivated aquatic plants for nutrition, materials or energy	I, M	Floods, tsunami	Flow speed or wave impact
	Reared terrestrial animals for nutrition, materials or energy	I, M	Floods, forest fire, drought, diseases, heatwaves	Forest fire
	Reared aquatic animals for nutrition or materials	I, M	Floods, tsunami, drought, diseases	Pests
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	I, M	Floods, wind storms, forest fire, drought	Floods, drought, heatwaves
	Wild animals (terrestrial and aquatic) for nutrition or materials	I, M	Floods, wind storms, forest fire, drought	Forest fire
	Genetic material from plants, algae or fungi	I, M	Forest fire, drought	Diseases, antibiotics resistance
	Genetic material from animals	I, M	Forest fires, drought, diseases	Venomous bites, vaccines, serums
	Surface water used for nutrition, materials or energy	I, M	Drought, contamination	Drought, forest fire
	Groundwater used for nutrition, materials or energy	I, M	Drought, contamination	
	Other aqueous ecosystem outputs	I, M	Floods, drought	
Regulation and maintenance (biotic)	Mediation of wastes or toxic substances of anthropogenic origin by living processes	M	Floods	Contamination
	Mediation of nuisances of anthropogenic origin	M	Floods, drought	Wind speed
	Regulation of baseline flows and extreme events	M	Floods, drought	Extreme floods and drought
	Life cycle maintenance, habitat and gene pool protection	M	Diseases, disruption of balance between prey, predator and vector disease	Pests, pandemics
	Pest and disease control	M	Heatwaves	Epidemic
	Regulation of soil quality	M	Drought	Floods
	Water conditions	M	Drought	Drought
	Atmospheric composition and conditions	M	Drought, heatwaves, wind storms	Pollution mixing
Cultural (biotic)	Physical and experiential interactions with the natural environment	I	All	
	Intellectual and representative interactions with the natural environment	I	All	
	Spiritual, symbolic and other interactions with the natural environment	I	All	
	Other biotic characteristics that have a non-use value	I	All	

3 Quantifying the economic costs of ecosystem services losses.

The real cost of disaster to ecosystem services is much higher than the current assessment predicts. Additional attempts are being made to create a full overview of the economic value of ecosystem services and to understand the economic costs of hazards to ecosystem services.

Natural capital and particularly ecosystems play a dual role in disasters and climate change from an economic perspective, as ecosystem services are affected by disasters and they can help to mitigate them (see Section 2). On the one hand, hazards and climate change have direct impacts on exposed ecosystems, affecting their structure and functioning. These impacts create economic costs through the changes in the ecosystem services to people, the economy and society. On the other hand, ecosystems have the potential to provide a cost-efficient or cost-effective way to reduce the impacts, and thereby reduce the need to allocate resources to risk reduction measures or emergency response. In the standard ecosystem service classifications, this is categorised as a regulating service. They are the foundation for nature-based solutions (see Sections 1 and 6).

In this subchapter, we describe the challenges and current attempts to develop a comprehensive understanding of the economic impacts of disasters and climate change in addition to the loss of life. However, assessments of the economic impacts of disasters and climate change on ecosystem services are scarce. To date, the assessment of the economic impacts has been limited to standard, market-based services, mainly in agriculture and forestry, and not focused on ecosystem services, which do not have market prices. For instance, an assessment published in 2009 estimates that climate change could reduce agricultural production in Europe by 10 %, which would translate into additional losses of 0.32 % of annual gross domestic product (Ciscar and Soria, 2009).

The challenge with monetising the impacts of disasters and climate change on ecosystem services is that, in most cases, ecosystem services do not have markets, and therefore they do not have market-determined prices. This has led to the development of various methods to assess the economic value of ecosystem services. The methods are based on people's stated or revealed valuation of the benefit. The stated preferences are assessed by asking people how much they are willing to pay for the ecosystem service (Wainger et al., 2018), or what kind of ecosystem loss they would accept. The revealed preferences are assessed by studying people's actual behaviour and related costs, for instance by collecting data on the money that people allocate to travel to the ecosystem in question (the travel cost method).

The first step in understanding the economic costs of hazards to ecosystem services is up-to-date knowledge of the current value of ecosystem services. Abiotic (such as fossil fuels and minerals) and biotic (ecosystems) natural capital is a concept used to emphasise the crucial role of the natural environment as a life-sustaining system on Earth. Efforts to incorporate natural capital in decision-making include the UN System of Environmental-Economic Accounting (SEEA), which provides an international framework for developing integrated physical and monetary environmental-economic accounts (United Nations et al., 2014a). Within this context, the EU Regulation on European environmental-economic accounts (EU, 2011) provides a legal basis for harmonised collection of comparable data from countries.

The seventh environment action programme and the EU biodiversity strategy to 2020 include objectives to develop natural capital accounting in the EU, with a focus on ecosystems and their services. The knowledge innovation project on an integrated system of natural capital and ecosystem service accounting aims to develop a set of experimental accounts at the EU level, following the SEEA – Experimental Ecosystem Accounts (United Nations, 2014). Ecosystem service accounts are constructed following three main steps: (1) biophysical assessment; (2) translation into monetary terms; and (3) accounting in both biophysical and monetary terms.

Monetary valuation is thus an inherent component of natural capital accounts: the translation into monetary terms implies a direct connection between the amount of change in biophysical terms and the value it presents to the economy. Moreover, valuation techniques employed in natural capital accounting should comply with traditional economic accounting to allow consistent integration and analysis with economic accounts that follow the System of National Accounts (SNA).

Work is ongoing to establish the relationship between ecosystem service accounts and the monetary estimates of ecosystem assets through ecosystem capacity accounts (Hein et al., 2016; La Notte et al., 2019b). The concept of ecosystem capacity becomes important in considering resilience: the current status of capacity accounts and the trend over time can show in what ways ecosystems are more or less resilient in different countries, and how their values change as a consequence of legal directives, policy actions and management practices that lead to increase/decrease in degradation (see the water purification example in La Notte et al., 2019a).

An important advantage of dealing with accounting frameworks, and specifically with ecosystem service accounts, lies in the supply–use structure, which allows one to track (1) which ecosystems provide the service flow and (2) which users/beneficiaries receive the service flow. Use tables are classified by economic sectors (e.g. agriculture, manufacturing, transport, construction, wholesale) and households. Economic sectors and households represent the demand side, which, by interacting with the ecosystem potential supply, generates the ecosystem service flow used (i.e. the actual flow). Once each actual ecosystem service flow is assessed (and valued), it is systematically allocated to its users and beneficiaries. One of the most important advantages of SEEA (and thus of Integrated System for Natural Capital and Ecosystem Services Accounting in the EU - INCA) lies in its consistency and alignment with the SNA: all the measurements generated can be used to make direct comparisons with economic indicators, from interregional trading to macroeconomic impacts.

4 Drivers of ecosystem services losses

Human activities such as urbanisation, intensive cropping and grazing animals, deforestation or intensive forest management accelerate land degradation and reduce the capacity of ecosystems to deliver precious services..”

Human activities take advantage of many kinds of ecosystem services in providing natural resources and living environments, but they also affect ecosystem services intensively (Zheng et al., 2003). The degradation of ecosystem services caused by anthropogenic activities often triggers significant harm to human well-being in both the long and short terms (Millennium Ecosystem Assessment, 2005). Herein, we present some of the anthropogenic threats to ecosystem services, other than those related to climate change. The aim is not to provide an exhaustive list of human-related activities that might deplete the provision of ecosystem services. Instead, we will only address those that by decreasing some ecosystem services could potentially exacerbate the impact of an extreme event.

Substantial effort has been invested in quantifying the individual directional impacts of humans on nature and nature on humans (Milner-Gulland, 2012). The potential damage on ecosystem services due to anthropogenic activities has been extensively documented, and covers the three familiar sections of provisioning, regulating and maintaining, and cultural ecosystem services (UNEP, 2016). Some of the anthropogenic activities that negatively affect ecosystem services and biodiversity worldwide are land use changes such as urbanisation, cropping and grazing animals, deforestation or intensive forest management practices, industrial development and, to a lesser degree, mining. Besides land use and land use change, pollution, introduced invasive alien species and resource exploitation are major drivers of biodiversity loss. These pressures can trigger direct or indirect effects when an extreme event happens.

Through soil sealing, urbanisation reduces the surface area through which rainwater can percolate, thus reducing the inflow to aquifers, increasing the risk of drought and exacerbating the speed of surface water flow, worsening the impact of both extreme flash and riverine floods. Soil sealing is one of the worldwide threats to the functioning of soils; healthy soils can provide regulating and maintenance services such as recycling of wastes or flood mitigation (FAO, 2017). The United Nations estimates that 4.2 billion people live in cities, and projects that another 2.5 billion will join them by 2050. While cities offer opportunities for jobs and resources for human needs, one element closely tied to well-being is often overlooked or neglected: connection to nature. Jiang and O'Neil (2017) predict that the level of urbanisation in western Europe could increase from 77 % to 99 % in 2100. As a result, the number of hectares affected by soil sealing is also expected to rise. This could potentially decrease rainwater infiltration, thereby making urban areas more vulnerable to flooding and lower groundwater levels under the cities, leading to subsidence. Akter et al. (2018) found that in central Europe flood risk would increase significantly with both urbanisation and climate change.

Recently, governments and companies have increasingly turned to nature for disaster risk mitigation (Tyrväinen et al., 2014; Nesshöver et al., 2017; Lafortezza et al., 2018). For example, in managing flooding, nature-based solutions include widening of natural floodplains, protecting and expanding wetlands, restoring oyster and coral reefs and investing in urban green spaces to reduce runoff (Jongman, 2018). Improved planning, through a land-use approach, can also be used to mitigate flood risk by prohibiting building in flood-prone areas. Areas with a high risk of flooding can be developed for nature or recreational purposes (Akter et al., 2018).

