Introduction

Key threats to soil in Europe

Maintaining soil condition is essential for ensuring the sustainability of society. However, soil is under increasing threat from a wide range of human activities. The threats are complex and although unevenly spread across Europe, their dimension is continental. For simplicity they are presented separately below. However, in reality they are frequently inter-linked. When many threats occur simultaneously, their combined effects tend to increase the problem. Ultimately, if not countered, soil will lose its capacity to carry out its functions. This process is known as soil degradation.

In the European Union, an estimated **52 million hectares, representing more than 16% of the total land area, are affected by some kind of degradation process.** In the new Member States this figure rises to 35%.

Soil degradation, when occurring in dry areas, is known as **desertification** which is caused by climatic conditions (droughts, aridity, irregular and intense precipitation regimes) and human activity (deforestation, overgrazing, soil structure deterioration). The affected land can no longer support vegetation. According to the UNEP World Atlas of Desertification areas under desertification risk include central and southeast Spain, central and southern Italy, southern France and Portugal and extensive areas of Greece. Worldwide desertification has extremely serious socio-economic consequences and can ultimately cause the destabilisation of societies and the migration of human populations.

Climate change presents an overarching but as yet uncertain factor linked to degradation processes.

In the communication of the European Commission to the Council and the European Parliament, entitled "Towards a Thematic Strategy for Soil Protection" (see Page 118), **eight main threats to soil** were defined.

- **Soil sealing** occurs mainly through the development of technical, social and economic infrastructures, especially in urban areas. In 1996, 43% of the area on the Italian coast, generally containing fertile soil, was completely built-up.
- **Erosion** is mainly due to the inadequate use of soil by agriculture and forestry, but also through building development and uncontrolled water runoff from roads and other sealed surfaces. In more than one third of the total land of the Mediterranean basin, average yearly soil losses can exceed 15 tons/ha.
- **Loss of organic matter** is mainly due to intensive use of the land by agriculture, especially when organic residues are not sufficiently produced or recycled to soil. Agronomists consider soil with less than 1.7% organic matter to be in pre-desertification stage.
- **Decline in biodiversity** is linked to the loss of organic matter, because biodiversity depends on organic matter, which means that all soil biota live on the basis of organic matter.
- **Contamination** can be diffuse (widespread) or localised and is due to many human activities, such as industrial production, traffic, etc., mainly through the use of fossil material, such as ores, oil, coal, salts and others, or due to agricultural activities.
- **Compaction** of soil is a rather new phenomenon caused mainly from high pressures on soil through heavy loads by vehicles in agricultural and forest land use. An estimated 4% of soil throughout Europe suffers from compaction.
- **Hydro-geological risks** are complex phenomena, resulting in floods and landslides deriving partly from uncontrolled soil and land uses (e.g. sealing, compaction and other adverse impacts) as well as uncontrolled mining activities.
- **Salinisation** is mainly a regional problem but in those areas where it occurs, such as the Mediterranean basin and Hungary, agricultural, forestry and the sustainable use of water resources are severely endangered. An estimated 1 million hectares in the EU are affected.

In a first approach, it is important to analyse these threats in two ways:

- to understand the driving forces behind them and the resulting pressures which lead to adverse effects on soil.
- to understand how the impacts of these threats negatively influencing the functions of soils for humankind and the environment.

Issues to consider include the protection of open water and ground water, control of air contamination and pollution, protection of the food chain through biomass production, protection of human health in the case of direct contact with soil and finally the maintenance of biodiversity of the soil, which is as important as the biodiversity on the earth surface.

The analysis of the impacts arising from the threats is an absolute prerequisite for the development of operational procedures or responses for the mitigation of these threats.

Regarding the state of the different threats in Europe, in many cases there is not enough information available about their spatial distribution and their changes with time. One of the important tasks facing soil scientists in Europe will be to create a soil monitoring system to provide detailed information about the development of these key threats in Europe.

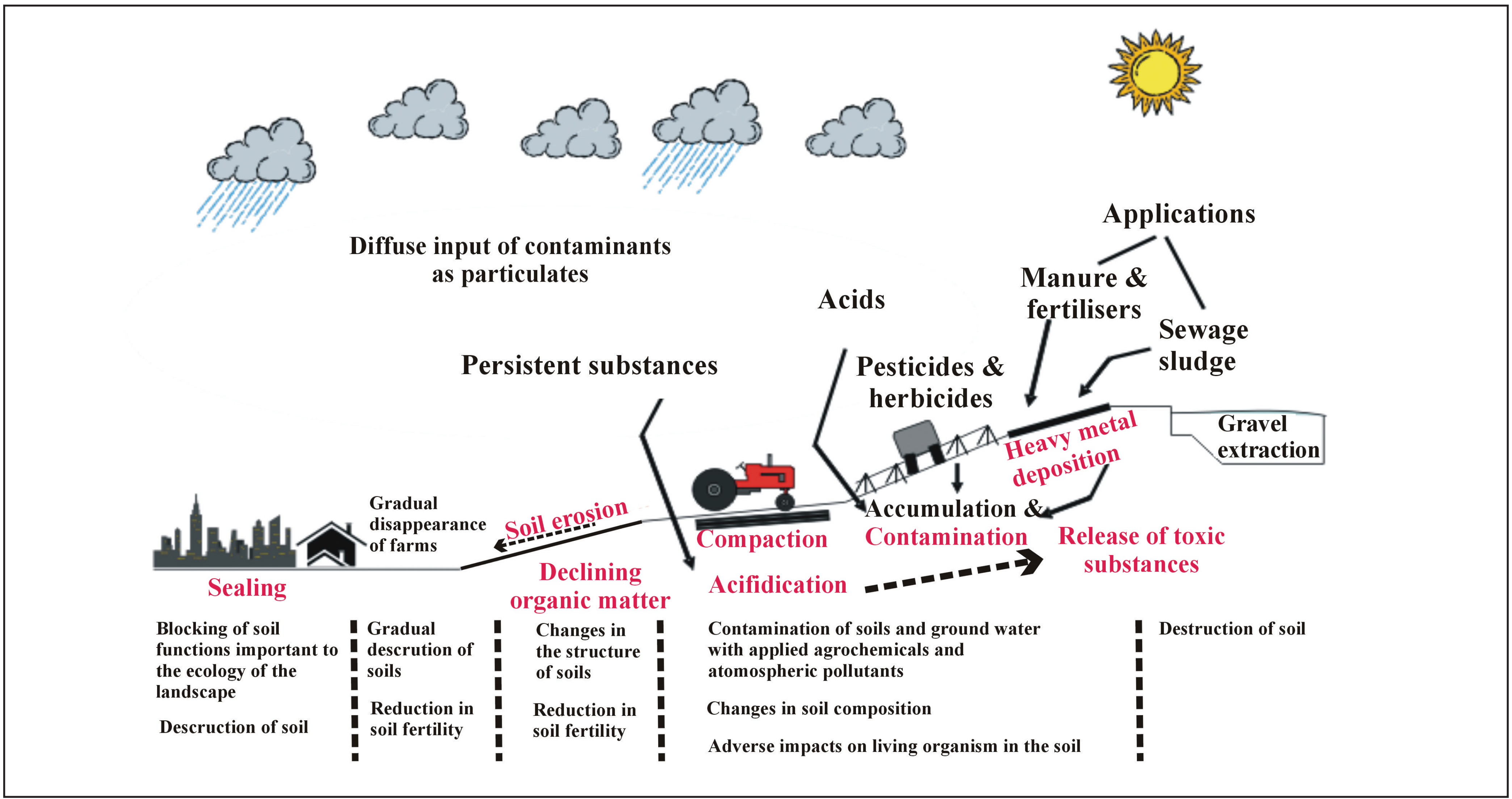
Relating the main threats to driving forces and pressures, through cross-linking with European and national strategies reveals that many agricultural, regional planning, environmental protection, transport, energy development, single market and other policies may have an important influence, because they are partly triggering or inducing threats.

