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Land degradation knowledge base: policy, concepts and data

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Showing erosion control on a slope with straw sock catch, silt fence

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- In the second phase the report was updated according to new and emerging initiatives by Eva Ivits (EEA), Gundula Prokop (Environment Agency Austria) and Mirko Gregor (space4environment).

Abbreviations

ACT	Archetypical Change Trajectory
ANNP	above ground net primary productivity
BFAST	Break for Additive Season and Trend
CAP	Common Agriculture Policy
ESR	Effort Sharing Regulation
ETa	actual evapotranspiration
FAO	Food and Agriculture Organisation of the United Nations
GCI	Global Change Issues
IPBES	Intergovernmental Platform for Biodiversity and Ecosystem Services
LC/LU	Land Cover / Land Use
LDN	Land Degradation Neutrality
LDNW	Land Degradation Neutral World
LPD	Land Productivity Dynamics
LULUCF	Land Use and Land Use Change and Forestry Regulation
NPP	Net Primary Production
RDP	Rural Development Programme
SDG	Sustainable Development Goal
SPI	Science Policy Interface
MAES	Mapping and Assessment of Ecosystems and their Services
NDVI	Normalized Difference Vegetation Index
RUE	Rain Use Efficiency
SSM	Sustainable Soil Management
SPOT-VGT	SatellitePour l'Observation de la Terre –Végétation
UNCCD	United Nations Convention to Combat Desertification
WAD	World Atlas of Desertification
WOCAT	
WUE	Water Use Efficiency

Executive Summary

Land degradation has been recognised as a threat to the European and global ecosystems with direct impacts on climate change adaptation, ecosystem condition, human well-being, food-security, and social welfare. However, up-to-date, there is not a single strategic policy framework, that preserves and enhances land resources in the European Union. Moreover, objectives to halt and revert land degradation are dispersed over a range of strategic documents and policy guidelines at the EU and so are the topics of land and soil, which can be found across policy instruments of various sectors.

A lot of scientific effort has been devoted to the concepts and approaches for the monitoring and assessment of land degradation and to the question of how land resources determine ecosystem functions and the delivery of ecosystem services. To answer this, the European Commission and its Member States need information to track progress towards a more sustainable use of land within a harmonized framework for monitoring the state and trend of land degradation. Harmonized maps and geospatial datasets of the condition and changes in terrestrial ecosystems in Europe are an essential part of this framework. Based on established methodologies, relevant data and geospatial datasets should be collected, analysed and provided to the public in a user-friendly way. Furthermore, a land degradation assessment framework should enable the European Commission, countries, regional authorities and environmental organizations to explore the state of land degradation phenomena in their territories, on the local level, with local knowledge to track the progress towards sustainable land use.

This report is not a land degradation assessment report. Understanding that land degradation is a global; phenomenon with local manifestations, often times using local perception of “degrading” and “degraded” land, this report attempts to summarise the knowledge base. In that, the report describes the present policy context, land degradation definitions and concepts and gives examples for some assessments methods. Please note, the report is not exhausted on the latter as methods are too abundant to summarise them, nor is that the goal of this report. The goal is rather to give examples for what types of assessments can be conducted using geo-spatial data, combined with expert-knowledge. The EEA is working on an infrastructure for supporting faster, more transparent geospatial data assessment, notably the Integrated Data Platform project. Several products are now in place, which facilitate integrated Land Systems assessments, among others those addressing land degradation. These products indicate land under stress (or improvement) by providing geospatial and statistical information on the status and trends in the condition of our land resources. By identifying potential impacts of human activities, such as intensive land use or urbanisation, potential research needs can be identified and decision-makers can be empowered to take actions.

1 Introduction

Land degradation has been recognised as a threat to the European and global ecosystems with direct impacts on human well-being and social welfare. The significance of the impacts of land degradation has been mentioned in reviews of environmental policy frameworks, assessments by intergovernmental bodies and scientific advisory panels for policy makers, and research projects[1]. The media also report symptoms of land degradation induced by interactions of climatic and human influence, for instance the damage to forests and the victims caused by wildfires swept over southern Europe by the heatwave 'Lucifer' in the summer of 2017, affecting eleven countries and causing serious water shortages for the agricultural sector.

Land degradation is mostly understood in terms of a long-term loss of functionality and productivity of land or land-based ecosystems[2]. The term refers to the degradation of all components of the land system, including soil, vegetation, animals, air and water (WOCAT 2017). Examples of forms of land degradation are erosion by water and wind, soil pollution and fertility decline, soil compaction, decline of water quality, vegetation and loss of habitats, or soil sealing due to urbanization and construction (FAO 2017a). Land degradation assessments differ with regard to the forms of land degradation, but the most frequently mentioned topics include soil sealing, the contamination of soil and water, soil compaction and the loss of organic matter in soils, loss of biodiversity, nutrient imbalances, habitat fragmentation, loss of land productivity and the invasion of alien species.

It has to be noted that land degradation and soil degradation are often confused and used as synonyms. Soil degradation is a sub-set of land degradation with a specific focus on impairment of soil functions. This is in more detail explained in chapter 3.1.

Land degradation phenomena observed in Europe must be considered in the context of global land use changes, which have an impact on land quality. Major trends are

- Urbanisation is an ongoing global trend and describes the movement of people from rural areas to urban agglomerations. Urbanisation creates land take, soil sealing and landscape fragmentation in order to fulfil the needs of new settlers for new housing, commercial areas, roads and other infrastructure.

- Agricultural intensification. The increasing global demand for food, bio fuels and renewable resources triggers intensive forms of agriculture, with negative side effects such as erosion, salinisation, compaction, loss of biodiversity and other.

The recent study on global land use and land degradation by the Netherlands Environmental Assessment Agency (PBL), in support of the Global Land Outlook (Van der Esch et al. 2017), shows that land degradation is a global problem, with particularly negative impacts in African, Middle Eastern and South Asian regions. For the drylands of these regions, a high population increase is expected. This means more people in regions where the land is already degraded, where water is scarce and the vulnerability towards climate change is high. The study projects that pressures on land will increase worldwide due to the growing demand for land and for the production of food, construction materials, bio-energy and due to the growing urbanisation. The scenarios in the study show that the demand for land-based products will increase by 30% to 80% until 2050, and that this demand would require an expansion of areas in use for agriculture and livestock in an order of 8 mio. km². The European region is increasingly challenged in its approaches

1 e.g. Jones et al. 2012, (BIO by Deloitte 2014, EEA 2015c, EEA 2016a, UNEP/UNECE 2016, FAO 2015b, Hart et al. 2013, Stolte et al. 2016, Berge et al. 2017, EASAC 2017, and Van der Esch et al. 2017.

2 see chapter 3.2

towards sustainable land use, by avoiding and mitigating land degradation elsewhere in the world as well as in its own territory.

In addition, the region will have to adapt to climate change, which is increasingly showing adverse effects on land conditions in Europe as shown by the assessment from (EEA 2017). In response to these concerns over land degradation, various policy programs, strategies and guidelines on sustainable management of land and soils emerged in the past decade; e.g.:

- The Soil Thematic Strategy of the European Commission (EC 2006a) (EC 2012a).
- The FAO Voluntary Guidelines for Sustainable Soil Management (FAO 2016).
- Partnerships of governments and companies were established, most notably the Global and European Soil Partnerships[3] and the World Business Council for Sustainable Development[4].
- An attempt was made to create a legislative framework for the EU in this domain (EC 2006c).
- The European Commission has funded many research and innovation projects and actions related to land resources and natural capital[5], and organised scientific support through the Expert Group on Soil Protection and the *MAES* Initiative.
- A comprehensive scientific assessment of land degradation and restoration was delivered by the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES) in 2018[6].

Currently the main interest of the European Commission with regard to land policy is to comply with targets for land

- as set out in the 7th Environmental Action Plan (European Parliament and Council of the European Union 2012), and
- in the 2030 Agenda for Sustainable Development of the United Nations (EC 2016).

The EC and Member States need information to track progress towards a more sustainable use of land. Harmonized maps and geospatial datasets of the condition and changes in terrestrial ecosystems in Europe are an essential part of this information. A lot of scientific effort has been devoted to the concepts and approaches for the monitoring and assessment of land degradation[7], and to the question how land resources determine ecosystem functions and the delivery of ecosystem services[8].

3 the Global Soil Partnership: http://www.fao.org/global-soil-partnership/en/

4 World Business Council for Sustainable Development: http://www.wbcsd.org/

5 see the European Union’s research Portal CORDIS: http://www.cordis.europa.eu

6 see also chapter 0 (page 14) for more details

7 e.g. Reynolds et al. (2007) and, (Vogt et al., 2011)

8 e.g. Hurni et al. (2015), (FAO 2015a), (FAO 2015b), (IPBES 2016)

In response to this need, EEA is building a knowledge base on land degradation mapping and assessment at the European level. This concerns both summarising existing methods and listing readily available geospatial datasets. An expert meeting was held in March 2016 followed by a technical workshop in June 2016 to clarify issues with mapping practices. The outcomes of these two workshops led to the following conclusions:

Box 1.1 Workshop conclusions on land degradation monitoring in Europe.

- Land degradation status and trends cannot be mapped as single indices at the European scale.
- Only certain, well defined aspects and processes of land degradation can be mapped, using a combination of spatial information layers, local variables, and interpretation by experts.
- A flexible approach to mapping land degradation is required because land degradation is a multidimensional phenomenon: it comes in many different forms and is hard to measure consistently.
- There are combinations of land degradation, originating from multiple causes and times.
- Benefits and values derived from land in terms of food, feed, timbre, energy and environmental and social goods and services are very differently perceived by individuals and organizations (Blaikie & Brookfield 2015) (Mirzabaev et al. 2015). This leads to the conclusion that land degradation need to be mapped in combination with delivered eco-system services.
- Land management practices can trigger land degradation directly or in other parts of the world, including time lags of years or decades. This dependency is currently not understood.

Mapping and monitoring methods should enable the European Commission, countries, regional authorities and environmental organizations to explore the state of land degradation phenomena in their territories, and to track progress towards sustainable land use. The connection to ecosystem services should support a more balanced consideration of planning decisions on land use and land management, a line of thought expressed in several policy agendas[9]. The envisaged use of the mapping framework is to guide environmental assessments in which expert knowledge and spatial information are combined in order to map land degradation impacts on ecosystem services. This should facilitate the identification of regions in Europe where land degradation affects ecosystem services. As a consequence, investments for the restoration of degraded land should focus on those regions.

A spatial modelling infrastructure is required to efficiently map the various aspects of land degradation. This infrastructure needs to enable users to combine expert knowledge with spatial and statistical data, and optionally with results from biophysical and socio-economic models. In view of much geospatial information is increasingly available through high spatial and temporal resolution time series derived from Earth Observation sources, the geospatial infrastructure should enable big data processing. This should be facilitated by cloud environments and efficient data cubes.

The objectives of the present report are:

- to provide an overview of the current policy context and of definitions and concepts related to land degradation (given in chapters 2 and 3).
- to summarise a selection of previous attempts and currently available methods to map land degradation in Europe (described in chapters 4 - 7), and
- to suggest a geo-spatial data architecture and a system infrastructure underpinning a user friendly land systems platform, which enables the assessment and mapping of land degradation impacts on ecosystem services. (chapter 8 and ANNEX 2 – Spatial Data Catalogue).

9 e.g. EC (2013d), Masson & Strassburger (2015), Delsalle (2016), Berge et al. (2017)

2 Policy Context

2.1 Introduction

The aim of this chapter is to give a short - and non-exhaustive - overview of key policy programs at the European and international level with ambitions to remediate land degradation.
Furthermore, this chapter aims to give indications of those elements which could be included in a common approach for land degradation mapping.
For in depth information on these policy programs we refer to:

- recent assessments of European Union policies with implications for land and soil by (EEA 2016d), (Frelih-Larsen et al. 2017) and (ECORYS et al. 2016),
- and to the documentation on Land Degradation Neutrality from the UNCCD ((Orr et al. 2016), (UNCCD 2016a), (UNCCD 2016b)). The overview below is based on these information sources.

2.1.1 EU policies on land and soil protection are non-binding

Although the protection of soil and other land components is addressed in many EU level policy instruments, a binding legislative mechanism for the sustainable management of land and soils at the level of the European Union (EU) is lacking (Frelih-Larsen et al. 2017). This is considered a problem since the sustainable management of land and soils is crucial to ensure that land continues to provide its functions now and in the future.

2.1.2 Due to a UN initiative land degradation in Europe reaches a new momentum

With the adoption of the UN Sustainable Development Goals in 2016, European countries which are party to the UNCCD and the EU have committed themselves to implementing 'Land Degradation Neutrality' (LDN) in their mandate areas in the period up till 2030. The actions of Member States to address soil threats are considered important in the process to improve soil protection (Frelih-Larsen et al. 2017). Therefore, the European Commission wants to support Member States to address threats to soil and other symptoms of land degradation in their national sectoral policy mechanisms, and in their efforts to achieve *LDN*. Providing a framework with common standards to map the actual state and development of land degradation could support this process. Despite the wide range of approaches to map symptoms of land degradation, and the evidence base available in the numerous spatial datasets available (see chapters 4-6), such a framework is currently not available for the European scale. The main reason seems to be that land degradation includes a range of symptoms, leading to the loss of a range of ecosystem services, and that there is no consensus on how to measure and assess these in an integrated way according to a common standard for Europe and EU Member States. In addition, the implications of land degradation for human well-being are perceived and valued differently between actors in European societies.

2.2 Strategic documents and policy guidelines at European level

The **Soil Thematic Strategy** (COM(2006) 231) (EC 2006a), published in 2006, has the overall objective to protect soil functions and to promote a sustainable use of soil resources across the EU. The guiding principles are the prevention of soil degradation and the restoration of degraded soils. The Strategy aims to coordinate the integration of soil protection in national and EU policies, including policies for agriculture, regional development and transport (EEA 2016c).

The **Roadmap to a Resource Efficient Europe** (EC 2011a)[10] states as a milestone that 'By 2020, EU policies take into account their direct and indirect impact on land use in the EU and globally, and the rate of land take is on track with an aim to achieve no net land take by 2050, soil erosion is reduced and the soil organic matter increased, with remedial work on contaminated soils well underway.'

The **7th Environmental Action Program** (7EAP) (2014-2020) (EC 2013d), published in 2013 and endorsed by the European Council and Parliament, has two land-related objectives: 1. protect and improve the EU's natural capital; 2. transformation of the EU into a resource efficient, green and competitive and low carbon economy. It explicitly refers to land degradation effects on the provision of ecosystem services. The target for land under the first objective is (for 2020): ' ...land is managed sustainably in the Union, soil is adequately protected, and the remediation of contaminated sites is well under way.' The 7EAP also refers to the goal of a 'land degradation neutral world', resulting from the 2012 Conference on Sustainable Development (Rio +20) and strives to '... increasing efforts to reduce soil erosion and increase soil organic matter, to remediate contaminated sites, and to enhance the integration of land use aspects into coordinated decision-making, involving all relevant levels of government, supported by the adoption of targets on soil and on land as a resource, and land planning objectives'.

The **EU Strategy on adaptation to climate change** (EC 2013a), adopted by the European Commission in 2013, provides a coordination mechanism, funding and knowledge to make Europe more resilient to adverse impacts from climate change. It encourages Member States to adopt climate adaptation strategies, and promotes adaptation measures in, among others, areas vulnerable to land degradation, e.g. from increased frequencies and intensity of heat waves, forest fires, heavier precipitation and flooding.

The **EU Biodiversity Strategy to 2020** (EEA 2016d) has six targets to protect and enhance ecosystems and their services, by conserving and restoring nature (1), establishing green infrastructure and restoring degraded ecosystems (2), sustainable agriculture, forestry and fishery (3, 4), combatting invasive alien species (5) and addressing the global biodiversity crisis (6). Measures encouraged by the strategy - e.g. measures to integrate biodiversity protection into the CAP, such as cover and catch crops - could help to remediate multiple forms of land degradation[11] apart from the types of biological degradation (e.g. soil erosion, decrease of average soil moisture content and soil compaction for the example given). The European Commission has developed a **Green Infrastructure Strategy** (EC 2013c) to promote the use of green infrastructure to protect, conserve and enhance the EU's natural capital, and to ensure that green infrastructure becomes an integral element of spatial planning and territorial development.

Two other strategies adopted by the European Commission recognise changes in land use and infrastructure development as drivers for land degradation, specifically in forested and urban land: the **EU Forestry Strategy** (EC 2013b) and the **Thematic strategy on the urban environment** (EC 2006b). The management responses called for by these strategies include a sustainable use of forests to ensure their multiple ecological, economic and social functions, land use planning and regeneration of brownfield sites for the urban environment (EEA 2016c).

Very recently, **The European Court of Auditors (ECA, 2018)** published a special report whether the risk of desertification and land degradation was appropriately addressed in the EU. This report concludes that, despite the growing imminence of those two phenomena, the Commission lacks a clear picture of the situation and has only taken incoherent steps to combat those threats. The ECA, therefore, strongly recommends to establish a methodology and relevant indicators to better understand and assess desertification and land degradation and their extent. Based on the established methodology, relevant

10 The Resource Efficiency Roadmap is part of the Resource Efficiency Flagship of the Europe 2020 Strategy. The Europe 2020 Strategy is the European Union's growth strategy for the next decade and aims at establishing a smart, sustainable and inclusive economy with high levels of employment, productivity and social cohesion.

11 see chapter 3.1 for the typology of land degradation types used in this report.

data should be collected, analysed and provided to the public in a user-friendly way. In addition, the appropriateness of the existing legal framework should be assessed and enhanced, if deemed necessary, in order to meet the commitment made by the EU and member states to achieve land degradation neutrality by 2030.

2.3 Sectoral EU policies

In the report “*The direct and indirect impacts of EU policies on land*” (EEA 2016d), objectives and impacts on land degradation of four sectoral EU policies, namely **Cohesion Policy, Transport Policy, Energy Policy and the Common Agriculture Policy (CAP),** were analysed. The study found large differences in the coherence of policy and legislation of these four domains with the land objectives of the EU in the strategic documents listed above.

The CAP was found to have increasingly taken on objectives for land management, while the Cohesion Policy was found to not to consider impacts on land or soil. Although quantitative evidence across the EU was not presented, all four policy sectors were found to have important impacts on land degradation in Europe, above all

- urban sprawl and land take due to Cohesion Policy,
- soil sealing and land fragmentation due to Transport Policy and Energy Policy, and
- land degradation resulting from land use change and intensive agriculture due to Energy Policy and the CAP.

The study found that the impacts were not all negative: structured planning was found to contribute to mitigating negative impacts of Cohesion Policy instruments on soil and biodiversity; and cross-compliance under the CAP was concluded to have helped reducing land degradation.

There are opportunities for soil protection in the **climate and energy policies** for the period 2020-2030 through improved management of soil organic matter and the reduction of the use of inorganic fertilisers. Among these, the Land Use and Land Use Change and Forestry Regulation (LULUCF) and Effort Sharing Regulation (ESR) require a reduction of greenhouse gas emissions from among others the agricultural sector up to 2030 (Frelih-Larsen et al. 2017).

The ‘*Updated Inventory and Assessment of Soil Protection Policy Instruments in EU Member States*’ by (Frelih-Larsen et al. 2017) collected information on existing soil protection policies and measures at EU-level and in all 28 EU Member States. The study examined how soil threats and functions were covered in EU policies, and how Member State instruments complemented and addressed the gaps found in the EU legislation. It highlights the lack of a strategic policy framework for a good soil status in Europe. It finds that soil protection in policy instruments is an outcome mostly derived from targets addressing other environmental resources. For most Member States, the study concludes that gaps from EU policies were only partly overcome by nationally initiated policy instruments. Also, the study points out that EU law are not very explicit regarding the functions and services provided by soils.

The Updated Soil Inventory study identified the **CAP** as the key policy to protect the soil component of agricultural and forest land. The rules under Green direct payments in Pillar 1 oblige Member States to define minimum standards for soil protection at the national or regional level. In the Rural Development Programmes (RDP) of Pillar 2, Member States and regions can get financial support to fund measures for sustainable land management tailored to their specific priorities and needs.

However, according to a recent assessment of CAP instruments (ECORYS et al. 2016), the funding available and the intended use in the CAP are insufficient to address environmental and climate needs and priorities of the Member States. In Pillar 1, the opportunities from greening measures to establish a basic level of environmental management across EU farmland have not been fully used. The study found that the environmental and climate targets identified within the RDPs are low considering the scale of the challenges faced. The study concluded that 'Overall, there is still considerable room for improvement in designing approaches that use multiple measures and instruments across both Pillars in ways that are synergistic to achieve the outcomes required to address the CAP general objective 'sustainable use of natural resources and climate action'.

2.4 Strategic documents and policy guidelines at the international level

The UN Rio+20 Summit's call for a 'land-degradation-neutral world' (LDNW) and the 'target of zero net land degradation' (LDN) were included in the approved **Sustainable Development Goals (SDGs)** and are part of target 15.3. The EU has subscribed to the SDGs and will need to implement them by 2030. The SDG negotiation process has achieved an international consensus on the implications of these goals. The UNCCD invited all Parties to formulate voluntary targets to achieve LDN in accordance with their specific national circumstances and development priorities. The UNCCD has reached an international consensus on a definition of LDN. Furthermore, the UNCCD Science-Policy Interface (SPI) has developed a scientific conceptual framework for LDN to guide countries in operationalising this definition (UNCCD/Science-Policy-Interface 2016) (Orr et al. 2016).

This framework proposes that monitoring of LDN be based on evaluating the significant changes (positive and negative) of three global indicators, which serve as proxies for most ecosystem services:

- land cover/land cover change
- land productivity/NPP
- carbon stock/SOC.

In 2018 the first round of national reporting took place, when Member States were provided with prefilled data sets for land degradation. The framework encourages countries to complement the 3 global indicators with national (or sub-national) level indicators and local contextual information to provide full coverage of the ecosystem services associated with the land that are important in each context. The LDN-framework is discussed in relation to land degradation mapping for Europe in chapter 7.

The other environmental conventions of the UN, the Convention on Biological Diversity and the UN Framework Convention on Climate Change also have aspirations to improve land conditions, because biodiversity underpins ecosystem services from land, and because land plays a major role in climate adaptation and mitigation (e.g. through climate-smart agriculture). (Wunder et al. 2016) signal that opportunities exist to achieve land degradation neutrality through actions under the three conventions, referring to the publication of (Akhtar-Schuster et al. 2016).

The assessment report on land degradation by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (see page 12) was prepared in view of meeting two global targets, namely (i) to achieve land degradation neutrality by 2030, as agreed in SDG 15.3), and (ii) to restore at least 15% of degraded ecosystems globally, by 2020 as defined in Aichi Biodiversity Target 15 (CBD, 2011).

The **World Soil Charter** endorsed by the members of the Food and Agriculture Organisation of the United Nations is a non-legally binding policy instrument to promote and organise Sustainable Soil Management (SSM). The related **Voluntary Guidelines for Sustainable Soil Management (VGSSM)** have been adopted by all FAO members at the FAO General Assembly in December 2016.

2.5 Considerations for land degradation mapping

Respond to environmental policy targets. The above overview of key strategies and policies addressing land degradation shows, that there is not a single strategic policy framework that preserves and enhances land resources in the EU. Moreover, objectives to halt and revert land degradation are dispersed over a range of strategic documents and policy guidelines at the EU and international level, and across policy instruments of various sectors and land uses. This suggests that a framework for monitoring the state and trend of land degradation should use mapping variables that can be related to environmental targets. For example targets for climate mitigation or biodiversity conservation.

Visibility of Driving Forces. Also, a mapping framework should include spatially explicit information on drivers related to sectoral policies, for example on agricultural management practices, population dynamics or the spatial impact of structures for renewable energy.

Multiple information for regional assessments. A mapping framework should provide answers to questions such as: which land degradation types occur in a defined region, do they relate to each other, and which drivers are behind them?

Impact assessment of implemented measures. Ecosystem services are negatively impacted by land degradation but can also improve through land restoration. The mapping framework should support the evaluation of implemented measures, for example green infrastructure, nature protection or climate-smart agricultural practices. Policy impact assessments often lack quantitative and spatially explicit information on the uptake and actual implementation of measures resulting from plans and investments. Such information is only partly available in national agencies or in EUROSTAT. Important collections of this information at national and regional level are being made in EU-funded research projects and projects under the LIFE Programme, and will be made for the implementation of the LDN-framework. Environmental assessments under the SEA and EIA legislations could provide another source of spatial information at country level on the implementation of programs and projects.