In the near future, urban environments need to develop into high-functioning, low-maintenance systems for municipalities and the public. This needs to be achieved not only to improve flood management but also because they contribute to water filtering, waste treatment, reducing stormwater runoff, cooling down the cities and mitigating effects of climate warming (Eggermont et al., 2015; Pauleital et al., 2019; Eldridge, 2019). Urban green solutions, considered as a multifunctional network of urban green spaces situated within the boundary of the urban area, are a promising opportunity to adapt cities to climate warming, mitigate the impact of disasters and preserve ecosystem services. Nonetheless, the right mix of them (street trees, green areas, green roofs and walls, urban gardens and parks) needs to be selected and adapted to the local context (Maes et al., 2016; Rocha et al., 2015). In the next decade, efforts towards the development of sustainable cities will lay the framework for future growth that will substantially affect global sustainability throughout the 21st century.

Soil erosion can be accelerated through intensive agriculture, deforestation and grazing, which could generate off-site costs that are generally paid by society. These include siltation in reservoirs, impacts of sediment on fisheries, poorer water quality for irrigation or other uses (e.g. water eutrophication) downstream, loss of wildlife habitat and biodiversity (Tsiafouli et al., 2015), increased risk of flooding, damage to recreational activities, land abandonment and destruction of infrastructure such as roads, railways or other public assets (Telles et al., 2011). Land degradation due to soil compaction from crop farming or grazing intensification is one of the potential drivers of the increasing flood magnitudes in Europe in recent years (Alaoui et al., 2018). Extreme flooding is not the only impact when soil is lost. The process cannot be reversed. The area will subsequently remain prone to droughts and landslides and in some cases agricultural productivity will be reduced significantly. Even though the ecosystem services and other functions of soils play an essential role in the urban and agricultural ecosystem, they are still poorly taken into consideration in land planning.

Likewise, soil erosion constitutes a subindicator for SDG 2.4 (target 2.4.1; UN General Assembly, 2015): 'By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.' In a worldwide analysis, Liu et al. (2018) found that well-designed and properly managed mixed-species plantations can be more productive and have more advantages in biodiversity, economy and forest health than monocultures. Moreover, Zald et al. (2018) suggested that intensive plantation forestry characterised by young forests and spatially homogenised fuels was a more significant driver of wildfire severity than pre-fire biomass'.

5 Ecosystem services and a hotter climate

World climate warming will lead to unexpected changes in ecosystem functions (carbon storage in soils, nutrient cycling, water purification, pollination, etc.) that will increase disaster risks, especially, but not only, with regard to river floods, coastal floods, heatwaves and wildfires. Understanding of local ecosystems in climate change scenarios is needed to anticipate the risk and to protect the ecosystem services.

A failure to mitigate and adapt to climate change is seen as the risk with the greatest potential to cause economic damage in the world in the years to come; this is the first time ever that the World Economic Forum has ranked an environmental issue as the highest risk (WEF, 2016). A report by the European Environmental Agency, based on over 40 indicators, predicts profound impacts of climate change on ecosystems; unfortunately, there are still major uncertainties about the response of ecosystem services to a hotter climate (EEA, 2017). In 2019, the WEF already listed five environmental risks in the top 10 disasters most likely to occur. Biodiversity and ecosystem collapse is mentioned in the eighth position, before asset bubbles in the economy.

Broadly speaking, increased temperature is accompanied by heat and precipitation extremes, floods, droughts, storms, hail, glacier retreat and rise in sea level. All of them can become true disasters with a high risk of loss of ecosystem services as we know them now. Gradual warming first affects species phenology and then causes alterations of species composition and functional traits (including increases in alien invasive species, loss of highly specialised species and northward migration of economically important species). In turn, for instance, predator–prey and pathogen–host interactions will change and this domino effect might lead to system reorganisation, altering processes such as biogeochemical cycling and changing the stability thresholds of our ecosystems (Bahn et al., 2014). In Figure 1 a warming trend all through several decades can be observed for Europe according to the data registered in the European Drought Observatory.

Climate change is envisaged to have different, but not exclusively negative, effects on ecosystem services across Europe (EEA, 2017), and these are very complex and difficult to fully anticipate. First, long-term warming might have different impacts on some ecosystem services from extreme weather events: the maintenance service of carbon sequestration in soils, for instance, is expected to increase as a result of the warmer climate and increased vegetation productivity in temperate and boreal regions; disasters such as heatwaves, droughts and storms (and associated disturbances) might, however, completely nullify this expected increase (Reichstein et al., 2013).

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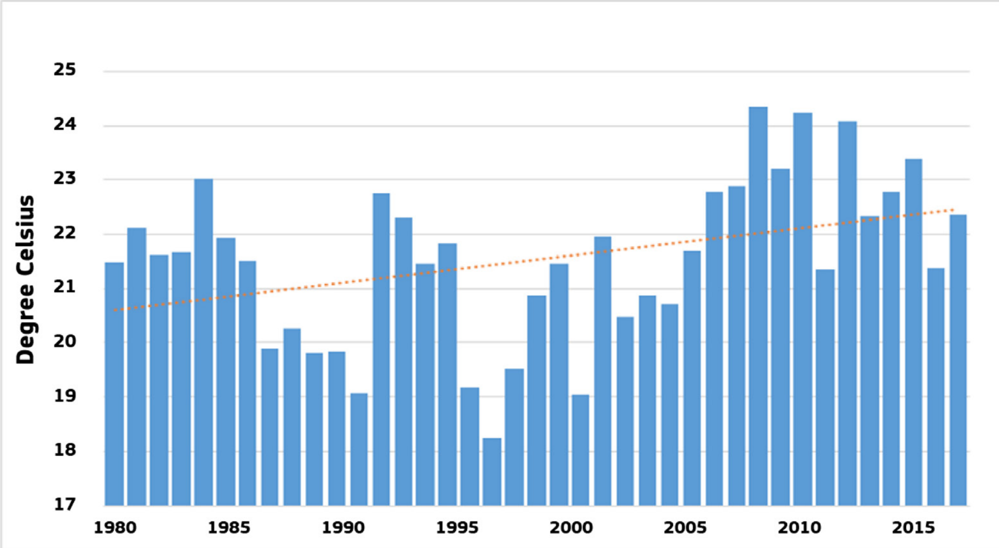
Another example illustrates this complexity. Provisioning services such as timber production are projected to increase in northern Europe (accompanied by substitution of coniferous with broadleaf trees), and to substantially decrease in global South (Kovats et al., 2014). At the same time, this increase in the provision is jeopardised by the risk of decreasing the regulating services in global North (increase in forest pathogens and damage from winter storms; see for example Malmström and Raffa, 2000). Moreover, summer droughts and warming are expected to increase wildfire risks in the Mediterranean area (Moreno, 2014), and have already led to significant forest damage in central Europe in recent years (because of drought, storm or pest disasters in conjunction with mono-species production forest ecosystems)

Figure 1: *Averaged high temperature, of the first ten days of June from 1980 to 2018, in Europe from the Atlantic Ocean up to the Caspian Sea, displaying annual variability up to 6 degrees but also a warming trend.* ***Source****: Authors using data from EDO, n.d*



However, increased biomass accumulation and changed weather can also induce wildfire risks in areas so far not prone to burning, such as in the Greek mountains (Koutsias et al., 2012) or Siberia (Malevsky-Malevich et al., 2008). Furthermore, for instance, bumblebees, insects that provide the important regulating service of pollination, will not be able to migrate northwards, and their habitat will be seriously restricted (Kerr et al., 2015). On the other hand, pollination in European grasslands might be maintained by complex interactions of climate change and alien species, in a rather new, unexpected manner (Schweiger et al., 2010).

In general, provisions from natural and ecologically fragile (especially Mediterranean and Alpine) ecosystems are expected to be at the highest risk. Furthermore, climate warming will exacerbate the risks posed by the existing pressures (habitat fragmentation, urbanisation, intensive agriculture, deforestation and grazing, pollution and biodiversity loss, as mentioned in section 4. Hence, while we wait for science to come up with early warning signs of critical transitions in our ecosystems and deliver operational guidelines on ecosystem service vulnerability and priority actions (Schulp et al., 2014; Dunford et al., 2015), we can choose to follow the best available practice (e.g. Bonn et al., 2014). In the case of ecosystem services, good stewardship that increases ecosystem resilience (in particular, maintenance of biodiversity and habitat connectivity; Harrison et al., 2014) is a safeguard option to give nature a chance.

The list displays the problems that civil protection and other local authorities have to address the various extreme events through evacuation. If events occur in conjunction then the evacuation advice might even be contradictory. Especially if diseases occur after an extreme event, the situation might get out of control. If as a result of war or other conflicts the civil protection service is malfunctioning, all disasters might become potentially deadly for human beings. Warlords, strategically thinking politicians and generals also use such scenarios during conflicts. Evacuation is normally temporary but, especially during conflicts, part of the population might not be willing or able to return.Extreme events have also a negative impact on the ecosystem service and can even permanently damage (a part of) an ecosystem. For example, a coastal storm can wash away a beach used for access by fishermen. In Table 3, we focus on the natural adaptation methods to lessen the potential impact of an extreme event. In the third column, some of these adaptation methods are listed. Typically, one can choose engineering methods to adapt to the occurrence of an extreme event or choose a method that collaborates with nature. Floods, droughts and wildfires are the most typical events that present us with such choices.