Analysing the impacts of threats by relating them to important soil functions reveals that erosion can be correlated with air pollution, water pollution, decline in biomass production, endangering of human health and decline in biodiversity.

In the following pages, the cause and implications of the eight main threats are explained.

Threats to soil in the New Member States and Candidate Countries are essentially similar to those in the European Union.

- The average degree of soil sealing in parts of Germany between 1999 and 2001 was 5.3 hectares (seven football fields) per day. Analysis of the CORINE Land Cover 2000 dataset indicates that due to economic growth, soil sealing is a significant and increasing issue in the New Member States.
- The extensive floods that affected the Czech Republic in August 2002 caused more than 220 000 inhabitants to be evacuated and caused an estimated 2.7 billion Euros of damages (Ministry of Environment, Czech Republic).
- **Erosion** is a major environmental issue, although there are significant differences between countries regarding its extent and intensity. Areas affected range from 5% to 39% of the total surface.
- The European Environment Agency estimates the number of contaminated sites within the European Union to be between 300,000 and 1.5 Million depending on the definition taken. **Local contamination** associated with the 3000 former military facilities constitutes a major problem not yet fully evaluated.
- Several forms of **diffuse contamination** have been reported. Acidification is affecting about 35% of Poland, Hungary and Lithuania. Many parts of Lithuania have high levels of Barium but this may be strongly influenced by extremely high natural background concentrations.
- **Soil compaction** is widespread particularly in Bulgaria.
- In Hungary 8% of the territory is affected by **salinisation**, mostly of natural origin. In the other candidates countries it does not appear to be a major problem.



The process and inter-relationships of soil degradation. Decline in organic matter may cause erosion, facilitate compaction, decrease water infiltration and increase the danger of floods and landslides (RJ).

SOIL SEALING is the loss of soil resources due to the covering of land for housing, roads or other construction work.

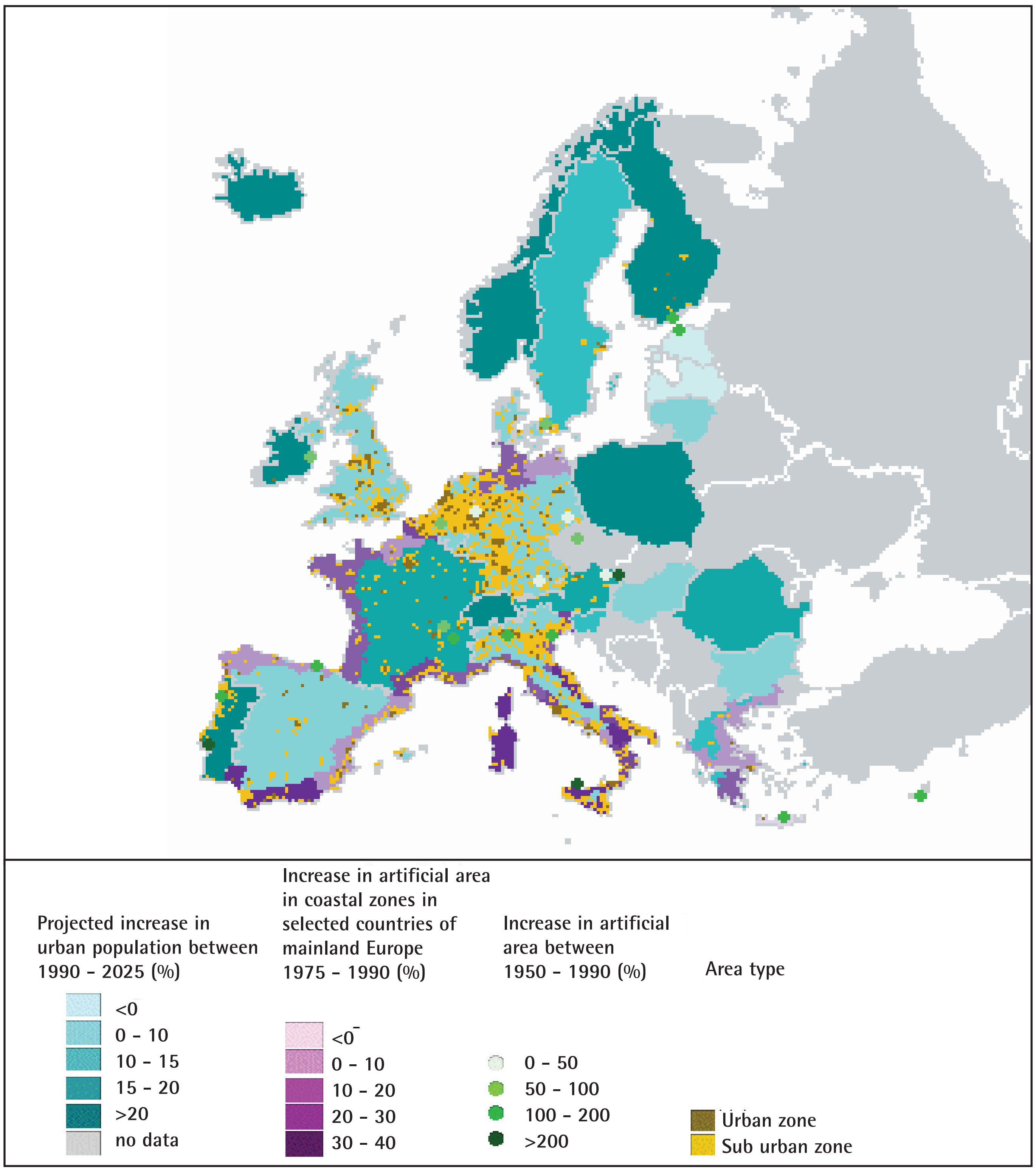
The building of new roads, houses, shops offices work seals off soil (ED).

The covering of the soil surface with impervious materials as a result of urban development and infrastructure construction is known as soil sealing. The term is also used to describe a change in the nature of the soil leading to impermeability (e.g. compaction by agricultural machinery). Sealed areas are lost to uses such as agriculture or forestry while the ecological soil functions are severely impaired or even prevented (e.g. soil working as a buffer and filter system or as a carbon sink). In addition, surrounding soils may be influenced by change in water flow patterns or the fragmentation of habitats. Current studies suggest that soil sealing is nearly irreversible.