Distinction between historic and current land degradation. Land degradation phenomena can result from processes in the past, for example historic contamination from industry and mining, or the 'badland' landscapes in Mediterranean countries. A mapping framework should enable the distinction between historic and active land degradation.

3 Current approaches towards land degradation mapping

The aim of this chapter is to briefly list some of the key concepts relevant for a method to map impacts of land degradation on ecosystem services, and how these are currently approached by policy and scientific communities.

3.1 Definitions of land degradation

Many definitions of land degradation have been postulated since the beginning of the 20th century, expressing different perspectives on the relationships of people to land. The UNCCD definition for land degradation (see Box 3.1) is globally most frequently used.

Box 3-1: Land degradation according to UNCCD

"Land degradation is defined as the reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or rangeland, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation"

Source: UNCCD (1994)

Although initially confined to drylands, in its ten-year strategy, the UNCCD is increasingly positioning itself as an instrument that can make a lasting global contribution to the achievement of sustainable land management, also in areas not labelled as drylands. Vogt et al. (2011) emphasized the need to have an agreed definition for monitoring and assessing land degradation and response programs, and provided an instructive overview of the discussion on the definition of land degradation.

Several definitions can be found in influential reports:

- the *Millennium Ecosystem Assessment* (Reid et al 2005),
- the book on *Land Degradation, Desertification and Climate Change* by (Reed & Stringer 2016), endorsed by the UNCCD,
- the *Status of the World's Soil Resources Report* from the Intergovernmental Technical Panel on Soils (FAO 2015b),
- the *Assessment Report on Land Degradation and Restoration* of the IPBES (IPBES 2018),
- the IPCC special report for 2018 (IPCC 2018), and
- the JRC report *on Land Productivity Dynamics in Europe* (Cherlet et al. 2013).

This confirms, that despite many attempts there is no generally accepted definition of land degradation in environmental science and policy. As phrased by several experts participating in the expert meeting on land degradation organised by EEA in 2016, a problem with defining land degradation is that what one group of people might view as degradation, others might view as a benefit or opportunity[12]. The policy report with scenarios for the UNCCD's Global Land Outlook by (Van der Esch et al. 2017) makes an explicit choice to not directly quantify 'land degradation' because of the differences among definitions and the subjectivity of the term itself. Instead, the study assessed changes in land condition and ecosystem functions relative to the natural or undisturbed state to determine human impact.

There are common elements in the definitions however: declining land functions, soil functions, ecosystem functions or ecosystem services, all expressions providing information on the benefits humans derive from terrestrial ecosystems. The definition of Reed et al. (2015) in Box 3-2 refers specifically to those human benefits by referring to 'the flow of ecosystem services to society', 'the capacity of the land system to meet its user demands' and 'the populations who depend on the ecosystem'.

12 Hill, J., Ten Brink, B. and Van Lynden, G. (pers. comm.)

Box 3-2: Some recent definitions and concepts of land degradation.

"In summary it can be said that land degradation is

- a phenomenon caused by human activities and exacerbated by certain climate and topographic characteristics,
- is characterized by changes in ecosystem processes and levels of natural capital that affect the flow of ecosystem services to society,
- causes an effectively permanent decrease in the capacity of the land system as managed to meet its user demands, and
- is a threat to the long-term biological and/or economic resilience and adaptive capacity of the ecosystem and the populations who depend on it."

Source: Revised definition by Reed et al. (2015): Outcomes from the UNCCD 3rd Scientific Conference on Climate Change and Land Degradation.

"In Europe land degradation can be considered in terms of the loss of actual or potential productivity or utility as a result of natural or anthropic factors; it is the decline in land quality or reduction in its productivity. ....
In the context of productivity, land degradation results from a mismatch between land quality and land use."

Source: EEA (2016): The direct and indirect impacts of EU policies on land

"…degraded land" is defined as land in a state that results from persistent decline or loss of biodiversity and ecosystem functions and services that cannot fully recover unaided within decadal time scales.
'Land degradation', in turn, refers to the many processes that drive the decline or loss of biodiversity, ecosystem functions or services and includes the degradation of all terrestrial ecosystems.
'Restoration' is defined as any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state."

Source: IPBES (2015)

" …long-term loss of ecosystem function and productivity caused by disturbances from which land cannot recover unaided"

Source: Bai et al. (2008)

'..the persistent reduction or loss of land ecosystem services, notably the primary production service'

Source: Vogt (2011)

3.2 Land degradation and ecosystem services

As expressed in most commonly used definitions, land degradation comprises a spectrum of processes which can lead to a loss of ecosystem functions and/or productivity, leading to a reduction in ecosystem services. Since the Millennium Ecosystem Assessment (Hassan et al. 2005) many policy documents seem to have adopted the Ecosystem Service Approach as a basis for policy design and monitoring. However, many different terms are used to describe land as a terrestrial ecosystem with functions that provide services and benefits:

- The EU Soil Thematic Strategy introduces soil functions as the underlying mechanisms to deliver soil-based ecosystem services.
- The 7th EAP addresses ecosystem services, ecosystem conditions and soil functions.
- The 'land (use) functions' concept was introduced in 2006 by the EU SENSOR project (Helming et al. 2008).
- DG Environment introduces the concept of 'land (use) services' in 2008 (e.g. (IEEP & Alterra 2010).
- The soil function approach is followed by several research groups; i.e. Tóth et al. (2013), the MAES Soil Pilot (MAES Working Group 2017) and the EU LANDMARK and RECARE projects ((Schulte et al. 2014) (Schwilch et al. 2016)).
- In the EU approach towards implementing the LDN-framework (Delsalle 2016) the focus is on 'land use functions based on natural capital'.

- EEA published a report that for the first time assesses land cover changes and their effect on soil functions (ETC/ULS 2019)

As explained in chapter 5.1, soil degradation is a central factor of land degradation, but covers a smaller range of aspects as it is limited to soil functions and soil threats.

3.2.1 Mapping and Assessing Ecosystem Services

The **MAES initiative** (Mapping and Assessment of Ecosystems and their Services) undertakes the mapping of ecosystem conditions and ecosystem services in support of the EU Biodiversity Strategy 2020 and the Europe 2020 strategy to build smart, sustainable and inclusive growth for the EU[13]. EU Member States are actively involved in mapping and assessing the state of ecosystems and their services in their national territory. At EU level MAES-related activities are supported by the European Environment Agency and its Topic Centers, the Joint Research Centre, Eurostat, DG Research & Innovation.
The achievements of the MAES action include among others the mapping and assessments of the condition of ecosystems in Europe and in EU Member States and recommendations for 'Best available indicators' for ecosystem services (Maes et al. 2016, EEA 2015b). There were 6 MAES pilot projects on agro- and forest ecosystems, marine and freshwater ecosystems, urban ecosystems and the 'soil pilot'. The latter is considering integration of soil as a separate ecosystem type in the MAES.

Another recent activity to support the development and sharing of knowledge on ecosystem services and natural capital is the **OPPLA platform**[14], a collaboration between research institutes, universities, agencies and enterprises, launched under the OPERAs and OpenNESS projects funded by the European Commission.

***3.2.2** Global initiatives mapping land degradation*

Mapping the outcomes of various land degradation processes to a single expression of a 'degraded state' of the land is difficult, if not impossible. This is because the processes operate over different domains of space and time, in different regions, and are difficult to observe and measure.

This is why the **World Atlas of Desertification** (WAD) has taken the approach to map 'issues' related to land degradation without attempting to interpret these in terms of land degradation as a state or an ongoing process (see chapter 6.2). Instead, it is left for those using the land to interpret these issues as a land degradation process or not. Furthermore, the WAD addressed land degradation in terms of "convergence of evidence" of several issues affecting the land instead of quantifying the degraded state.

The IPBES report 'Mapping global land degradation and restoration' (IPBES 2018) and "The Global Land Outlook" by UNCCD (Van der Esch et al. 2017) have taken a different approach. These reports addressed changes in functions and services of terrestrial ecosystems due to the change in land condition in separate thematic layers. The land condition is defined in the study as the potential of land to provide people with various types of services. This project created a model framework that can produce global maps of historic and future changes in four types of 'land functions': water-related functions, food production, biodiversity and climate functions. These output variables are clear expressions of some of the main well-recognised ecosystem services in all categories of the ecosystem service framework, which are easy to interpret and to use for policy response.

13 Mapping and Assessment of Ecosystems and their Services - MAES http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm

14 OPPLA, the EU Repository of Nature-Based Solutions. http://www.oppla.eu

3.3 Land restoration

Land restoration refers to what societies can do to fight situations of degradation, or the 'Response' component of the DPSIR-framework[15]. Mapping restoration activities and their impacts on land condition is necessary to assess and monitor the state and trend of land degradation. The term 'land restoration' is used as synonym for improving the land capacity to provide goods and services.

Following the concepts and definitions of FAO and WOCAT, these activities can be subdivided into prevention, mitigation and rehabilitation (FAO 2017b):

- Prevention implies the use of conservation measures that maintain natural resources and their environmental and productive properties.
- Mitigation stands for intervention intended to reduce ongoing degradation.
- Rehabilitation is required when the land is already degraded to such an extent that the original use is no longer possible and the land has become practically unproductive.

The UNCCD's conceptual framework for LDN reserves the term 'restoration' to indicate options for reversing land degradation to obtain the 'original state' or some reference condition (Akhtar-Schuster et al. 2016). This 'original state' may not correspond to the condition desired by stakeholders. In addition, the definition by FAO and WOCAT allows more activities to be considered as 'land restoration'. For these reasons we employ the definition of land restoration by FAO and WOCAT in this document.

Land restoration in the European context is addressed in many ongoing land-related research projects, often under the name Sustainable Land Management (e.g. in the EU-funded projects SOILCARE, RECARE, CASCADE, LANDMARK, SMARTSOIL, DESIRE, the Global Restoration Project, ISQAPER, ECOPOTENTIALS, INSPIRATION) and is also included in the science-policy developments at the UNCCD (the Scientific Conceptual Framework for LDN, UNCCD Global Land Outlook), the FAO and the Global Soil Partnership (the Revised World Charter on Soils, the Voluntary Guidelines on Sustainable Soil Management) and other international bodies dealing with land (e.g. the IPBES Thematic Assessment on Land Degradation and Restoration, WOCAT).

In recent years the initiative Economics of Land Degradation (ELD[16]) has gained importance. ELD emphasises that the cost of action to mitigate or restore land degradation was six times lower than the cost of inaction. The aim of the ELD Initiative is to increase and strengthen awareness of the economics of land degradation and sustainable land management in the scientific, political and public discourse. The ELD initiative is mainly active in Asia and Africa with measures regarding research, capacity-building, and active knowledge exchange.

3.3.1 IPBES Assessment on Land Degradation and Restoration

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is an independent intergovernmental body, established by more than 100 governments in 2012. The objective of IPBES is to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development. In 2018 IPBES published *The Assessment Report on Land Degradation and Restoration* (IPBES 2018).

The report is a scoping document and includes the latest scientific peer-reviewed literature and published knowledge in the public domain in order to assess the extent, causes and processes of land degradation

15 The causal framework for describing the interactions between society and the environment adopted by the European Environment Agency: D = driving forces, P = pressures, S = states, I = impacts, R = responses (extension of the PSR model developed by OECD).

16 The Economics of Land Degradation initiative, https://www.eld-initiative.org/en/publications/eld-publications/#c768

and the resulting consequences for people and the land. The report represents a comprehensive knowledge base of land degradation; discussing perceptions to land degradation but also land restoration. It discusses status and trends of land degradation and restoration and associated changes in ecosystem services and functions and human-well being. It evaluates responses to restoration and rehabilitation of degraded lands and how future degradation can be avoided and reduced. Last not least the report includes a summary for policy makers.

Objectives. The IBPES assessment report follows two major objectives with regard to halting and restoring land degradation, namely (i) to achieve land degradation neutrality by 2030, as agreed in SDG 15.3 (see also chapters 2.4 and chapter 7), and (ii) to restore at least 15% of degraded ecosystems globally, by 2020 as defined in Aichi Biodiversity Target 15 (CBD, 2011).

Methodology. Each chapter is summarised by key findings, of which the degree of confidence is qualified by four levels of confidence, being

- Well established: comprehensive meta-analysis or other synthesis or multiple independent studies that agree.
- Established but incomplete: general agreement although only a limited number of studies exist; no comprehensive synthesis and/or the studies that exist address the question imprecisely.
- Unresolved: multiple independent studies exist but conclusions do not agree.
- Inconclusive: limited evidence, recognizing major knowledge gaps.

Figure 3-1: The qualitative communication of confidence according to IPBES

Source: IPBES (2018)

Responses. The assessment goes far beyond monitoring land degradation as it examines societal and economic dependencies of land degradation and calls for a low per capita consumption and less growth oriented world economy. A large part of the report discusses possible responses to degradation processes that are induced by humans and also qualifies responses according to their effectiveness. Table 3-1 provides an overview of responses to different degradation types and their effectiveness, addressing cropland degradation, forest land degradation, rangeland degradation, urban land degradation, and wetland degradation.

Key findings. The report concludes that

- Economic growth and per capita consumption, more than poverty, are among the biggest threats to sustainable land management globally.
- The most cost-effective approach to reduce land degradation in the long run is to follow the adage “prevention is better than cure”. The benefits of taking action (restoring degraded land) are higher than the costs of inaction (continuing degradation).
- There is an urgent need for the development of appropriate degradation and restoration indicators and strengthening of existing measurement and monitoring programmes.
- A global consensus on the definition and baseline for land degradation does not exist, precluding sound scientific assessment of the extent and severity of global degradation, as well as the possibility of measuring success towards quantitative restoration targets such as Aichi Biodiversity Target 15 reinforced in Sustainable Development Goal 15.

Table 3-1: Summary of direct biophysical and technical responses, their nature and relative effectiveness in avoiding, reducing or reversing degradation of cropland, forest land, rangeland, urban land and wetland

Source: IPBES 2018

LAND USE OR DEGRADATION DRIVER	RESPONSE OPTIONS	NATURE OF RESPONSE	RESPONSE EVALUATION CRITERIA AND EFFECTIVENESS RANKING (COLOUR-CODED)					
		Avoid (Av), Reduce (Rd), Reverse (Rv)	Economic feasibility	Social accepta-bility	Environ-mental desirability	Cultural accepta-bility	Technical feasibility	Political accepta-bility
CROPLAND MANAGEMENT	Conservation agriculture	Av, Rd	High effectiveness	High effectiveness	High effectiveness	High effectiveness	Moderate to high effectiveness	Low effectiveness
	Agroforestry	Av, Rd, Rv	Moderate effectiveness	Moderate to high effectiveness	High effectiveness	High effectiveness	Moderate to high effectiveness	Moderate effectiveness
	Integrated crop, livestock and forestry systems	Av, Rd, Rv	Moderate effectiveness	Moderate to high effectiveness	High effectiveness	High effectiveness	Moderate to high effectiveness	Moderate effectiveness
	Enhanced plant genetics	Rd	Moderate to high effectiveness	Moderate effectiveness	Moderate to high effectiveness	Low effectiveness	High effectiveness	Low effectiveness
	Agroecology	Av, Rd, Rv	Moderate to high effectiveness	High effectiveness	High effectiveness	High effectiveness	Moderate effectiveness	Moderate effectiveness
	Landscape approach	Av, Rd, Rv	High effectiveness	Moderate effectiveness	High effectiveness	Low effectiveness	Moderate effectiveness	Moderate effectiveness
FOREST LAND MANAGEMENT	Agroforestry	Av, Rd, Rv	Moderate to high effectiveness	High effectiveness	High effectiveness	Moderate effectiveness	Moderate to high effectiveness	Variable effectiveness (low to high)
	Protected areas	Av	Low to moderate effectiveness	Moderate to high effectiveness	High effectiveness	High effectiveness	High effectiveness	Variable effectiveness (low to high)
	Sustainable forest management	Av, Rd	Moderate to high effectiveness	Variable effectiveness (low to high)	High effectiveness	Low effectiveness	High effectiveness	Variable effectiveness (low to high)
	Reduced impact logging	Rd	Moderate effectiveness	Low effectiveness	High effectiveness	Variable effectiveness (low to high)	High effectiveness	High effectiveness
	Landscape approach	Av, Rd, Rv	High effectiveness	High effectiveness	High effectiveness	High effectiveness	High effectiveness	High effectiveness
	Restoration (active and passive)	Rv	Variable effectiveness (low to high)	Moderate to high effectiveness	High effectiveness	Variable effectiveness (low to high)	Moderate to high effectiveness	Variable effectiveness (low to high)
RANGELAND MANAGEMENT	Grazing management	Av, Rd, Rv	Moderate to high effectiveness	Moderate to high effectiveness	Moderate to high effectiveness	Low to moderate effectiveness	Low to moderate effectiveness	Variable effectiveness (low to high)
	Pasture rotation	Av, Rd	High effectiveness	Moderate effectiveness	Moderate to high effectiveness	Low to moderate effectiveness	Moderate effectiveness	Low effectiveness
	Controlled burning	Av	High effectiveness	High effectiveness	Low effectiveness	Moderate effectiveness	High effectiveness	Low effectiveness
	Fencing	Av, Rd	Low to moderate effectiveness	Low to moderate effectiveness	Low effectiveness	Moderate effectiveness	Moderate effectiveness	Moderate effectiveness
	Replanting	Rv	Moderate to high effectiveness	Moderate to high effectiveness	Moderate to high effectiveness	Moderate to high effectiveness	Moderate to high effectiveness	Low effectiveness
	Intercropping	Av, Rd, Rv	High effectiveness	Moderate effectiveness	Moderate to high effectiveness	Moderate effectiveness	Low to moderate effectiveness	Low effectiveness
	Weed and pest control	Rd, Rv	Moderate effectiveness	Moderate effectiveness	Low to moderate effectiveness	Low effectiveness	Low effectiveness	Moderate effectiveness
URBAN LAND MANAGEMENT	Green space management	Av, Rd	Moderate effectiveness	High effectiveness	High effectiveness	Moderate effectiveness	High effectiveness	Moderate to high effectiveness
	Street tree planting	Rv	Moderate effectiveness	High effectiveness	High effectiveness	Moderate effectiveness	Moderate to high effectiveness	Moderate effectiveness
	Brownfield restoration	Rv	Low effectiveness	High effectiveness	High effectiveness	High effectiveness	Moderate effectiveness	High effectiveness
	Removal of invasive species	Rv	Moderate effectiveness	High effectiveness	High effectiveness	High effectiveness	Moderate effectiveness	High effectiveness
	Green infrastructure development	Av, Rd	Low to moderate effectiveness	Moderate effectiveness	High effectiveness	Low effectiveness	Moderate effectiveness	Low to moderate effectiveness
	Amelioration of contaminated soils and sealed soils	Rv	Moderate effectiveness	Moderate effectiveness	High effectiveness	Moderate effectiveness	Moderate effectiveness	Moderate effectiveness
	Sewage and wastewater treatment	Av, Rd	Low effectiveness	Low to moderate effectiveness	High effectiveness	Variable effectiveness (low to high)	Moderate effectiveness	Moderate to high effectiveness
	River channel/beach site restoration	Rv	Moderate to high effectiveness	High effectiveness	High effectiveness	Moderate effectiveness	Variable effectiveness (low to high)	Low to moderate effectiveness
WETLAND MANAGEMENT	Protected areas	Av	Moderate to high effectiveness	High effectiveness	High effectiveness	High effectiveness	High effectiveness	Variable effectiveness (low to high)
	Control of point pollution sources	Av, Rd	High effectiveness	Moderate effectiveness	High effectiveness	Low to moderate effectiveness	Moderate to high effectiveness	Moderate effectiveness
	Control of non-point pollution sources	Av, Rd	Low effectiveness	Low effectiveness	High effectiveness	Low to moderate effectiveness	Low to moderate effectiveness	Low effectiveness
	Passive measures to allow natural recovery (e.g., control of human/ livestock pressures)	Rd, Rv	Low effectiveness	Moderate to high effectiveness	High effectiveness	High effectiveness	High effectiveness	High effectiveness
	Active restoration measures (e.g., reshaping topography and hydrology, revegetation, invasion control)	Rd, Rv	Moderate to high effectiveness	Variable effectiveness (low to high)	High effectiveness	High effectiveness	High effectiveness	Variable effectiveness (low to high)
	Constructed wetlands	Rv	Low effectiveness	Moderate effectiveness	Moderate to high effectiveness	Low to moderate effectiveness	Moderate effectiveness	Moderate effectiveness

EFFECTIVENESS RANKING OF RESPONSE OPTIONS

High effectiveness | Moderate to high effectiveness | Moderate effectiveness | Variable effectiveness (low to high) | Low to moderate effectiveness | Low effectiveness

4 Evolution of land degradation mapping

The chapter explains the evolution of land degradation assessments over time and discusses their knowledge gain and weaknesses.

4.1 Introduction

Land degradation may be defined in various ways, as discussed in chapter 3.1. A common denominator in all these definitions is that land degradation is a change in the condition of land over time, that is considered to be detrimental to ecosystem services. Land degradation is most often associated with the degradation of soil resources.

Ecosystems functions, and productivity are, however, results of multiple factors, including

- natural factors like inherent soil properties, hydrological conditions and climate,
- management factors, including soil, water, nutrient and pest management, and
- plant properties, including resource use efficiency and adaptability (which can be improved).

Consequently, degradation of the natural conditions of land productivity does not necessarily result in an actual decrease in productivity. **Productivity may even improve under degraded soil conditions, with changing natural factors (i.e. climate and hydrology), improvement of technology or new cultivars.** Degradation and productivity can increase at the same time on the same site.

4.2 Land degradation mapping at global scale

Caspari (et al. 2015) provided an overview of land degradation assessments that involved mapping at global scale. Many of the assessments included mapping of soil degradation as a basis for land degradation. The review showed that mapping of global land degradation started in the 1970's after the severe drought in the Sahel from 1968-1972. The focus initially was on drylands and on desertification. For example, UN General Assembly (1977) and Mabbutt (1984), both using expert judgement, arrived at similar global desertification status figures that indicated that about 75% of all productive land in the drylands was desertified (Caspari et al. 2015). As described by Caspari et al. (2015), these figures are nowadays usually considered too pessimistic, partly because at the time of the research no distinction was made between degradation level and degradation risk. Since these early attempts, several other maps of global land degradation have been produced, in particular

- GLASOD (Global Assessment of Human-induced Soil Degradation; Oldeman et al 1991),
- the Millennium Ecosystem Assessment (MA, 2005),
- GLADA (Global Assessment of Land Degradation and Improvement), and
- GLADIS (Global Land Degradation Information System).

These are described in detail by Caspari et al (2015).

Table 4-1: Global assessments of land degradation

Source: based on (Caspari et al. 2015)

	Method	Results	Advantages	Criticism and limitations
GLASOD (1987-1990)	Drylands; semi-quantitative judgement by 300 experts worldwide	About 15% of land surface degraded	First global assessment of land degradation; succeeded as awareness raising tool	Subjective, Focus on human-induced changes, focus on soil erosion
MA (2001-2005)	Desktop study with 1000 experts, analysis of land degradation only for drylands; based on remotely sensed greenness	10-20% of drylands affected by desertification between 1981 and 2000	Looked at the link between ecosystems and human well-being; very large amount of information assembled that facilitates new assessment technologies	NDVI as proxy for land degradation, focus on production function, costs of degradation not included
GLADA (2006-2009)	Desktop study using NDVI, focussing on production function	Nearly 24% of the world's land area has undergone degradation in the period 1981-2003 (Bai et al. 2008); 78% of degraded areas were outside the drylands	Implementation of reproducible and quantitative approach; relatively cheap and rapid	8 km resolution, focus on NPP, information about change not about state, NDVI as proxy for land degradation
GLADIS (2009-2011)	Desktop study (GIS, indices), looking at delivery of ecosystem services	Biophysical status of 9% land are very low, 31% low	Ecosystem approach looking at several goods and services (thus broader than GLADA), using interdisciplinary approach and time dimension; does justice to complexity of degradation	Lack of data with sufficient detail and resolution, which limits the calculation of aggregated indices
Global Land Degradation Hotspots (Le et al, 2014)	Desktop study using long-term trend of inter-annual NDVI (considered a follow-up of GLADA by (Caspari et al. 2015))	Degradation hotspots cover about 29% of global land area	Addresses limitations of use of NDVI identified in earlier studies	Not clear to what extent limitations of using NDVI have successfully been addressed; this is not evaluated.