Table 2. *Impacts of extreme events.* ***Source****: authors*
Note: *Very quick evacuation represents an evacuation of around 15 minutes, quick evacuation in the order of hours, medium quick in the order of a day, slow in the order of 2 days.*

Event	Positive impact ecosystem	Negative impact ecosystem	Adaptation means	Evacuation
Volcano outburst	Fertile ashes deposition	Fires, loss of forest, air quality. Harvest loss. In degraded soils, ash deposition may increase soil erosion and wind erosion Arnalds et al., 2016.	non-burnable construction materials, flight restrictions	Quick, out of the area
Earthquake	Landscape formation, topography formation, the release of minerals	Instability of slopes, avalanches	Absorbent (ground floor) wooden constructions	Difficult to predict, to open spaces, using tents
Tsunami	Could have helped seeds to colonize remote islands and to shaping community structures and biodiversity in local and regional habitats (Urabe et al., 2016)	Destruction of beaches, impacting coral reefs, sea life, fish stocks	Partial abandoning low coastal areas, alarm systems, nature-based solutions (coral reef, coastal vegetation and mangrove protection)	Very quick, to higher grounds
Flood	Sedimentation of fertile earth, increased elevation of low terrain, washes out pesticides and toxic waste.	Soil erosion due to heavy rain, decreased soil fertility upstream, partial harvest- or livestock loss, displacement and downstream accumulation of toxic materials	Grey infrastructures for control and flood regulation (levees, dykes, etc), nature-based solutions (vegetation, river and watershed meandering, floodplain soil water infiltration, etc)	Slow and predictable, to higher grounds
Drought	Provoking roots to root deeper, stabilizing vegetation	Depletion of both ground and surface water resources, escalating to other disasters such as wildfires, low air quality, dust, wind erosion. Drought can potential lengthening of the fire season (Cardil et al., 2019). Eventually, also soil erosion, decreased fertility. Important harvest loss. Cracking of soils might provoke damage to roots, foundations and pipelines, wildlife loss	Building reservoirs, river diversion, irrigation systems, groundwater pumping. Nature-based actions (drought-tolerant crops, sustainable soil management practices, sustainable agricultural, grazing practises, reforestation)	Not needed if the water supply and eventually food supply are guaranteed. If land becomes increasingly arid (desertification) it might trigger migration and abandonment
Wildfire	Contributes to the vegetation cycle and it could enhance local biodiversity	Reduce C fixation and increases CO_2 emissions, losing climate change mitigation capacity. Genetic impoverishment. Soil becomes more vulnerable to water and wind erosion. Burned wildlife and/or livestock.	Construction standards, cleaning, grazing, biomass management, selecting and planting native vegetation with the most fire-resistant genes, forest fire prescription. Citizen awareness campaign and legislation (cigarette butts, pyromaniac behaviour)	Quick, direction difficult to advice
Storm/Wind	Renewal of vegetation, old branches, cleaning and mixing	Some loss of forest, mostly over-stressed and damaged trees. Partial harvest loss	Specific construction standards. Increasing forest resilience and healthy trees, enhancing native species and forest heterogeneity.	Medium quick evacuation to strong shelters
Hail	Renewal of vegetation	Harvest loss, small areas, soil compaction	insurance	No, shelter
Thunder	Weathering of rocks, mineral release	Fires, loss of forest	adaptation of constructions often omitted in poor households	No, shelter
Diseases	Largely unknown, some proteins of viruses appear to be useful to combat cancer	Disruption of balance in ecosystems between predators and prays. Pest may therefore follow	Vaccination, hygienic standards, sewage systems, clean water supply, separation humans – animals, wild-animals - livestock	Quarantine

Table 3. *Selected engineering and ecological adaptation methods.* ***Source****: authors.*

Extreme event	Engineering adaptation	Ecological adaptation
Flood	Dike, deepening of riverbeds	Vegetation along embankments, meandering, unleveling upstream fields, increasing storage and draining capacity
Drought	Reservoir, irrigation	Afforestation, agroforestry, silvopasture, unleveling, increasing retention capacity, sustainable agricultural practices
Wildfire	Traditional forest fuel reduction	Introducing (wild) grazing animals, changing forest structure, native fire-resistant vegetation

Engineering adaptation and ecological adaptation are not mutually exclusive, but an overall strategy is needed, in general within a watershed, in order to reduce the risk of impact. Measures can be very different in their impacts on society and on the landscape. For example, by creating a reservoir to reduce the risk of drought impact, farmers can continue to produce the crops they are used to. If the area converts to agroforestry, then the economy of the area will change.

The advantage of this agroforestry option is, however, that it reduces the risk of suffering from so great a drought that no harvest at all can be collected. The reservoir option will fail if the reservoir is emptied, leading potentially to complete loss of the harvest. With floods, a similar sequence of events can be expected. If the dyke breaks during an exceptionally high flood, all is lost, whereas the ecological solution might lead to flooding when waters are high but the system as a whole will not generate a destructive flood, since the flow velocity of the water is reduced and the watershed as a whole can cater for more water storage. The eminent advantage of the ecological adaptation is that the positive ecosystem impact of an extreme event is preserved (see Table 2), whereas this is not the case with engineering solutions. The challenge for the engineer and the ecologist is to quantify, for both options, the expense of construction or occupation of land as well as the risk to life if the adaptation fails in the case of an extreme event. If both options are equally competitive, the tendency should be to choose the ecological solution, since then the positive ecosystem impact is also preserved (sedimentation of fertile ground in a floodplain for floods, improved deep rooting for drought, continued CO^2 sequestration for wildfires).

6 Working towards solutions: restoration and ecosystem-based solutions

Restoration actions and ecosystem-based solutions can help protect biodiversity, enhance resilience and improve the quality and quantity of ecosystem services. The ecosystem-based approach stands as a promising approach that can influence all elements of the disaster risk equation.

6.1 Restoration and disaster risk reduction

The United Nations Office for Disaster Risk Reduction examined the links between DRR and economic development in the context of the 2030 Agenda for Sustainable Development and the Sendai framework for disaster risk reduction 2015–2030. In the resulting document, Aitsi-Selmi et al., (2015) emphasises that reducing risk and building resilience should be addressed from a multidimensional perspective in which ecosystems play a central role. The UN General Assembly declared on 1 March 2019 that we are about to enter the UN Decade on Ecosystem

Restoration 2021–2030 (Cross et al., 2019; UNEP 2019). The United Nations Environment Programme called ecosystem restoration among the most profitable public investments for economic growth and overcoming poverty (Nellemann and Corcoran, 2010). Throughout the past few years, ecosystem restoration has increasingly been promoted and funded as an important contribution to urgently needed responses to environmental degradation, biodiversity loss, and anthropogenic and climate change throughout the world. Restoration actions, when implemented effectively and sustainably, contribute to protecting biodiversity; improving human health and well-being; increasing food and water security; delivering goods, services and economic prosperity; and supporting climate change mitigation, resilience and adaptation (Gann et al., 2019).

Ecological disturbances such as wildfires and insect outbreaks can interact with climate variability to precipitate abrupt changes in ecosystems and landscapes. These changes may concern biotic components of the ecosystem first, and then the abiotic framework, and can be virtually irreversible without human intervention on a short time scale (Whisenant, 1999).

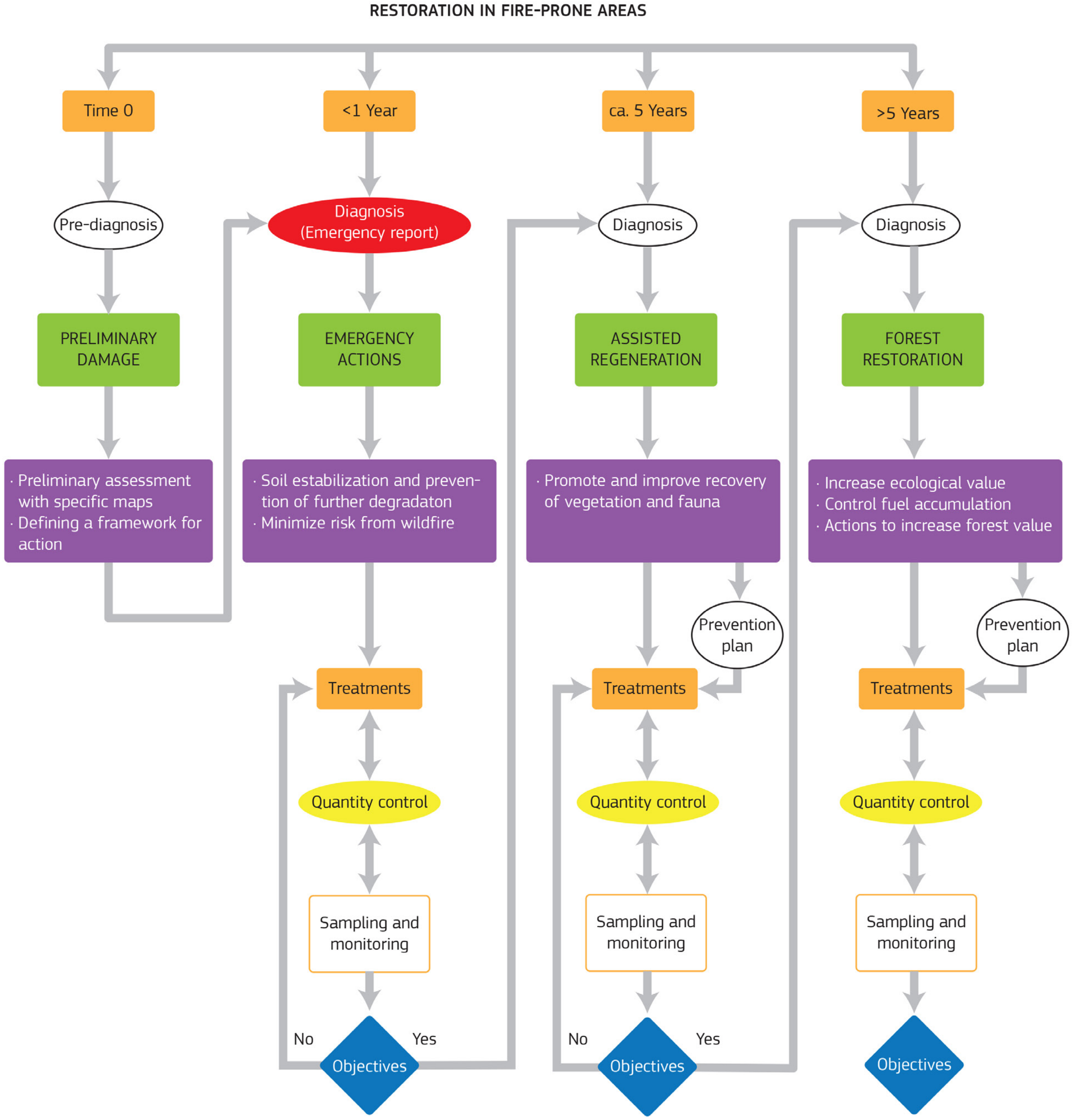
Ecosystems have an intrinsic capacity for recovery after a disturbance, which depends on the intensity and magnitude of the disturbance and the resources available (Holl and Aide, 2011). Underground bud banks, also known as lignotubers, are crucial for regeneration after disturbance (Ott et al., 2019). The presence of a seed bank in the soil, the heterogeneity of the landscape and the seed dispersal capacity of the adjacent systems increase ecosystem and landscape resilience following disturbance (Pausas et al., 2008).