The greatest impacts of soil sealing are observable in urban and metropolitan areas. The **Figures right** illustrate the areas in Europe where the rates of soil sealing are high and where the greatest pressures are likely to occur. In already intensively urbanised countries like Holland or Germany the rate of soil loss due to surface sealing is high. There is little space for further urbanisation. Most of the growth will presumably take place within or on the edge of the suburban areas. In the Mediterranean region, soil sealing is a particular problem along the coasts where rapid urbanisation is associated with the expansion of tourism. Very high rates of sealing are now predicted for countries like Portugal, Finland or Ireland where urbanisation levels are generally low.

In Central and Eastern Europe soil sealing has been comparatively modest in the past decades. An accelerated increase of built-up areas can be recorded as a consequence of the political and economic changes during the late 1980s. Rural populations migrated to the cities and new settlements were developed. Rising pressures on soil can be expected in the course of a strengthened economic growth in these countries. Generally the enlargement of the EU and the integration of new countries in the common market will lead to a heightened movement of people and transport of goods. More infrastructure will be built in order to ensure a good connection between peripheral regions and the centre.

Built-up areas have been mainly enlarged at the expense of agricultural land. Progressive soil sealing will take place especially for Western Europe where the area of built-up land increases at a faster rate than the population. Besides the influence of tourism, the rising demand for land resources can be mainly caused by changes in population behaviour such as people's preference for living outside the city centres, an increased demand for bigger houses or out-of-town developments such as supermarkets, leisure centres and associated development of transport infrastructure.

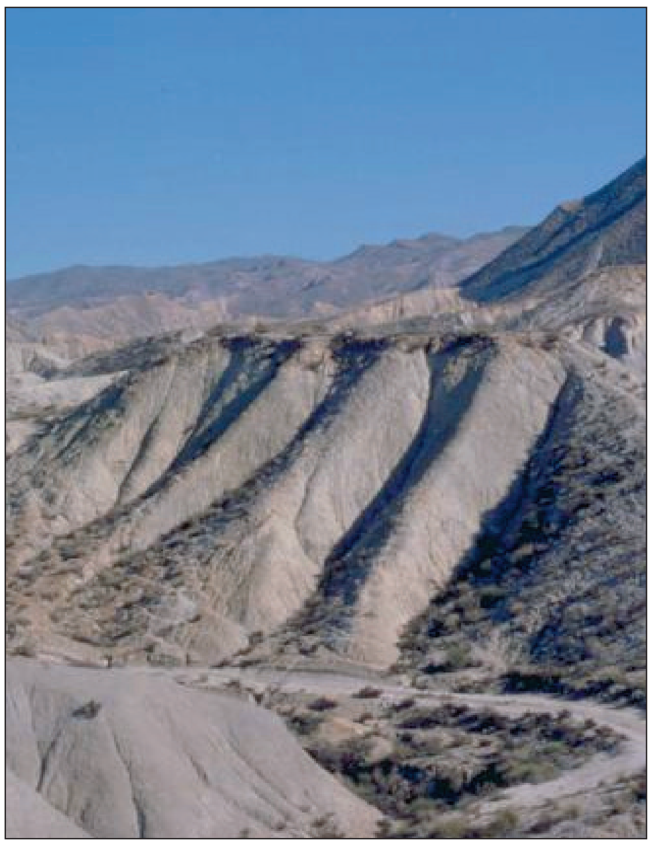


Probable problem areas of soil sealing in Europe (Source European Environment Agency)

Spatial planning strategies determine to a great extent the progression of soil sealing. Unfortunately neither the economical nor the ecological or the social effects of irreplaceable soil losses have been considered adequately so far. In the meantime the necessity to include environmental concerns and objectives in spatial planning, in order to reduce the effects of uncontrolled urban expansion, is widely recognised in the EU. A rational land-use planning to enable the sustainable management of soil resources and the limiting of sealing of open space is demanded. Possible measures include the redevelopment of brown-fields and the rehabilitation of old buildings.

This image was taken by the U.S. Air Force Defence Meteorological Satellite Program from about 800 km above the Earth's surface at approximately midnight local time. The detector in the satellite is sensitive to city lights. This picture clearly shows the extent of urbanisation throughout Europe and is a good indication where the pressures of soil sealing are at their greatest (NOAA).

EROSION is a physical phenomenon that results in the removal of soil and rock particles by water, wind, ice and gravity.



Severe gully erosion in Spain (JI).

Erosion is a natural process, occurring over geological timescales, that has been largely responsible for shaping the physical landscape we see around us today. The action of rain, wind, ice (in the form of glaciers) and temperature (by freezing and thawing) wear down and shatter rock surfaces. Subsequently, geomorphic processes have distributed the weathered materials, produced by these agents, over the surface of the Earth. For millions of years, erosion has transformed the landscape, wearing down mountain and upland areas whilst sedimentation has filled in continental basins with the resulting debris. Thus erosion is a process that is essential for soil and landscape formation and has taken place since time began.

Most present-day concerns about soil erosion, leading to its perception as a process of degradation, are related to accelerated erosion, where the natural rate has been significantly increased by human activities. These activities include the stripping of natural vegetation especially clearing of forests for cultivation, changing land cover in other ways through cultivation, grazing, controlled burning or wildfires, levelling of the land surface, and varying the intensity of land management, for example through poor maintenance of terrace structures and cultivation of steep slopes. The resulting changes to the soil cover allow natural forces to remove soil particles much more rapidly than normal soil-forming processes can replace them, hence the term *accelerated erosion*. Soil losses > 2 t/ha/yr are considered by experts in many parts of the world to be irreversible within a timescale of 50-100 years.

Soil erosion is regarded as one of the most widespread forms of soil degradation, and as such, poses potentially severe limitations to sustainable land use in Europe. Soil can be eroded away by water and wind. Erosion by water occurs due to the energy of water when it falls to the earth and flows over its surface. Strong wind, depending on its strength and duration (persistence), can blow away loose soil from flat or undulating terrain. Soil erosion by water is a widespread problem throughout Europe and the main processes are rain-splash, rain-wash, rill-wash and sheet-wash. Whilst these processes are often localised they produce distinct features such as rills, gullies and, in extreme cases, badlands. There are other forms of water erosion, for example snowmelt erosion in northern Europe which can also produce surface features such as rills and gullies, and bank erosion where streams, rivers and lake waters wash bank material into suspension to be carried downstream, or away from the shore, until the velocity of flow or movement diminishes sufficiently for deposition to take place. Several other types of soil erosion have been recognised and studied by researchers. For example, wind erosion occurs in areas where soil is dominantly sandy or silty, dry and not stabilised by plant roots; cultivation, levelling of land for example to create terraces, trampling by animals destroying surface cover and soil removal by harvesting of root crops cause further losses of soil.