In recent years, several assessments have been conducted, or are being conducted. These include:

- IPBES 2018 (intergovernmental Platform for Biodiversity and Ecosystem Services): Land Degradation and Restoration Assessment.
- World Atlas of Desertification (WAD; http://wad.jrc.ec.europa.eu/atlas). The introductory brochure (Cherlet et al, 2015) presents the framework that underlies the atlas. The WAD presents a number of global datasets to identify ongoing processes that can result in land degradation, and relies on a convergence of evidence in these datasets to identify land degradation locally.
- FAO (2015b): Status of the World's Soil Resources. Detailed report based on well documented and peer reviewed information; thus providing a baseline of available knowledge in 2015.

- UNCCD: Global Land Outlook (UNCCD 2017) and LDN framework. This framework proposes that monitoring of LDN be based on evaluating the significant changes (positive and negative) in three global indicators (via associated metrics) which serve as proxies of most ecosystem services flowing from land-based natural capital: land cover/land cover change, land productivity/NPP, carbon stock/SOC. The LDN framework is elaborated in chapter 0.
- IPCC: Special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (IPPC 2018).

This multitude of recent and ongoing assessments shows the relevance of the topic, e.g. in relation to SDGs (in particular 15.3) and for issues of global relevance, such as food security and climate change adaptation. Global agreements require that degradation is monitored, and Land Degradation Neutrality is achieved. Thus, policy relevance is high at global as well as at EU and national levels. However, the large number of assessments also suggests duplication of efforts as there are overlaps and commonalities in the different approaches. On the other hand, there are also differences in focus and methods, so that the different assessments also complement each other.

(Caspari et al. 2015) divided the different approaches at global level in the following categories:

- Expert-based or qualitative assessments.
- Remote-sensing-based assessments.
- Modelling approaches.

They also discussed advantages and drawbacks of each approach, and concluded that a combination of approaches is needed to tackle the challenge of land degradation, in particular to combine data from remote sensing with in-situ measured data. This is ascribed to the fact that degradation is a complex issue; it is multi-dimensional, multi-scale, transitional, multi-perspective and there are multiple drivers and actors. Similar conclusions regarding the complexity of degradation have been drawn by various other authors, including Reynolds et al. (2007), Vogt et al (2011), Hessel et al (2014a) and (Cherlet 2015). These publications show that land degradation occurs in coupled human-environmental systems, and that therefore any framework for assessment or response must simultaneously involve both biophysical and socio-economic factors. The complexity of the issue also results in site-specific problems; hence solutions need to be site specific too, as recognised by e.g. Cherlet (2015).

5 Soil degradation mapping as central factor for land degradation mapping

The chapter explains why soil degradation is central to land degradation. We illustrate the key concept of soil degradation mapping and how it is mapped at continental scale.

5.1 Definitions of soil degradation

In most cases, soil degradation is the major underlying process of land degradation, therefore its assessment is essential in understanding the complete system of land degradation.

Box 5-1: Soil degradation according to FAO

Soil degradation is defined "as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries". Degraded soils "have a health status such, that they do not provide the normal goods and services of the particular soil in its ecosystem".

Source: FAO (2017a)

Soil degradation occurs in various forms. Main types of human induced soil degradation includes erosion, compaction, secondary salinization, and acidification, loss of organic matter, contamination, landslides and soil sealing (EC 2006a). These degradation processes threaten the functioning ability of soil, therefore often called soil threats. However, while threat is the possibility of degradation to occur, degradation itself is a process when harm occurs. In this case degraded soil means soil of altered status with inferior properties compared to the initial status.

5.2 Key facts of soil degradation mapping

As described above, degradation has occurred if the state of the soil has deteriorated over time. To determine whether this is the case, one would need to compare the state for at least two different moments in time, the first of which would be the reference. The reference state could be a perceived original state, or the state at some particular moment in the past. This determination of state should be done using the same methodology for both moments to avoid that the data source or the methodology influence the assessment. In practice, such an assessment may be difficult as earlier assessments may not have been done with current methodology, and the data to assess the state in the past using current methodology may not exist. Furthermore, for some degradation processes and soil threats it may not be easy to determine what the level is, for example because no reference is available. For example, the state of the organic matter content can be determined, but it is not always known whether this content was higher in the past, Thus the level of organic matter decline may be uncertain. Similarly, the density of soil can be determined, but any change may be uncertain, as well as the reason for change; high density could be the result of compaction, or be natural. Finally, degradation is also a matter of perception; what some consider to be degradation others consider improvement. For example, soil sealing interrupts almost all soil functions but at the same time triggers economic progress. Hence, there is a social dimension to degradation. In this chapter, however, the focus is on bio-physical aspects, as soil degradation is expressed in terms of changes to bio-physical properties. It should be recognised, however, that the drivers for these changes are often socio-economic, and that even 'natural' drivers such as climate related ones are influenced by humans.

For the reasons described above, research on soil degradation has been focusing on the factors that influence degradation, and in particular on the bio-physical factors. Within these, a distinction can be made between intrinsic factors that do not change rapidly, and rapidly changing factors that may be unpredictable and are therefore perceived as stochastic. Reynolds et al (2007) made a similar distinction between slow and fast variables that may influence desertification.

- **Intrinsic factors** are for example soil type, slope angle and also land use, although land use can change faster than e.g. soil type.

- **Stochastic factors** (random processes) are for example rainfall or the occurrence of earthquakes.

In soil/land degradation studies, assessments that look only at the intrinsic factors determine vulnerability to degradation, while assessments that look at the more stochastic factors determine also the risk to degradation. For example, the MESALES model[17] simulates sensitivity to soil erosion if rainfall is not considered, and erosion risk if rainfall is considered (Hessel et al, 2014b), while several other erosion models that simulate soil erosion risk, including PESERA[18] (Kirkby et al 2008), use a stochastic model to generate predictions of future rainfall data. Hence, when looking at risks we are dealing with likelihood, as the events have not happened yet (Science for Environment Policy, 2015). In a recent assessment of soil erosion by water in European Union with RUSLE2015[19], Panagos et al (2015b) used high temporal resolution rainfall records to estimate rainfall erosivity and simulate soil erosion risk. It should be noted that alternative terms to describe degradation exist, such as hazard, and that the terms that are used here have been defined in various ways in the literature. For example, in disaster risk assessment (e.g. flooding, landslides, earthquakes), risk is defined as the resultant of hazard (the chance that an event occurs), exposure and vulnerability (the damage that would result from an event) (Cardona et al. 2012). However, terminology used in degradation assessment generally does not distinguish between hazard and exposure, and uses the terms vulnerability and risk with different meanings. On the other hand, degradation assessment and mapping uses additional terms like state and rate.

In this report we use the terms as they are commonly used in soil degradation literature. Table 5-1 provides an overview of the differences between state, rate, vulnerability and risk, as they are used in this report. Map legends reflect the semantic approach applied in the degradation mapping. Various options are available to characterise degradation either by (i) its state from the viewpoint of soil function/health parameters, (ii) the level/degree of unfavourable alteration by the time of the mapping, (iii) the temporal dynamics of the degradation process, or (iv) the vulnerability of the soil as a receptor of degrading processes. The applied metrics in map legend depends on the aim of the map, but also on practical reasons, such as data availability, the type of the applied model (e.g. qualitative or quantitative) or its reliability.

Table 5-1: Types of map legends used for characterisation of soil degradation and soil threats[20].

Map legend type	Definition	Metric	Remarks & References
State	The condition of the soil	Nominal, ordinal, or interval scale	State can be the overall goodness or fitness for certain functions or the situation of a property or set of properties
Level	Current degradation compared to a reference	Ordinal classes, e.g. ++, +, 0, -, --	This can be considered to be the degree of degradation.
Rate	The speed at which degradation processes occur	Scalar values per unit of land and unit of time, e.g. t/ha/yr.	
Vulnerability / Sensitivity / Susceptibility	The intrinsic responsiveness of land to degradation	Ordinal classes, e.g. low, moderate, high	Has also been defined in quantitative terms as the expected rate of degradation caused by relatively permanent factors, and not considering management (after ISSS 1996), but in

17 MESALES - Modèle d'Evaluation Spatiale de l'ALéa Erosion des Sols - Regional Modelling of Soil Erosion Risk https://esdac.jrc.ec.europa.eu/themes/mesales-model

18 PESERA - Pan-European Soil Erosion Risk Assessment https://esdac.jrc.ec.europa.eu/themes/pesera-model

19 RUSLE2015: https://esdac.jrc.ec.europa.eu/themes/rusle2015

20 Nearly all soil degradation and soil threat mapping apply their own definition for their output category and consequent map legend. The current table (4.1) provides a general typology to which map legends can be classified. Types of this typology are used in this report to describe outputs of various products in a consistent framework.

Map legend type	Definition	Metric	Remarks & References
			practice it is currently usually given in ordinal classes. Vulnerability is often used interchangeably with susceptibility and sensitivity.
Risk	The rate at which degradation would occur assuming a certain scenario	Scalar values per unit of land and unit of time, e.g. t/ha/yr.	After ISSS (1996) the definition would be: The rate of degradation expected in the near future, due to drivers, and depending on the combined and interactive effects of all hazard factors

5.3 Mapping soil degradation at continental scale in Europe

5.3.1 Evolution

Mapping soil degradation at European scale has become more feasible and more advanced over time. Initial assessments at European and global level, such as GLASOD (Oldeman et al 1991) were based on expert opinion. Modelling of soil degradation at increasingly fine scales has become possible, due to the evolution of knowledge on soil degradation processes, the growing number of data, the increasing computer modelling capacity and new statistical tools.

For example, currently most assessments of soil degradation and degradation threats are done at 1 km resolution for the whole of Europe, while some assessments are already being performed at 100 m resolution. However, such assessments usually focus on one degradation process and do not combine different soil degradation types and soil threats.

5.3.2 Combined assessments of soil degradation

At continental scale, assessments of various degradation processes have been conducted in the last decades. Tóth et al (2008) published maps of main soil threats and soil degradation types. Stolte et al (2016) provide an overview on the state, drivers, indicators and consequences of soil degradation and soil threats. Annex 1 gives examples to summarise the current status of mapping for the different soil degradation processes. These examples represent the most recent and most complete mapping assessments known to the authors of this report. The table in Annex 1 shows that recent data are available for most soil degradation processes. They indicate that a lot of relevant work has been performed over the last years, and that a substantial amount of knowledge about the spatial dimension of degradation processes in Europe has been obtained. However, the table also shows that there is much diversity concerning what is mapped (level, susceptibility, risk etc. of threat or degradation) and also the geographical coverage. This diversity can be explained with heterogeneous data availability, different importance give to soil degradation processes and different mapping approaches.

Stolte et al (2016) combined separate degradation and soil threat maps into one single map. They performed a tentative analysis in which they classified the level of each soil threat as low, medium or high (see details in Stolte et al., 2016), and then performed a weighed counting of soil threats. The resulting map is shown in Figure 5-1.

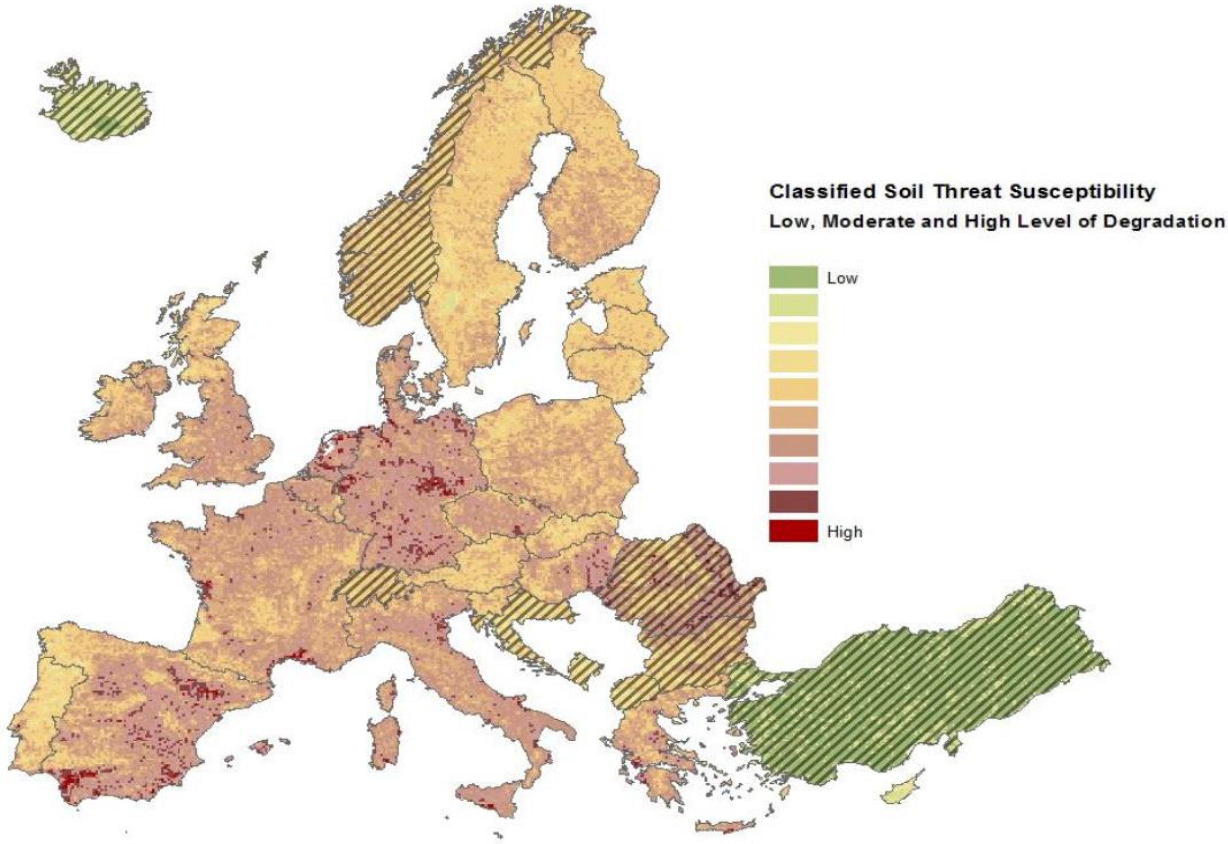

Figure 5-1: Soil threat map of Europe summarized

Source & Explanation: for the low (weighing coefficient 1), moderate (weighing coefficient 2) and high (weighing coefficient 3) category of degradation. For the shaded areas, not all threats are mapped (Stolte et al., 2016)

Figure 5-1 indicates the highest level of vulnerability to soil threats in parts of Netherlands, Germany, Czechia, France, Spain and Romania. However, it should be stressed that the map has to be used with caution for several reasons:

- As indicated in Figure 5-1 and in Appendix 1, there are no data for all soil threats in all countries of Europe.
- As shown in Appendix 1, the type of available data differs in their nature as some data sets refer to the state of a soil threat (i.e. soil sealing, local contamination) and others refer to the vulnerability towards a soil threat (i.e. wind erosion, compaction). It is therefore problematic to combine these datasets into a single map by summing them.
- Different soil threats also interact. If they reinforce each other, combining the different threats into a single map may result in double-counting. For example, soil compaction may result in loss of soil biodiversity and in increase of flooding and soil erosion (Stolte et al 2016). In a combined map this would be displayed as the occurrence of 4 soil threats, while in fact it reflects one problem.
- Data have been obtained in various ways (e.g. modelling, GIS, expert opinion).
- Different soil threats are of different nature. For example, different soil threats may have different importance or effect, even if their levels are the same according to the classification used. The final result, as shown in the map, may not accurately reflect the overall threat to soils.
- As indicated earlier, different people view changes in different ways. For example: for some, soil sealing is degradation, while for others it is development.
- Figure 4.1 addresses soil threats, not at the management that is used. For example, soils that are vulnerable to erosion may not erode if they are managed well. On the other hand, soils that are not vulnerable to erosion may still erode if poorly managed.
- Not all soil threats are equally suitable for mapping. For example, point sources of contamination can be mapped but may be a threat for larger areas (depending on the type of contamination).

- The map shows how many soil threats occur, but not which ones. This information is available, but cannot be shown in such a map as it would make the map illegible.
- Finally, the map counts soil threats, but does not give information on what this means for ecosystem services. Different degradation processes affect different ecosystem services in different ways, and to different extent. Furthermore, for some soil threats, not only the degradation itself is important, but also the state. As degradation represents a process in which the state of the land deteriorates, only sites in which there is a change in state are shown in the map. However, for several soil threats, the actual state should also be considered as it does influence the ecosystem services that can be provided. For example in the case of salinisation, the actual salt content affects crop growth and yield. Hence, the actual salt content (state) is of as much importance as the degradation (increase in salt content).

Nevertheless, the map may provide some indication as to where in Europe hotspots of combined degradations can be found. By looking at the data behind the map, information can also be obtained on which degradation processes are relevant for these hotspots. As such, it can be included in an approach in which different approaches are combined to tackle the challenge of land degradation.

In order to perform an improved and integrated degradation assessment, which characterises the overall level of soil degradation in a spatial manner across Europe, the following assessment steps are needed:

- Cataloguing existing maps including their data requirement, type of applied model and type of map legend
- Evaluating map legends by their transferability to other output categories
- Harmonizing map legends
- Assigning quantifiable values (or at least rank order) and importance (weight factors) to the individual degradation types and degrees
- Combine soil threat/degradation maps of harmonised legends by applying the established weights

6 Remote sensing based approaches for land degradation mapping

The aim of this chapter is to inform on four recent methods to apply remote sensing data for land degradation assessment in Europe. These include

- the World Atlas of Desertification (3rd Edition),
- the approach to land degradation mapping (by JRC),
- the 2DRUE method, the segmented trends method developed by Horion (2016a), and
- the method for mapping net land take based on Copernicus land monitoring data

6.1 Introduction

Since 2000, many earth observation data sets with fine spatial resolution have become available. The usability of this information has increased enormously due to advances in data collection, storage and processing. However, while Earth Observation data provide information on reflected solar radiation, it does not directly inform on land degradation types, processes or drivers.

A lot of scientific work has been done regarding the use of satellite information for land degradation mapping and the difficulty of interpreting, for example, NDVI trends[21]. These works make it clear that proxies[22] of land degradation derived from remote sensing images need to be translated into the information that policy makers actually need to address land degradation. This translation requires information on the drivers behind the observed changes in vegetation dynamics.

One of the most recent recommendations by Hill and Stellmes (2016) on using satellite remote sensing techniques for land degradation assessments concludes:

> *"The availability of suitable data from earth observation is better than ever, processing capacities and methods for parameter extraction have improved, conceptual approaches have matured. For the interpretation of remote sensing data it is necessary to (i) provide precise definitions of degradation types and put them in a regional context, (ii) provide context-dependent indicators for land degradation, (iii) decouple human and natural factors in land degradation, and (iv) to handle trade-offs between ecosystem services and functions."*

6.2 The World Atlas of Desertification (3rd edition) approach to land degradation mapping

6.2.1 Introduction

Assessing the extent of land degradation is challenging; there is no consensus among experts neither on the status nor on the trends of land degradation, even in well-studied areas like Europe and North America.

The third edition of the World Atlas of Desertification (WAD) is a collaborative project coordinated by the Joint Research Centre (JRC) of the European Commission, in partnership with the United Nations Convention to Combat Desertification (UNCCD) and a network of international experts (Cherlet et al, 2018). The WAD looks beyond conventional land degradation analyses to consider, more generally, the status and trends in global land cover and human activities, which affect the land. The WAD looks at various aspects of the land: croplands, rangelands, forests, water resources, biodiversity, and soil conditions. It builds on recent scientific advancements and aims at being a pragmatic exercise and example of the implementation of up-to-date concepts of land degradation.

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21 NDVI = Normalized Difference Vegetation Index

22 A "proxy of land degradation" is an indicator for land degradation. For example can NDVI satellite data be used to monitor vegetation changes and to derive biomass productivity.

Given the multiplicity of drivers and factors that underlie land degradation and the need for context-specific responses, it is difficult to develop a single indicator or index to represent or map land degradation. Hence, the WAD relies on a systematic framework that provides a 'convergence of evidence' on human-environment interactions. This allows for the identification of thematic pathways and geographically explicit patterns of coinciding processes that can potentially lead to land degradation. This approach to providing and combining geospatial information with local level indicators is consistent with the monitoring and evaluation framework of the UNCCD (UNCCD 2013) and the application of landscape-level approaches to the implementation of the land degradation neutrality target (SDG 15.3, see also chapter 7.3). Key aspects of the WAD global mapping approach are:

- The identification of areas affected by persistent land degradation.
- Indicating areas showing signs of recovering their productive capacity.
- Referring to a past period of 15 to 20 years, approximately the time since the last Atlas was published.
- Taking into account the findings of the Millennium Ecosystem Assessment in 2005 (Hassan et al. 2005).
- Information on the land productivity dynamics is overlaid with information on the most commonly documented direct and indirect causes of land degradation, and also includes, when available, data on sustainable land use and management practices, such as agroforestry and conservation agriculture.

The systematic and transparent framework employed in the WAD makes it possible to discern where the main human-environment processes and interactions coincide. This geographic convergence of evidence features areas and possible pathways of land degradation, together with responses including the protection, sustainable management, and restoration of land resources. The third edition of the WAD focuses on global datasets that allow spotting potentially stressed areas. The combination of these potential pressures is filtered through a variety of stratifications representing a range of stakeholder interests, such as cropland or rangeland perspectives. As a global scale exercise, the WAD remains limited in its ability to interpret specific local situations, which need to be addressed with contextual information and interpreted based on the understanding of their interactions at that scale. Nevertheless, the WAD convergence framework can be useful in providing background information for more detailed studies at national or sub-national scales.

6.2.2 Methodology for assessing the status of land cover

In the past, the significance of land degradation maps was frequently doubted, given the multidimensional nature of the problem, the complexity of the processes involved and the difficulty of interpretation at a global scale. Yet, the accuracy of this type of analysis has been enhanced through the availability of improved global datasets, a better understanding of the underlying processes, and rapidly advancing analytical tools.

The state of the Earth's vegetative cover and its development over time is a generally accepted representation of the land productivity and its dynamics. It reflects integrated ecological conditions and the impact of natural and anthropogenic environmental change. The term "land productivity dynamics" (LPD) as used in the WAD reflects the fact that the primary productivity of a stable land system is not a steady state, but is often highly variable between different years and vegetation growth cycles due to natural variation and/or human intervention. This implies, that land productivity changes cannot be assessed meaningfully by comparing land productivity values of single reference years or averages of a few years. Therefore, approaches based on longer-term trends are needed. The availability of time series datasets coupled with model-derived biophysical variables is increasingly improving, both from national and international Earth Observation Systems, such as the Group on Earth Observations (Yengoh et al. 2016; GEO 2017).

6.2.3 Land Productivity Dynamics

Land productivity addresses the net primary production (NPP) per unit of area and time. It reflects the overall quality of land and soil that results from environmental conditions and land resource use/management. Persistent decreases in land productivity point to the long-term alteration of the condition and productive capacity of the land. Such decreases directly and indirectly impact virtually all terrestrial ecosystem services, i.e., the benefits that form the basis for sustainable livelihoods and economic growth in all human communities. This index relies on multi-temporal and thematic evaluation of global long-term time series of remotely-sensed vegetation indices equivalent to NPP, at high spatial resolution (1 km or better) and operationally addressed by existing Earth Observation Systems.

The Land Productivity Dynamics (LPD) dataset used in the WAD refers to the standing biomass productivity within the growing season. It is derived from a 15-year time series (1998-2013) of global normalized difference vegetation index (NDVI) observations from SPOT-VGT[23], composited in 10-day intervals at a spatial resolution of 1 km.

The map in Figure 6-1 shows 5 classes indicating areas of negative or positive change or stability. These classes indicate the land's capacity to sustain the dynamic equilibrium of primary productivity in the given 15-year observation period.

The WAD's key message is that land degradation is a global phenomenon with distinct variations between regions and across key land cover/land use systems. Indications of decreasing productivity can be observed globally, with up to 18 million km^2 affected, i.e., approximately 20 per cent of the Earth's vegetated land surface shows persistent declining trends or stress on land productivity.

- At the global scale declining or stressed land productivity is being observed for 20 per cent of cropland, 16 per cent of forest land, 19 per cent of grassland, and 27 per cent of rangeland (i.e., shrublands, herbaceous and sparsely vegetated areas).
- For grasslands and rangelands, the global extent of the areas experiencing decreases in productivity exceeds that showing increases.
- In absolute terms productivity declines account for approximately 37 per cent for Australia, 27 per cent for South America, and 22 per cent for Africa.