Many human-impacted ecosystems have lost both their capacity to recover after disturbance and the ability to provide ecosystem services. There is a need to assist the recovery of these systems by reinforcing the ecological processes that support resilience: resistance, recovery and reorganisation (Falk, 2017). Targeting ecosystem resilience and social-ecological resilience in international environmental management programmes has gained increased attention but it still needs to be included in disaster risk management, climate change adaptation, impact assessment and land planning. For instance, the Intergovernmental Panel on Climate Change, in its special report on climate change and land 2019 (IPCC, 2019), draws special attention to amplifying social and ecosystem resilience by supporting ecological restoration. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Montanarella et al., 2018) underlines that there is a body of evidence suggesting a positive association between diversity, especially functional biodiversity, ecosystem services and ecosystem resilience to disturbance. Therefore, restoration measures are considered a good tool to build resilience, reduce disaster risk and increase adaptation to climate change.

Restoration efforts have been applied worldwide to assist in recovery and increase ecosystem and landscape resistance and resilience. Thus, increasing ecosystem resistance for soil protection and hydrological control have been and still are major motivations of large-scale tree planting in drylands (Del Campo et al., 2014; Garcia-Peman and Hierro, 2017). In forests in Arizona (USA), post-fire restoration efforts involve assisted gene flow – selecting and planting native pines with the most fire-resistant genes in the most vulnerable areas (Falk, 2018). They include assisted migration and thinning dominant fire-prone species while introducing fire-resilient species. The implication of this is to generate an ecosystem that is adapted to changes in forest fire regime.

Similarly, restoring stand structure and modifying landscape configuration are being implemented at large scales to change wildfire regime and protect human settlements (Alloza et al., 2014; O'Donnell et al., 2018). Establishing resprouting species in pine forests as a way to increase their resilience has also been integrated with forest management programmes in the Mediterranean basin (Gavinet et al., 2015, 2016). These and other measures can be found in more detail in the Super Case Study 4 on the forest fires in Portugal. Notably, the region of Valencia in eastern Spain has developed a framework for the restoration of fire-prone areas that takes into account both the risks generated and amplified by wildfires and actions to increase ecosystem resistance and resilience to wildfires (Figure 2). Such a local-driven restoration solution and ecological approach could be scaled up to a larger area, or serve as an example for other European regions with similar forest fire and wildfire risks.

***Figure 2**. A conceptual framework for the different phases of a restoration project in a fire-prone area*
***Source:** Translated from Spanish, from Alloza et al., 2014.*
***Note:** In this figure, preparedness actions are allocated to time 0. The forest fire event triggers response actions (emergency actions to be conducted in less than 1 year): soil stabilisation to avoid further degradation, and wildfire risk reduction. Over a period of 1 to 5 years, mitigation actions (assisting regeneration) will start. After 5 years, the restoration actions focus on a prevention plan that increases the ecological value of the area, meanwhile controlling biofuel accumulation and promoting the recovery of native forest vegetation.*



In Europe, there are also context-driven and local solutions that focus more on reducing forest fire risk.

This is the case of the fire blocks project promoted by the European Agroforestry Federation, in which cattle are used to reduce forest fire risk in some areas of Catalonia. An important recognised driver of increased fire risk is the abandoning of rural areas in hilly and mountainous areas in Europe, leading to growth of the forest understorey, no longer cleared for firewood harvesting, and spontaneous growth of fire-propagating shrubs and bushes on abandoned fields. Reforestation policies in most areas of Europe have focused solely on planting trees and not on restoring native forests or addressing the rural exodus itself (see the conclusions of Super Case Study 4).

Rewilding is a subset of practices under the broader umbrella of restoration: all rewilding is restoration (of species, but especially ecological processes), but not all restoration is rewilding (Anderson et al., 2019). Trophic rewilding, in which large and potentially dangerous mammals clear the understorey, is an option poorly exploited in Europe, mainly because of the presence of remaining human population, the interests of hunters and shepherds, and the unorganised character of the rural exodus thus far.

The upfront cost of restoration is expensive and may become economically and technically infeasible as abiotic resilience thresholds are crossed, even when the trade-offs of restoration scenarios result in long-term benefits. Ultimately it is the benefit–cost ratio that matters, as stated in the TEEB 2010 report on restored wetlands (Kettunen et al., 2010): the project would deliver net benefits to the community of some USD 2 million in 2010 value terms, after deducting the costs of restoration and opportunity costs. The benefits were mainly accounted for by biodiversity (USD 2.6 million), recreation (USD 663 000) and increased flood storage capacity (USD 417 000), and far outweighed the current benefits provided by agriculture (Olsen and Shannon, 2010).

Peh et al. (2014) suggest that restoration is associated with a net gain to society in the order of USD 200 per ha per year, for a one-off investment in restoration of around USD 2 400 per ha. Recently, Logar et al. (2019) conducted a cost–benefit comparison showing that river restoration is economically justified. It is not all about cost; there are many examples of restoration and rehabilitation programmes launched to reduce the risk of environmental disasters. For example, along the Mediterranean coast near Guardamar in south-eastern Spain, shifting sand dunes threatened the village by the end of the 19th century. A large-scale project was implemented to stabilise the dunes.

The project relied on techniques that had been previously developed in France and elsewhere, which were introduced and adjusted for the needs of this particular semi-arid landscape. After a few decades, trees had stabilised the dunes and the people of Guardamar adopted this new landscape as part of their cultural identity. According to Pagán et al. (2017), the restored dune system acts as a dyke preventing inland flooding but there is concern about the increasing rate of beach erosion.

Mainly, beach erosion is due to the lack of sediment supply, the cut-off in the longshore transport by breakwaters and other anthropic actions. Dune restoration and habitat protection have substantially reduced vulnerability to wind storms and coastal flooding, and ultimately helped the local population to comprehend the limits to urban growth (Murti and Buyck, 2014).

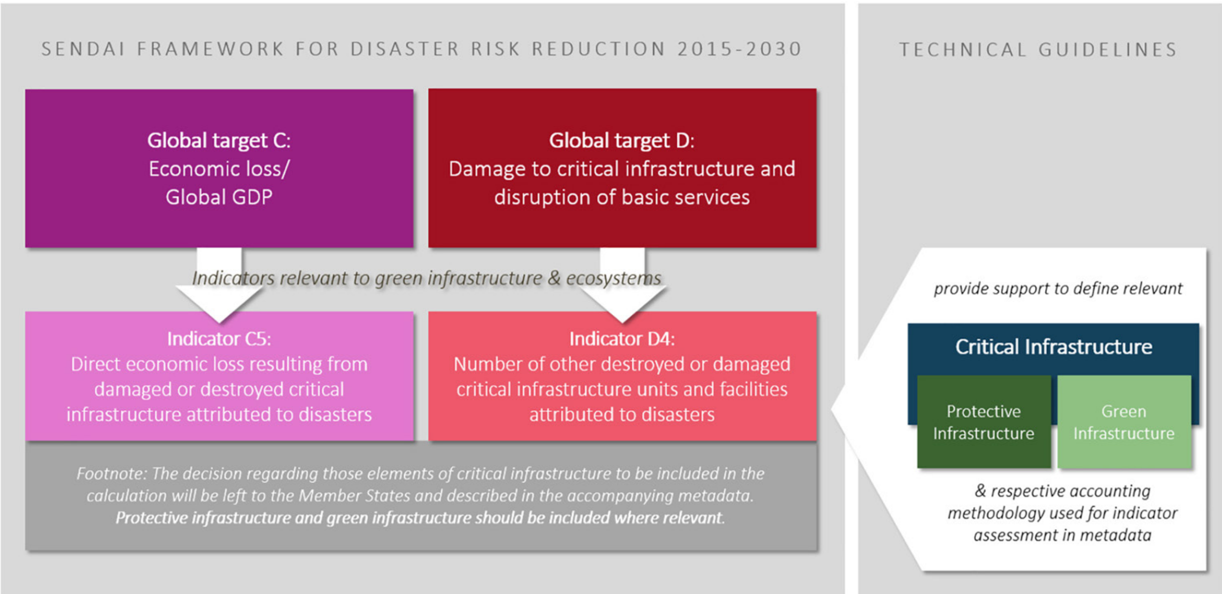
6.2 Ecosystem based adaptation to increase resilience and reduce vulnerability of societies

Ecosystem-based adaptation includes sustainable management, urban green infrastructures, nature-based solutions, conservation and restoration, and makes use of biodiversity and ecosystem services as part of an overall strategy to help people adapt to the adverse effects of climate change. Ecosystem-based solutions have gained attention to complement or replace grey infrastructure (Sebesvari et al., 2019). Ecosystem-based adaptation contributes to repairing ecological damage and rebuilding a healthier relationship between people and the rest of nature. It aims to maintain and increase the resilience, and reduce the vulnerability, of ecosystems and people in the face of the adverse effects of climate change (Gosnell et al., 2017).

