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Review

The superior effect of nature based solutions in land management for enhancing ecosystem services

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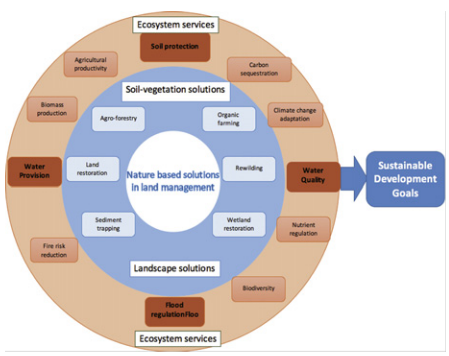
HIGHLIGHTS

- Nature based solutions (NBSs) should become mainstream land management strategies.
- NBSs are divided in soil-vegetation and landscape solutions.
- Soil-vegetation solutions are based on the concept of soil health.
- Landscape solutions are based on the concept of connectivity.
- NBSs can provide solutions for restoring ecosystem services.

GRAPHICAL ABSTRACT



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ABSTRACT

The rehabilitation and restoration of land is a key strategy to recover services -goods and resources- ecosystems offer to the humankind. This paper reviews key examples to understand the superior effect of nature based solutions to enhance the sustainability of catchment systems by promoting desirable soil and landscape functions. The use of concepts such as connectivity and the theory of system thinking framework allowed to review coastal and river management as a guide to evaluate other strategies to achieve sustainability. In land management NBSs are not mainstream management. Through a set of case studies: organic farming in Spain; rewilding in Slovenia; land restoration in Iceland, sediment trapping in Ethiopia and wetland construction in Sweden, we show the potential of Nature based solutions (NBSs) as a cost-effective long term solution for hydrological risks and land degradation. NBSs can be divided into two main groups of strategies: soil solutions and landscape solutions. Soil solutions aim to enhance the soil health and soil functions through which local eco-system services will be maintained or restored. Landscape solutions mainly focus on the concept of connectivity. Making the landscape less connected, facilitating less rainfall to be transformed into runoff and therefore reducing flood risk, increasing

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soil moisture and reducing droughts and soil erosion we can achieve the sustainability. The enhanced eco-system services directly feed into the realization of the Sustainable Development Goals of the United Nations.

Contents

1. Introduction

1.1. Nature-based solutions for a sustainable world

The Earth System has been affected by human abuse of resources, mismanagement of planning and land uses, and impacted by climate change induced alterations to the natural Earth System Cycles such as the water, carbon or nitrogen cycles, which is resulting in land degradation and Desertification (Vu et al., 2014; Tarrasón et al., 2016). Therefore, the UN has defined the Sustainable Development Goals (Griggs et al., 2013). Many of the 15 goals defined, have a strong link to land and water management (Keesstra et al., 2016a) and call for a sustainable use of resources, ecosystem restoration, biodiversity, carbon sequestration and sustainable catchment management. For these challenges a common solution can be found in rehabilitating ecosystems. For this, new holistic approaches are needed which are more time and cost effective and can tackle multiple problems efficiently (Favretto et al., 2016; Turner et al., 2016). However, each climate zone, each ecosystem, each bioma, each region calls for a tailor-made solution.

The rehabilitation and restoration of land-based ecosystems is a key strategy to recover services (goods and resources) ecosystems offer to the humankind (Galati et al., 2016). However, most restoration and rehabilitation projects are focused on artificial, man-made and high-maintenance strategies, which are costly and usually, not successful over a longer period of time, as they depend on external inputs of energy and money, in addition to human management and control (Miao et al., 2000; Ramos et al., 2007). Restoration and rehabilitation strategies that are based on natural processes and cycles are sustainable as they use natural flows of matter and energy, take advantage of local solutions and follow the seasonal and temporal changes of the ecosystems (Meli et al., 2014). Therefore, nature based solutions (NBSs) to restore and rehabilitate degraded ecosystem can be a sustainable and successful strategy (Temmerman et al., 2013; Laughlin, 2014; Nel et al., 2014).

For the successful implementation of NBSs a deep understanding of nature's functioning and processes is needed. By working together with the forces of nature well designed measures need less maintenance, are more cost effective, and if constructed in a good way, may even be more effective over a long time span because nature's forces increase the efficiency of the structure (e.g. build up of terrace like structures upslope from lines of vegetation, naturally meandering rivers, wetlands, resprouting species in wild fire effected areas) and the contribution to the sustainable economy and society of the region (Kabisch et al., 2016; Villegas-Palacio et al., 2016; Schaubroeck, 2017).

In this paper we aim to show the superior effect of nature based solutions to enhance the sustainability of catchment systems by promoting desirable soil and landscape functions. We first explain the concepts behind NBSs, the cascade of processes that occur when we work together with nature to manage land and water. We review how these processes interact with the functions of the soil, the flow of water, sediment and nutrients and the ecosystems that are part of the landscape. This will be illustrated by showing several case studies in which NBSs have proved their usefulness in real life examples from both the Mediterranean and northern European climatic zones. Each example will show the risk and which solution was applied to achieve success and will evaluate the management strategies from several sides: (i) the impact it has on the ecosystem; (ii) which physical processes are the foundation of the measure; and (iii) how the measure contributes to enhancing ecosystem services. Finally, we also aim to show policymakers and stakeholders the contribution of the scientific community to achieve sustainability through NBS.

2. Why is systems approach a good research framework?

The theory of system thinking forms the basis of the approaches that are the basis for the NBSs. System thinking has been defined as thinking in wholes rather than thinking only in the properties of individual elements and how they interact; understanding emergent behaviour of a system - as opposed to the reductionist approach (Forrester, 1994; Flood, 2010). Most natural systems behave in a system equilibrium way. This means the system has internal negative feedback loops that dominate the behaviour of the system and brings it back to the equilibrium state (Chorley and Kennedy, 1971; Hack, 1975; Ahnert, 1994; Heimsath et al., 1997). A second important background to understand a system is that natural systems are adapted to their environment. This environment consists of natural forces, such as climate, parent material, but also management.

To design effective NBSs and similar concepts in a proper way concepts like system thinking, and parallel ones such as connectivity, are useful tools to understand an predict how a system will behave in reaction to the implantation of a certain strategy. It may be useful to link the benefits of the strategies to ecosystem services as in done in ecology, where this more holistic way to approach research is mainstream, while in land management it is not (Machovina and Feeley, 2017; Steger et al., 2018).