Considering that immense effort and resources are being committed to maintain and enhance the productivity of arable and permanent cropland as well as the fact that there are clear limitations to the further expansion of cropland, these figures are cause for concern and action.

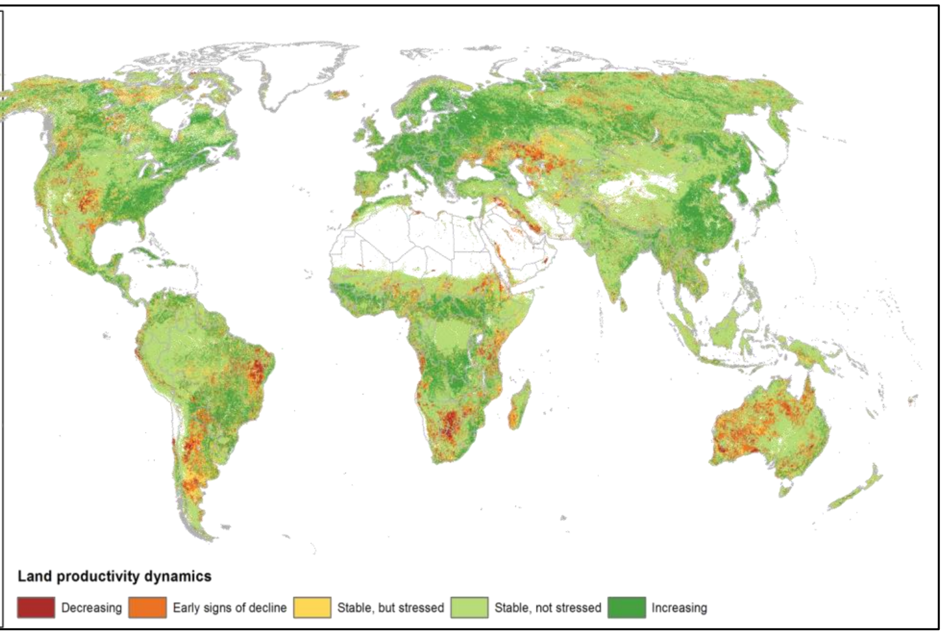


Figure 6-1: Land productivity dynamics derived within the growing season.

Source & Explanation: Analysis of a 15-year time series (1998-2013) of global normalized difference vegetation index (NDVI) observations from SPOT-VGT, composited in 10-day intervals at a spatial resolution of 1 km. Approximated productivity was derived as the integral within the growing season.

The distribution of LPD classes can be further broken down to coarse land cover/land use categories at global and continental levels:

- Cropland including arable land, permanent crops, and mixed classes with over 50 per cent crops.
- Grassland including natural grassland and managed pasture land.

23 SPOT-VGT: SatellitePour l'Observation de la Terre –Végétation

- Rangelands including shrub land, herbaceous, and sparsely vegetated areas.
- Forest land including all forest categories and mixed classes with tree cover over 40 per cent.

In **Europe**, the severity of declining productivity trends within the above mentioned land cover/land use categories are typically below global averages. However, being the continent with the highest proportion of croplands, European farmland is proportionally the most affected when compared to the other land cover types considered. An estimated 18 per cent of the croplands may be subject to significant drivers leading to productivity declines, especially in the south of Eastern Europe where, similar to Central Asia, large-scale collective arable and livestock land use systems have been substantially transformed as a result of the economic crisis.

Some hotspots of declining land productivity in Western Europe, especially in the Mediterranean region, are characterized by agricultural intensification often intermingled with the rapid expansion of infrastructure and built-up areas at the expense croplands. In many cases, yield capacity is sustained at the costs of biodiversity and quality of freshwater resources.

When disaggregated and viewed by broad land cover/land use categories, the LPD allows for the identification of meaningful patterns of land transformations occurring at continental to national levels. Thus, the LPD provides a first approximation and comparison of different regions or even countries according to their capacity to sustain primary productivity in land use systems. In order to substantiate this type of information in the context of underlying causes and drivers of land degradation, the WAD promotes the concept of convergence of evidence.

6.2.4 Developing global maps on convergence of evidence

To accommodate the complex interactions and dynamics that trigger land cover/use change, the World Atlas of Desertification (WAD) relies on the concept of 'convergence of evidence': when multiple sources of evidence are in agreement, strong conclusions can be drawn even when none of the individual sources of evidence is significant on its own. Convergence maps are compiled by combining global datasets on key processes, using a reference period of 15-20 years. Combinations are made without prior assumptions in the absence of exact knowledge of land change processes at variable locations. Patterns indicate areas where substantial stress on the land resource is to be expected (Craglia & Shanley 2015).
The resulting convergence maps demonstrate one approach by which these data can be combined, viewed, and analysed for multiple land use/land cover strata. Convergence is undertaken in two steps:

- **Step 1**. A global land cover/use stratification is compiled representing shares of cropland and rangeland (Ramankutty et al. 2008), and tree cover in 2007 (Hansen et al. 2013) - other preliminary stratifications could be based on climate, soil, or ecosystem services, depending on the available data.
- **Step 2**. For each class, zonal or class statistics are calculated for each dataset representing a potential issue relevant to land degradation. The issues are reclassified as being above or below a statistically derived threshold, taking into account their expected effect in terms of land degradation (positive or negative). The resulting layers have values of 0 (no stress) and 1 (potential stress), and are summed together to provide the number of coinciding issues at any geographical area. The method is flexible and can be applied at all scales.

Based on the literature (for example, Geist 2005), datasets relating to the various issues have been grouped as follows:

Table 6-1: Typical data sets for the convergence of evidence methodology

Context	Phenomenon
Related to the human environment	changing population densities
	migration and urban sprawl
	agriculture expansion
	agriculture industrialization
	livestock density and practices
	deforestation, fragmentation, and fires
Related to the natural environment	land productivity
	water availability and use
	soil condition
	changed aridity and drought

Global datasets are now available for most of these issues and the WAD analysis illustrates convergence based on 14 consistent and geographically continuous datasets on socio-economic and biophysical issues. As land degradation in itself is a process, it would be ideal to use only dynamic datasets, but the availability of consistent and harmonized such data with global coverage is currently limited. The datasets included in the exercise presented in the WAD given in Table 6-2.

Table 6-2: Global change issues used in WAD convergence of evidence maps

Type	Issue	Data set
Biophysical data	Land biomass productivity dynamics (1999-2013)	Ivits, Cherlet, Sommer, et al. 2013; Ivits, Cherlet, Mehl, et al. 2013; Kutnjak et al. 2016
	Tree loss (2000-2014)	Hansen et al. 2013
	Aridity (in the period1981-2010)	Spinoni et al. 2015
	Climate and vegetation trend anomalies	Ivits et al. 2016
	Soil erosion by water (2001-2012)	Borrelli et al. (2017)
	Fire occurrence (during period 2000 to 2013)	Roy et al. 2008
	High water stress	Gassert et al. 2015
Socio-economic data:	High population density in 2015	Center for International Earth Science Information Network - CIESIN - Columbia University 2016
	High change in population density (between 2000 and 2015)	Center for International Earth Science Information Network - CIESIN - Columbia University 2016
	High livestock density	Robinson et al. 2014
	High proportion of area equipped for irrigation	Siebert et al. 2013
	High Nitrogen balance (landscape level)	West et al. 2014
	Low Nitrogen balance (landscape level)	West et al. 2014
	Increase in built-up coverage (2000 - 2014)	Pesaresi et al. 2015
	Low gross national income in 2015	The World Bank 2017

6.2.5 Global maps on convergence of key issues

Together with land use and environmental histories, a range of variables influences the occurrence and rate of land degradation, such as interest rates, livestock prices, and agricultural support policies. The progression of this change is guided by slow or fast variables (Geist & Lambin 2004). However, both the pathways towards degradation and the variable interactions that steer them are numerous, volatile, and generally unknown, making it difficult to model land degradation at a global scale. The physically-measurable outcomes that can be observed through the use of satellite data, such as LPD, or ground observations (e.g., decreases in biomass, biodiversity, soil organic carbon, or increases in soil erosion or undesirable plant species), cannot be interpreted meaningfully without an understanding of the social and economic conditions at all scales considered.

Maps of the convergence of evidence show where human–environment land change processes are impacting European croplands (Figure 6-2 and Figure 6-3) and forests (Figure 6-4 and Figure 6-5). They show distinct patterns suggesting areas under different levels of pressure; however, the higher or lower number of concurring issues does not necessarily imply a higher or lower impact or outcome in terms of land degradation. In cropland, where more potential pressures are present, more attention is generally required in terms of land management and further monitoring of the situation, even though the analysis does not mean that land degradation is currently underway everywhere. As much as possible, interpretation needs to take into account ancillary contextual knowledge and evidence. Paper maps are limited and cannot represent the full depth of data, therefore a digital portal has been developed (https://wad.jrc.ec.europa.eu/countryreport) that allows for more complete data and information query (Cherlet et al, 2018).

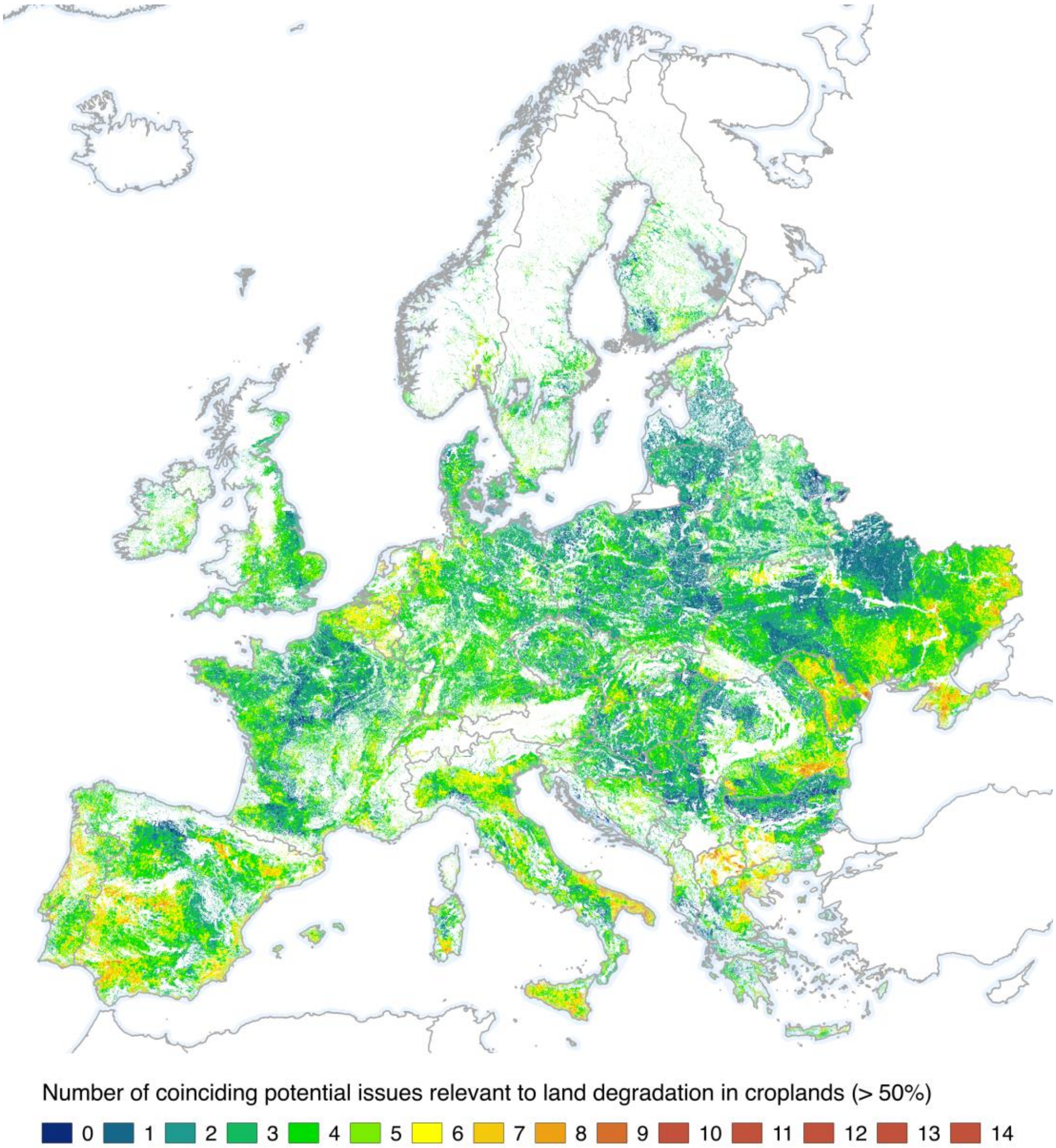


Figure 6-2: Convergence of evidence map in croplands of Europe.

6.2.6 The state of land in the croplands

The analysis of the data presented in Figure 6-2 show that less than 1% (or 20 thousand km2) of European cropland suffers from potential pressure from 8 to 14 coinciding issues that trigger land change processes relevant to land degradation. This is significantly less than the 8.7 % observed at global level. Around 46 % are subject to 4 to 7 issues, compared to 59 % globally. Only 2% of Europe and global cropland does not face any pressure from the 14 issues assessed.

The most frequent bio-physical variables linked to land degradation in croplands are aridity (28%) and water stress (26%). On the socio-economic side, high livestock density (48%) and low nitrogen balance (26%) come ahead.

When a number of related cropland issues combine with a decline in land productivity, this suggests that an observable transformation has happened or is underway. This can be a good proxy for ongoing degradation in those areas. The bar chart at the top left of Figure 6-3 shows that the number of coinciding variables seems to relate to the land productivity: proportionally more concurrent issues appear where the land productivity is stressed or declining.

In Europe, the main cropland areas facing multiple pressures include, but are not limited to, intense agricultural areas in the Mediterranean and central Europe. Input-intensive food production systems are driven by mechanization and high fertilizer applications that have made farmland dependent on continuous inputs of nutrients to ensure high yields, resulting in water and wind erosion and other degradation phenomena, which cannot be precisely captured with available datasets. This is a risky balancing act, but favourable economic situations have so far made it possible to keep the land resource mostly in equilibrium.

6.2.7 *The state of land in the forests*

A convergence of evidence map of European forests is given in Figure 6-4. The available data for the assessment is presented Figure 6-5.

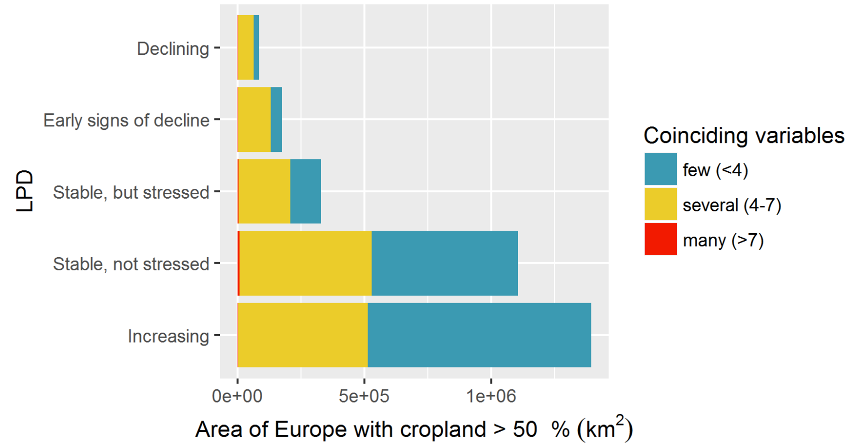
Only 1 243 km^2, representing less than 0.04% of forests in Europe, are affected by more than 7 coinciding issues potentially leading to land degradation. The analysis shows that around 30 % of European forests are impacted by 4 to 7 coinciding issues, while 7% see none.

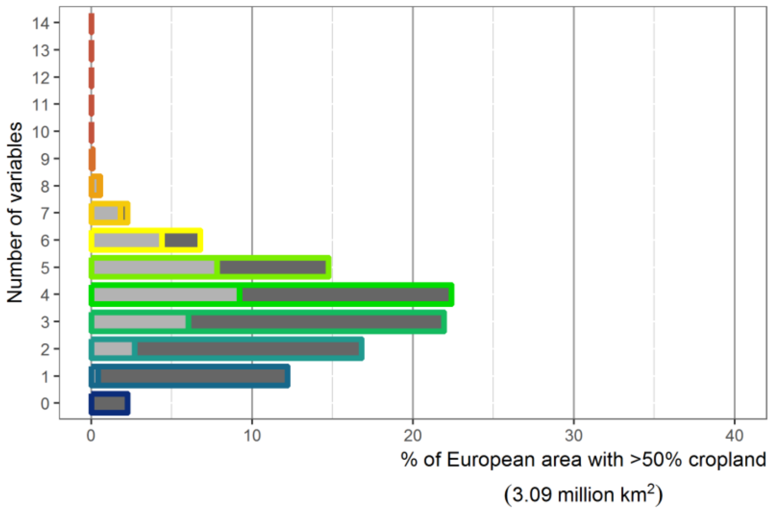
The main biophysical issue is tree loss, covering 45% of all forest area. The biophysical issue of declining or stressed land productivity is observed in only 4% of the forests of Europe well under the 15% at global level. High population and livestock density are the most common socio-economic variables, both covering more than 50% of the forest area. Like in croplands, but to a lesser extent, the number of coinciding variables increases with the stress on the land productivity. Around 7% (corresponding to 2.6 million km^2) of European forests are not impacted by GCIs.

top left: increase / decrease land productivity of European croplands in absolute values and according to frequency of Global Change Issues

bottom left: percentage of European croplands and number of Global Change Issues

bottom right: percentage of European cropland area per Global Change Issue





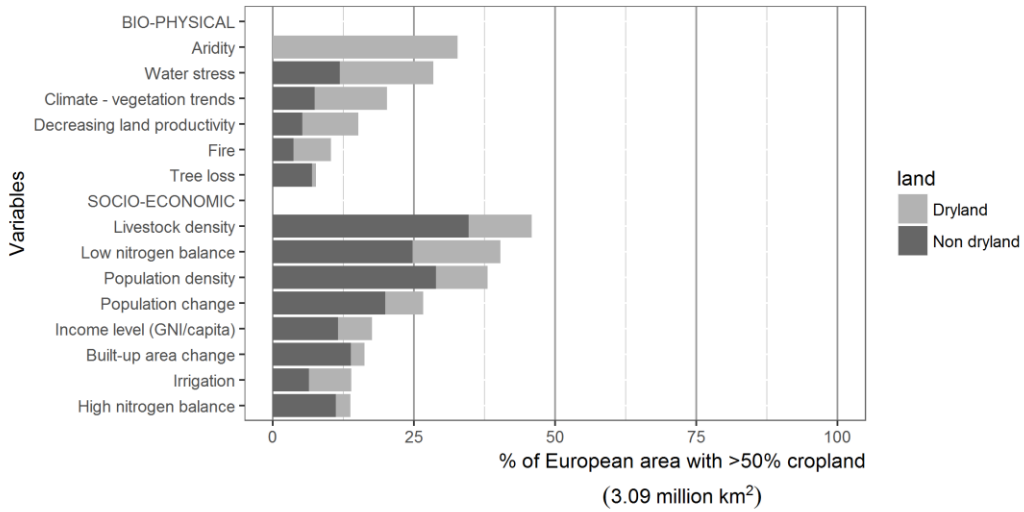


Figure 6-3: Convergence of evidence assessment in croplands of Europe.

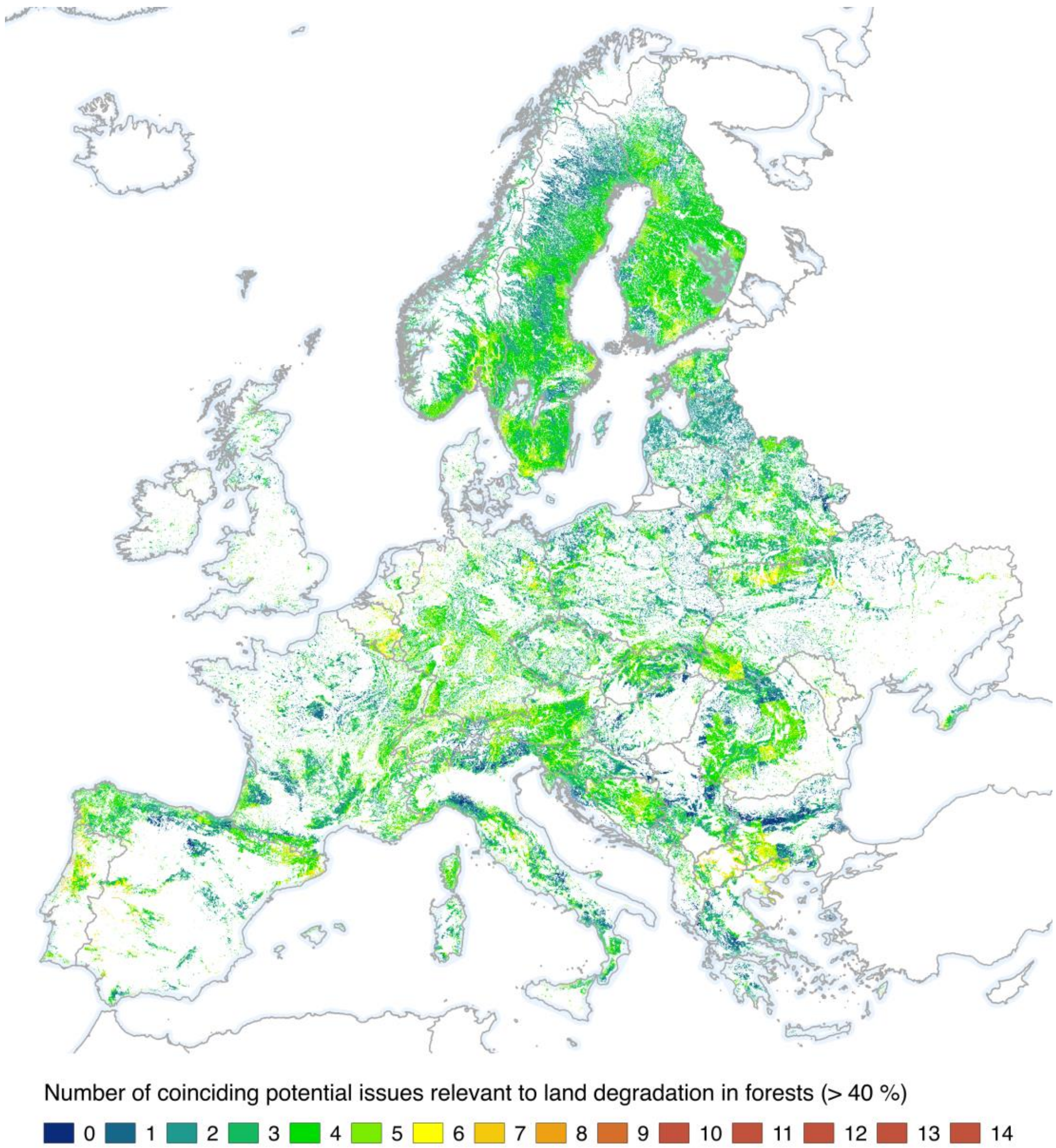


Figure 6-4: Convergence of evidence map in forests of Europe.