Meanwhile, the ecosystem-based approach is also relevant to various dimensions of DRR; it is one of the few approaches that can have an impact on all elements of the disaster risk equation: mitigating hazards, reducing exposure, reducing vulnerabilities and increasing the resilience of exposed communities (Renaud et al., 2013). In addition, Sebesvari et al. (2019) highlighted that an ecosystem-based approach can reduce physical exposure to hazards and increase socioeconomic resilience. Nature-based solutions in restored and maintained wetlands, such as floodplains, marshes, peatlands and lakes, help to increase rain infiltration and thus reduce peak river discharge (Javaheri and Babbar-Sebens , 2014) but also buffer low-flow events and thus water scarcity (Acreman and Holden, 2013), sustaining local livelihoods and providing essential natural resources.

Over the past few years, there seems to have been increasing interest in the opportunities presented by the ecosystem-based approach as a response to the increasing frequency of extreme disaster events (Renaud et al., 2013). Nevertheless, there is a need for better comprehension of how ecosystem-based approaches can be effectively implemented and governed across different spaces and scales to benefit human resilience against hazard impacts (Triyanti et al., 2017). Sebesvari et al. (2019) proposed that customising targets and indicators to countries' needs within the SFM (Sendai Framework of Disaster Risk Reduction) (Figure 3) might be a more practical way to report on both losses and progress.

***Figure** 3. Indicators on green infrastructure and ecosystems in the Sendai Framework. **Source**: Sebesvari et al., 2019.*



7 Case study 1: damaged ecosystem services at increased risk in a floodplain

How far can we stretch our ecosystems? Here we present a long-term study, hardly feasible under real-life conditions in Europe, of a worst-case scenario in a mining industry with high risks, where everything that could have prevented a disaster failed. We show that in the long run our ecosystem can be unexpectedly highly resilient and adaptive, but, if human negligence is combined with the effects of climate change, further disasters are inevitable.

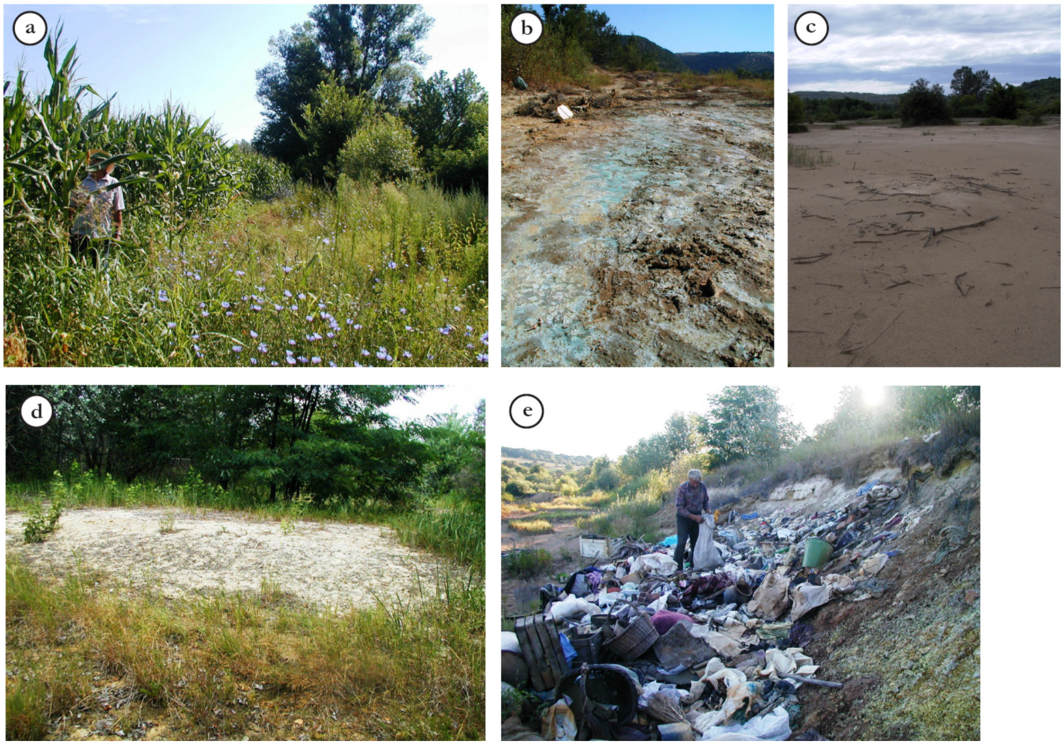
Risks intrinsic to copper (Cu) extraction are high even when the best available practices are followed. Cu mining generates more waste (solid and liquid) than that of any other metal (Dudka and Adriano, 1997); tailing dams (containing toxic slurry after ore processing) have a failure risk more than two orders of magnitude higher than that of conventional water dams (ICOLD, 2001); finally, if the ore contains sulphides, which are prone to oxidation to sulphuric acid when exposed to the air, the combination of metal toxicity, acidification and nutrient deficiency in affected soils becomes a very serious obstacle to restoration (Bradshaw, 1997). The RTB Bor mining complex in eastern Serbia, which exploits one of the largest sulphidic copper deposits in Europe, has had the reputation of an infamous regional environmental hotspot for the last 100 years.

Negligence gradually turned all these risks into an enormous disaster when RTB Bor, back in the early 1940s, ignoring all the legal and ethical issues, began to release the untreated, highly sulphidic Cu tailings into the local river system, estimated at 22 million m3 annually (Wolkersdorfer and Bowel, 2005). Unprecedentedly in Europe, this discharge of pollution went on for about 50 years (Nikolic and Nikolic, 2012). The provision services in the Timok floodplain (a former major granary of this part of Serbia, spread along about 40 km of the meandering river (Figure 4), till the confluence with the Danube) are permanently lost for agriculture and timber production (Nikolic et al., 2011; Nikolic and Nikolic, 2012). The pollution has also affected neighbouring Bulgaria and Romania.

The public has remained silent. Although the operations of RTB Bor provoked the first successful environmental uprising in Europe as early as 1935 (see Nikolic, 2014), this problem remained virtually invisible during the period of the state-controlled economy, when industrialisation was set as an absolute priority; the issue of soil productivity loss for local farmers was ignored. Neither have the intermittent political tensions with Bulgaria and Romania over this pollution issue (UNECE, 2003; Peck, 2004; Stuhlberg et al., 2010) prompted any land reclamation efforts.

Most of the deposited toxic sediments have so far, due to particular geomorphic processes, remained in this floodplain; our very conservative estimates are based on at least 300000 tons of Cu per ha (to a profile depth of 50 cm), highly prone to the risk of oxidative weathering and further Cu release into the environment. If left without vegetation, for instance, 10–35 tons per ha of Cu can be leached down the soil profile in a couple of decades, with pH lowered by 4 (Nikolic et al., 2016, 2018). The persistence of dense vegetative cover is an absolute necessity for the build-up of soil organic carbon (SOC) and the phytostabilisation of Cu (Mendez and Maier, 2008), i.e. for the immobilisation of Cu by plant roots and their metabolites, which thus keep it at bay. The process of spontaneous revegetation is extremely dependent on free floods, in terms of both water supply and nutrient fluxes (Nikolic et al., 2018). Unluckily, in the period immediately after the mine closure (early 1990s), critical for the revegetation onset, climate change accelerated: the affected floodplain received up to 45 % less precipitation, and the temperature increased five times faster, than when the tailings were leaking and pollution was being deposited (Popović et al., 2006). Concomitantly, floods are considerably decreasing.

Figure 4. *Fertile floodplain fields (a) have been destroyed by long-term deposition of mining effluents: Cu toxicity (b) and extreme nutrient deficiency (c) turned them into wastelands (e). Spontaneous restoration fails (d) when, due to increasing droughts, floods cannot reach the area any more. Photos were taken 20–50 km downstream from the leaking tailing ponds.* ***Source****: © Nikolic.*



Currently, 30 years after cessation of pollution influx, more than 10 000 ha is still barren, while a far larger area is covered with three discernible types of spontaneous forest vegetation with practically no economic value. They have a well-defined spatial pattern, very different species composition and structure parameters, and markedly distinct potential for the delivery of the major regulating and maintenance service of Cu stabilisation and SOC build-up. Lowland poplar forests (natural vegetation of this riparian area) are re-establishing themselves at the lowest pollution levels (farthest from the river channel). These are the oldest, densest formations, with the highest retention of Cu in soils (nowadays over 200 parts per million plant-available fraction), the highest SOC levels and the highest plant species diversity, but they cannot spread to the most polluted areas. There, the imposed abiotic stresses pass the resilience thresholds of the natural ecosystem, and only a novel, sparse and depauperate birch and aspen forest, very atypical of the region and limited to the proximity of river channels, eventually appears (Nikolic et al., 2016). Some of the underpinning natural processes of such 'novel ecosystems' (Hobbs et al., 2009) are functional adaptations to low pH and soil phosphorus, and other mineral stresses (Nikolic et al., 2014). The development of a third forest type (the slow-growing, xerothermic black locust and Hungarian oak communities) is solely a consequence of the increased drought incidence and decreased reach of floodwaters. These forests have about 50 % less area of trunks per ha, and about 30 % less potential to sequester organic carbon in soils, than the birch and aspen forests growing on the most polluted and degraded soils (Nikolic et al., 2018, 2019).

To summarise the cascading sequence of events: risky metal-mining operations lead to a disastrous loss of production service of polluted floodplain agricultural land; the public is not informed and remains silent; no restoration is undertaken; nature tries to recover and keeps the metals immobilised by spontaneous regreening; climate change has adverse effects; now even regulating and maintenance services are declining; and the area is again at high risk of further spreading of metal.