The key in working with nature-based solutions is the dynamics of the system. The success lies in a deep understanding of the processes and feedbacks that determine the sediment and water fluxes in a landscape and how these fluxes interact with the existing landscape. The solutions available roughly fall apart in two main categories, the first category are solutions that are based on changes in the soil, enhancing the soil functions and with that the resilience the ecosystem has to external driver. These solutions have their fundamentals in the concept of soil health (Weil and Brady, 2016). The second category comprises of solutions that are based on changing the fluxes (water, sediment, nutrients, pollutants) in the landscape and is based in the concept of connectivity (Parsons et al., 2015).

3. Lessons from coastal and river research

The success of the role of nature-base solutions can have, is clearly shown in coastal research, where the concept of building with nature is fully accepted. In coastal defense projects using old style engineered structures have proven to be expensive and require continuous maintenance. Building with nature projects like the Zandmotor at the Dutch coast (van den Hoek et al., 2012; Stive et al., 2013) where a large volume of sand has been put just offshore in the sea close to De Hague to use the natural current along the coastline to transport and deposit sediment on the beaches and dunes to enforce the coastal defense. This project showed that the understanding of the system dynamics the forces of nature can be used, to defend the Dutch coast from erosion. The coastal managers have seen their efforts go to waste in one storm; urging them to rethink the strategies they were using, and finally adopt building with nature based strategies. They are low-cost in construction and maintenance.

Also managers of large rivers have adopted the building with nature concept. A good example of this, are the projects that were implemented after two large subsequent flooding events in Rhine-Meuse delta in the Netherlands. A project called 'Room for the River' (Wiering and Arts, 2006; Rijke et al., 2012) respects the water and sediment dynamics in the river, to allow the river to use a larger part of its former floodplain to mitigate flood risk. In the same time these projects have been used to make new green spaces in the floodplain areas which were formerly used for agriculture.

Then, coastal and river management are well advanced to use NBSs. However, in land management in agricultural and forest systems NBSs are not widely accepted, while similar success stories can be expected as in coastal and riverine systems (Nesshöver et al., 2017; Xing et al., 2017).

4. Case studies

With an array of case studies we want to show a few examples of opportunities for the NBSs implementation in different environmental conditions to show the superior use of the NBSs for land management and restoration. The case studies show how multiple ecosystem services can be enhanced by the NBS and mitigate hydrological risks and land degradation.

4.1. Organic farming changes the fate of agriculture land in Mediterranean orchards

Mediterranean type ecosystems are heavily affected by intense soil erosion processes due to high rainfall intensities, recurrent droughts, erodible parent materials and a long history of abuse of soil, water, and vegetation resources. In agriculture soils, erosion rates are extremely high due to the lack of vegetation cover, intense tillage, widespread use of herbicides and the soil compaction due to the heavy machinery used (López-Vicente et al., 2015; Taguas et al., 2015). Especially in new chemically treated citrus plantation and vineyards soil erosion rates are extremely high due to the sloping terrain, soil compaction and crust development as a consequence of the lack of vegetation (Rodrigo Comino et al., 2016c; Cerdà et al., 2017). The use of herbicides favours a landscape where the cover of vegetation is reduced to the crop, and the soil erodibility is high. To reduce soil and water losses in agriculture soils different strategies were used: mulches, geotextiles, cover crops, catch crops, chipped branches, no-tillage or terraces (Keesstra et al., 2016b; Prosdocimi et al., 2016a; Mandal et al., 2017).

However, all these solutions are not solving the problem as they do not achieve a global strategy to reduce the soil losses and improve the soil quality, and they use to be applied individually. Organic farming integrates some of the mentioned solutions to reduce soil erosion with the strategies to increase biodiversity, protect traditional cultivars and breeds and achieve sustainability from a biophysical and socio-economic point of view. The most applied strategies to reduce soil and water losses are the use of weeds, but also chipped branches, catch crops and mulches are applied, which can reduce the soil losses and improve soil functions like water holding capacity and infiltration capacity. These soil functions, in turn change the ecosystem services such as water retention and biodiversity increase. In addition, the landscape is more attractive for tourism and adds to the cultural heritage of these areas.

Organic farming, moreover, has shown a positive effect on ecosystem service via carbon sequestration (Fig. 1). The application of best management practices (cover crop, amendments, minimum tillage and mulches), which are the key elements of organic farming system, can contribute to reduce climate change due to the sequestration of CO_2 (Novara et al., 2016; Pereira et al., 2017). The soil organic carbon stock increase with organic farming application is related to the increase of carbon input into the soil through plant residues or cover crops, reduction of soil organic matter oxidation through minimum tillage, the use of organic fertilizers, stabilization of organic matter, soil structure improvement and reduction of soil carbon losses with eroded sediment (Fig. 1).

In a recent study in Mediterranean vineyards the application of best management practice using cover crops after 5 years raised of 14% the total soil organic carbon content in comparison to traditional soil management (García-Díaz et al., 2016; Kirchhoff et al., 2017). Such SOC increase was equivalent to 11.9 Mg CO_2 ha^{-1} sequestered in five years, which has an important impact on CO_2 mitigation if a catchment vineyard area is considered. Organic farming also controls the losses of organic carbon by reducing eroding organic rich soils and avoiding the decomposition of organic matter during sediment transport (Novara

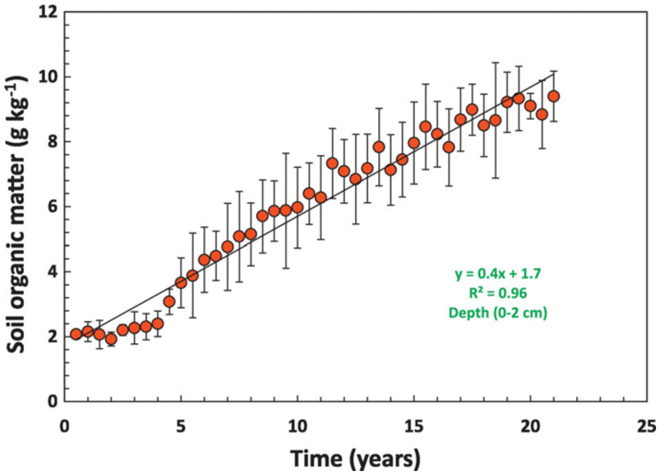

Fig. 1. Soil Organic Carbon (SOC) after the management during 22 years of AEM measure in citrus orchards in Eastern Spain. The soil surface layer is enriched with organic carbon.

et al., 2016). In this way organic farming can also contribute to initiatives like the "4 per mille" that are associated to the SDGs. This initiative is mend to counteract carbon emissions by promoting carbon sequestration in soils. This initiatives strives to increase the soil organic matter every year with 0.4% (4 pour 1000 initiative) which should be enough to achieve this goal (Muñoz-Rojas et al., 2015; Rhodes, 2016).