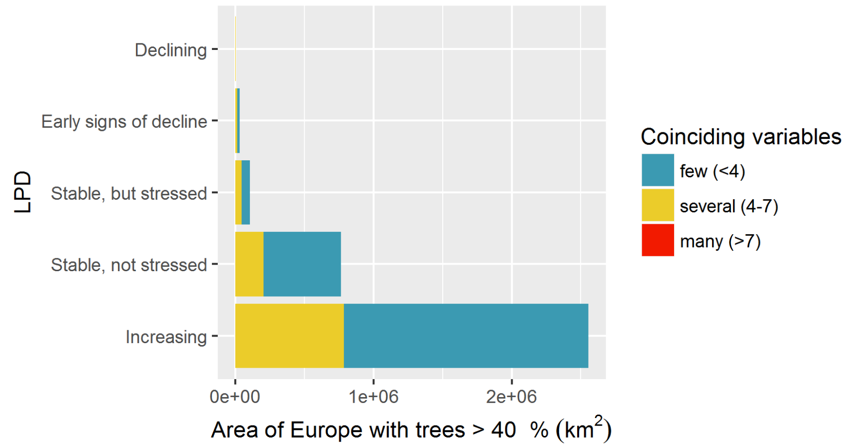
6.2.8 Conclusion

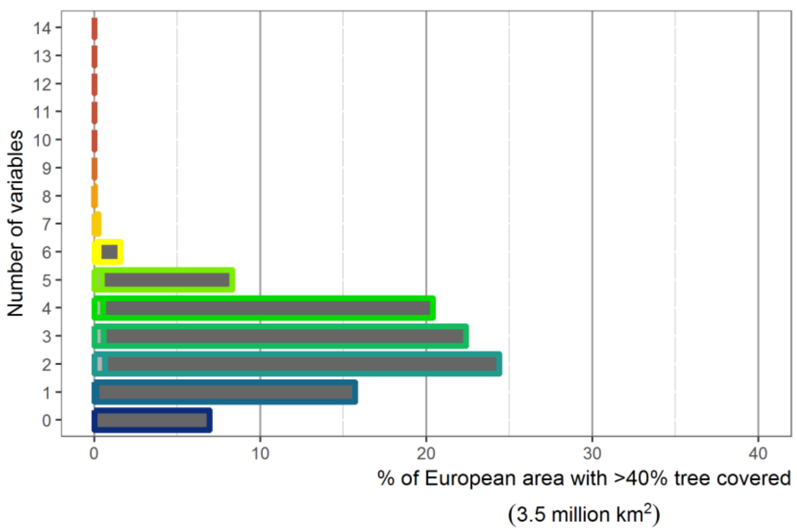
Maintaining or improving the productive capacity of land and its associated resources requires a move towards land degradation neutrality whereby countries maintain and surpass a position of "no net loss" of land quality. More sustainable management of land resources can help close yield gaps, increase resilience to stress and shocks, and thus support to human health, wellbeing, and security in the long term. The WAD provides a useful global overview of status and trends in the condition of our land resources as well as the potential impacts of human activities. By identifying those areas under stress, decision-makers can be empowered to take remedial actions and create a supportive environment for stakeholders to do the same.

top left: increase / decrease land productivity of European forests in absolute values and according to frequency of Global Change Issues

bottom left: percentage of European forests and number of Global Change Issues

bottom right: percentage of European forest area per Global Change Issue





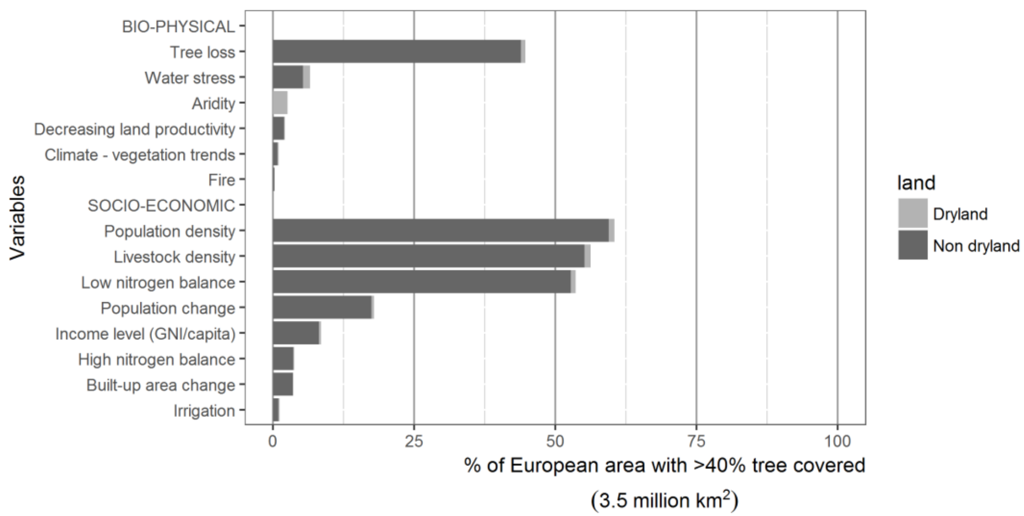


Figure 6-5: Convergence of evidence assessment in forests of Europe.

6.3 Combining remote sensing with climate data

One example for such a data combination is a study (Horion et al (2019)) performed on Water-Use Efficiency and vegetation productivity time series. The method enables large-scale assessments of the current state as well as changes in ecosystem functioning. The main assumption of the study was that land degradation and disturbances of vegetation traits cannot be sufficiently captured by using traditional methods based on earth observation time series, such as singular linear trend models[24]. For instance, land cover disturbances (e.g. fires, land clearing, and change in land management practices) or extreme climate events (e.g. extreme drought, flood) often occur abruptly and/or may only be evident for a short period in the time series. Nevertheless, they can have long-lasting effects on ecosystems. Likewise, slower changes (e.g. climate-induced land degradation, increasing grazing/human pressure) will gradually affect the ecosystem productivity. For such reasons change in ecosystems properties in relation to land degradation may be better captured by separating the series into individual segments, which capture specific vegetation conditions or stages of degradation through time.

The segmented trends method takes into consideration non-linear changes in ecosystem functioning. The term 'ecosystem functioning' refers to the ecosystem state or trajectory, and to the sum of the processes that sustain the ecosystem, following the definition of Jax (2010). In this definition, land degradation can be seen as an extreme case of change in ecosystem functioning. For the map of land degradation hotspots in Europe, a breakpoint analysis method was used to characterize hotspots in Europe with abrupt changes in ecosystem functioning signalling past or on-going land degradation processes.

The Water Use Efficiency (WUE) index was used to serve as a proxy for changes in ecosystem responses to hydro-climatic conditions. The WUE was calculated as the ratio between above-ground net primary productivity (ANPP) and actual evapotranspiration (ETa). WUE was derived at European scale based on long time series of Earth Observation data and EEA modeled actual evapotranspiration.

By looking for abrupt changes (i.e. breakpoints, Verbesselt et al. 2010) in the WUE, the method aimed at identifying tipping points in the functioning of European ecosystems in relation to land degradation. This trend segmenting method enables the detection of trend shifts within earth observation or climate time series assuming that nonlinearity can be approximated by fitting a piecewise linear model. This type of analysis provides valuable information on the occurrence of trend shifts, as well as on the timing and magnitude of related break points in the time series[25].

Several classes of ecosystem change types were identified (Figure 6-6):

- No significant change: no significant break point and no significant trend detected in the time series
- Monotonic increase and monotonic decrease: no break point was detected, a significant positive (/negative) trend detected in the time series.

24 as for example described in de Jong et al. 2012; de Jong et al. 2013; Fensholt et al. 2015a; Horion et al. 2016

25 see also de Jong et al. 2012; de Jong et al. 2013; Verbesselt et al. 2010

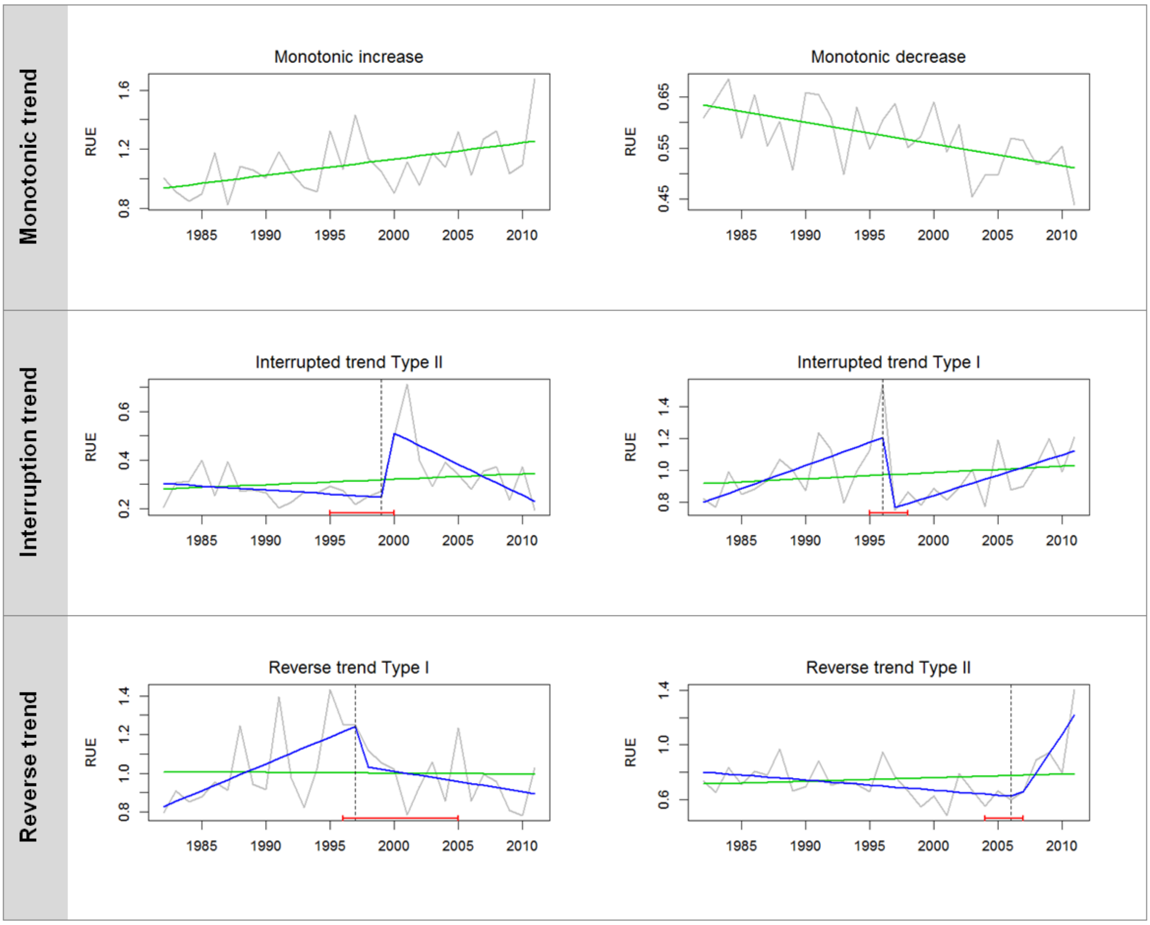


Figure 6-6: Illustration of the type of trend shifts in Water-Use Efficiency.

Source & Explanation: The grey line represents the development of the variable through time, the green line represents the fit for a single linear model, and the blue line represents the fit of each segment to the adjusted linear piece-wise model. The dotted vertical line indicates the year of a detected significant breakpoint and the red mark shows the confidence interval for the estimated timing of the break. Model fits, detected year of break and related confidence intervals are given for illustration purpose (Source: (Horion et al. 2016)).

The four other classes were based on pixels showing a significant trend in one or both segments:

- **Interruption Type I** and **Interruption Type II**: a break point was detected and both segments of the time series (before and after the break) were characterized by a trend with the same direction. Time series characterized by positive trends before and after the break are referred to as Interruption type I; whereas time series characterized by segments with negative trends are classified as Interruption type II.
- **Reversal Type I** and **Reversal Type II**: a break point was detected and both segments of the time series (before and after the break) showed opposite trends. Time series characterized by a positive trend followed by a negative trend (i.e. increase to decrease) are referred to as Reversal type I; whereas Reversal type II corresponds to the opposite situation, i.e. a negative trend followed by a positive trend (decrease to increase).

A positive trend in WUE does not systematically correspond to an increase in vegetation activity but can also be the result of decreased ETa with limited change in the vegetation activity. By applying the classification scheme, a map of ecosystem change types (ECT) was derived for European ecosystems (Figure 6-8), with the timing of the detected breakpoints and the significance of the observed changes. This information served as basis for identifying hotspots of potential land degradation.

The study considered changes in WUE in protected areas of the Natura 2000 network. More than 60% of the Natura 2000 sites showed significant change in the functioning of their ecosystem and about 10% showed a monotonic increase in WUE that could suggest an improvement of the functioning of the ecosystems if we assume no invasive human intervention on these sites. At the country level, large shares (>15% of the total area covered by the NATURA 2000 sites) of trend types with negative development in WUE in recent years (i.e. interrupted decrease and reversal trend type I – increase to decrease) were registered in Bulgaria, Greece and Sweden; whereas a large share of trend types with a positive development in WUE in recent years (i.e. in Belgium and Luxembourg).

Observed changes in WUE can be the reflection of a series of processes, from land use/cover change to climate induced change in vegetation productivity. Using the Archetypical Change Trajectory product (ACT, Levers et al. 2015) the study further analysed how changes in land cover and use can be reflected into the functioning of ecosystems (Figure 6-7).

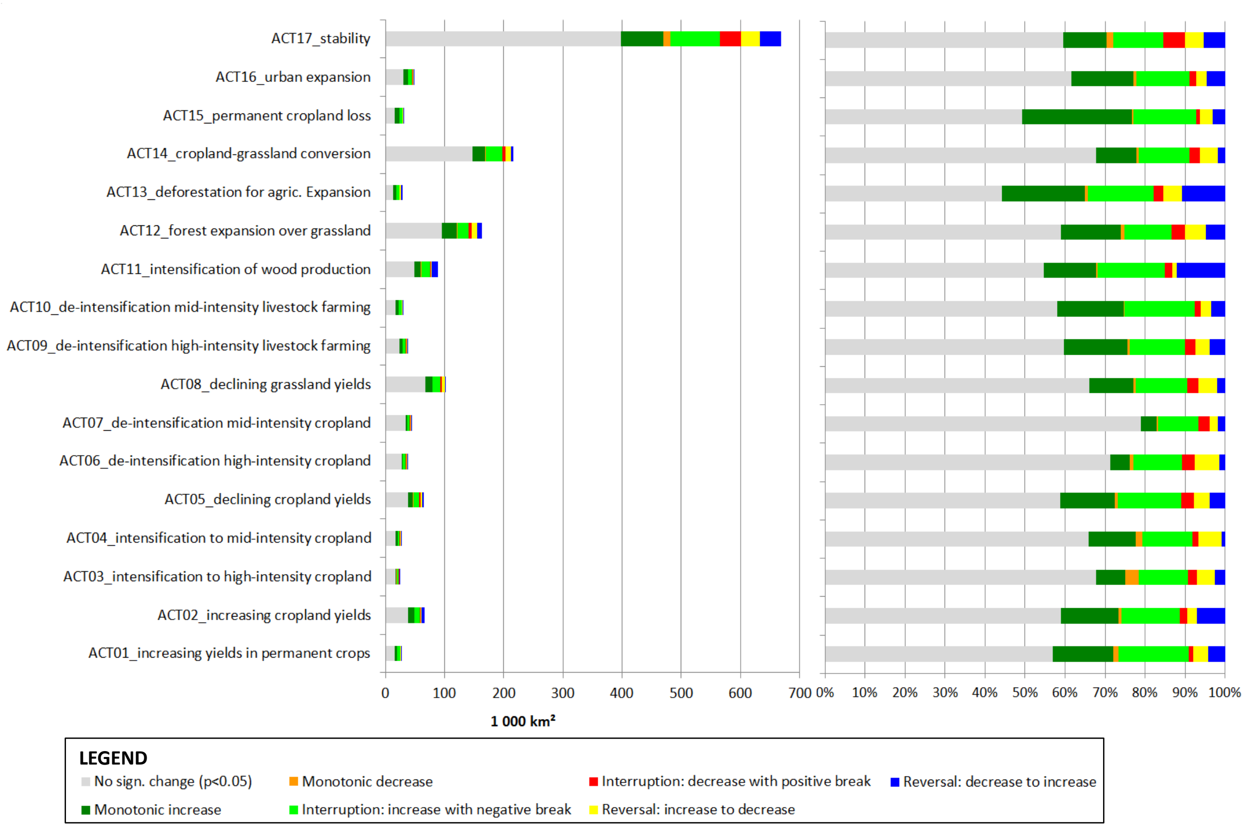


Figure 6-7: Cross-analysis ACTs vs. trend shifts in WUE.

Source & Explanation: (Left) Absolute area (in km²) covered by the different classes of trend shifts in WUE within each ACT; (right) relative area as compared to the total area covered by the ACT class.

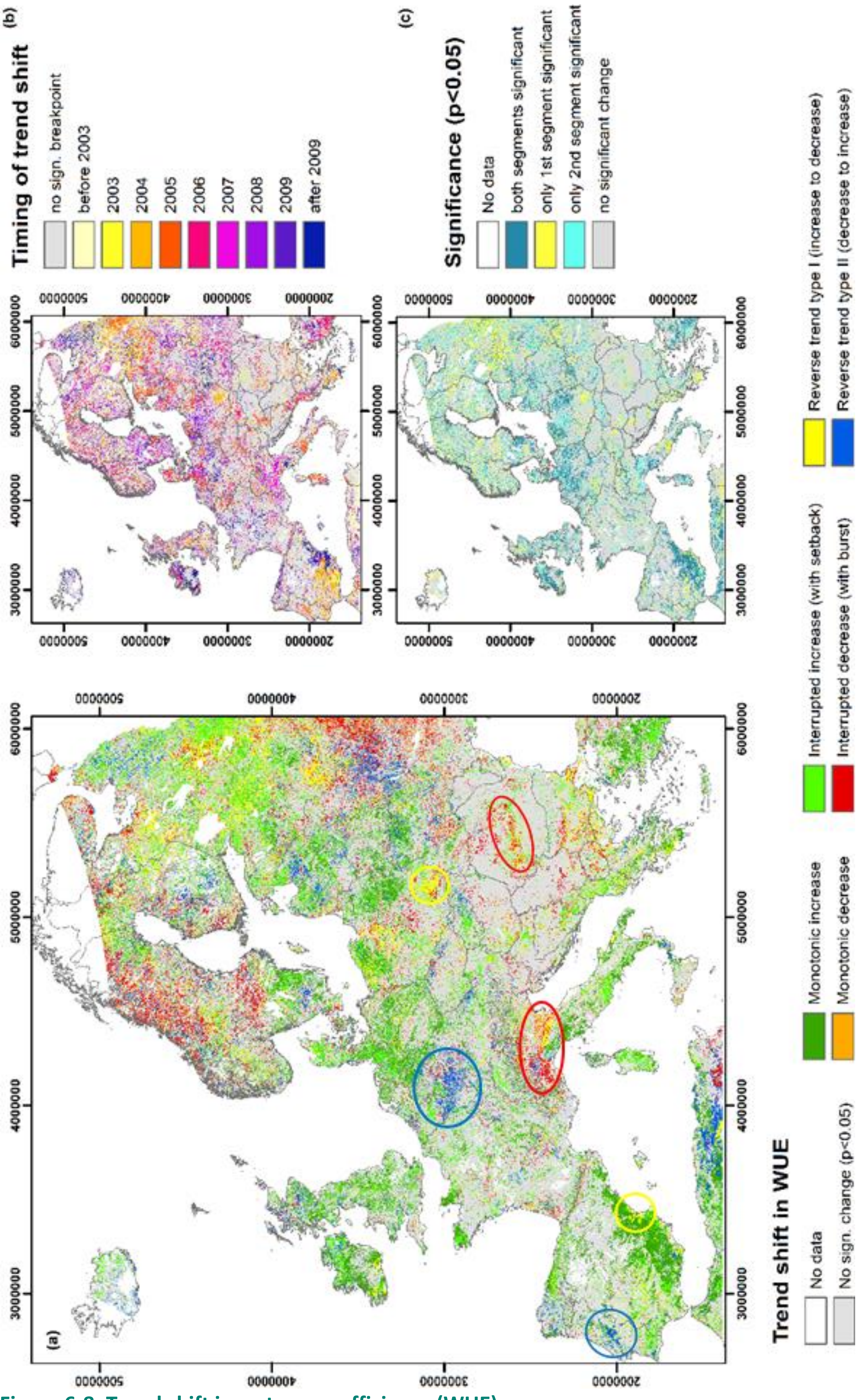


Figure 6-8: Trend shift in water-use efficiency (WUE).

Source & Explanation: (a) type, (b) timing of the breakpoint and (c) statistical significance (observation period 1999-2013). Statistical significance was set to $p < 0.05$.White areas correspond to water or no data. Selected cases are circled.

6.4 Land use analysis: example on accounting for land take

The pan-European component of the Copernicus land monitoring program is coordinated by the European Environment Agency (EEA). Currently the two datasets, which are most relevant in the mapping of land degradation processes are:

- **The CORINE Land Cover (CLC) inventory** was initiated in 1985 (reference year 1990). Updates have been produced in 2000, 2006, 2012, and 2018. The land take indicator (CSI 014, LSI 001) [Abbreviation] is based on CLC change data and is defined as the change in the amount of agricultural, forest and other semi-natural and natural land taken by urban and other artificial land development.(EEA 2011, Land take indicator specification, https://www.eea.europa.eu/data-and-maps/indicators/land-take-2).
- **High Resolution Imperviousness layers** are produced as a time series for the years 2006, 2009, 2012, and 2015. The indicator on imperviousness and imperviousness change (LSI 002) is based on imperviousness change data and aims at documenting changes in the amount of sealing of land surfaces by artificial impervious cover (EEA 2013, Imperviousness and imperviousness change, indicator assessment,https://www.eea.europa.eu/data-and-maps/indicators/imperviousness-change-1/assessment.

Land take and imperviousness change indicators are targeted at estimating similar processes; there is a significant overlap in areas affected by both land take and imperviousness change. On the other hand, there are key differences resulting from the nature of input datasets and indicator definitions:

- **Targeted land degradation processes.** The imperviousness change indicator measures changes of impervious land surfaces, like the creation (or destruction) of roads, buildings and other sealed surfaces. The definition of the land take indicator is based on specific land cover change types (see also Box 6.1).
- **Reliability of estimated values.** Both land take and imperviousness change indicators are primarily estimating the area affected by urbanisation within a certain reference unit. The reliability of area estimation is influenced by the applied methods
  - CLC change areas are delineated manually with strong visual control of each spot, considering a 5 ha minimum mapping area. As a consequence, the reliability of the CLC change map is usually high, but land cover changes smaller than 5 ha do not appear in the dataset.
  - Imperviousness cover is estimated by a mostly automated image classification methodology with 20m resolution, corresponding to the resolution of source satellite imagery. The consequence is, that significantly smaller changes may appear in imperviousness change data compared to a CLC change map. However, the lower reliability of changes detected from the HRL Imperviousness Density Layer is due to the algorithm used to estimate the percentage of impervious area as a percentage of the artificially sealed area within 20 m cells. This algorithm is based on a correlation with the vegetation index. As the available vegetation content is changing seasonally, and not all non-vegetated areas are artificially sealed, there is a certain uncertainty in the measurement method.

The land take indicator is calculated from CLC change data during the periods 2000-2006, 2006-2012 and 2012-2018. Changes from agricultural (CLC class 2xx), forest and seminatural / natural land (CLC class 3xx), wetlands (CLC class 4xx) or water (CLC 5xx) to the artificial class (CLC class 1xx) are grouped into the so called land cover flows according to the land cover accounts methodology (EEA 2006). Land take is defined as a combination of certain land cover flow (LCF types). Table 6-3 explains relevant CLC change types in more detail.

Box 6-1 Land take calculation

Land take = LCF2 (21+22) + LCF3 (31+32+33+34+35+36+37+38) + LCF13 (development of green urban areas over previously undeveloped land) - part of LCF38 (conversion of sport and leisure facilities from previously developed land)

The analysis of net land take is based on the idea to calculate land take in the reverse direction.. This means, for example, the land cover change from continuous and discontinuous urban fabric (classes 111 and 112) to agricultural areas (class 2xx). Net land take is hence the result of land take minus reverse land take.

All values have been calculated based on rasterized CLC change datasets following the LEAC method, using 1km statistical grid as basic aggregation unit for presented charts. The European overview map presented in Figure 6-9 is based on a further aggregated layer of 10 km resolution.

Table 6-3: Definition of Land take indicator explained with included CLC changes.