Lessons learned

Public awareness of environmental issues and a thorough understanding of the complex and occasionally rather unexpected adaptive responses of nature are crucial for risk mitigation. For example, if all the provision services of a former agroecosystem are lost as a result of a pollution disaster, the ecologically fragile, spontaneously establishing forest vegetation with little economic value still performs the key regulating service of metal immobilisation and soil carbon sequestration. However, accelerating climate change and increasing droughts in this floodplain are severely modifying the course of the spontaneous restoration process, and hence jeopardising the delivery of this essential ecosystem service, exacerbating the risks of pollutant mobilisation and extended damage to adjacent ecosystems.

8 Case study 2: the 2014–2016 South Africa droughts

Southern Africa was affected by a prolonged drought from 2014 to 2016, which was the worst in 23 years and had serious impacts on people's livelihoods, assets, the economy and the environment. The low rainfall was exacerbated by the strongest El Niño weather pattern for 50 years, which affected the whole Southern African Development Community region during the southern winter of 2014/2015. The disastrous effects of this drought event led South Africa to declare a national state of disaster. However, KwaZulu-Natal, North West, Free State and Western Cape were the worst affected provinces, with the sectors of agriculture, tourism, rangeland and water supply hit hard. South Africa is ranked as the 30th driest country in the world and is considered a water-scarce country.

Taking into account climate change and population development predictions, South Africa's water demand may outstrip water supply by 2025 (National Treasury of the Republic of South Africa, 2012) (Hippo, 2016). The average annual rainfall amounts to 492 mm, having a decreasing gradient from west to east, while the temperature and evaporation increase from west to east (Rijsberman, 2006; Unesco, 2006; Rand Water, 2017). The South African Weather Services has over the years observed a decreasing trend in rainfall and an increasing trend in temperature, resulting in changes in evaporation, relative and specific humidity, and soil moisture. Most of these changes are associated with the effects of climate change, made more visible by frequent droughts and extreme rainfall events since the 1950s (Cisneros et al., 2014). Besides being a water-scarce country, South Africa loses between 37 % and 42 % of municipal freshwater owing to human factors such as leakage, wastage, illegal abstraction, pollution and poor water management (South African Government, 2015). Water pollution, for example, creates functional water scarcity even in countries with abundance of freshwater supply (Frauendorfer and Liemberger, 2010; Mckenzie et al., 2012; Musingafi and Tom, 2014).

The 2014–2016 drought in South Africa severely affected the water sector. Reservoir levels dropped from 70 % of full capacity in 2015 to 40 % in January 2016 (Piesse, 2016). Agricultural production was severely affected and dropped by more than 20 %. Maize production decreased from 14.3 million tons in 2014 to 7.2 million tons in 2016, and sugar cane production reportedly fell by about 33 % (Piesse, 2016). The planting surface for potatoes and onion reduced by about 10 000 ha and, in many areas, planting periods had to be delayed by more than 2 months (Piesse, 2017). The tourism and energy sectors were not spared; electricity interruptions occurred (load shedding), businesses (especially small businesses such as car washes) closed down and the general environment suffered (rangeland conditions were very dry. The agricultural sector employs about 800 000 workers; in the commercial agriculture sector an estimated 30 000 jobs were lost in Western Cape Province alone. Municipal revenue from water fell considerably as, for example, the agricultural sector, which is the highest consumer of water, had to cut water use by about 60 %. For the Western Cape Province, losses on the province's gross value added due to the 2014–2016 drought were estimated to add up to ZAR 5.9 billion, which is approximately EUR 95 billion. This represented 20 % of the Western Cape provincial production decline.

The response applied consisted of four actions: water restrictions, water supply, supply of animal feed and renovation works.

- Water restrictions. Some individuals responded by storing water using rainwater collection tanks, and most municipalities instituted water restriction measures such as valve management and lowered water pressure to control the use of water, and restricted water use to certain periods and for certain users only. Severe punitive measures were put in place for those who violated water restrictions. The city of Cape Town tried to desalinate seawater using reverse osmosis techniques but this proved very expensive, so an alternative option of inter-basin water transfer was contemplated.
- Water supply. Following the declaration of the state of drought disaster by the South Africa National Disaster Management Authority, government departments adopted extraordinary measures. The Department of Water Affairs and Sanitation supplied many cities, towns and rural areas with water tankers. Non-governmental organisations such as the Gift of the Giver also came in with water tankers and bottled water, to help mitigate the drought impacts on vulnerable communities.
- Supply of animal feed. Farmers were assisted with animal feed, first by the Department of Agriculture, Forestry and Fisheries (DAFF) and later by donors. Most farmers did not have enough fodder to last them through the drought, and the prolonged drought made assistance to the farmers from DAFF unsustainable. Supplies came in late and some farmers had already lost stock. In most cases, the response activities were not properly coordinated. A long and uncoordinated supply chain was also a problem. For example, at one point, potatoes imported from Ireland were brought in from Cape Town to feed cattle in the Free State, whereas local supplies could have been bought, which would have been cheaper and faster.
- Renovation of old boreholes and drilling of new boreholes. DAFF tried to renovate many boreholes and drilled new boreholes in farming areas, especially in the Free State and Limpopo provinces. The danger of this response strategy was that no feasibility studies were made to ascertain the quantity and quality of the groundwater in most areas where these boreholes were drilled.

Lessons learned.

The comprehensive impacts of the 2014–2016 drought disaster in South Africa have not ended, since some response strategies are still being implemented more than 2 years down the line. However, some key lessons should be learned from the 2014–2016 drought disaster. (1) Issuing, understanding and acting upon early warning systems are crucial. (2) Drought preparedness and response plans are needed at municipal level. (3) Drought disasters require extensive national coordination. (4) Constant monitoring and rehabilitation of water sources and watercourses, including wetlands, are needed and were missing. (5) Provinces need to undertake a scientific drought risk assessment. (6) Sustainable use of water, energy and other natural resources is not negotiable. Most of these lessons also apply to the European context, especially to areas with high water use for agricultural use or areas where soils are drained to enable access for heavy equipment. During droughts such practices become very counterproductive and regional authorities mostly lack insight into the extent of these practices, so during a disaster they are surprised at the extent of the impact.

9 Lessons learned about the role ecosystem services play in disaster risk reduction

The risk of applying short-term economic thinking to ecosystem services exists, and this misperception could lead to undervaluing any single ecosystem service. Only a valuation that captures the large-scale, long-term benefits to society is likely to provide the correct incentive to reduce degradation. We know from the literature that there is a network of interconnection among ecosystem services at different scales. Ecosystem services present mutual interdependencies, diversity and underlying complexity of ecological processes (Barnaud et al., 2018), which complicate a comprehensive framework for ecosystem management. Bearing in mind this complexity, we therefore list in the following subsections a series of incentives for four groups of users of the ecosystem services, which can help them to be more patient with and respectful of the offerings of nature. Besides the various groups of users (policymakers, economic actors, households and civil protection) we address legal instruments, avoiding vague terms such as 'stakeholders'.

9.1 Long term incentives for policymakers

European laws require international collaboration and enforcement. In order to create incentives in the political system, guardians of the long-term interest are to be empowered, both judges enforcing the law and constitution as well as citizens who are not constrained by short-term interest groups. Member States need to keep working on sharing data on successful initiatives in nature-based solutions.

Policymakers, provided they are backed up by a functioning democratic state, have an incentive to satisfy their voters within terms of 4 to 5 years. Most of the time, politicians are organised in interest groups and political parties, aiming at longer time spans, even up to the length of a professional career. Therefore, policymakers have a long-term interest in keeping their party in power and in their personal career. If the voters are not concerned about the environment, which can be the case for many reasons, ranging from ignorance to selfishness or political motivation to counteract state influence, then the politicians elected by these voters will have no incentive to protect the environment.

Some authors (Van Reybrouck, 2016) propose introducing into the decision-making process citizens selected randomly and therefore not representing a specific interest group. Administrators with long-term experience to make up for the limited knowledge of randomly appointed temporary officials can support such citizens selected by partitioning. Thus they can play a role in safeguarding the long-term interests of society. The challenge of the 21st century is to develop economic, social, and governance systems capable of ending poverty and achieving sustainable levels of population and consumption while securing the life support systems underpinning current and future human well-being. Essential to meeting this challenge is the incorporation of natural capital and the ecosystem services it provides into decision-making (Guerry et al., 2015), and these efforts need to be shared and upscaled among Member States.

9.2 Long-term incentives for economic actors

Reputation is probably the main driver for economic actors to make sure that ecosystem services function well. Other profit drivers, such as the product's price and the variable and fixed costs, remain limited to the economic domain. Companies that do not deliver directly to the consumers have therefore few motives to take care of the environment. Labelling might help, as might a universal legal obligation to enhance the resilience of (socio)ecological systems within a reasonable time.

Economic actors such as industries, fishers or farmers act in competition with each other. The lowest possible price for their products is their main way of dominating the market. As well as the lowest price, the reputation of the company and the quality of the product also play roles, and environmental protection incentives can be found in these areas. For extractive industries, such as mining, drilling or timber-producing companies, the incentives of reputation and product quality are of less importance, since these companies tend to create products not sold to the consumer market. Working behind the scenes, their main incentives are shareholder value and market dominance due to low pricing and delivery guarantees.

The current economic model cannot provide appropriate incentives to protect ecosystem services from the extractive behaviour of these types of economic activities. Therefore, as long as the political model, as mentioned before, does not create explicit incentives to contain the expansive behaviour of economic actors, utmost care must be taken with regard to their proposals. Before mining companies are allowed to extract material from the subsoil, a landscape repair fund must be set up into which a fixed percentage of the profit should be transferred. Such funds must be free of links to the company in order to avoid the fund being tapped if the company goes bankrupt. Disaster repair funds can also be set up for oil extraction and chemical factories, which can potentially lead to disasters that damage ecosystem services, quite apart from loss of life. The latter is often dealt with by legislation whereas damage to the ecosystem services is not.