4.2. Rewilding in Slovenia

In many parts of the Mediterranean large scale land abandonment has taken place due to socio-economic changes causing small scale farmers to find their livelihood in different economic sectors such as industry and tourism (Petanidou et al., 2008). In the 1950 due to the political influence the Slovenian agricultural hinterland was left to reforest naturally. A 70 km^2 catchment in the west of Slovenia rewilded for about 70% of the catchment over a period of 30 to 50 years, which caused the catchment system to behave in a different way from a sediment and water connectivity point of view and has changed the soil properties and functions. The area is located in a humid Mediterranean climate which means around 800 mm of rain is received predominantly in autumn, winter and spring, with a dry summer, with occasional summer storms.

Rewilding has shown to have both soil as well as landscape benefits. A recent study in the area (van Hall et al., 2017) found that soil organic matter content, total nitrogen, bulk density and aggregate stability all improved in terms of the functions a soil can have. This clearly shows the benefits this nature based solution has on soil quality, which has a positive effect on soil biodiversity (Korthals et al., 2001), carbon sequestration (Knops and Tilman, 2000) and water holding capacity (Li and Shao, 2006). An important finding of this study was the fact that the benefits of rewilding were found to take effect in the first years after the land abandonment (5–10 y), in the time that the soil is covered with herbs and grasses and the forest is yet to be developed. The positive recovery of the vegetation after abandonment has been widely demonstrated, although sometimes there are contrasted responses (Romero-Díaz et al., 2017).

The landscape effect of this nature based solution was demonstrated by the studies of Keesstra et al. (2005, 2009). Flood risks have been reduced; erosion reduced by 90%, and runoff discharge as well (Fig. 2). But the forest cover seems to have had also a negative effect in the area. In the original agricultural system intensive storms caused flood events with high sediment loads, however, there was a certain baseflow in summer. In the reforested landscape the flood risks have been reduced, but, the river nowadays runs dry in summer due to the higher water demands of the forest cover. The famous sponge effect does not apply in these Mediterranean ecosystems due to the high evapotranspiration of the trees during the dry summers as was also found in the Pyrenees by García-Ruiz et al. (2005). Although the dry river beds in summer may be the natural state of the riverine system, the ecosystem services in the area may decline under this extensive rewilding. Therefore, a managed rewilding may be a better solution to come to a sustainable situation from multiple points of view, to come to a desirable state of the catchment system from a management point of view. When not the whole catchment area would be forested, but areas with low erosion risk are transformed in extensively managed grass land, this would have multiple benefits: (i) better water resource management over the year, no floods and still sufficient base flow; (ii) higher biodiversity, especially endangered bird species in grass land areas; (iii) eco-tourism, summer activities in the area are more attractive in a riverine system that has running water in summer; (iv) agro-tourism, extensively or organically run farms can attract day tourists to their properties.

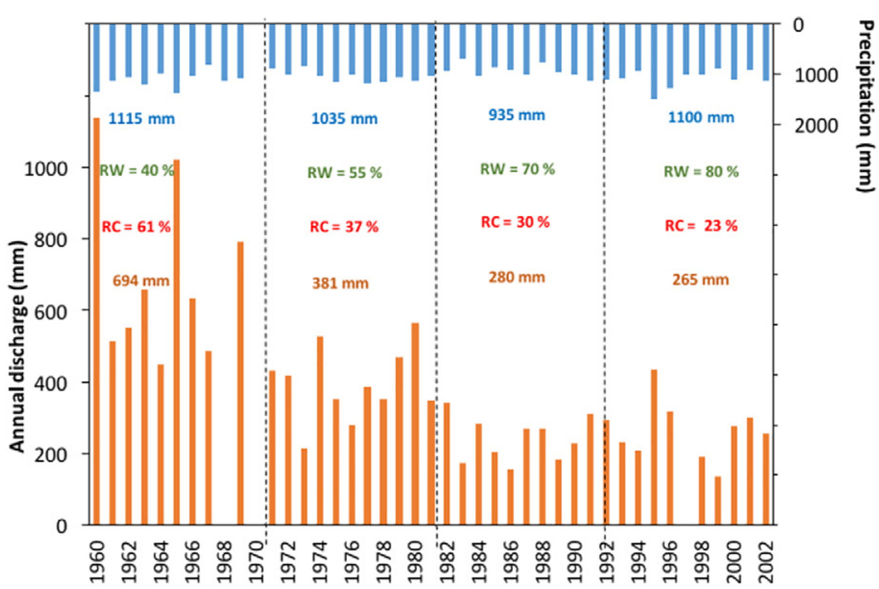

Fig. 2. Effects of successive rewilding (RW) in Slovenia from 1960 to 2002; with stable precipitation, the annual discharge and runoff coefficient reduce.

4.3. Land restoration in Iceland. Water resources and flood prevention

Iceland is an ideal location to investigate anthropogenic impacts on the resilience of natural ecosystems and its services. The dramatic deforestation after the arrival of the first settlers 1100 years ago, the subsequent year round livestock grazing along with devastating ash emissions during volcanic eruptions and a harsh sub-polar oceanic climate have led to severe degradation of large areas of Icelandic soils (Aradóttir et al., 2013; Arnalds, 2005). Overgrazing has been seeing as a worldwide land degradation threat (Pulido et al., 2017). Since the beginning of the 20th century diverse restoration measures have been implemented at a large-scale on the lowland areas of Iceland making them an ideal case study to investigate the effects of restoration on the resilience of water resources. Since over 100 years the Soil Conservation Service of Iceland (SCSI) has been restoring and investigating degraded landscapes, collecting valuable information and data on restoration research in Iceland, and specifically of the Rangárvellir area in southern Iceland, which is stored in a metadatabase (Finger et al., 2016). The combined effect of all restoration efforts have had a subsequent effect on the runoff dynamics in the main rivers of Rangárvellir (Fig. 3a). One can distinguish between three phases of restoration: i) present conditions (Fig. 3b); ii) degraded conditions as was the case 100 years ago (Fig. 3c); iii) fully restored ecosystems (Fig. 5d). The effects of restoration of runoff dynamics indicate that: i) high discharge peaks decreased due to successful restoration; ii) ground water levels are depleting with low rates during dry periods and erosion rates in the rivers is reduced due to the lower soil erodibility. These first results suggest that restoration of original ecosystems present an effective method to reduce flood risks, enhance the resilience of fresh water resources and improve water quality due to soil erosion reduction.