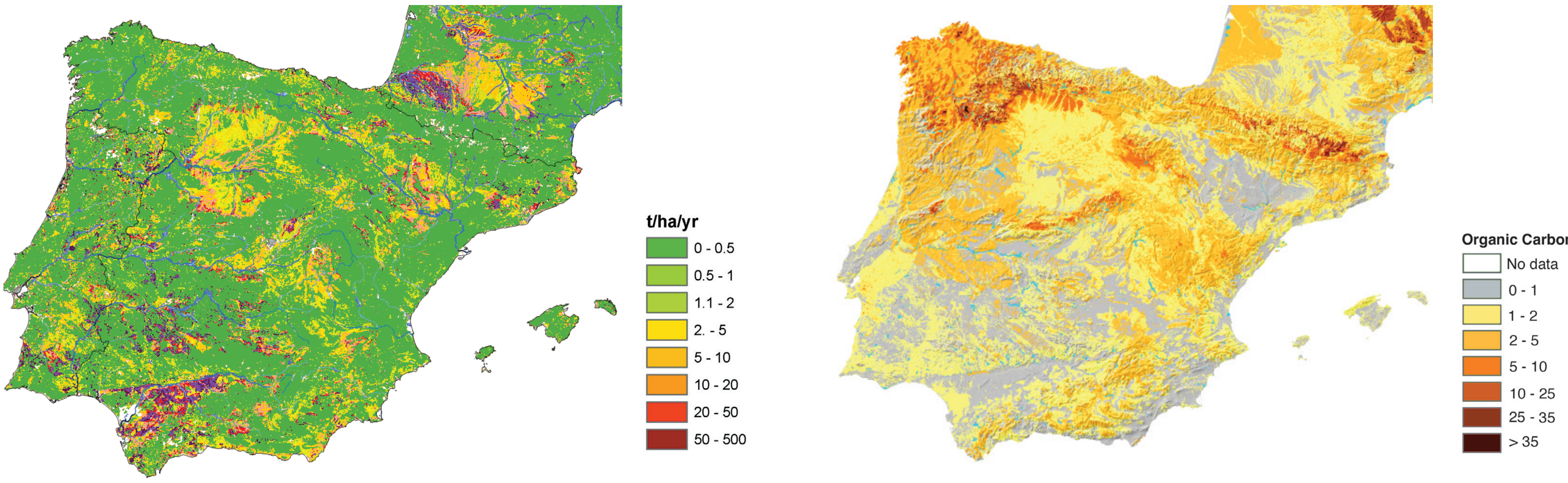
The most dominant effect is the loss of topsoil, which may not be conspicuous but nevertheless potentially very damaging. If soil loss by these various forms of accelerated erosion is to be reduced or eliminated, the amounts of soil removed must be quantified and this requires a different approach for each type of erosion. On-site measurements can quantify soil loss at the field scale and accumulation in reservoirs can reveal the amount of sediment removed within individual catchments or basins. Lakes and reservoirs act as large sediment traps and sedimentation rates can provide valuable comparisons between environments. However, complications arise because soil loss in one part of a catchment or basin can lead to deposition (sediment yield) in another part. Not all the material eroded on a hillslope will arrive at the outfall of the catchment or accumulates in reservoirs, a significant part may remain in intermediate storage on slopes, in alluvial fans, as colluvium along foot-slopes and as outwash on plains.

Climate, topography and soil characteristics are important physical factors affecting the amount of erosion. The Mediterranean region is particularly prone to accelerated soil erosion because it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on steep slopes often with shallow soil low in organic matter. The introduction of agriculture and grazing during Neolithic times (6000-8000 years ago), in and around the Mediterranean Basin, marked the start of progressive forest clearance which has continued until the present day. A well known example of one of the effects of this is the Ebro Delta, the growth of which is linked to deforestation and expanding agricultural activities that took place between the Middle Ages and the 19th century. In parts of the Mediterranean region, erosion has reached a stage of irreversibility such that, in some places, erosion has practically ceased because there is no more soil left. This contrasts with NW Europe where there is less loss of soil, because rain falls mainly on gentle slopes and is more evenly distributed throughout the year than in the south. Consequently the area affected by erosion is less extensive than in southern Europe. However, erosion is still a serious problem, particularly off-site, in northwest and central Europe, and is on the increase largely as a result of sheet erosion on bare soil surfaces, the area of which has increased significantly in Europe since the Second World War.

Erosion causing a 1m deep rill in the Severn Valley UK, January 2001 (PNO).

There are very few sites in Europe where soil erosion has been or is still being monitored but the measurements of soil loss that do exist show average rates varying from less than 0.5 to more than 200t/ha/yr. The highest losses, sometimes as high as 500 t/ha/yr, have been measured following single storm events of short duration but with heavy rain falling on bare soil surfaces. Erosion literature commonly identifies 'tolerable' rates of soil erosion, but these usually exceed the rates that can be balanced by natural weathering of parent materials to form new soil particles.

Soil loss in some places may be considered acceptable from an economic standpoint but some modern cultivation methods are causing overall erosion rates that are becoming increasingly unacceptable from a long-term point of view. Two examples of this are the use of herbicides to kill the vegetation on the ground in olive groves and vineyards, thus reducing competition for water and nutrients, and cereal cultivation on hilly land previously in pasture for stock rearing. Both these systems currently receive financial support from the European Common Agricultural Policy yet are visibly degrading the land. It is clear that on some productive land there is an overall loss of soil material that is becoming irreversible. By contrast, there are some ancient farming systems that have proved to be sustainable over a long period, for example the dehesas in Spain, the *montados* in Portugal and the bocage in France. Unfortunately, these systems tend to be labour intensive and mainly practised by the older people in rural communities.



*The **above** maps show the relationship between erosion and organic matter levels in soil. The map on the **left** shows estimated soil erosion rates for Spain, Portugal and southwestern France **(see Page 102)**. Areas with very low erosion rates are indicated in green while high-risk zones are red or purple. The map clearly highlights the problems of soil erosion in Andalucia, along the Tajo Valley and just north of the Pyrenees. The map on the **right** shows the levels of organic carbon in the topsoil. Note the close correspondence between the areas of low organic carbon (shown in grey) and the high risk of erosion (RJ).*

LOSS OF ORGANIC MATTER. An imbalance between the build-up of soil organic matter and rates of decomposition is leading to a decline in soil organic matter contents in many parts of Europe.

A Histosol, a soil rich in organic matter. Most mineral soil contains less than 10% organic matter (6% organic carbon) in the topsoil (EM).

The presence of organic matter is extremely important in all soil processes, acting as a storehouse for nutrients and a source of soil fertility, contributing to soil aeration, thereby reducing soil compaction, and ensuring good structure. Other benefits are related to the improvement of infiltration rates and the increase in storage capacity for water. Furthermore, organic matter serves as a buffer against rapid changes in soil pH and it acts as an energy source for soil micro-organisms.

The amount of organic matter stored in soil is thus of great importance and, in the past few years, there has been increasing concern about declining levels leading to increased soil degradation (loss of structure and fertility), erosion and desertification. There are two groups of factors that influence the inherent levels of soil organic matter content: natural factors (climate, soil parent material, land cover and/or vegetation and topography) and anthropogenic or human-induced factors (land use, management and degradation).