		FROM			TO	
LCF2: Urban Residential Sprawl	LCF21: Urban dense residential sprawl	2xx	Agricultural areas	➔	111	Continuous urban fabric
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF22: Urban diffuse residential sprawl	2xx	Agricultural areas	➔	112	Discontinuous urban fabric
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
LCF3: Sprawl of economic sites and infrastructures	LCF31: Sprawl of industrial and commercial sites	2xx	Agricultural areas	➔	121	Industrial or commercial units and public facilities
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF32: Sprawl of transport networks	2xx	Agricultural areas	➔	122	Road and rail networks and associated land
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF33: Sprawl of harbours	2xx	Agricultural areas	➔	123	Port areas
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF34: Sprawl of airports	2xx	Agricultural areas	➔	124	Airports
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF35: Sprawl of mines and quarrying areas	2xx	Agricultural areas	➔	131	Mineral extraction sites
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF36: Sprawl of dump sites	2xx	Agricultural areas	➔	132	Dump sites
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF37: Construction	2xx	Agricultural areas	➔	133	Construction sites
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
	LCF38: Sprawl of sport and leisure facilities	1xx	Artifical Surfaces (2)	➔	142	Sport and leisure facilities
		2xx	Agricultural areas			
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			
LCF1: Urban land management	LCF13: Development of green urban areas	1xx	Artifical Surfaces (3)	➔	141	Green urban areas
		2xx	Agricultural areas			
		3xx	Forest areas (1)			
		4xx	Wetlands			
		5xx	Water bodies			

(1) Forest areas without 335 (glaciers and perpetual snow)
(2) Artificial Surfaces without 142 (sport and leisure facilities)
(3) Artificial Surfaces without 141 (green urban areas)

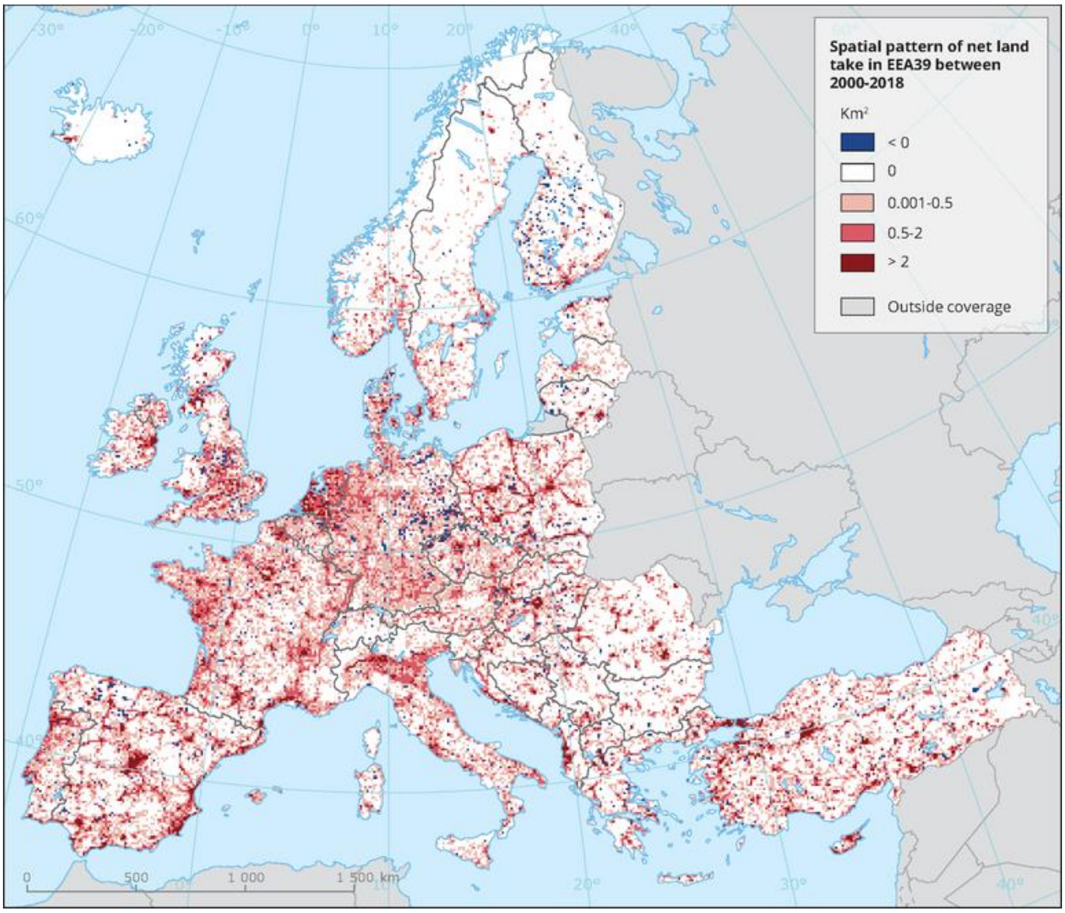


Figure 6-9: Spatial pattern of net land take in EEA39 during 2000-2018.
Source EEA: net land take values were aggregated within a 10 x 10km grid for visualisation purposes.

The overview map of annual net land take shows high degradation level in larger contiguous areas around existing settlements, industrial areas and road networks. The coastlines in the Mediterranean region are highly affected as well. Statistical analyses have shown, that the largest amount of mapped land take represents (in decreasing order of significance) land uptake by construction sites, industry and commercial units, mines, quarries & dump sites and finally housing, services and recreation.

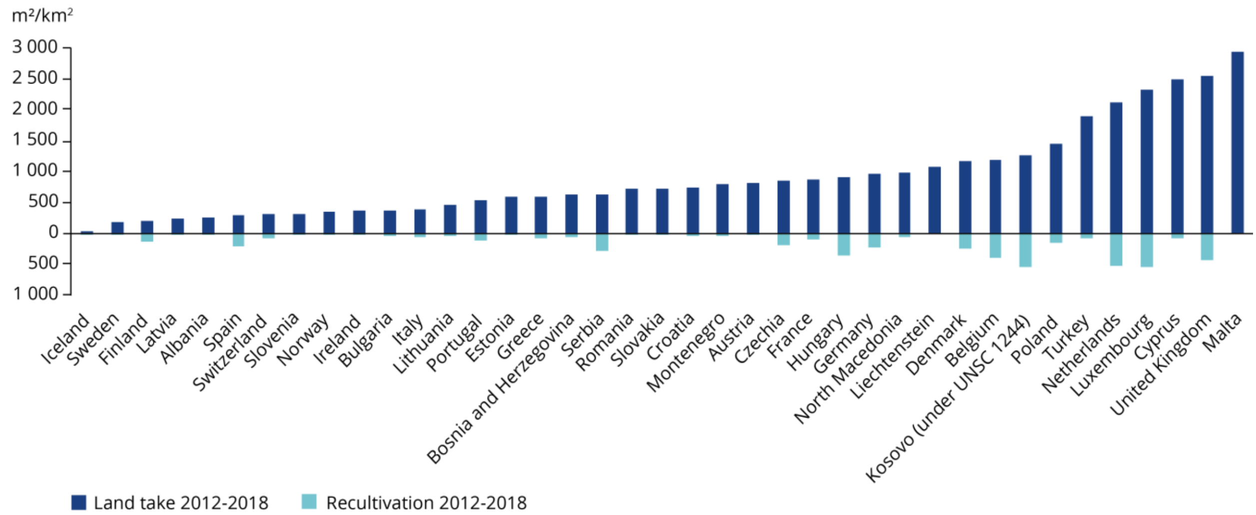


Figure 6-10: Land take and net land take in proportion of the country`s area during 2012-2018.

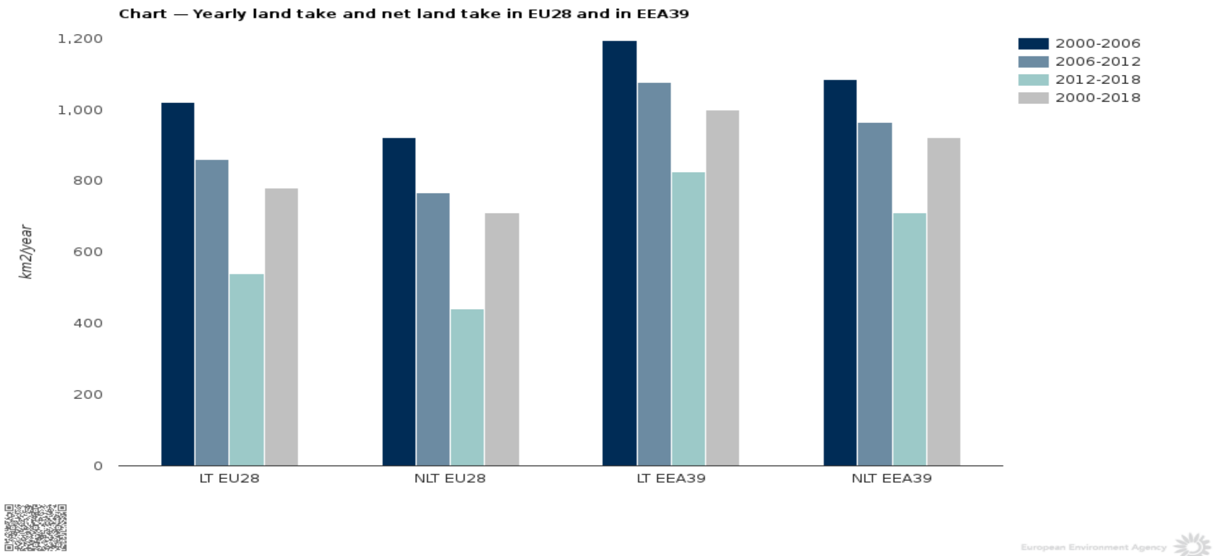


Figure 6-11: Yearly land take and net land take in EU28 and in EEA39.

Figure 6-11 shows net land take rates in 39 European countries and for three subsequent periods, namely 1990 to 2000, 2000 to 2006 and 2006 to 2012[26]. The highest rates of net land take can be observed in the period from 2000 to 2006, while the subsequent period shows significantly lower net land take values.

6.5 Conclusions

The examples of recently developed methods using earth observation for mapping land degradation shows that a wealth of spatio-temporal information at high spatial and temporal resolution is available to assess changing land conditions in space and time.

However, the few examples given also shows that it remains difficult to distinguish different types of land degradation and to derive information on the rate of land degradation., From earth observation alone, only general patterns of changes in land cover and functioning of vegetation covers can be detected. In order to interpret these changes in terms of land degradation (type(s), status and trend), information is needed as to which socio-economic or biophysical factors trigger these changes at local to regional levels.

The **WAD method** provides a solution to accommodate the complex interactions and dynamics that trigger land use changes, by following the concept of 'convergence of evidence'. WAD uses global data sets on global changes issues. These 'issues' are a mixture of what could be labelled as drivers, pressures, states and impacts according to the DPSIR-framework for land systems from the EEA (EEA 2015c). The **segmented trend method** provides a more detailed analysis of the change dynamics. Analyses which combines time-series of remotely-sensed vegetation index with times series of actual evapotranspiration (into the water use efficiency) deepens the understanding of climatic drivers. . Analyses which also use information on likely anthropogenic drivers of land degradation —, and the relation of these to the observed ecosystem response, are on the right path to understand the complex human-ecosystem interactions leading to land degradation.

The strength of the concept of 'converging evidence' is that numerous drivers can be added on demand, and that it leaves the interpretation of land degradation (history, type(s), state and rate), and the factors having caused or causing these, to users of the land system.. Only they have sufficient knowledge about the history of changes in land cover and in land use and in baseline conditions in that region, and only they

26 Note, that CLC1990 data were not created in all EEA39 countries yet and were not exactly bound to 1990 as a reference year. The first "CLC1990" dataset was created in Portugal in 1986, the last one was created in Slovenia based on 1996 imagery. Additionally, countries applied two different methods for mapping CLC 1990-2000 changes, which resulted some distortion in the statistics.

have access to more detailed information sources. The concept could be improved by describing the 'potential issues relevant to land degradation' as probability functions instead of binary states based on a statistically derived threshold, for example by using binomial logistic regression techniques (e.g. (Steinbuch et al. 2017). JRC did attempts to derive empirical probability functions for the 'issues', and to combine these in a non-compensatory indicator of susceptibility to land degradation (Weynants et al. 2016).

7 The UNCCD Framework for Land Degradation Neutrality

This chapter explains the Land Degradation Neutrality concept as proposed by UNCCCD and its link to the UN Sustainable Development Goal 15.3. “*to combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world by 2030*”, and its applicability for Europe.

7.1 Introduction

Box 7.1 Land degradation neutrality (UNCCD)
The UNCCD uses the conceptual framework of Land Degradation Neutrality (LDN) which is defined as: *“A state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable, or d, within specified temporal and spatial scales and ecosystems”*.

Figure 7-1 illustrates the interrelationships among the major elements of the scientific conceptual framework for LDN. The target at the top expresses the vision of LDN, emphasizing the link between human prosperity and the natural capital of land – the stock of natural resources that provides flows of valuable goods and services. The balance scale in the centre illustrates the mechanism for achieving neutrality: ensuring that future land degradation (losses) are counterbalanced through planned positive actions elsewhere (gains) within the same land type (same ecosystem and land potential). The pivotal point of the scale depicts the hierarchy of responses: avoiding degradation is the highest priority, followed by reducing degradation and finally reversing past degradation. The arrow at the bottom of the diagram illustrates that neutrality is assessed by monitoring the LDN indicators relative to a fixed baseline. The arrow also shows that neutrality needs to be maintained over time, through land use planning that anticipates losses and plans gains, and applies adaptive learning methods (where tracking impacts permits mid-course adjustments to help ensure that neutrality is maintained in the future).

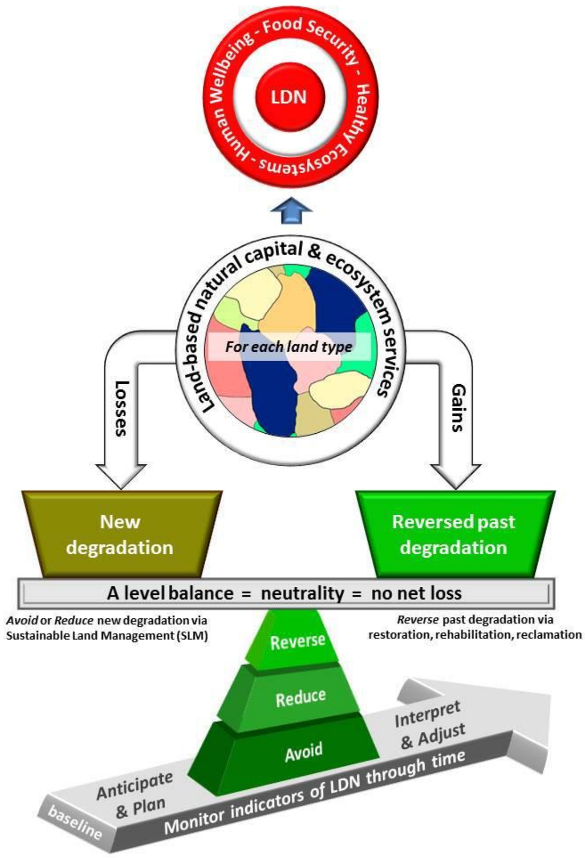


Figure 7-1: Framework of Land Degradation Neutrality (LDN).
Source: (UNCCD/Science-Policy-Interface 2016).

7.2 Linking Land Degradation Neutrality with SDG 15.3.1

In March 2016, half a year after the adoption of the SDGs an agreement on indicators was achieved. With regard to SDG goal 15.3 "*By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.*",the indicator 15.3.1 was agreed: the "*proportion of land that is degraded over total land*", see Figure 7-2.

The minimum set of indicators recommended (but not compulsory) for tracking progress towards LDN against a baseline is:

- Land cover
- Land productivity (metric: net primary productivity)
- Carbon stocks above and below ground (metric: soil organic carbon)

These indicators are part of a set of six progress indicators used by the UNCCD to track progress in the implementation of the Convention through national reporting. They have also been included as suggested indicators for the implementation of target 15.3. (Global Mechanism of the UNCCD 2016a).

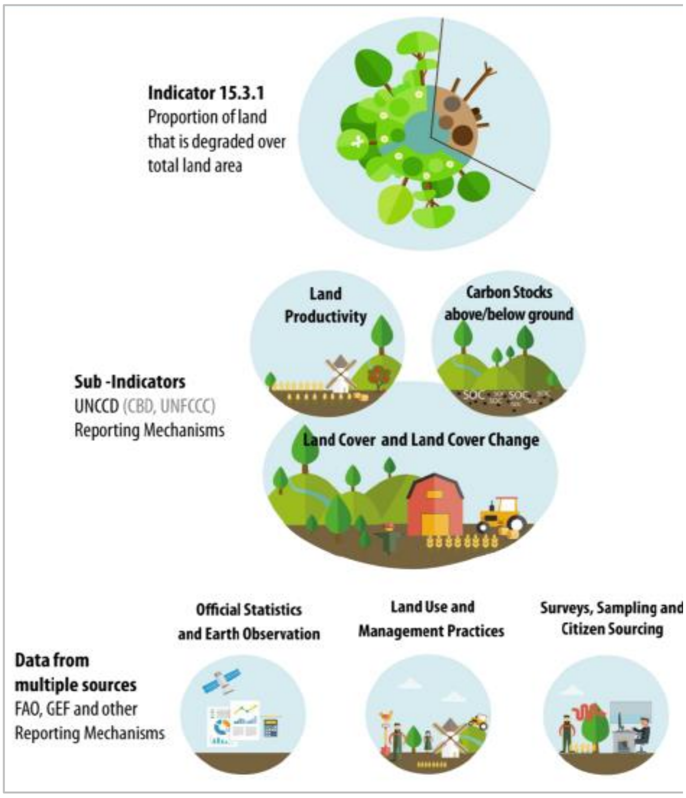


Figure 7-2: Indicators for monitoring SDG 15.3.1.
Source: (UNCCD/Science-Policy-Interface 2016).

7.3 Conceptual Framework of LDN

From 2018 on, UNCCD national reporting monitors progress made in the implementation of the 2018-2030 strategic framework, containing five strategic objectives and an implementation framework (UNCCD, 2018). The strategic objectives address:

1. Improvement of the condition of affected ecosystems, combat desertification/land degradation, promotion of sustainable land management and contribution to land degradation neutrality;
2. Improvement of the living conditions of affected populations;
3. Mitigating, adapting to, and managing the effects of drought in order to enhance resilience of vulnerable populations and ecosystems;
4. Generating global environmental benefits through effective implementation of the UNCCD; and
5. Mobilization of substantial and additional financial and non-financial resources to support the implementation of the Convention by building effective partnerships at global and national level

For the reporting on strategic objective no.1, SDG indicator 15.3.1. and its three sub-indicators (as listed above) can be supplemented, as needed, by other sustainable development goal (SDG) indicators and national indicators. The "one-out, all-out" approach is used to interpret the results of the three global indicators: if any of the three indicators/metrics shows significant negative change, it is considered a loss (and conversely, if at least one indicator/metric shows a significant positive change and none shows a significant negative change it is considered a gain). A simplified example, provided in Figure 7-3.

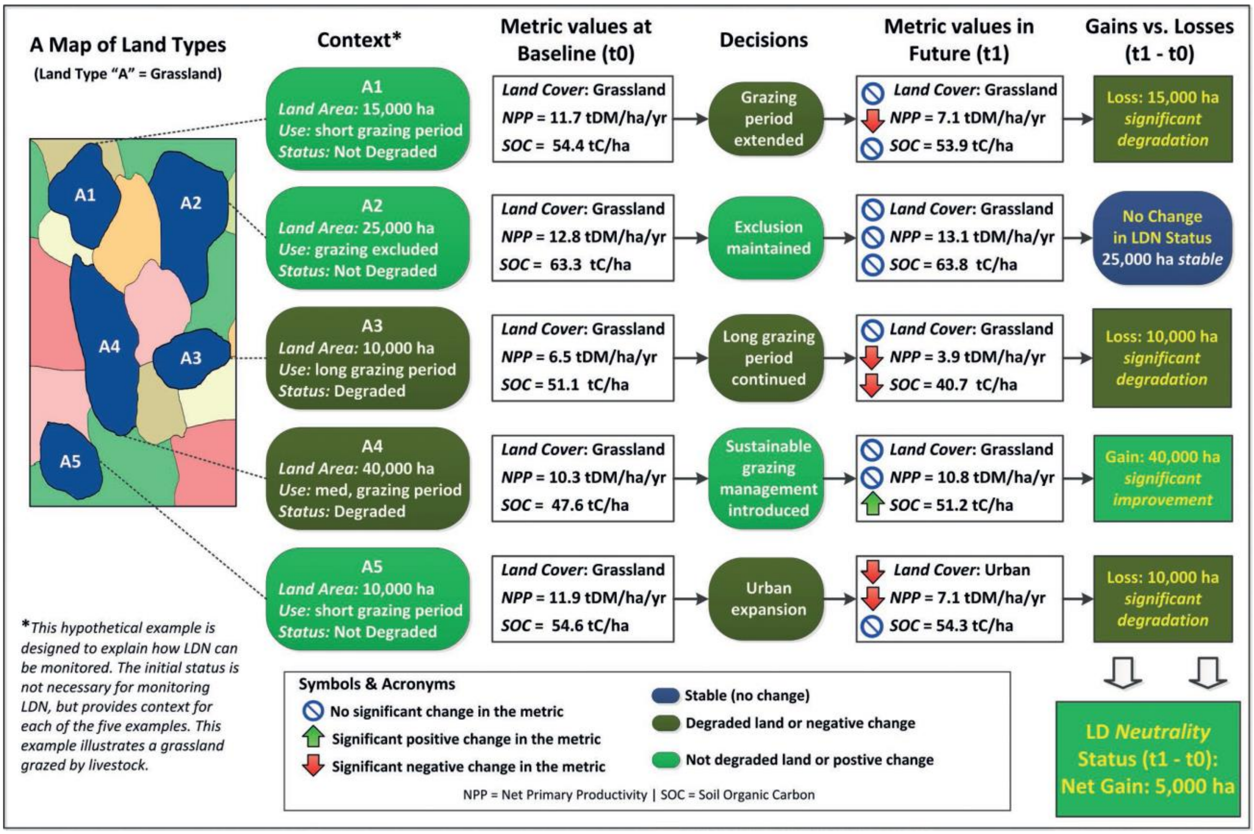


Figure 7-3: Example application of the LDN framework.
Source: (UNCCD/Science-Policy-Interface 2016).

7.4 Implementing LDN in Europe?

With respect to the application of the LDN approach in Europe, the following remarks can be made:

- The debate on LDN is strongly tied to the question of which functions and threats are of highest relevance within a region. Key soil threats have already been recognized at the EU level. The Communication of the Commission to the European Parliament and the Council "Towards a Thematic Strategy on Soil Protection" identifies eight main soil degradation processes. These are erosion, organic matter decline, contamination, salinisation, compaction, soil biodiversity loss, sealing, landslides and flooding. These are not captured by LDN, as food security has the highest priority.
- It is understood, and also suggested by UNCCD, that their framework can be adjusted to local conditions and to specific assessment frameworks. As a consequence, other, Europe specific datasets, or high-resolution national datasets, can be used for Europe.
- In the LDN approach (Figure 7-3), changes in metrics in separate land cover/land use types are treated as if they were islands without interaction with surrounding land units. For instance, what are the implications of manure, from cattle grazing in a certain land, is sold to a surrounding land to benefit arable farming? This situation occurs in many EU countries. Consequently, the LDN approach could be insufficiently sensitive to allow loss in NPP caused by grazing in one land type to be compensated by an increase in NPP in another land type to determine the LD neutrality status of the whole area.
- Not taking into account spatial interactions between land types could possibly unintentionally result in a 'non-compliant status' of LD Neutrality with the SDG target for a country.
- The indicators used in the LDN approach are not always independent indicators; for example, an increase in certain land covers might also results in an increase in Carbon Stocks. This interdependency of indicators calls for attention when adding and subtracting indicators for the calculation of LDN.

- Target setting and implementation of LDN must take into account regional circumstances and particularities and requires decisions that are often of a political nature.

7.5 Conclusion

The UNCCD approach to calculate LDN based on the indicators 1) Land Cover Change, 2) Net Primary Production, and 3) Soil Organic Carbon is only suited for Europe as a base layer, due to large regional differences and abundance of good data on a more regional scale. By including more detailed datasets on land use, land use intensity, socio-economic variables and climatic impacts however, land degradation can be better addressed by using local knowledge and local data..

8 Integrated Land Systems Data Platform to support the mapping of land degradation impacts on ecosystem services

The EEA is working on an infrastructure for supporting faster, more transparent geospatial data assessment, notably the Integrated Data Platform project. This chapter illustrates how the Integrated Data Platform could facilitate land degradation monitoring. Several products are now in place, which facilitate integrated Land Systems assessments, among others those addressing land degradation. These products indicate land under stress (or improvement) by providing geospatial and statistical information on the status and trends in the condition of our land resources. By identifying potential impacts of human activities, such as intensive land use or urbanisation, potential research needs can be identified and decision-makers can be empowered to take actions.

8.1 Introduction

Many policy processes require spatial data integration. Key policy drivers are:

- the 7th EAP, in particular, priority 1 "maintaining natural capital" and priority 5 "to increase the knowledge about environment and widen the evidence base for policy", and
- target 2, action 5 of the EU Biodiversity strategy to 2020 about maintenance and restoration of ecosystems and of mapping and assessing ecosystems and their services also requires the integration of geospatial data.