4.4. Agroforestry in southern Portugal: modern nature-based solutions improve a traditional and sustainable land-use for semi-arid regions

A large area of the southwestern Iberian peninsula is occupied by a savannah-like traditional agroforesty system called montado in Portugal and dehesa in Spain. These systems are open oak formations (usually Mediterranean evergreen oaks) with a scattered tree cover, usually associated with rainfed pastures with extensive grazing of sheep, pigs and other livestock. This landscape is a human nature-based solution for the inter-annual fluctuations of water availability and vegetation productivity typical of semi-arid Mediterranean climates, designed to prevent degradation and minimizing work input.

Pinto-Correia (1993) provided one of the earliest descriptions of the functioning of the system. More recent research has highlighted how this system takes advantage of local climate and soil conditions. The canopy cover of ca. 40% seems to be optimal, since lower tree cover is associated with lower soil water retention and less infiltration, but a denser cover leads to water competition between trees (Gouveia and Freitas, 2008). Similarly, montado systems have a higher density and richness of ectomycorrhizal (ECM) fungal communities than regions with denser tree and shrub cover, due to lower competition; this can increase the resilience of the managed system due to improved nutrient acquisition, drought tolerance and pathogen resistance (Azul et al., 2010). The montado landscape has also been shown to have other effects such as lowering land surface temperature (Godinho et al., 2016) or affecting soil microbiology (Shvaleva et al., 2015) and soil fauna (Martins da Silva et al., 2015).

This system, however, has been under threat by recent developments caused by changes in climate and land use. An increase of droughts and wildfires has led to a general decrease in tree cover by increasing tree mortality and limiting regeneration (Acácio et al., 2009). Also, while land abandonment on some areas led to intensification and an increase in competition for water between trees and shrubs, the intensification of pasture on others led to an increase in soil degradation, with a consequential loss of productivity and tree health (Pinto-Correia and Mascarenhas, 1999; Pinto-Correia et al., 2016). Relatively moderate changes could therefore threaten the equilibrium which has kept this landscape sustainable, with consequences not only for land degradation and human desertification, but also for water resources in this region, already threatened by climate change (Nunes et al., 2017b).

To adapt to these changes, recent initiatives have tried to maintain and improve the sustainability of this landscape with non-traditional nature based solutions. Ng et al. (2016) note the adoption of practices such conservation tillage, mulching, adapting cropping to microclimate (e.g. more intensity in the north side of hills), used elsewhere. Locally developed solutions include: i) sowing biodiverse permanent pastures

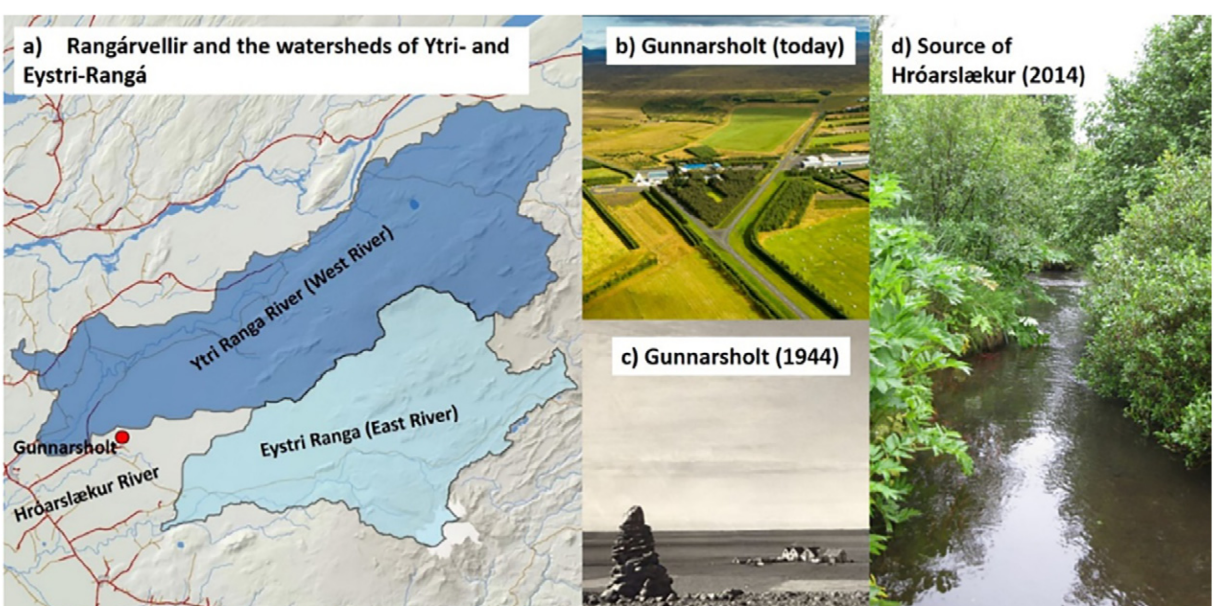

Fig. 3. Overview of the two watershed of Ytri- and Eystri Rangá in Rangárvellir in southern Iceland (a). Picture of Gunnarsholt, the headquarters of the SCSI in 1944 (b) and 2012 (c) (photo from land.is). Picture (d) Visualizes natural succession of birch trees in a protected area around the source of Hróarslækur.
(photo taken in 2014 by Finger)

rich in legumes (Teixeira et al., 2011). These consist of a mix of different seed varieties in pasture, which ensure that species are suited for different soil conditions in a pasture, and provide cover in different parts of the year. This has been shown to also increase soil organic matter through enhanced productivity. The second solution is, ii) water retention landscapes (Pijnappels and Dietl, 2012; Fig. 4). These consist of a series of artificial lakes designed for water retention and to promote percolation, increasing soil and groundwater availability at the expense of surface runoff, complemented by measures such as swales and keylines (Yeomans, 1954). There is an ongoing debate about the most effective mix between lakes and other measures.

Increasingly these solutions are adopted in a holistic approach to landscape management, including adapting montado tree cover, using shrubs for erosion control in steep slopes, rainwater harvesting, restoration of riparian vegetation and other measures; Campos et al. (2016) describes an example of how vegetation management can increase the resilience towards land abandonment and climate change impact. These solutions are implemented and supported by a network of sustainable communities which also promote the systematization and dissemination of these nature-based solutions through bottom-up approaches (Campos et al., 2016; Esteves, 2017).