Responsibilities in the economic value chain, in which many providers together create one final product, should be made more explicit. This can be done by labelling the full origin of a product using understandable, not legalistic, language. Such labelling, and especially its certification, comes at a cost, however. The 'commons' such as – air, fresh water, soil, subsoil, landscapes and sea with its seafood – lack a clear price and custodian in our economic model. If they are damaged or altered, no consequences are faced by the party that caused the reduction in the functioning of the Ecosystem Services (ES). In order to make a level playing field, economic actors need internationally enforced rules allowing their expenses in taking care of the commons to be comparable.

Probably the best example of functioning policies protecting a part of the commons is the various freshwater regulations, in which industry is allowed to extract water provided it is delivered back to the river with the same composition and at the same temperature. For the commons with an unbounded geographical scope, such as the sea and the air, such policies are lacking or have been only partly successful up to now. Often pricing is proposed, such as CO2 pricing. The pricing can, however, only be successful if the acquired funds are used to restore the composition of the air to its initial state. Otherwise, altering the composition of the atmosphere becomes a privilege for the more prosperous economic parties, leading to further exacerbation of an already unequal economic playing field.

The use of nature-based solutions for adapting to climate change is justified by their multiple benefits, and one of the reported benefits is their cost-effectiveness compared with alternative solutions (Kabisch et al., 2016). However, there have been very few systematic assessments of the economic benefits and costs of nature-based solutions, only since 2014 studies started to inventory the projects done to date (Doswald et al., 2014). In assessing the benefits and costs of ecosystem services, social and environmental costs and benefits have been more systematically assessed than economic ones. According to Doswald et al. (2014), the majority of published economic efficiency evaluations assess the economic costs and benefits at a rather general level. In the majority of reported cases, the net present value of a nature-based solution is positive when considering social, environmental and economic benefits. Projects such as NAIAD (see Section 1 above) seem to be good initiatives to assess the insurance value of nature-based solutions to prevent disasters, especially flooding and drought risk.

The economic benefits of nature-based adaptation are avoidable damage costs, especially from extreme weather phenomena; new or improved business opportunities; savings compared with alternative adaptation solutions; and a better quality of life. Costs have been calculated including setting up and maintaining the nature-based solutions (or ecosystems), as well as opportunity costs (i.e. accounting for what else could have been done with the same investment) (Doswald et al., 2014). Systematic cost–benefit analyses and reporting of results are important for increasing the interest, and thereby investment, in nature-based solutions for disaster risk management and climate change adaptation, and for increasing the use of long-term funding and public–private partnerships in the set-up and maintenance of them (Kabisch et al., 2016).

Economic actors such as industries, fishermen or farmers act in competition with each other in which the lowest possible price for their products is main incentive to dominate the market. In the competition for the lowest price, also the reputation of the company and quality of the product play a role and environmental protection incentives can be found in this area. For extractive industries, such as mining, drilling or timber-producing companies the incentives on reputation and product quality are of less importance since these companies tend to create products not sold at the consumer market. Working behind the scenes their main incentive is shareholder value and market dominance due to low pricing and delivery guarantees.

The current economic model cannot provide appropriate incentives to protect ecosystem services from extractive behaviour of these types of economic activities. Therefore, as long as the political model as mentioned before does not create explicit incentives to contain expansive behaviour of “economical actors behind the scenes”, utmost care must be taken with regard to their proposals. Before mining companies are allowed to extract material from the subsoil a “landscape repair fund” must be instantiated into which a fixed percentage of the profit should be transferred, such funds must be free of links to the company in order to avoid the fund to be ripped when the company goes bankrupt. Disaster repair funds can also be instantiated for oil extraction activities and chemical factory activities, potentially leading to disasters that damage ecosystem services apart from loss of life. The latter often taken care of by legislation whilst damage to the ecosystem services is not taken care of.

Responsibilities in the economic value chain, in which many providers together create one final product, should be made more explicit. This can be done by labelling the full origin of a product using understandable, not legalistic, language. Such labelling, and especially its certification, comes however with a cost. The earlier mentioned “commons”; air, fresh water, soil, subsoil, landscapes, and sea with its seafood lack a clear price and custodian in our economic model. If damaged or altered no consequences are faced by the party that caused the reduction on the functioning of the ES. In order to make a level playground, economic actors need international enforced rules allowing having comparable expenses in taking care of the “commons”. With various freshwater regulations, in which industry is allowed to extract water, provided it is delivered back with the same composition and temperature to the river, is probably the best example of functioning policies protecting a part of the commons.

For the commons with an unbounded geographical scope such as the sea and the air, such policies are lacking or only partial successful up to now. Often pricing is proposed, such as CO2 pricing. The pricing can however only be successful if the acquired funds are used to restore the composition of the air to its initial state. Elsewise altering the composition of the atmosphere becomes a privilege for the more prosperous economical parties leading to further exacerbation of an already unequal economic playground.

The use of nature-based solutions for adapting to climate change is justified by their multiple benefits, and one of the reported benefits is their cost-effectiveness compared to alternative solutions (European Commission 2015; Kabisch, et al., 2016). However, there have been very few systematic assessments of the economic benefits and costs of nature-based solutions (Doswald et al., 2014; Kabisch, et al., 2016). In assessing the benefits and costs of ecosystem services, social and environmental costs and benefits have been more systematically assessed than economic. According to Doswald et al. (2014), the majority of published economic efficiency evaluations assess the economic costs and benefits at a rather general level. In the majority of reported cases, the net present value of a nature-based solution is positive when considering social, environmental and economic benefits. The economic benefits of climate change adaptation are avoidable damage costs, especially from extreme weather phenomena, new or improved business opportunities, savings compared to alternative adaptation solutions and income from subsidies. Costs have been calculated from setting up and maintaining the nature-based solutions (or ecosystems), as well as from opportunity costs (i.e. also accounting for what else could have been done with the same investment) (Doswald et al., 2014). Systematic cost-benefit analyses and reporting of results are important for increasing the interest, and thereby investment, toward nature-based solutions for disaster risk management and climate change adaptation, and for increasing the use of long-term funding and public-private partnerships in the setup and maintenance (Kabisch, et al., 2016).

9.3 Long-term incentives for households

In DRR, households play a marginal role if we focus on their impact. However, in households, new ideas are tried out and motivation can be shared with household members or neighbourhoods.

Actions for households to take with respect to DRR and ecosystem-based solutions can be confusing. To keep a house cool during heatwaves, it might be advised to plant trees close to the house to provide shade, while a wildfire protection scheme might urge that all trees close to the house should be cut down. Besides the confusing message, neither measure, if taken in isolation by only one household, will have a significant impact on the exposure to either disaster. The latter obstacle – the fact that the work of one family in isolation has no significant impact – can be demotivational, leading to inactivity on even minor aspects of environmental awareness such as separating litter or maintaining a green garden.

It is therefore important to give individual citizens the tools to make an impact on DRR and ecosystem services. The most obvious measure is to involve citizens at the level of a neighbourhood in the planting of trees and the design of green spaces in their immediate living and working environment. Such actions will lead to better knowledge of the immediate environment, which can be essential during the onset of a disaster. Apart from that, if people are involved in decision-making they will feel responsible for the well-being of the ES, leading them to give assistance during, for example, a period of drought. Recent studies such as that of Santoro et al. (2019) have demonstrated that, in flood risk management, approaches based on physical phenomena are not enough and they should be integrated with household actions. To that end, facilitating a dialogue to reconcile differences of opinion and promote the social acceptance of nature-based solutions is essential.

9.4 Incentives for civil protection

Civil protection agencies have to choose between contradictory measures, alleviating different disasters by choosing the most appropriate measure. Their way of working can ideally lead to localised advice, thanks to their knowledge of the area, to be complemented with scientific knowledge on the complex functioning of ecosystems.

Civil protection agencies have hitherto focused on the aftermath of a disaster; they work to be on the right spot as quickly as possible with the right aid workers.

Preparations beforehand are limited to preparation of supplies and evacuation routes. Incentives for civil protection agencies are straightforward: once the risk of disasters caused by extreme weather events or industrial activities with potential hazardous impacts on ecosystem services is reduced, they can allocate more funds to other protection measures, ranging from cybersecurity to preventing disasters related to criminal behaviour. With limited funding and a wide range of potential disasters, they always benefit from reduced exposure.

Legislation for compensating an EU Member State after a disaster has taken place is linked to measures being taken to reduce the risk of repetition of the same disaster. Civil protection agencies are probably the best organisations to assess locally how far measures taken are beneficial to DRR.

The main problem for civil protection agencies and the way they work in relation to ES and DRR is that DRR by enhancing or restoring ecosystem services will yield softer figures on quantitative risk. For grey solutions, such as dykes, an engineering company can give a hard number of how many times in 1 000 years the dyke will be flooded. For a river allowed to meander again, such figures are absent; the river is to a certain extent even expected to flood the area.

Furthermore, measures related to ES and DRR can be contradictory. The example of heatwaves, wildfires and tree planting, above, is clearly contradictory. The recently introduced policy in Portugal to clear trees up to 4 m from the road, in order to preserve an escape route during wildfires, is similar. The cleared area next to the road will regrow with dry grasses that catch fire much more easily than a tall tree trunk with no under-storey. Roads and trees are anyway part of a complex debate in which a tree is considered an impact risk but it is also known that car drivers slow down on a road with trees compared with a road lying in an open landscape, thus reducing the impact risk themselves.

For civil protection authorities it is therefore of the utmost importance to acquire knowledge of the landscape of the area to protect so that all measures can be compared for their local impact. Civil protection exercises should include an ES component, improving the knowledge of ES in the area and potential losses associated with hazards. Projects such as RECONECT could be used as examples (see Section 1).

9.5 Legal instruments to protect ecosystem services

The long-term sustainability of ecosystem services depends not entirely on the extensive EU environmental laws available but also on the Member States' capacity to adapt and mitigate natural and human-made disasters.