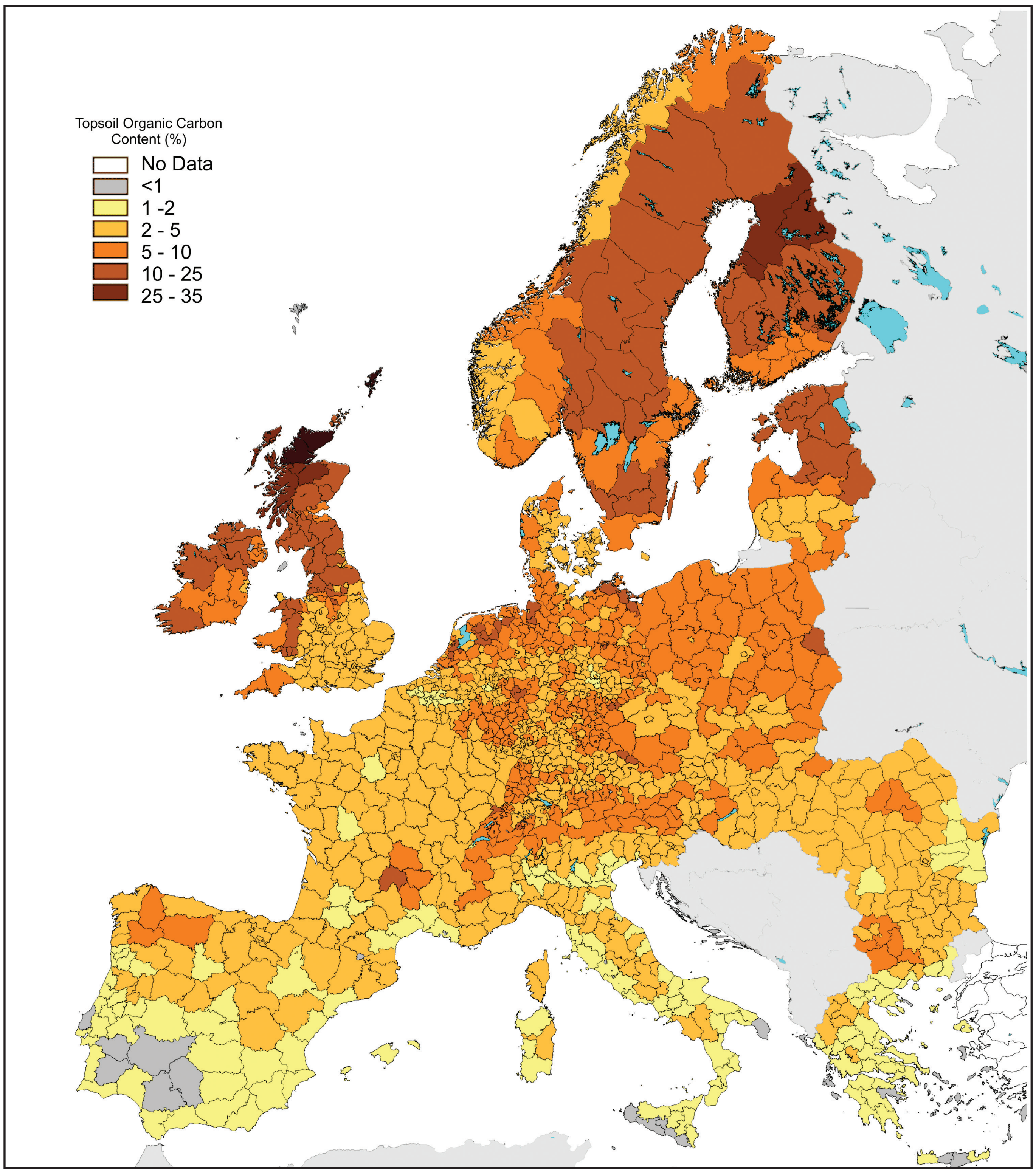
Concerning climate, within belts of uniform moisture conditions and comparable vegetation, the average amount of organic matter increases by two to three times for each 10 deg C decrease in temperature, because decomposition rates reduce as temperatures decline. In general, organic matter increases as the effective soil moisture becomes greater, poorly drained soils generally having much higher organic matter contents than their better-drained equivalents. This is because decomposition of organic matter requires oxygen and this is in short supply in waterlogged soils.

A sandy soil usually contains less organic matter than a soil of finer texture, e.g. heavy loam or clay. This is because oxygen is required for decomposition of organic matter and poorly drained soils have low oxygen contents and fine textured soils are generally poorly aerated.

There are several factors responsible for the decline in soil organic matter and many of them stem from human activity:

- Conversion of grassland, forests and natural vegetation to arable land;
- Deep ploughing of arable soils causing rapid mineralisation of organic matter:
- Overgrazing;
- Soil erosion;
- Forest fires.

In essentially warm and dry areas like Southern Europe, depletion of organic matter can be rapid because the processes of decomposition are accelerated by high temperatures. Some areas in southern Spain for example have experienced serious depletion of organic matter through changing land use and recently adopted management practices. It is clear that human occupation over the past 5000 years in this part of Europe gives us an idea of how other parts of the continent could be affected in the future.



The map above shows the distribution of soil organic carbon, a major component of organic matter, according to administrative units; it emphasises the generally low levels in southern Europe compared to the north (RH).

This is an area east of Sevilla where olive cultivation has become almost a monoculture. The removal of soil and hence organic matter from the soil upslope is clearly visible (white area), the topsoil becoming browner lower down (RJ).

Degradation of peat soil in the Netherlands

There is evidence to suggest that the organic matter content of soils in Europe is decreasing, in some cases at an alarming rate.

- In Roman times, 45% of the Netherlands was covered by peat. Today, the figure is around 8%, most of which is used as pasture.
- In the 1970's the area of peat was about 290,000 ha. In recent years, water levels in ditches in the peat areas has been lowered to 60 cm – 120 cm below the surface (compared to originally 20-30 cm), which resulted in an increased oxidation of the peat and an average subsidence of the soil of 1 cm per year.
- Nowadays, the area of peat soil is about 220,000 ha. Thus, over the last thirty-five years, 70,000 ha of peat soil has degraded to an other soil type.
- A subsidence of 1 – 2 cm per year equals to 14 tons of peat per hectare (ha) per year. The oxidation of 1 cm per year results in a production of 22.6 tons/ha/year of CO_2.
- In the Netherlands the CO_2 emission of peat soil is about 3% of the national CO_2 production (in 1990). In a country like Norway the production of CO_2 from peat in agricultural use is higher than the production of CO_2 by the traffic.

Organic or mineral?

Soil scientists often use the term "*mineral soils*" to describe soils composed predominantly of mineral material which are low in organic matter or humus content. The soil profile below the A horizon is normally all mineral soil. A mineral is a natural crystalline inorganic substance. Silica is a mineral but coal is not because it is derived from organic material (i.e. plants).

DECLINE IN SOIL BIODIVERSITY is the reduction of forms of life living in soils, both in terms of quantity and in variety.

Soil contains a huge variety of life ranging from microbes, worms and insects to mammals. This picture illustrates the diversity within soil mites (DW).