4.5. Vegetative sediment trapping measures in Ethiopia grassed waterways

For millennia African farmers have been using NBSs, without calling them as such. They have been using measures such as grass strips, stone bunds and agroforestry to sustainably make use of the soil and landscape resources (Gebremichael et al., 2005; Vancampenhout et al., 2006). In recent years when land degradation has become a widespread problem in the countries like Ethiopia, the pressure of population growth and extensive livestock grazing has caused overgrazing and subsidence agriculture on unsuitable areas. Due to the widespread soil erosion taking place there have been many projects focusing on on-site soil and water conservation techniques (Gebremedhin and Swinton, 2003; Amare et al., 2014; Lemann et al., 2016).

These techniques can partially be classified as NBSs. Techniques such as grass strips and soil or stone bunds that catch water and sediment from upstream enhance the initially created structure to slowly form a terrace like structure as a result of the forces of nature (Fig. 5; Atnae et al., 2015; Mekonnen et al., 2015). However, the large amounts of sediment accumulating in reservoirs and lakes downstream show that trying to conserve the soil on the fields is an insufficient way to reduce the fluxes of sediment on a landscape scale. It is necessary to trap the sediment in its transport path. Also for this there are NBSs, that do this, grassed waterways, and finally in wetlands where the water can be filtered and retarded before entering a larger water body (Mekonnen et al., 2015). The most efficient species of grass to trap the sediment and the amount of grazing possible are important things to take into account (Mekonnen et al., 2016). However, all these measures are individually not sufficient to come to sustainable landscape management; but a cascade of these NBSs has the potential to solve the degradation problems. A combination of soil solutions such as intercropping and mulching on the agricultural fields (Prosdocimi et al., 2016b; Tanveer et al., 2017) and landscape solutions in the pathways as well as in the form of wetlands close to the outlet of a catchment may solve these issues.

4.6. Blue-green infrastructure in Sweden

Blue-green infrastructure is currently seen as a way to reduce the negative effects of urbanisation (flooding) and to adapt to anticipated climate change (flooding and droughts). Blue-green infrastructure is a possible way to create multifunctional surfaces with environmental and social functions. Apart from stormwater management (sustainable urban drainage systems), it includes greenways and ecological networks, which are important components in the concept of green infrastructure (Demuzere et al., 2014). The overall aim with blue-green infrastructure is to mimic valuable functions supplied by nature, such as purification of water, flood control, water storage and heat control. The Augustenborg area in southern Sweden is one example, where a several of the concepts related to nature-based solutions for stormwater control were installed 15 years ago. The main objectives were to adapt to more extreme rainfall events, achieve sustainable urban development, involve residents in development of their neighbourhood and increase biodiversity in the area by making the environment greener (Sörensen and Emilsson, 2017; Stahre, 2008). The blue-green infrastructure system in Augustenborg includes trenches, ditches, ponds and wetlands for retention of flows from roofs, roads and car parks, and also green roofs built after 1998 and retrofitted on 10,000 m^2 of an existing building (the largest green roof in Scandinavia) (Sörensen and Emilsson, 2017; Fig. 6).

The systems have been continuously monitored and investigated over the 15 years since installation and many articles and reports have been written about different aspects of the Augustenborg redevelopment project, e.g. citizen involvement (Marsalek et al., 2004), environmental assessment (Ludzia et al., 2014), green roof water quality (Berndtsson, 2010) and quantity (Bengtsson et al., 2004) and design and maintenance (Kalantari and Folkeson, 2013). As a result of the

Fig. 4. Water retention strategies in Portugal, retention lines and keylines.

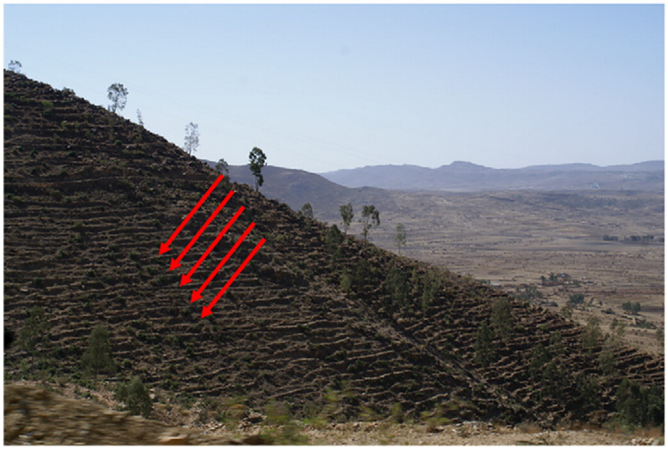

Fig. 5. Soil and Landscape nature based solution in Ethiopia, stone and soil bunds (red arrows indicate sequence of soil bunds) collect water and sediment to form after some years a micro-terrace. The combined effect of a whole hillslope with soil bunds magnifies the effect.

implementation of the blue-green initiative, there have been no floods in the area (2009–2014), compared with five floods between 1994 and 1999 (Sörensen and Emilsson, 2017). Moreover, Shukri (2010) found a 50% decrease in runoff in the Augustenborg area following heavy rainfall in summer 2007 that led to severe flooding in most parts of Malmö city (Bengtsson and Milotti, 2010). In addition to flood risk reduction during minor and severe flood events (Villarreal et al., 2004; Sörensen and Emilsson, 2017), there are reports of positive effects of the blue-green infrastructure system in Augustenborg on socio-economic improvement and environmental impacts (e.g. Ludzia et al., 2014), as well as increased biodiversity (50%) by providing a better environment for local plants and wildlife (Manso and Castro-Gomes, 2015).

5. Discussion

We critically assess what the case studies show in terms of what we think is the superior effect of NBSs to mitigate issues such as flood risk, fire risk, droughts and pollution. In this assessment we take into account the role of parameters that influence the designs on different scales (Table 1) and how the integrated designs influence ecosystem services (Table 2).

5.1. Classification of nature based solutions

Table 3 gives an overview of different types of NBSs that have been implemented to areas with various land-use systems, roughly divided into agricultural areas, managed grassland and forests and riverine areas. In all these systems soil as well as landscape NBSs can be found. The assessment of the usefulness and choice of NBSs benefits from classifying them into Soil-Vegetation and Landscape solutions.