Although land degradation is a global phenomenon, it manifests in local patterns having various local processes as drivers. Furthermore, land degradation is a largely a perception of those who use the land. Therefore, in many cases, there may be several maps of land degradation; in some areas, frequent and intensive droughts may be the main drivers, whereas in other areas land take, soil contamination or strong landscape fragmentation, or their combination may drive land degradation. This means, that datasets reflecting local drivers need to be integrated, thresholds need to be adjusted to local conditions and assessment need to be performed by those who know the impacted area the best. Still, effective policies need quantitative assessments and statements on the condition of our lands. Therefore, there is a need for a platform where such assessments are possible.

EEA's Integrated Data Platform (IDP) addresses the transparent, repeatable, effective and sound integration of spatial datasets (as explained in the next chapter. Being an efficient way of integrating geo--spatial and tabular datasets, the platform offers an efficient way for addressing land degradation by using local knowledge for assessments.

8.2 The Integrated Data Platform in short

The Integrated Data Platform targets integrated geo-spatial data assessments. Through discovering semantic and contextual linkages between datasets, the IDP supports system thinking and understanding how various elements of our natural capital are in relationships with each other and with other systems. The IDP project addresses three working areas:

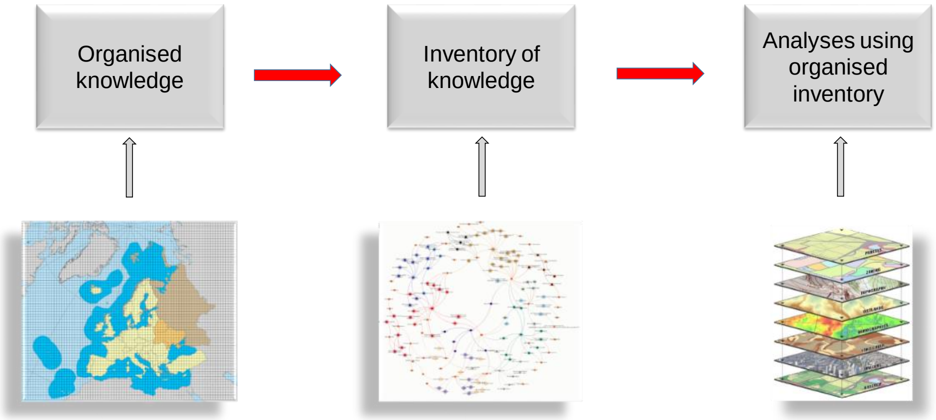


Figure 8-1: Working Areas of the Integrated Data Platform

- **Organise knowledge - spatial data management:** identifies, describes and integrates key spatial datasets into EEA's Spatial Data Infrastructure (SDI).
    - **Inventory of knowledge - semantic inventory of spatial datasets:** simplifies the complexity around geo-spatial data caused by numerous working areas and analytical expertise by discovering, organizing and structuring semantic information about geo-spatial data. Interactive contextual data inventory
    - Interactive entity relationships diagrams
    - Interactive web map platform
- **Integrated assessments:** directly enables integrated assessments (using local knowledge as well) by a system infrastructure combining geo-spatial datasets from a wide range of data sources and properties.
    - Data cubes
    - Interactive cube viewers
    - Integrated assessments

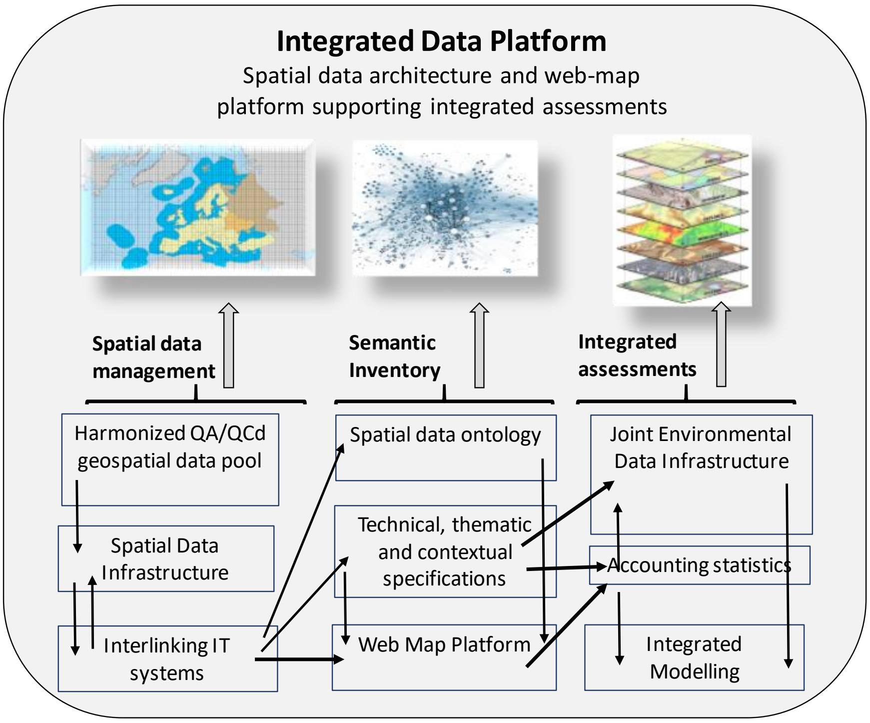


Figure 8-2: Architecture of the Integrated Data Platform

8.3 Detailed description of the Integrated Data Platform

8.3.1 Spatial data management

Spatial data QA/QC and harmonization. All of EEAs spatial datasets must be harmonized and managed correctly so that they have the best possible quality. A spatial data delivery workflow was designed with Quality Assurance (QA) and Quality Control (QC) criteria for spatial datasets to be harmonized.

Spatial data registration in EEA's Spatial Data Infrastructure. All the EEA internal spatial datasets are registered in EEA`s Spatial Data Infrastructure together with their web map services. The datasets, once validated, are physically stored in the SDI file system and depending on the specific case they will be visible in both the internal and public catalogues or, in case of restrictions in the usage, just in the internal catalogue.

Contextual Data Inventory. Today if we want to work with data, we ask around for relevant datasets hoping that someone can point us to the right direction. Once we found that dataset, we have to guess how to interpret it, whether it is right for the analysis. We hope that the data is accurate, correct and that it does not contain errors. Despite these uncertainties, we use the data for our assessments. When the next data seeker comes along, they start the same process all over again.

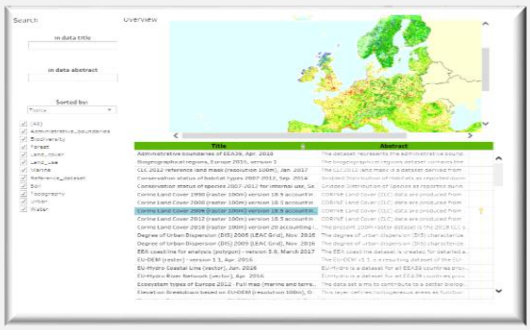
Organised and harmonised storage of spatial datasets and their metadata is indispensable for a data architecture, which is to enable a transparent and repeatable accounting of our natural capital. This information is stored in several distinct systems, such as the SDI, the EEA Website CMS (Content Management System), the Semantic Data Service and the server for web map services. These are brought together in EEA`s Contextual Data Inventory:

- https://www.eea.europa.eu/data-and-maps/data/cdi/@@view

8.3.2 Semantic inventory of spatial datasets

Interactive Contextual Data Inventory. Integrated spatial assessments can only be effective if geo-spatial data are inventoried in a transparent way, which enables the immediate understanding of the context and the analytical potential of our datasets. While the majority of the required technical and contextual information is available in various systems, the information is difficult to retrieve for thematic experts, because it is not organised in a way that optimally targets the analytical community. The interactive visualisation of the CDI summarizes technical, thematic and contextual information of spatial datasets, which are used for accounting for the condition and status of our natural capital.

Example view [explore]



Interactive entity relationships. The geospatial data inventory is supported by interactive entity relation diagrams in order to increase the transparency and accessibility of the contained information.

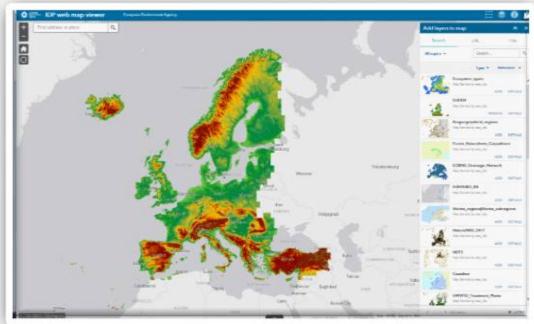
In such a visual analytics tool, connections are established on demand, following the users' interest, in order to facilitate the efficient identification of similarities, differences, gaps and complex relationships between datasets. Much of the interdisciplinary information is hidden in second or third order relationships; visual analytics will

Example view

facilitate the design of integrated spatial data assessments by unlocking knowledge from various domains and actors.

Web map platform: The Integrated Data Platform also visualizes spatial datasets by producing web map services and visualizing them in web map viewers. Web map viewers enable spatial overlays so that the datasets can be interactively explored also by project managers without GIS expertise or without immediate access to a GIS software. Once a web map service is quality controlled the services are registered in the SDI and are transferred into the IDP Web Map Viewer through the Contextual Data Inventory application.

Example view [explore]



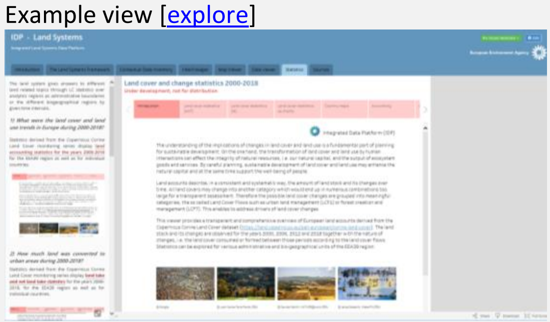
8.3.3 Integrated assessments

Data cubes. The demand for analysing datasets from different environmental topics is growing exponentially. The complexity of integrating these datasets is very high because of their diversity (vector polygons, lines, points, raster, satellite imagery), their size (Giga or terra bytes), spatial resolution (100 meter or more), temporal resolutions (time series update of an interval of few days) and their many different topics (Water, Air, Land, Climate, Biodiversity).

A first solution for integrated assessments via data cubes is built at the EEA (Joint Environmental Data Infrastructure – the 'JEDI system'). The JEDI system uses cloud infrastructure to integrate diverse data types in near real time. JEDI is component based in order to accommodate flexibility and change, while new user requirements are shaped over time. JEDI prepares tabular data dimensions from geo-spatial datasets, integrates them into multi-dimensional cubes and serves these data cubes to the Business Intelligence software Tableau for subsequent assessments. The database is a *.csv file and hence can be opened with other software than the default choice of Tableau. Year to year changes, area statistics of land surface processes and drivers of these processes can then be calculated and displayed in a user friendly, attractive and interactive way. JEDI stores the integrated geo-spatial data dimensions. These are ready to be integrated into various cubes on demand. With that, the source of geospatial assessments is always transparent and searching and pre-processing data, which is sometimes significant part of integrated assessment, can be saved as the dimensions of geospatial data are readily available in JEDI. JEDI allows the integration of tabular data as well, as long as there is a common field with the geospatial data, so that other information sources can complement the assessments.

Interactive cube viewers and integrated assessments. Accounting for changes in our natural capital is the process of calculating the total stocks and flows of natural resources in a given ecosystem or region. Examples are reporting land cover change statistics such as net changes in km^2, in ha or in % of country`s or a region's area. The use of standard grids has been recognised as key point for the integration of heterogeneous sources of data. The standard codification of grid cells makes them suitable for splitting the territory into a number of regular pieces that can be used as analysis units.

Example view [explore]



Besides general statistics on land cover stock or land cover change over time, the other main purpose of land and land degradation assessments is integrating the various processes that have occurred on the land.. Climatic drivers such as droughts or floods, disasters events such as storm damage, fire outbreaks or landslides, other variables related to soils such as compaction, contamination, erosion and socio-economic variables such as land abandonment or population density can be all integrated in the assessments using the data cube approach. The integrated analysis of drivers, pressures and impacts complement and improve land degradation assessment, and facilitates adjusting the assessment to local conditions.

There is a constantly growing stock of land system statistics being produced by the Integrated Data Platform project. First products are on land cover stock statistics whereas newer products also integrate biophysical time series data. The growing stock of products can be found under the statistics tab of the IDP Land Systems platform[27].

8.4 Summary

Montoring land degradation is a complex process, requiring an integrated assessment of various geo-spatial data. Transparent, repeatable, effective and correct integrated modelling of geo-spatial data has prerequisites, which are addressed by the various modules and sub-modules of the Integrated Data Platform described in this document.

The data inventory enables the planning of land degradation assessments across different topics, through the better understanding of the available data. It enables the display and spatial overlay of the datasets so that planning integrated assessments will further benefit from visually exploring the data. The data inventory is accessed and operated through a web interface which facilitates sharing, planning, communication. The JEDI system infrastructure enables the fast integration of the geospatial data which was identified by the data inventory. The interactive data viewers offer an analytical platform where expert knowledge can be incorporated into statistical information for assessment of land degradation.

The next step of the Integrated Data Platform project is the implementation of a mapping module in JEDI where assessment results can be written out into maps. Furthermore, an Integrated Land Systems Analytical platform is being designed where all elements of the Integrated Data Platform will be available.

27 IDP Land Systems platform https://eea.maps.arcgis.com/apps/MapSeries/index.html?appid=55fd81a5fdce457eab1a988554bf24b0

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RECARE preventing and Remediating Degradation of Soils in Europe through land Care
FP7 EU research project
https://www.recare-project.eu/

CASCADE CAtastrophic Shifts in drylands
FP7 EU research project
http://www.cascade-project.eu/

LAND MARK Land Management Assessment Research Knowledge Base
H2020 EU research project
http://landmark2020.eu/

SMARTSOIL Sustainable farm Management Aimed at Reducing Threats to SOILs under climate change
FP7 EU research project
http://smartsoil.eu/

DESIRE development of a System of Indicators for a Resource Efficient Europe
FP7 EU research project
http://fp7desire.eu/about

INSPIRATION Integrated Spatial Planning, land use and Soil management Research Action
H2020 EU research project
http://www.inspiration-h2020.eu/

ECOPOTENTIAL Improving Future Ecosystem Benefits
H2020 EU research project
http://www.ecopotential-project.eu/

ISQAPER Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience
H2020 EU research project
http://www.isqaper-project.eu/

MAES Mapping and Assessment of Ecosystems and their Services
http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm

OPPLA, the EU Repository of Nature-Based Solutions
http://www.oppla.eu

LANDSUPPORT Development of Integrated Web-Based Land Decision Support System Aiming Towards the Implementation of Policies for Agriculture and Environment
https://www.landsupport.eu/

ANNEX 1 - Examples of Mapping soil and land degradation processes in EU

Partly based on Stolte et al (2016)

Soil and land degradation process	Name/Theme	Type of study	Resolution	Map cover (countries)[a]	Temporal cover	Type of result	Summary of results	References
Soil erosion by water	PESERA	Model	1 km	(24)	Not specified (used data available in 2008)	Risk (scalar)	High erosion risk: (i) southern zone with severe risk; (ii) a northern loess zone with a moderate risk; and (iii) an eastern zone where the two prior zones overlap. Within all three zones, however, hotspots of soil erosion risk do occur.	Kirkby et al 2004
	MESALES	Model	1 km	(24)	ESDB data 2012	Vulnerability/ risk (ordinal)	High values mainly in Central Europe and Italy	Hessel et al, 2014b
	eRUSLE	Model	1 km	(33)	Corine data 2006	Risk (scalar)	130 million ha in the EU-27 countries are at risk of being affected by soil erosion by water and that this risk is moderate to high for about 14 % of the European territory. Highest values found in Greece, Italy, Alps, Norway and Iberian Peninsula	Bosco et al 2015
	RUSLE	Model	100 m	EU-28	2010	Risk (scalar)	Highest in Italy, Alps, Iberian Peninsula and Scotland	Panagos et al, 2015
	Cerdan et al 2010	Extrapolation of erosion plot results	100 m	(28)	Erosion plot data reported between 1971-2006; soil data	Rate (scalar)	Erosion rates comparatively high in the hilly loess areas of Western and Central Europe, marked spatial variation in the	(Cerdan et al. 2010)

Soil and land degradation process	Name/Theme	Type of study	Resolution	Map cover (countries)[a]	Temporal cover	Type of result	Summary of results	References
					2004; DEM 2004/2006; Corine 2006?		Mediterranean Zone, being high in many areas in Italy as well as in some areas in Spain. Erosion rates also varied strongly for Europe as a whole, as 70% of the total erosion originated from 15 % of the territory.	
Soil erosion by wind	ILSWE	GIS overlay of maps most influential factors	500 m	36	Climate data 1981-2010	vulnerability	Highest values in E Spain, SE France, S Italy, S Greece, Denmark and parts of Rumania, UK, Belgium, Netherlands and Norway	Borrelli et al. 2016, Borrelli, Lugato et al. 2017
	RWEQ model	Assessment of wind erosion soil loss in agricultural soils	1 km	EU28	from January 2001 to December 2010	Average annual soil loss due to wind erosion on arable soils	Highest values in Denmark, Eastcoast of England, East Bulgaria	Borrelli, Lugato et al. 2017
Decline organic matter (mineral soils)	CENTURY	Model	164000 combinations of soil, climate and land use	35 (EU-27 + Serbia, Bosnia and Herzegowina, Croatia, Montenegro, Albania, Macedonia and Norway	LUCAS data 2009; climate 1900-2010, Corine 2006, ESDB at time writing	Risk (scalar)	In the long term decreases in Southern and Eastern Europe	Lugato et al, 2014
	De Brongniez et al 2015	Extrapolation of LUCAS data using co-variates	500 m	25 (23 countries LUCAS sampling 2009 + Malta and Cyprus)	LUCAS data 2009	State of SOC (scalar)	Lowest in Mediterranean and parts of FR, D, PL, CZ, SL, HU, were land use is cropland	De Brogniez et al 2015

Soil and land degradation process	Name/Theme	Type of study	Resolution	Map cover (countries)[a]	Temporal cover	Type of result	Summary of results	References
Soil compaction	SPADE8	Subsoil density state	Not specified in Stolte et al 2016	28	SPADE8 date	State of density (scalar)	Quite variable, high densities a.o in parts Baltic States, most of Denmark, most of Czech Republic, parts of Portugal and Greece	Koue et al., 2008 In Stole et al 2016
	Topsoil physical properties	Extrapolation of LUCAS data	500 m	25 (EU-28 minus Bulgaria, Romania and Croatia)	LUCAS data 2009; remote sensing 2009; Corine 2000	State of density (scalar)	Quite variable, highest in (large) parts of Baltic States, DK, D, FR, SP, UK, HU	Ballabio et al. 2016
Soil Sealing	EEA map	Sealing state based on Remote Sensing	NUTS3, 20&100 m raster maps	EU-27/38	2006/2013 (GEOLAND2)	State (classes), rate can be obtained using CORINE	Highest in NL, BE and parts of GE, UK and FR	Prokop *et al.*, 2011; EAA, 2013
Contamination	Point	EIONET questionnaire	-	38 countries addressed, 33 responded	2016	State/Level	2.5M sites identified, 11.7M sites potentially polluted	Panagos *et al.*, 2013 JRC, 2018
	Heavy metals	Model for 8 heavy metals	1 km	26 (FOREGS dataset)	Data in database at time of writing	State/Level	High values of Cr and/or Ni are mainly found in central Greece, northern Italy, the central Pyrenees, northern Scandinavia, Slovakia and Croatia and are correlated with geology. Cadmium, Cu, Hg, Pb, Zn present a high concentration in Central Europe and are mainly related with agriculture and with quaternary limestone. The use of fertilizers, manure and	Lado *et al.*, 2008

Soil and land degradation process	Name/Theme	Type of study	Resolution	Map cover (countries)[a]	Temporal cover	Type of result	Summary of results	References
							agrochemicals are important sources of these elements.	
	Heavy metals in agricultural soils	Extrapolation of LUCAS data	NUTS2	EU27	2009-2012 (LUCAS data)	State	Different for different heavy metals. An estimated 6.24% (137,000 km^2) of the agricultural land needs local assessment and eventual remedial action, based on the guideline concentrations applied in our study	Toth et al, 2016
	Copper distribution in European topsoils	Modelling & Lucas interpolation	400 m	EU 28				Ballabio et al., 2018
	Herbicide application	State	Country level	29		Level	Highest values in Benelux	EEA, 2015c
Salinisation		State	Not specified	Whole of Europe		State of salt content	Areas with naturally saline soils; coastal areas with salt water intrusion; (agricultural) areas with higher	Toth et al, 2008; Stolte et al, 2016; Daliakopoulos et al, 2016

Soil and land degradation process	Name/Theme	Type of study	Resolution	Map cover (countries)[a]	Temporal cover	Type of result	Summary of results	References
							evaporation than rainfall/irrigation	
Desertification	DISMED	GIS analysis	1:1M	12 (AL, BA, BG, CS, ES, FR, GR, HR, IT, PT, RO, SI)	Not specified	Vulnerability	Most severe in Southern Portugal, Southern Spain and Sicily	Domingues and Fons-Esteve, 2008
Flooding and landslides	LISFLOOD	Model	5 km	Whole of Europe	Control: 1961-1990; climate scenarios: 1961-2100	Risk	Varies depending on which climate model is used; most suggest increase in Western/Central Europe, and decrease in Eastern Europe and Spain. Results for Scandinavia variable.	Rojas et al, 2012
	ELSUS2		200 m	EU28 without Malta, Albania, Andorra, Bosnia and Herzegovina, Croatia, FYR Macedonia, Iceland, Kosovo, Liechtenstein, Montenegro, Norway, San Marino, Serbia, and Switzerland		Landslide Susceptibility		Wilde, Günther et al., 2018
	landslides	Model	1 km	35 (EU-27 minus Cyprus, but with Norway, Switzerland and Baltic countries)	GTOPO 1996; ESDB 2012; land cover: PELCOM 1999	Vulnerability	Highest in areas with largest relief, such as Alps, Apennines and Balkan	Günther et al, 2013
Decline soil biodiversity	European Atlas of Soil Biodiversity	GIS-analysis and expert opinion	1 km	23	Knowledge at time of writing	Level of threat (to soil	Especially high in UK. Also high in NL, BE, FR,	Jeffery et al, 2010

Soil and land degradation process	Name/Theme	Type of study	Resolution	Map cover (countries)[a]	Temporal cover	Type of result	Summary of results	References
						biodiversity) (ordinal)	GE. Lowest in Eastern and Southern Europe	
	Orgiazzi et al 2016	Expert opinion, indices and GIS analysis	500 m	27	GIS data 2000-2015 (different dates for different data)	risk	Separate maps for soil microorganisms, soil fauna and soil biological functions, showing similar patterns: highest in NW Europe and in parts of SP, IT, HU and RO.	Orgiazzi et al 2016
Biological degradation: Loss of habitats	Habitat change (change in land use)	GIS-analysis	Not specified	39	2000-2006	Type of conversion	One of the main issues over period 2000-2006 was urban land take and sealing	EEA, 2016a
Biological degradation: Decline of quality, species composition and diversity	Invasive species (plants)	Extrapolation of vegetation plot results using habitat type	250 m	Whole of Europe minus Iceland, Norway, Andoraa, Switserland, Serbia, Montenegro, Kosovo, Belarus, Ukraine, Moldova and Russia	Vegetation plots since 1970s, Corine 2006	Level	Highest in W, C and E Europe, patches in S Europe	EEA, 2016a; (Chytry et al. 2009)
	Pollution (nitrogen)	Emissions and modelling?	Not specified	Whole of Europe	1980-2030	Level	Exceedance of critical loads has decreased since 1980, but still occurs in most of Europe, in particular NW Germany, NL, Po Valley and parts of France	EEA, 2015c

a Value in brackets means it was not reported in the publication. In these cases the number of countries was estimated from the maps in the publication. This estimate may not be fully accurate as resolution of the maps does not allow to determine whether small countries like Andorra, Liechtenstein, Monaco, Malta, Vatican and Gibraltar have been included or not.