Humans have degraded natural conditions and amplified environmental problems since the Palaeolithic era, and have faced repeated environmental crises since then, which can be divided into three categories: (1) those caused by purely natural conditions, (2) those caused or aggravated by human activity and (3) those arising from increasing human demand for sources of energy (Bentley, 2013). The capacity of an ecosystem to cope with a disaster (human-made or natural) is limited. There is a degradation threshold that, when passed, the system cannot recover from; subsequently it threatens the stability of the society, which can no longer benefit from the ecosystem services. A well-known historical example is the Easter Islanders who cut down the last tree, and rats (an invasive species) ate the trees' seeds before they could regerminate.

The main ecosystem service of the trees on the island was the provision of wood to build canoes. Once the wood was run out, the population was trapped on the island without access to fishing. The ecological catastrophe triggered civil war and social collapse.

How can we make the ecosystem work with us and not against us? As stated in Section 6, well-managed ecosystems and restoration efforts can avoid ecosystem collapse and can support various dimensions of disaster risk management. Regulations and legislation tools need to be designed to avoid risk to the population or the environment. Subsequently, the state has to enforce such regulations, a task often blurred by changing priorities. Pressure groups such as Client Earth bring cases against authorities they consider not bold enough in protecting the long-term interests of society, while using the legislation created by the state.

An exhaustive list of the EU's legal tools (directives, regulations, decisions) addressing ecosystem degradation would be out of the scope of this book, but some of them are listed here: the Water Framework Directive, the habitats and birds directives, the Environmental Impact Assessment Directive, the Strategic Environmental Assessment Directive, the seventh environmental action programme and the resource efficiency roadmap. Further non-binding strategies have been agreed on, such as the biodiversity strategy, the forest strategy and the adaptation strategy.

The Institute for European Environmental Policy estimates that the body of EU environmental law amounts to well over 500 directives, regulations and decisions. Nevertheless, the Earth's condition in Europe and worldwide has continued to deteriorate since 1997 (UN Environment, 2019). Without changes, the situation looks bleak for all of its inhabitants; we are talking about a global issue of catastrophic dimensions. It is partly in our nature to react to an event instead of working on preparation and mitigation.

For example, metal mining, in particular, results in waste (tailings) that may contain dangerous chemicals and heavy metals, which need to be stored safely in heaps or ponds behind retention dams. The subsequent collapse of such tailings dams, e.g. in Baia Mare, Romania, in 2000 (European Commission, 2000; UNEP and OCHA, 2000) or in Aznalcóllar, Spain, in 1998 (Hudson-Edwards et al., 2003), and the resulting environmental and socioeconomic consequences have led to the adoption or amendment of EU legislation to ensure the safe management of mining waste.

Part of this post-event legislative reaction was the Extractive Waste Directive (EU, 2006), which complements the Seveso Directive on the control of major accident hazards (EU, 2012). In addition to these legal instruments, the Environmental Liability Directive (EU, 2004) provides a cross-cutting framework for the protection of environmental assets. It is aimed at the implementation of the polluter-pays principle, whereby a company causing environmental damage is liable and has to take preventive or remedial action and bear all associated costs.

10 Conclusions and key messages

We offer the reader a wrap-up of the main concepts, facts and conclusions extracted from the literature search conducted for this subchapter on ecosystem services relation to DRR, climate change adaptation and reversing land degradation. Meanwhile, we highlight key messages and lessons learned for scientists, decision-makers, practitioners and citizens. We address each societal actor separately; however, human behavioural problems related to the environment require well-organised sectoral cooperation. To pursue that, it is essential to integrate knowledge of ecology, restoration and nature-based solutions into disaster-planning policies, to promote cross-border management and long-term monitoring programmes in which climate change scenarios should be included.

The general messages of the subchapter are:

- The scientific literature supports the view that there is a relation between vulnerability to disasters and ecosystem service degradation. Human activities will be able to reduce the impact and risk of natural disasters if they look for a more integrative, long-term and upscaling approach that brings nature closer to land use planning for DRR. Human activities such as urbanisation, intensive cropping and grazing animals, deforestation or intensive forest management accelerate land degradation and reduce the capmore effectacity of ecosystems to deliver precious services.

- Locating ecosystem functioning in the centre of decision-making, as done by the ecosystem service approach, could assist the decision-making process and ecosystem-based management strategies (Elliff and Kikuchi, 2015).

- Nature-based solutions have been proven a cost-effective tool to prevent and mitigate extreme natural events, thanks to their role in enhancing ecosystem services. However, the real cost of this type of disasters to ecosystem services is much higher than the current assessment predicts. So far, additional efforts have been made, and valuation techniques employed in natural capital accounting could help if they comply with traditional economic accounting to allow consistent integration and analysis with SNA economic accounts.

- It is urgent to work on prevention, not only on reaction. Regulations and legislation tools need to be designed to avoid risk to the population or the environment. Subsequently, the state has to enforce such regulations, a task often blurred by changing priorities in Europe.

- A disaster could trigger long-term effects on ecosystem services that are already damaged or under pressure. Provisioning, cultural and regulating ecosystem services can be substantially affected by disasters. For example, the cooling effect of a forest can be lowered by a pest or during a drought. At the same time, regulating ecosystem services can mitigate disasters as well. During a drought, a forest will hold much more groundwater than adjacent areas without forest cover, providing a higher groundwater table. Human activities such as urbanisation, intensive cropping and grazing animals, deforestation or intensive forest management accelerate land degradation and reduce the capacity of ecosystems to deliver precious services. It can be assumed that damage costs of disasters are higher in the absence of the mitigating functions of ecosystems. Economic impacts of disasters and climate change on ecosystem services have so far been only partially captured. Additional attempts are being made to create a full overview of the economic value of ecosystem services and to understand the economic costs of hazards on ecosystem services.

In addition to this, we can extract the following lessons for specific audiences.

Policymakers

It seems that most legislation is based on post-event reaction and adaptation. Instead, policy frameworks would do better to focus on prevention, thus avoiding the loss of valuable ecosystem services. Following the prevention approach, policy-makers should support nature-based solutions and implement them at a larger scale that contributes to hazard prevention. Meanwhile, reducing grey solutions and substituting them with green infrastructure, when possible, will help prevention and mitigate hazards (e.g. to impact lessening the effect of flooding in urban areas, to preparing large-scale reforestation projects, restore natural grasslands, restore water retention in agro-ecosystems, tree planting in areas suffering recurrent droughts). Policy-makers should promote transboundary agreements between neighbouring countries leading to the implementation of ecosystem-based solutions at a larger scale. Policymakers in the meantime need to learn how to communicate the often complex messages based on scientific findings. To address the degradation of ecosystem services and its consequences, in an effective manner, it would be best for governments to support activities with low impact on biodiversity. Essential to meeting this challenge is the incorporation of natural capital and the ecosystem services it provides into decision-making (Guerry et al., 2015), and these efforts need to be shared and scaled up significantly.

Practitioners

Practitioners are interested in acquiring more knowledge of implementation, monitoring and successful examples of nature-based solutions across Europe. However, there is a shortage of information about successful projects for the non-scientific or non-English-reading community. Civil protection practitioners should receive education and training taking into account knowledge of ecosystem services. One of the main limitations civil protection will need to deal with is that some impacts on ecosystem services are intangible, but still important, and practitioners will require training, learning networks and information sharing to implement a (site-specific) matrix to prioritise the ecosystem services under risk. In order to achieve that, it is essential to build transdisciplinary collaboration between scientists and civil protection practitioners. Guidelines based on successful local cases of nature-based solutions to improve disaster risk management, mitigation and adaptation could be used to overcome limitations and might become possible examples allowing to scale up in other regions. They would therefore remove the onus from policymakers to decide exactly when and where these interventions might be appropriate while keeping irresponsible projects from taking place. Further studies are needed to investigate and quantify the reduction of maintenance cost of nature-based solutions compared to classical grey solutions, and that practitioners should be involved in these cost assessment studies. Private-sector capital can be incentivised to scale up landscape restoration initiatives. To that end, it is essential to have a business plan template derived from successful case studies, making it easier for financiers to step in and contribute to scaling up nature-based solutions and restoration actions.

Scientists

Climate change, but also rural abandonment, among other processes, are game-changers for ecosystem services; nature-based solutions can help divert impacts and shocks, although more research is needed to monitor long-term effects. Climate change scenarios need to understand local ecosystems to anticipate risk and to protect the ecosystem services. We know that damaged ecosystems, especially humid ones such as wetlands, can be restored and, after a while, a reduction in the risk of disaster can be measurable. Ecosystems damaged in dry conditions can be restored as well, but substantially longer times are needed, often greater than the life span of a human being. Understanding how key functions determine ecosystem service supplies and how they depend on and foster biodiversity is crucial in the search for local nature-based solutions. The scientific community should keep on promoting innovation and improving science communication and disseminate the latest scientific findings. Researchers generate information that is often context-specific and hedged in language that prevents the application of their findings and recommendations. Meanwhile, scientists should also ensure that models are tested and replicable under different ecosystem management regimes, across various climatic regions and in different socioeconomic contexts.

Citizens

People are interested in getting informed about the important role ecosystems play in DRR, prevention and mitigation capacity, but they also want to better appreciate the impact of climate change on their environment and livelihoods. Citizen science initiatives using social media could promote collection of data about the impact of hazards on the daily lives of citizens. Citizens play a vital role in implementing nature-based solutions, and it has been widely recognised that the effort of citizens is far more effective if done collectively. Therefore, citizens should find a way to engage with others and to actively participate in decision-making.

We identified shortcomings in the awareness with the named key players in society (scientists, citizens, decision-makers and practitioners) and their perception of the importance of ecosystem services in DRR. We hypothesise that this could be due to a lack of knowledge on the mechanism behind ecosystem services affected by disasters. Furthermore, ecosystem services are often delivered free of cost, leading to a first-come, first-served approach, promoting non-collaboration between societal actors. It is the task of the legislature to protect ecosystem services from this detrimental behaviour.

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