5.1.1. Soil-vegetation solutions

Soil-Vegetation solutions can be characterized by measures that enhance soil functions and soil resilience and are based on the concept of soil health (Abbott and Manning, 2015). Parameters and associated processes (Tables 1 and 3) can be grouped in soil and surface changing measures. Better infiltration, soil stability and soil roughness reduce overland flow and associated sediment transport (Rodrigo-Comino et al., 2016a, 2016b). Apart from the soil related parameters also surface parameters influence the potential for rainfall to be transformed into runoff. Vegetation cover, mulch, surface roughness and crusts also impact the runoff and erodibility of the surface, impacting the water and sediment fluxes on the small scale. And finally, soil parameters related to soil structure (porosity, aggregate stability, organic matter content, water holding capacity) all create a more resilient soil ecosystem (Asmamaw, 2017; Hueso-González et al., 2014; Muñoz-Rojas et al., 2016). More resilient systems have a buffer against external impacts and create a better livelihood conditions for above and below life. In addition, a healthy soil will have a higher biodiversity, and can store more carbon (Blouin et al., 2013).

5.1.2. Landscape solutions

The second group of NBSs can be defined as landscape solutions. Geomorphological parameters such as hillslope morphology, runoff pathways, topographic wetness and water and sediment sinks determine the potential for water and sediment to be transported through a system. Holistically, the soil and landscape processes together form the connectivity of the landscape. The concept of connectivity (Bracken et al., 2015; Parsons et al., 2015; Masselink et al., 2017a) is

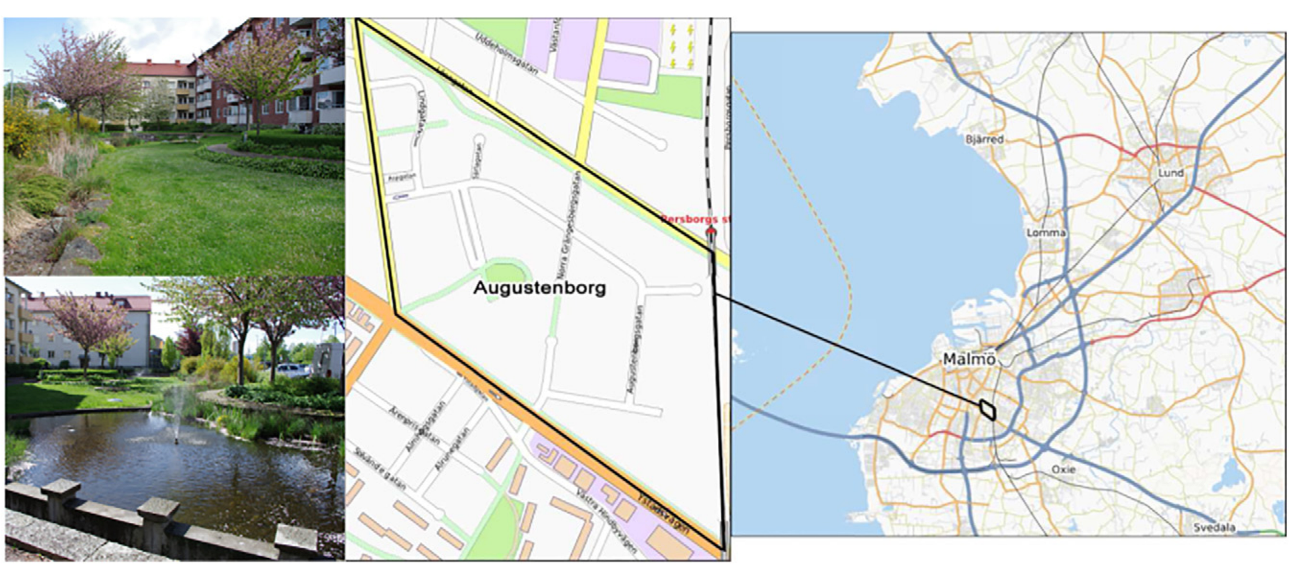

Fig. 6. Location map of Augustenborg Eco-City in Malmö in southern Sweden (55.50N, 13.00W; OpenStreetMap, 2017) and the Blue-green infrastructure in suburb of Augustenborg in the south part of Malmö, which was redeveloped in the framework of the blue green infrastructure implementation. Photos of suburb by Johanna Sörensen.

Table 1
Scale dependent parameters that can be influenced by nature based solutions.

Scale	Parameter
Soil processes	Porosity
	Soil structure
	Aggregate stability
	Soil organic matter
	Water repellency
	Water holding capacity
Surface processes	Vegetation cover
	Mulch cover
	Surface roughness
	Shear strength
	Surface crusts
	Combustible fuel load
Geomorphological processes	Hillslope geomorphology
	Runoff pathways
	Topographic wetness
	Water and sediment sinks
	Connectivity
Chemical processes	CEC
	Nutrient content
	Carbon content
	Solute transport and precipitation

the most useful approach to describe these water and sediment dynamics and assess how the system will react when the drivers in the system will change. Process understanding will make it possible to predict how the system will react to changes in the drivers in terms of water and sediment connectivity. And with this knowledge the system can be managed in such a way that it will evolve into the desired system state that land and water managers wish to have.

The design of these landscape solutions should be based in the cascade of processes that occur when we work together with nature to manage land and water. The measures can be linked to all parameters and processes that are of influence the structural and functional connectivity of the system. Using the insights of the role of these different processes and parameters can be used to design solutions that can reduce the connectivity of a system on different spatial levels in the system, from the plot to the whole catchment. As an example: mulching promotes disconnectivity on the plot scale infiltration can be promoted, reducing the runoff and increasing water availability for agriculture. In the same catchment a wetland can reduce the connectivity in the riverine system (Masselink et al., 2017b). These kinds of management strategies can mitigate risks like flooding, agricultural droughts and extreme soil erosion events (Rickson, 2014; Panteli and Mancarella, 2015) and can enhance biodiversity (Huang et al., 2017).

5.2. Nature based solution in specific systems

5.2.1. NBSs in agricultural systems

In agriculture soil strategies that are focused on reaching a healthier soil aim to improve soil organic matter content and structure to facilitate higher infiltration rates and lower runoff and erosion. Systems like organic farming are mainly focused on that. Other strategies focus on protecting the soil surface, like mulching, intercropping and the use of cover crops (Sharma et al., 2017).

Table 2
Ecosystem services relevant for nature based solutions.