The nature of soil biodiversity

Soil biodiversity is a term used to describe the variety of life below-ground. The concept is conventionally used in a genetic sense and denotes the number of distinct species (richness) and their proportional abundance (evenness) present in a system, but may be extended to encompass phenotypic (expressed), functional, structural or trophic diversity. The total biomass below-ground generally equals or exceeds that above-ground, whilst the biodiversity in the soil always exceeds that on the associated surface by orders of magnitude, particularly at the microbial scale. A handful of grassland soil will typically support tens of thousands of genetically distinct prokaryotes (bacteria, archaea) and hundreds of eukaryotic species across many taxonomic groups.

The soil biota plays many fundamental roles in delivering key ecosystem goods and services, and is both directly and indirectly responsible for carrying out many important functions (see Boxes).

Ecosystems goods and services provided by soil biota

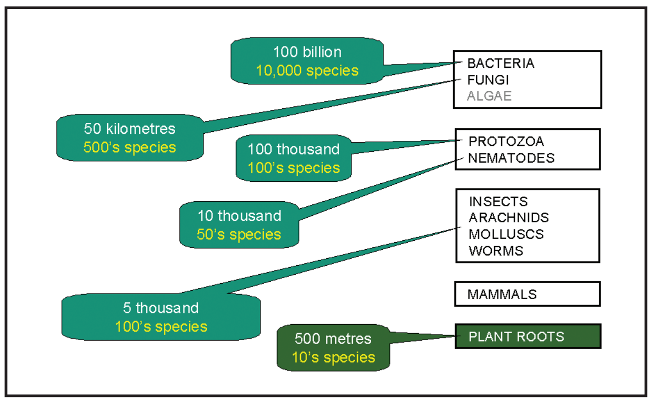
Goods:
- food production
- fibre production
- provision of secondary compounds (e.g. pharmaceuticals / agrochemicals)

Services:
- driving nutrient cycling
- regulation of water flow and storage
- regulation of soil and sediment movement
- regulation of other biota (including pests and diseases)
- detoxification of xenobiotics and pollutants
- regulation of atmospheric composition

The value of soil biodiversity

Soil biodiversity carries a range of values that depend on the perspective from which they are being considered. These include:

- **Functional** value, relating to the natural services that the soil biota provides, the associated preservation of ecosystem structure and integrity, and ultimately the functioning of the planetary system via connections with the atmosphere and hydrosphere
- **Utilitarian** ("direct use") value, which covers the commercial and subsistence benefits of soil organisms to humankind.
- **Intrinsic** ("non-use") value, which comprises social, aesthetic, cultural and ethical benefits
- **Bequest** ("serependic") value, relating to future but as yet unknown value of biodiversity to future planetary function or generations of humankind.



Approximate number and diversity of organisms typically found in a handful of temperate grassland soil (KR & JJIM).

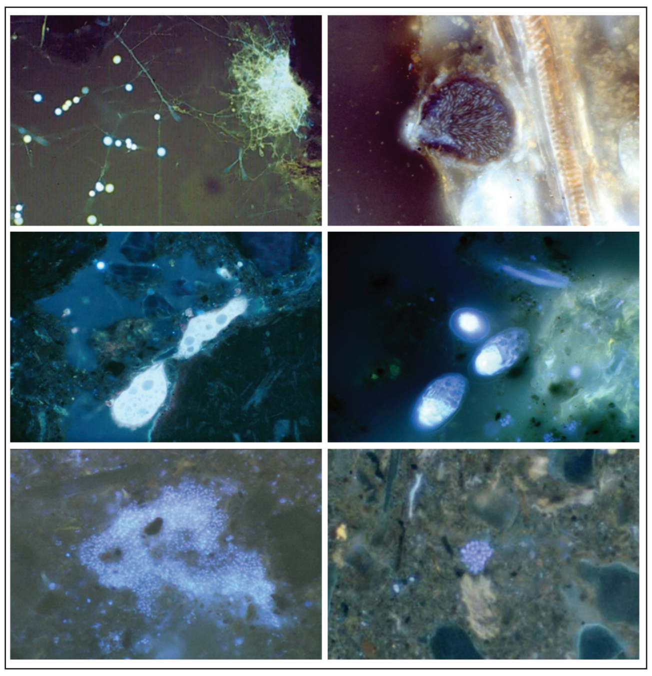
The ecological value of soil biodiversity is increasingly appreciated as we understand more about its origins and consequences. The monetary value of ecosystem goods and services provided by soils and their associated terrestrial systems, an entirely human construct which assists putting their significance into an economic context, was estimated in 1997 to be thirteen trillion US dollars ($13 x 1012). The soil biota underwrites much of this value.

Threats to soil biodiversity

A healthy soil biota needs an appropriate habitat. In soil, this is essentially the space denoted by the complex architecture of the pore network, and the associated supply and dynamics of gases, water, solutes and substrates that this framework supports. Hence threats to soil such as erosion, contamination, salinisation and sealing all serve to threaten soil biodiversity by compromising or destroying the habitat of the soil biota. Management practices that reduce the deposition or persistence of organic matter in soils, or bypass biologically-mediated nutrient cycling also tend to reduce the size and complexity of soil communities. It is however notable that even polluted or severely disturbed soils still support relatively high levels of microbial diversity at least. Specific groups may be more susceptible to certain pollutants or stresses than others, for example nitrogen-fixing bacteria that are symbiotic to legumes are particularly sensitive to copper; colonial ants tend not to prevail in frequently-tilled soils due to the repeated disruption of their nests; soil mites are a generally very robust group.

Consequences of soil biodiversity

The relationships between biodiversity and function are complex and somewhat poorly understood, even in above-ground situations. The exceptional complexity of below-ground communities further confounds our understanding of soil systems. Three important mechanisms underlying relationships between biodiversity and function are:



Some examples of the major groups of the microbial soil biota visualised in situ in arable soil. From top left: Fungus (filamentous hyphae and spores); fungus (spore-bearing perithecium in decomposing root); protozoa (naked amoeba); protozoa (testate amoebae); bacteria (large colony in vicinity of food source); bacteria (small colony isolated in soil matrix). As well as great species diversity, the physical form that soil organisms take is also extremely diverse, from long filaments, to naked cytoplasm, through silica-encased cells to minute single cells ñ the bacteria in the bottom image are 1 µm in diameter [KR].