ANNEX 2 – Spatial Data Catalogue for applications with Pan-European coverage

Drivers of Land Degradation

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
D1	Land use intensity on croplands	The map shows cropping frequency expressed as the number of years a cropland pixel was cropped over the observation period 2000-2012.	- (frequency)	2000-2012	The European continent and Turkey 231.6 m	-	(Estel et al. 2016) http://iopscience.iop.org/article/10.1088/1748-9326/11/2/024015
D2	Wood production	Wood production statistics for 29 European countries from 2000 to 2010 and comprehensive sets of biophysical and socioeconomic location factors were collected. Regression analyses were used to produce maps indicating the harvest likelihood on a 1 × 1 km^2 grid.	$m^3.ha^{-1}.y^{-1}$	2000-2010	Europe (29 countries) 1 km^2	http://datadryad.org/resource/doi:10.5061/dryad.mk067 Data are currently embargoed until publication in June 2020.	(Verkerk et al. 2015) http://www.sciencedirect.com/science/article/pii/S0378112715004302
D3	Land use change trajectories	Archetypical changes of patterns of land-use extent and intensity between 1990 and 2006, based on 14 explanatory factors of land use change and underlying drivers.	-	1990-2006	EU27 1 km^2	-	(Levers et al. 2015) http://link.springer.com/article/10.1007/s10113-015-0907-x
D4	Landscape fragmentation	Landscape connectivity expressed as the degree to which movements between	Efective mesh size	2000-2006, 2009,	EEA-39 1 km^2	-	(Jaeger 2000) https://link.springer.com/article/10.1023%2FA%3A1008129329289

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		different parts of the landscape are possible. The map is based on the method of Effective Mesh Size: the area that is accessible to an animal when starting a movement at a randomly chosen point inside a landscape without encountering a physical barrier, such as transport routes or built-up areas.	(meff, km^2)	2012, 2015			
D5	Imperviousness change	The High Resolution Layer Imperviousness Change (IMC) captures the spatial distribution of artificially sealed areas, including the level of sealing of the soil per area unit. The level of sealed soil (imperviousness degree 1-100%) is produced using an automatic algorithm based on calibrated NDVI. Time series of imperviousness data contain two products: a status layer for any reference year (e.g. degree of Imperviousness 2012), as well as an imperviousness density change layer between reference years (e.g.	Area %	2006-2009, 2009-2012, 2012-2015, 2015-2018	EEA39 100 m	Copernicus Land Monitoring Service http://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/view	-

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		evolution from 2009 to 2012), and based on the already existing imperviousness product for that previous reference year.					
D6	Regionalised Water Exploitation Index (WEI+)	The regionalised Water Exploitation Index (WEI+) is calculated as the ratio of water use (by source and sector) over renewable water resources at sub-basin or river basin scale. Quarterly average per river basin district as defined in the European catchments and rivers network system (ECRINS).	%	1990 - 2015	EEA39 Sub-basin or river basin	EEA https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3	-
D7	Drought frequency, intensity	Linear trends in drought frequency and intensity fitted over the Standardized Precipitation and Evapotranspiration Index within the vegetation growing season. Drought frequency was calculated as the number of negative SPEI values within the vegetation growing season for each year between 1999-2013. Drought intensity was defined as the negative values within the vegetation	-	1999-2013	Eurasia 8 km^2	-	(Ivits et al. 2016) http://onlinelibrary.wiley.com/doi/10.1111/geb.12472/pdf

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		growing season for each year between 1999-2013.					
D8	Grazing cattle	-	Livestock units	-	EU28 1 km?	EU-PEGASUS Project	*Not yet publicly available*
D9	Farm typology	Spatially explicit farm typology for the EU based on farm specialization, farm size and farm intensity, developed in the EU-SEAMLESS project. The typology helps to relate information on farm type to a bio-physical context and will therefore enable: the differentiation of farm types according to bio-physical environment within regions to integrate market response behaviour with environmental performance of farms to up-scale environmental performances of farms to farm type groups	-	2000 (FSS and CLC) 2003 (FADN) 2002-2006 (soil, relief, climate data)	EU25 Farm Mapping Units or Homogeneous Mapping Units	-	(Kempen et al. 2011) (Elbersen et al. 2006)

Soil threats and other land degradation types (LD)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
LD1	Soil erosion by water	Modelled risk for soil erosion by water based on the RUSLE model (RUSLE 2015). The input factors (rainfall erosivity, soil erodibility, cover/ management, slope length and steepness, and support practices) have been peer-reviewed and published at the ESDAC.	$t.ha^{-1}.year^{-1}$	2010	EU28 100 m	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015 http://esdac.jrc.ec.europa.eu/public_path/RUSLE2015_news.png	(Panagos et al. 2015)
LD2	Wind erosion susceptibility	The Index of Land Susceptibility to Wind Erosion (ILSWE) is based on the combination of the most influential parameters for wind erosion, i.e. climate (wind, rainfall and evaporation), soil characteristics (sand, silt, clay, CaCO3, organic matter, water-retention capacity and soil moisture) and land use (land use, percent of vegetation cover and landscape roughness).	-	1981-2010	EU28 and Montenegro, Serbia, the Former Yugoslav Republic of Macedonia, Albania, Bosnia and Herzegovina, Kosovo, Norway and	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre https://esdac.jrc.ec.europa.eu/themes/land-susceptibility-wind-erosion	(Borrelli et al. 2016)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
					Switzerland		
LD3	Landslide susceptibility	Landslide susceptibility levels at European scale, derived from heuristic-statistical modelling of main landslide conditioning factors based on 3 parameters: slope gradient, lithology and land cover.	5 classes: Very low (<0.2) Low (0.2-0.4) Moderate (0.4-0.6) High (0.6-0.8) Very High (>0.8)	GTOPO 1996; ESDB 2012; land cover: PELCOM 1999	EU27 (excl. Cyprus) and Albania, Bosnia and Herzegovina, Croatia, Kosovo, FYR Macedonia, Montenegro, Norway, Serbia and Switzerland 1 km	European Landslide Expert Group http://esdac.jrc.ec.europa.eu/themes/european-landslide-expert-group http://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus1000-v1	(Günther et al. 2014)
LD4	Heavy metals in agricultural soils	Maps of the concentration of heavy metals in agricultural topsoils in the European Union, including As, Cd, Cr, Cu, Hg, Pb, Zn, Sb, Co and Ni. Based on the LUCAS Topsoil Survey (2012). The dataset also	$mg.kg^{-1}$	2009-2012	EU27 NUTS2	European Commission - https://esdac.jrc.ec.europa.eu/content/maps-heavy-metals-soils-eu-based-lucas-2009-hm-data-0	(Tóth et al. 2016)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		includes maps of the share of soil samples with heavy metal concentrations above the threshold value.					
LD5	Eroded soil organic carbon	Distribution of average eroded SOC (Mg C ha-1 yr-1) for the decade 2000–2010, in agricultural soils of the EU. The map is a result of a recently developed high resolution pan-European simulation platform to assess the potential impact of six management practices on SOC stock levels of arable soil under two IPCC climate change scenarios to 2100: 1) arable to grassland conversion (and vice versa), 2) straw incorporation, 3) reduced tillage, 4) straw incorporation with reduced tillage, 5) ley cropping and 6) cover crops.	$Mg.C^{-1}.ha^{-1}.year^{-1}$	2000-2010	EU28	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/pan-european-soc-stock-agricultural-soils	(Lugato et al. 2016)
LD6	Saline and sodic soils	Spatial distribution of saline, sodic and potentially salt affected areas within the European Union. The accuracy of input input data only allows the designation of salt affected areas with a limited level of reliability (e.g. < 50 or > 50% of the	-	2008	EU27 1 km	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union	(G. Tóth et al. 2008)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		area); therefore the results represented in the map should only be used for orientating purposes.					
LD7	Natural susceptibility to soil compaction	Natural susceptibility of agricultural soils to compaction, based on pedotransfer rules using attributes of the European soil database: soil type, texture and water regime, depth to textural change and the limitation of the soil for agricultural use. Auxiliary soil properties used include impermeable layer, depth of an obstacle to roots, water management system, dominant and secondary land use.	-	2000 (land cover) 2006 (soil properties)	EU27 1 km	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/natural-susceptibility-soil-compaction-europe	(Houskova & Van Liedekerke 2008)
LD8	Drought vulnerability	Ecosystems vulnerable to drought in the period 1999-2013. Ecosystem vulnerability was calculated as significant correlations between the anomalies of the remote sensing derived vegetation index FAPAR and of the negative values of the SPEI03 dataset. The regression was run within the vegetation growing season. FAPAR= Fraction of	-	1999-2013	Eurasia 8 km^2	-	(Ivits et al. 2016)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		Absorbed Photosynthetically Active Radiation. SPEI03 =Standardized Precipitation and Evaporation Index. Anomalies show deviations from the long term mean.					
LD9	Number of agricultural related article 17 habitats	The map shows the total number of agriculture-related Article 17 habitats. For the list of habitats see Table 1 (page 11) under the publication link.	number	2007-2012	EU27 10 km	-	(Masante et al. 2015) https://ec.europa.eu/jrc/en/publication/indicators-biodiversity-agroecosystems-insights-article-17-habitat-directive-and-iucn-red-list
LD10	Land productivity dynamics	Land productivity dynamics are a measure for general productivity levels of the land or human-environment system. The map shows long-term linear trends in the remote sensing observed Spot Vegetation FAPAR productivity combined with current levels of productivity performance. Productivity was defined as the yearly FAPAR integral value within the vegetation growing season.	- (steadiness classes for standing biomass)	1982-2010	Europe, of Asia and North-Africa	-	(Cherlet et al. 2013) http://publications.jrc.ec.europa.eu/repository/bitstream/JRC80541/lb-na-26052-en-n%20.pdf
LD11	Potential threats to soil biodiversity in Europe	Dataset of 3 maps showing potential threats to soil biodiversity in Europe. A list of 13 potential threats to	-	2015	EU27 500 m	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre	(Orgiazzi et al. 2016) (Orgiazzi et al. 2015)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		soil biodiversity was proposed to experts to assess the potential for three major components of soil biodiversity: soil microorganisms, fauna, and biological functions.				http://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe	
LD12	Soil biodiversity potential	Overall potentials for soil biodiversity in Europe, assessed and mapped by means of several indicators which might affect the conditions of soils for biodiversity (pH, soil texture, soil organic matter, potential evapotranspiration, average temperature, soil biomass productivity, land use).	-	Datasets used have time stamps between 2006 and 2015	EU27 1 km	-	(Aksoy et al. 2017) http://www.sciencedirect.com/science/article/pii/S0048969717304229

Properties of the natural capital

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
NC0	Soil types	Soil types at European scale can be derived from two datasets: • the European Soil Database v2.0 • SoilGrids	-	ESDB v2.0: soil information up till 2001	ESDB v2.0: Europe and parts of Asia	ESDB v2.0: European Soil Data Centre (ESDAC), European Commission, Joint Research Centre and the	The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
					Rasters at 1 km SoilGrids: global 1 km 250 m	European Soil Bureau Network http://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data For SoilGrids: ISRIC - World Soil Information https://soilgrids.org ftp://ftp.soilgrids.org/	(Hengl et al. 2014) (Hengl et al. 2017)
NC1	Soil depth	Depth class of obstacle to roots.	-	-	EU25 1 km	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre https://esdac.jrc.ec.europa.eu/content/european-soil-database-v2-raster-library-1kmx1km	https://esdac.jrc.ec.europa.eu/content/european-soil-database-v2-raster-library-1kmx1km
NC2	Soil texture	Soil texture classes (USDA system) of topsoil (at depth 0 m)	- LEGEND=255:NODATA, 1:Cl, 2:SiCl, 3:SaCl, 4:ClLo, 5:SiClLo, 6:SaClLo, 7:Lo, 8:SiLo, 9:SaLo, 10:Si,	1930-2015 for the soil profile data underlying the SoilGrids 1 km database 2000-2015 for the covariates	Global 250 m	ISRIC - World Soil Information https://soilgrids.org ftp://ftp.soilgrids.org/data/recent/ TEXMHT_M_sl1_250m.tif	(Hengl et al. 2014) (Hengl et al. 2017)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
			11:LoSa, 12:Sa				
NC3	Topsoil organic carbon	Predicted topsoil soil organic carbon content in the EU-25, based on LUCAS 2009 soil point data. The map was produced by fitting a generalised additive model between organic carbon measurements from the LUCAS survey and a set of environmental covariates: slope, land cover, annual accumulated temperature, net primary productivity, latitude and longitude. The dataset also includes a map with the standard error of the SOC model predictions and a map with the point locations where soil was sampled in the LUCAS sampling campaign.	g $C.kg^{-1}$ dry matter	2014	EU25 (excluded Romania, Bulgaria, Croatia) 1 km	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/topsoil-soil-organic-carbon-lucas-eu25#tabs-0-description=0	(de Brogniez et al. 2015)
NC4	Soil pH	pH (H_2O) in topsoil (at depth 0 m)	Index.10	1930-2015 1960-2010 for the soil profile data underlying resp. the SoilGrids 1 km and	Global 250 m	ISRIC - World Soil Information https://soilgrids.org ftp://ftp.soilgrids.org/data/recent/ PHIHOX_M_sl1_250m.tif	(Hengl et al. 2014) (Hengl et al. 2017)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolutio n	Data holder and URL to downloadable data	Source publication(s)
				250 m databases 2000-2015 for the covariates in the SoilGrids databases			
NC5	Available soil water capacity	Available soil water capacity of topsoil (depth 0 cm) at pF 2.0	$cm^3.cm^{-3}$	1930-2015 1960-2010 for the soil profile data underlying resp. the SoilGrids 1 km and 250 m databases 2000-2015 for the covariates in the SoilGrids databases	Global 250 m	ISRIC - World Soil Information https://soilgrids.org ftp://ftp.soilgrids.org/data/recent/ AWCh1_M_sl1_250m.tif	(Hengl et al. 2014) (Hengl et al. 2017)
NC6	3D Soil Hydraulic Database of Europe	3D spatial database of soil hydraulic properties at 7 soil depths up to 2 m (EU-SoilHydroGrids ver 1.0).	Saturated water content (THS)	time frame of the soil (hydraulic) data used to develop	Europe and parts of Western Asia	https://eusoilhydrogrids.rissac.hu/ Metadata: http://mta-taki.hu/sites/all/files/linke	(Tóth et al. 2017) (Batjes et al. 2017)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		The database includes information on the soil water content at the most frequently used matric potential values, saturated hydraulic conductivity, Mualem-van Genuchten parameters of the moisture retention and hydraulic conductivity curves. Properties were calculated with the European pedotransfer functions (EU-PTF) (Tóth et al., 2017) based on the SoilGrids 250m and 1km dataset (Hengl et al., 2017).	$[cm^3.cm^{-3}] \times 100$ Water content at field capacity (FC) $[cm^3.cm^{-3}] \times 100$ Water content at wilting point (WP) $[cm^3.cm^{-3}] \times 100$ Saturated hydraulic conductivity (KS) $[cm.day^{-1}] \times 100$ Parameters of the moisture retention (MRC) and	(not to apply) the EU-PTF 1930-2015 1960-2010 for the soil profile data underlying resp. the SoilGrids 1 km and 250 m databases 2000-2015 for the covariates in the SoilGrids databases		d/eu_soilhydrogrids_further_information_30052017.pdf	

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
			hydraulic conductivity curve (HCC) × 10000 as specified in the metadata				
NC7	Soil chemical quality	Baseline concentrations of heavy metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc) in topsoils, predicted using 1588 georeferenced samples from the Forum of European Geological Surveys Geochemical database. The concentrations were interpolated using block regression-kriging (support size 5 m).	mg.kg^{-1}	2008	EU26	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/heavy-metals-topsoils#tabs-0-description=1	(Lado et al. 2008)
NC8	Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the	Three maps indicating the soil biomass productivity of grasslands and pasture, of croplands and of forest areas in the European Union (EU27). The soil biomass productivity is expressed as a productivity score based on soil properties,	-	-	EU27 1 km	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-	(Tóth et al. 2013)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
	European Union (EU27)	the climatic zone, response to fertilizers (for cropland) and the slope.				coplands-and-forest-areas-european	
NC9	Irrigation (agri-environmental indicator)	Share of the irrigable and irrigated areas and their share in the total utilised agricultural area (UAA). The irrigable area is the area which is equipped for irrigation. This area does not show so much variation from year to year as it is costly for the farmer to invest in irrigation equipment. The irrigated area measures the actual amount of land irrigated and can vary significantly from year to year due to for instance meteorological conditions or the choice of crop.	% of UAA	2013	EU28 and Norway	EUROSTAT http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_irrigation	(Eurostat 2016)
NC10	Global equilibrium groundwater table depth	The map is derived from global observations of water table depth compiled from government archives and literature, and fill in data gaps and infer patterns and processes using a groundwater model forced by modern climate, terrain, and sea level. Patterns in water table depth explain patterns in wetlands at the global scale and vegetation gradients at regional and local	m	Climate-based equilibrium conditions based on GWD observations since 1927	Global 1 km	Global Water Table Depth Observations and Model Simulations http://www2.mmm.ucar.edu/wrf/users/download/get_sources_wps_geog.html (dataset name: groundwater)	(Fan et al. 2013)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		scales. Units are expressed in meters.					
NC11	Vegetation cover	Greenness of the land surface expressed as yearly mean NDVI, calculated from time series of MODIS satellite images. The greenness change map shows the difference between the yearly mean NDVI values for the years 2011 and 2000.	NDVI-index normalised to values from 0-100	2000-2011	EU28 plus Iceland, Norway, Switzerland and part of Turkey 1 km	European Environment Agency	(Malak et al. 2013)
NC12	Topsoil physical properties	Data are available for the following Physical properties: Clay content (%) in topsoil (0-20cm) modelled by Multivariate Additive Regression Splines; Silt content (%) in topsoil modelled by Multivariate Additive Regression Splines; Sand content (%) in topsoil modelled by Multivariate Additive Regression Splines; Coarse fragements (%) content in topsoil modelled by Multivariate Additive Regression Splines; Bulk density derived from soil texture datasets (obtained from the packing density and the mapped clay content following the equation of Jones et al. 2003); USDA soil	various	2009	EU including WBC, CH and NO; 500m spatial resolution	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre https://esdac.jrc.ec.europa.eu/content/topsoil-physical-properties-europe-based-lucas-topsoil-data	(Ballabio C., Panagos P., Montanarella L., 2016, Mapping topsoil physical properties at European scale using the LUCAS database, *Geoderma*, 261 , pp. 110-123)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
		textural classes derived from clay, silt and sand maps; Available Water Capacity (AWC) for the topsoil fine earth fraction. Note that these data are based on the LUCAS topsoil data for ca 20,000 samples across EU.					
NC13	Chemical properties at European Scale based on LUCAS data	Data are available for the following Chemical properties: pH (measured in H2O); pH (n CaCl2 0.01 M solution); Cation Exchange Capacity (CEC); Calcium carbonates (CaCO3); C:N ratio; Nitrogen (N); Phosphorus (P); Potassium (K). Note that these data are based on the LUCAS topsoil data for ca 22,000 samples across EU.	various	2009	EU-26, excluding Cyprus and Croatia; 500m spatial resolution	European Soil Data Centre (ESDAC), European Commission, Joint Research Centre https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data	(Ballabio, C., Lugato, E., Fernández-Ugalde, O., Orgiazzi, A., Jones, A., Borrelli, P., Montanarella, L. and Panagos, P., 2019, Mapping LUCAS topsoil chemical properties at European scale using Gaussian process regression. *Geoderma*, 355: 113912.)

Properties of human, built and social capital

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
HC1	Population density	Population-grid dataset representing population density in Europe	Persons.km^{-2}	2011	EU28 1 km	EUROSTAT http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_grids	(Eurostat 2016)
BC1	Urban night light	Urban night light calculated from the Version 4 DMSP-OLS Nighttime Lights Time Series. The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. In cases where two satellites were collecting data - two composites were produced. The products are 30 arc second grids, spanning. In the spatial data catalogue the file F182013_v4c_stable_lights.avg_vis.tif is included. The cleaned up avg_vis contains the lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires have been discarded. Then the background noise was identified and replaced with values of zero.	Data values range from 1-63. Areas with zero cloud-free observations are represented by the value 255.	2013	-180 to 180 degrees longitude and -65 to 75 degrees latitude. 30 arc seconds	National Centers for Environmental Information (NCEI, part of NOAA) https://ngdc.noaa.gov/eog/data/web_data/v4composites/F182013.v4.tar https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html#AVSLCFC	Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by US Air Force Weather Agency.

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
SC1	Internet connectivity	Percentage of households who have internet access at home (per unit). All forms of internet use are included. The population considered is aged 16 to 74. Data represents the percentage of households with access to the internet at home, mostly NUTS2 level data distribution, but for some of the countries data is given in NUTS0 (country level, e.g. Iceland) or NUTS1 (e.g. Germany). Time series data starts from 2012 to 2016. Most of the data is from the latest year (2016). However, for some of the regions has break in time series or exist for only 1 year in the period. For those regions, only available or oldest data is used.	% (of households)	2003-present	EU-Member States, Candidate countries, Iceland and Norway.	EUROSTAT http://ec.europa.eu/eurostat/cache/RCI/#?vis=nuts2.infosoc&lang=en	http://ec.europa.eu/eurostat/cache/RCI/Eurostat_Regions_and_Cities_Illustrated_Help.pdf (interactive tool) http://bit.ly/2swX9Tg (tables)

Reporting units

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
R1	Land System Archetypes	This map shows land-system archetypes for the year 2006, defined as characteristic patterns of land-use extent and intensity. The analysis identified 15 land-system archetypes, with low-intensity archetypes dominating (ca. 55 % coverage) followed by high-intensity archetypes (ca. 26 %).	-	1990-2006	EU27	Christian Levers, University of Berlin	(Levers et al. 2015)
R2	Dominant land cover flows	Land accounting is based on organising land cover changes as reported by the Corine Land Cover (CLC) survey into different land cover flows (LCFs). These LCFs are spatial datasets based on grouping land cover changes according to the underlying processes or drivers.	-	2000-2018	CLC2000: 35 countries CLC2006: 38 countries CLC2012: 39 countries CLC2018: 39 countries 100 m	EEA and Eionet network National Reference Centres Land Cover Hosted through the Copernicus Land Monitoring Service http://land.copernicus.eu/pan-european/corine-land-cover/view For the period 2000-2006: http://www.eea.europa.eu/data-and-maps/figures/dominant-land-cover-flow-2000-2006/csi014_drivers_of_change_2000_2006.eps/image_large	

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
R3	Administrative units: Nomenclature of territorial units for statistics (NUTS)	The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU. The current NUTS 2016 classification is valid from 1 January 2018 and lists 104 regions at NUTS 1, 281 regions at NUTS 2 and 1348 regions at NUTS 3 level.	-	2013-present	NUTS 1: major socio-economic regions NUTS 2: basic regions for the application of regional policies NUTS 3: small regions for specific diagnoses	EUROSTAT http://bit.ly/2blJNVH	http://ec.europa.eu/eurostat/web/nuts/overview
R4	European river catchments	Dataset of European catchments at scale 1:1 million				European Environment Agency http://www.eea.europa.eu/data-and-maps/data/european-river-catchments-1	-
R5	The Environmental Stratification of Europe (EnS)	The Environmental Stratification of Europe (EnS) is based on climatic variables, altitude, slope, latitude and oceanicity. The stratification has 84 strata, which have been aggregated into 13 Environmental Zones.	-	1971-2000 (climate variables) 1996 (altitude, oceanicity) 1993-1996 (geomorphology)	'Greater European Window' with the following boundaries: 11° W, 32° E, 34° N, 72° N. 1 km^2	-	(Metzger et al. 2005)

Nr	Title	Description	Unit	Temporal coverage	Spatial coverage and resolution	Data holder and URL to downloadable data	Source publication(s)
R6	Biogeographical regions (v2, 2016)	European wide map of the biogeographical regions independent of political boundaries. Official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention).	-	2016	45 countries Varying resolution depending on scale: 1:1 000 000 (EU-countries), 1:1 000 000 or 1:10 000 000 for other regions.	European Environment Agency https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3	-
R7	Map of ecosystem types V2.1	Map of ecosystem types according to the EUNIS classification. The data set aims to combine spatially explicit land cover information with non-spatially referenced habitat information to improve our knowledge about ecosystems and their distribution across Europe.		2006 2013	36 countries 100 m 1 km	European Environment Agency http://www.eea.europa.eu/data-and-maps/data/ecosystem-types-of-europe Metadata: https://www.eea.europa.eu/downloads/d851e1b7f678468b8f0b1b98930ba3e1/1457619858/ecosystem-types-of-europe.pdf	(EEA 2016a) (EEA 2015b)

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