Ecosystem services
Soil protection
Flood regulation
Water quality regulation
Carbon sequestration
Fire prevention
Biomass growth
Biodiversity
Ecosystem resilience
Nutrient regulation

The landscape solution in agriculture are soil and water conservation measures that aim at dis-connecting the water and sediment fluxes when in transport. These strategies, like grassed waterways, vegetation strips, contour planting, and even the use of soil and stone bunds (Novara et al., 2013; Vancampenhout et al., 2006), all have the objective to slow down the surface runoff and enhance infiltration. These kind of structures have been used for many years, but the impact of the cascade of these strategies on catchment scale is usually unknown. These measures are designed for small scale, and how upscaling (for instance mass implementation of infiltration trenches on the hillslopes) (Paras-Alcántara et al., 2016) impacts the system downstream like the depletion of water and sediment downstream in the system is usually unknown. Modelling studies may prove to be useful to predict such catchment scale design sustainability. In a modelling study by Nunes et al. (2017a) different scenarios of land use management were tested for their successfulness to reduce water and sediment fluxes. This approach proved to be useful to assess the effectiveness of landscape measures that are based in natural processes.

5.2.2. Grass and forest systems

The NBSs in grasslands and forests are mainly focused on making the systems more biodiverse in order to make the soil and surface characteristics more favorable to buffer dry and wet conditions. The self-organization of the vegetation creates a resilient ecosystem, and continuously protects the soil surface from erosion (Rietkerk et al., 2002). The different layers and types of vegetation create a surface that intercepts more rainfall and prohibits overland flow more efficiently (Berendse et al., 2015; Osterkamp et al., 2012). When looking at spatial-temporal dimensions of soil functions, they can be improved by creating biodiverse managed landscapes, either in forest or grassland type of ecosystems. The natural self organization of the vegetation creates a more resilient ecosystem in terms of buffering the hydrological system to prevent droughts and floods (Shen et al., 2017). But also preventing the soil surface to be bare and vulnerable for erosion.

Rewilding of landscapes initially seems the same as natural biodiverse forest recovery. The benefits on 'soil scale' are the same, but in landscapes that are rewilded, the natural growth is only allowed on specific places. Areas which have a high erosion risk will be treated differently than areas that have a low erosion risk. This mosaic planning should be done to optimize the ecosystem services that can be found in such areas. In addition, the agricultural landscape ecosystem services benefit from natural parcel separations like hedges and tree rows.

In an agro-forestry system this self-organization is artificially mimicked. Undergrowth and canopy are managed in such a way that the surface is better protected because different layers of vegetation grow at different times in the seasons (Shen et al., 2017). In dry systems this also has the effect of optimizing water use and minimizing competition, with advantage for plants and for associated ecosystems (Gouveia and Freitas, 2008; Azul et al., 2010).

5.2.3. Riverine systems

River restoration projects all over the world nowadays use NBSs to restore the natural behaviour and ecosystem services of riverine systems (Surian et al., 2015). NBSs can be implemented in different parts of the riverine system, the river channel itself, the riparian zone and wetlands. In the channel allowing the river to behave naturally; meander, incise, flood its floodplains will create a biodiverse environment that retards high water flows and therefore mitigates flood risks, which is a common approach in river restoration. Riparian vegetation has a double function in terms of the benefits it can have. Not only does it enhance the riverine ecosystem itself, also it retards water and traps sediment coming from the hillslopes that need to pass the riparian zone before entering the channel. The final part of the riverine system are wetlands. The ecosystem services wetlands contribute to are flood

Table 3
Summary of the scale, the physical processes and the impacted ecosystem services that are relevant for nature based solutions that have been described in the case studies in this paper and in other papers.

Case	Process scale (soil/hillslope/landscape)	Physical parameters	Ecosystem services
1 Organic farming (Cerdà et al., 2016; Novara et al., 2016)	Soil/hillslope	Infiltration Interception Ponding Soil surface protection Ecosystem resilience	Soil protection Biodiversity Carbon sequestration Water quality regulation Biomass growth Nutrient regulation Flood regulation
2 Managed rewilding (Keesstra et al., 2009)	Soil/hillslope	Infiltration Interception Soil surface protection Ecosystem resilience Dis-connectivity	Soil protection Biodiversity Carbon sequestration Water quality regulation Flood regulation
3 Agro-forestry (Pinto-Correia, 1993)	Soil & landscape	Infiltration Soil water retention Soil surface protection Tree resilience	Soil protection Drought regulation Water quality regulation Carbon sequestration Biodiversity
5 Land restoration (Finger et al., 2016)	Soil/hillslope	Infiltration Interception Ecosystem resilience Dis-connectivity Water and sediment retention	Soil protection Biodiversity Carbon sequestration Water quality regulation Biomass growth Nutrient regulation Flood regulation
6 Wetlands restoration (Kalantari and Folkeson, 2013)	Landscape	Dis-connectivity Water and sediment retention	Biodiversity Water quality regulation Nutrient regulation Flood regulation
7 Trapping sediment with vegetational measures (Mekonnen et al., 2015)	Landscape	Dis-connectivity Infiltration Ponding Interception Water and sediment retention	Soil protection Carbon sequestration Water quality regulation Biomass growth Nutrient regulation Flood regulation

prevention, retarding and trapping sediment and filter pollutants from the discharged water (He et al., 2015). Because the wetlands are located in flat areas and divert the water into a large area, the discharge wave is flattened during a flood (Watson et al., 2016); and suspended sediment is trapped by the vegetation. Vegetation type and spatial distribution can be used to enhance the natural function of the system (Mekonnen et al., 2016).

5.3. Benefits for ecosystem services. Holistic management is useful

As shown in the previous sections NBSs can have multiple societal benefits: Biodiversity, Carbon sequestration, and Land Restoration, Food security and Water security. These can all be linked to the Sustainable Development Goals (SDGs). Keesstra et al. (2016a) clearly showed the link between the soil function, the ecosystem services and the SDGs.

Holistically, the soil and landscape processes together form a cascade of processes in the landscape; and if we work together with nature to manage land and water this will result in a more resilient system. In the end, NBSs can regulate four ecosystem services: water provision, flood regulation, soil protection, and water quality regulation (Fig. 7).

The first ecosystem service is water provision. It shows that while some NBS decrease the amount of water, most especially improve the timing of the provision, by promoting infiltration, storing water in the wet season and releasing it in the dry season (which is how the water retention landscapes prevent drought). Even though, in the Mediterranean area the infiltrated water will for a large part be evapotranspirated, and will never come to discharge. But this change in the hydrological distribution causes the water to be more available for plant growth, more water will infiltrate and therefore will not be transformed into surface flow, which causes erosion and flooding.