Key functions performed by soil biota

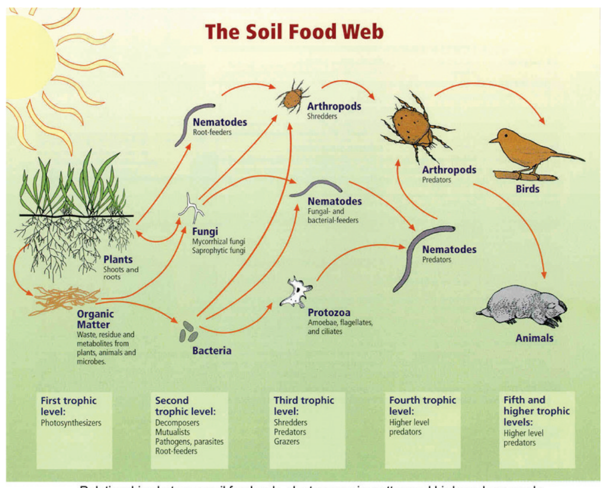
These map onto the 'goods and services' roles and are many and varied. Some of the most significant functions, and the main biotic groups that carry them out are:
- Primary production [plants, cyanobacteria, algae]
- Secondary production [herbivores]
- Primary decomposition [bacteria, archaea, fungi, some fauna]
- Secondary decomposition [some microbes, protozoa, nematodes, worms, insects, arachnids, molluscs]
- Soil structural dynamics [bacteria, fungi, cyanobacteria; algae, worms, insects, mammals]
- Suppression of pests and diseases [bacteria, actinomycetes, fungi, protozoa, nematodes, insects]
- Symbioses [bacteria, actinomycetes, fungi (notably mycorrhizae)]
- Soil organic matter formation, stabilisation and C sequestration [virtually all groups, directly or indirectly]
- Atmospheric gas dynamics, including generation and sequestration of greenhouse gases [bacteria for nitrous oxides, methane; all biota for CO_2]
- Soil formation [bacteria, fungi]

Repertoire: for a biologically-mediated process to occur, organisms that carry out that process must be present;
Interactions: most soil organisms have the capacity to directly or indirectly influence other organisms, either positively or negatively;
Redundancy: the more organisms there are that can carry out a function in a particular soil, the more likely it is that if some are incapacitated or removed the process will remain unaffected; those that remain fill the gap.

There is evidence that soil biotic communities are coupled to their associated vegetation, such that there is a mutual dependence between above-ground and below-ground communities, and hence that compromised soil communities may curtail particular plant assemblages from forming.

Consequences of decline in soil biodiversity

It is apparent that from a functional perspective, species richness *per se* is of little consequence; rather it is the functional repertoire of the soil biota that is critical. For processes such as decomposition, there is evidence that there is a high degree of redundancy at a microbial level. Other processes, such as nitrification (the oxidation of ammonium), are carried out by a narrower range of bacteria and there is less redundancy in this group, whereas for highly specific symbiotic associations, such as those between orchids and certain mycorrhizal fungi, there is total dependence and hence zero redundancy. A depletion of biodiversity will therefore have differing consequences in relation to different processes. In some circumstances it has been demonstrated that there are threshold levels of soil diversity below which processes are impaired, although these are usually related to narrow processes and are manifest under experimentally constructed systems of exceptionally low levels of diversity, as opposed to natural systems. From the intrinsic and bequest perspective, any loss of biodiversity is undesirable. Given our limited state of understanding of the consequences of soil biodiversity, it is common sense that a strong precautionary principle needs to be applied.



Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html.

Simplified soil food web. Energy and nutrient elements are transferred from one trophic level to another. Note that there is also a continual movement of material from all trophic levels back to the detritus/organic matter pool and the base of the series (Tugel, A.J. & A.M. Lewandowski, eds., Soil Biology Primer. Available on-line from: http://soils.usda.gov/sqi/concepts/soil_biology/soil_food_web.htm

CONTAMINATION is the occurrence of a substance in soil above a certain level. Contamination can be diffuse or local and is due to many anthropogenic activities, such as industrial production, traffic, farming practices and waste disposal.

Pesticides, used to protect crops from insects and diseases, can in certain circumstances lead to diffuse pollution of soils (AJ).

Soil acts as a sink for almost all substances released into the environment by human activities. Therefore, many pollutants accumulate in the soil due to the specific filtering and buffering properties of the soil. On the other hand, many substances occur naturally in soil (e.g. heavy metals). If the concentration of these substances is above a defined background value or so high that it potentially causes a risk to human health, plants, animals, ecosystems or other media (e.g. water), the soil is regarded as "contaminated". Many parts of Europe are contaminated by a range of contaminants. They originate from either local or diffuse sources of human activity.

Contamination from localised sources

Soil contamination from localised sources is often related to industrial plants that are no longer in operation, accidents or improper waste disposals. At industrial plants that are still operating, soil contamination may have its origin in the past but current activities still have significant impacts.

Contaminated sites are the legacy of a long period of industrialisation involving uncontrolled production and handling of hazardous substances and unregulated dumping of wastes. The expansion of industry and subsequent increase in the amount of industrial wastes have led to considerable environmental problems. Mining activities and former military sites are also giving rise to severe contamination problems.

Contaminated sites considerably endanger human health and the environment. Pollution of drinking water, uptake of pollutants in plants, exposure to contaminated soil due to direct contact, inhalation and ingestion are major threats. Soil and groundwater contamination can be caused by losses during production, industrial accidents and leaching of hazardous substances at waste disposal sites. Major pollutants include organic contaminants such as chlorinated hydrocarbons, mineral oil and heavy metals.

Assuming that areas with a high probability for soil contamination from local sources are concentrated in densely populated and industrialised regions, the largest and probably most heavily affected areas are concentrated around the industries from the Nord-Pas de Calais in France to the Rhine-Ruhr region in Germany, across Belgium and the Netherlands and the large cities of the UK (see population density map on Page 123).

Other areas where the probability of local soil contamination is high include the Saar region in Germany; northern Italy, north of the river Po area, from Milan to Padua; the so-called Black Triangle region located at the corner of Poland, the Czech Republic and the Slovak Republic. However, contaminated areas exist around most major cities and some individual contaminated sites also exist in sparsely populated areas.

The management of contaminated sites is designed to remediate any adverse effects where impairment of the environment has been proved and to minimise potential threats. Provision of public and private money for remediation, as well as restrictions on land use and the use of groundwater and surface water, are particularly important responses to deal with the existing contaminated sites. Although the "polluter-pays" principle is generally applied, a huge sum of public money must be provided to fund necessary remediation activities. A problem can arise when the polluter is not financially liquid or the polluter can not be made liable! Even though a considerable amount of money has been spent on remediation activities already, the share compared to the total estimated remediation costs is relatively low (only around 8%).

Contamination from diffuse sources

Intensive agriculture, forestry, mining, transport, industrialization and urbanization in densely populated areas in Europe have led to inter-related problems of contamination and other forms of land degradation. Transport of acidifying and eutrophying components as well as potentially harmful elements by wind has led to soil degradation even in distant areas. Additionally, certain agricultural practices cause diffuse soil contamination by direct application of pesticides, sewage sludge, compost, fertilisers and manure.

Continued contamination can lead to an accumulation of hazardous substances in top soils. Soil functions most affected by contamination are buffering, filtering and transforming capacities. When the buffering capacity of soil with respect to a certain substance is exceeded, the substance is released to the environment, causing impairment of groundwater and/or surface water. Currently, the most important problems from diffuse sources are acidification, the effects of a surplus of nutrients and contamination by heavy metals.

Emissions of acidifying sulphur and nitrogen compounds from industry and transport have led to soil acidification and pose threats to forest health and the quality of surface and/or groundwater. Aluminium, cadmium and many other metals are more mobile in acid soils causing risk of damage to plant roots and contamination of drinking water. Sulphur emissions and deposition have declined substantially. Excesses of acidifying components in terrestrial ecosystems are at present dominated by nitrogen deposition, although the situation is not homogenous throughout Europe. Nitrogen and phosphorus are essential elements for plant growth and are added to soil by fertilization. However, if fertilizers are applied beyond what plants can use and soils can retain, the excess may be leached from the soil, eroded or washed off into ground waters and/or surface waters. Besides over-application of fertilizers, accumulation of nitrogen can be caused by wet and dry nitrogen deposition. Elevated nitrogen content in forest soils can negatively affect the vitality of European forests. According to estimations based on critical load data the excess deposition of nutrient nitrogen will be much lower by 2010 in comparison to 1990, but still in some areas of central and western Europe only less than 10% of the ecosystems will be protected against negative effects of eutrophication.