The second service NBSs provide is flood regulation. Through the promotion of infiltration, soil water retention, vegetational obstructions in the drainage system and wetlands the system becomes less connected. All measures are designed to retard and divert the water to reduce the speed and the converging of water during a high intensity rainfall event. Soil solutions can be intercropping (Singh et al., 2016) or landscape solutions such as wetland construction (Kalantari and Folkeson, 2013) are solutions useful to improve this ecosystem service.

The third ecosystem service is soil protection. Most NBSs aiming to improve this ecosystem service are soil based solutions. Mainly the reduction of the erodibility of the soil and the reduction of overland flow are the key processes that will protect the soil from degrading. The main measure to reduce the erodibility is soil cover, this can be done by a vegetation cover or mulching with straw, chipped pruned branches or rock fragments (Zavala et al., 2010; Prosdocimi et al., 2016b; Abbas et al., 2017). The reduction of overland flow can be promoted through two lines of thought. Infiltration promotion or obstructions for the overland flow. Infiltration can be promoted through a better soil structure, better soil infiltration capacity. Organic farming can promote the soil structure permanently, but also ploughing may be viewed upon a nature based solution that enhances the infiltration capacity of the soil, although this is a effect that has a limited timeframe. The obstruction of overland flow can be promoted by increasing the roughness of the surface, either by vegetation (grass strips; Dillaha et al., 1989) or soil bunds (Amare et al., 2014).

The last key ecosystem service is water quality regulation. Water quality has two components, the suspended material and polluting solutes. When looking at suspended components and substances adsorbed to organic matter and clastic material in suspension, similar measures as to the flood prevention can be used. These measures are all directed to slow down the overland flow and therefore reduce the capacity of the

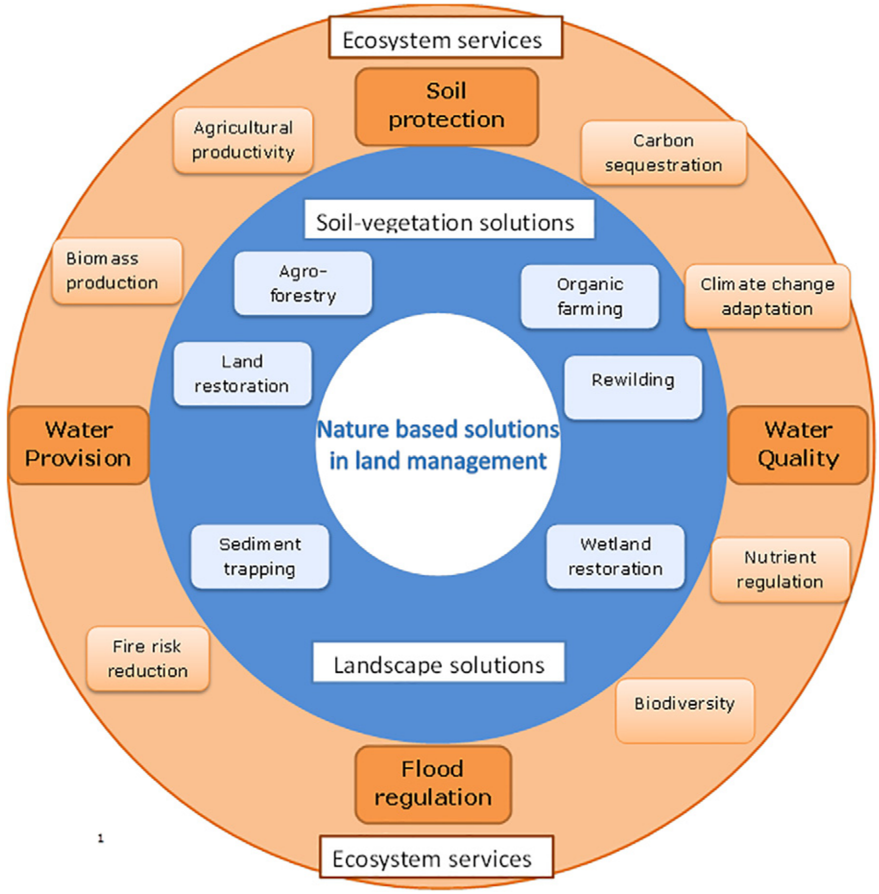

Fig. 7. Schematic overview of different types of nature based solutions.

water to transport sediment. However, also healthy soil will be able to filter pollutants from water (Keesstra et al., 2012).

Other ecosystem services like carbon sequestration, climate change adaptation, biomass production, biodiversity, nutrient regulation, fire risk reduction and agricultural productivity all benefit from the measures described above. We focused this paper on the processes behind these benefits, however, these ecosystem services are the ones that are more visible from a stakeholder point of view (Novara et al., 2015; Galati et al., 2016; Novara et al., 2016).

5.4. Way ahead for managers and policy makers: do NBSs form the solution for sustainability?

The array of NBSs presented in this paper clearly shows the benefits they have for ecosystem services and how they help to achieve the SDGs. However, how can we show that they are superior to traditional engineered structures? Engineered structures have been shown to be ineffective and costly in rapidly changing environment such as coastal and large riverine systems (de Vriend et al., 2014). In these kind of environments managers have searched (and found) alternative measures using with, instead of against the forces of nature. Also in areas where financial constraints do not allow costly engineered structures, people have referred to NBSs, sometimes with millennia old techniques. In addition, the engineered structures may feel safer when they are aimed for e.g. flood protection; however, they only serve this particular benefit and never have the multiple benefits that NBSs tend to have.

Although some successful examples were shown in this paper, there are of course many other situations where NBSs have been implemented. Currently it seems that there are certain NBSs that are generically generating positive effects for ecosystem services. For instance, organic agriculture, rewilding and landscape mosaic planning seems to be both worthwhile to do in boreal as well as Mediterranean climates. One issue that is uncertain, is how these measures would work if implemented over larger areas. Upstream measures may have downstream effects that may be undesirable. This is recognized by the EU, as nature based solutions are focal points in their calls for projects.

6. Conclusions

Nature based solutions (NBSs) form a cost-effective long term solution for mitigating and restoring land affected by degradation processes. NBSs can be divided into two main groups: soil solutions and landscape solutions. Soil solutions aim to enhance the soil health and soil functions through which local eco-system services will be maintained or restored. Landscape solutions mainly focus on the concept of connectivity. Making the landscape less connected, facilitating less rainfall to be transformed into runoff and therefore reduce flood risk, droughts and erosion problems. The enhanced eco-system services directly feed into the realization of the Sustainable Development Goals by the United Nations.

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