The application of new legislation at national and EU level (e.g. the Landfill Directive, Water Framework Directive, Environmental Liability Directive, Integrated Pollution and Prevention Control Directive) should result in better operational and technical requirements on waste and landfills (AJ).

Deposition of heavy metals and other potentially harmful elements cause diffuse soil contamination throughout Europe. In forest soils, contamination is generally linked to atmospheric deposition. In agricultural soils, heavy metals and other contaminants enter ecosystems as a result of the application of fertilizers and animal manure, compost and pesticides. The application of contaminated sewage sludge has the potential to create a threat to soil ecosystems due to input of heavy metals, organic compounds and pathogens. In Eastern and Northern Europe, the fallout from Chernobyl can be still identified as a diffuse radioactive contamination of surface soil, but at a lower value than in the late 1980's. Much attention has been paid so far to diffuse contamination by cadmium, lead and mercury. Other potentially harmful elements include arsenic, chromium, copper, nickel, zinc and several persistent organic pollutants (POPs).

Reductions in heavy metal deposition can be expected throughout Europe as the result of the implementation of lead-free petrol and the application of industrial techniques of emission reduction. Concerning direct input of contaminants to agricultural soils, common Good Agricultural Practices and water protection legislation have to consider avoidance of soil contamination and related EU legislation.

The risk of soil contamination from mining activities is associated with the storage or disposal of tailings, acid mine drainage and the use of certain chemical reagents in the processing of metal ores. This striking photograph shows an old copper mine in the UK more than 100 years after the mine was abandoned. Notice the lack of vegetation on the soil heaps. The pH of some of the old tailing ponds can be as low as 2.5, strong sulphuric acid! (AJ).

Compaction

SOIL COMPACTION is the term for the deterioration of soil structure (loss of soil features) by mechanistic pressure, predominantly from agricultural practices.

Driving heavy tractors on the subsoil during ploughing and harvesting is a major cause of subsoil compaction. The picture clearly shows how the wheels on one side of the tractor are driven in the plough furrow and press directly on the subsoil (JJHVDA).

Definition of the problem

Soil compaction is a form of physical degradation resulting in densification and distortion of the soil where biological activity, porosity and permeability are reduced, strength is increased and soil structure partly destroyed. Compaction can reduce water infiltration capacity and increase erosion risk by accelerating run-off. The compaction process can be initiated by wheels, tracks, rollers or by the passage of animals.

Some soils are naturally compacted, strongly cemented or have a thin topsoil layer on rock subsoil. Soils can vary from being sufficiently strong to resist all likely applied loads to being so weak that they are compacted by even light loads.

In arable land with annual ploughing, both topsoil and subsoil compaction is possible. A feature of compacted soils is the formation of a pan-layer, caused by the tractor tyres driving directly on the subsoil during ploughing (above). The pan-layer is less permeable for roots, water and oxygen than the soil below and is a bottleneck for the function of the subsoil. Unlike topsoil, the subsoil is not loosened annually, compaction becomes cumulative and over time, a homogeneous compacted layer is created.

The Impact

Large spaces in soils are known as macro pores and are created by plant roots, burrowing creatures and shrinkage caused by the drying of wet soil. These macro pores are usually continuous and form "highways" for air and water to travel deep into the soil. To an extent, continuous macro pores determine the soil's physical and soil biological quality. Macro pores are the most vulnerable pores to soil compaction.

The loss of macro porosity and pore continuity reduces strongly the ability of the soil to conduct water and air.

- Reduced infiltration capacity results in surface run-off, leading eventually to flooding, erosion and transport of nutrients and agrochemicals to open water.
- A poor aeration of the soil reduces plant growth and induces loss of soil nitrogen and production of greenhouse gases through denitrification in anaerobic sites.

Deformation of soil aggregates and higher bulk density increase the strength of the soil. This limits root growth which can result in a higher vulnerability of the crop to diseases. Subsoil compaction is a hidden form of soil degradation that can affect all the agricultural areas and results in gradually decreasing yields and gradually increasing problems with waterlogging.

The impact of subsoil compaction is most prominent in years with extreme dry or wet periods. Crop yield reductions of more than 35% have been measured. Subsoil compaction proves to be very persistent, even in subsoils with shrinkage and swelling or annual deep freezing. Reduced crop yields and reduced nitrogen content in crops were detected 17 years after a single compaction event with wheel loads of 50 kN or 5,000 kg.

A classic example of compacted topsoil. Note how the soil structure in the upper part of the profile has completely collapsed. This limits root growth and exploitation of soil water and nutrients by crops (JJHVDA).

Scale

All agricultural soils in developed countries display some degree of subsoil compaction. Estimates in 1991 suggest that the area of degradation attributable to soil compaction in Europe may equal or exceed 33 million hectares (ha). Recent research has showed that compaction is the most widespread kind of soil physical soil degradation in central and eastern Europe. About 25 million ha were deemed to be lightly compacted while a further 36 million ha were more severely affected.

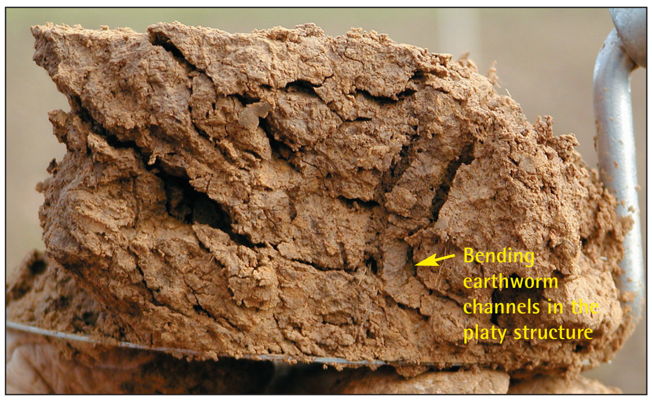
Well-structured soils combine good physical soil properties with high strength. Sandy soils with a single grain structure and compacted massive soils can be very strong. However, rootability and soil physical properties are then often bad. Roots have a binding action and increase the elasticity and resistance of a soil to compaction.

Soil moisture has a dominant influence on soil compactibility. Dry structured soils are strong with low compactibilty. However, extremely dry sandy soils can be deformed and compacted rather easily. As the moisture content increases, compactibility increases until the moisture content is approximately at the field capacity point, when a condition known as the optimum moisture content for compaction is reached. At still higher moisture content, the soil becomes increasingly incompactible as water fills ever more pore space. Although the compaction of an overloaded wet soil may be minimal, plastic flow may result in the complete destruction of soil structure and macro-pores.

Increasing the organic matter content tends to reduce soil compactibility and to increase its elasticity.

Solution

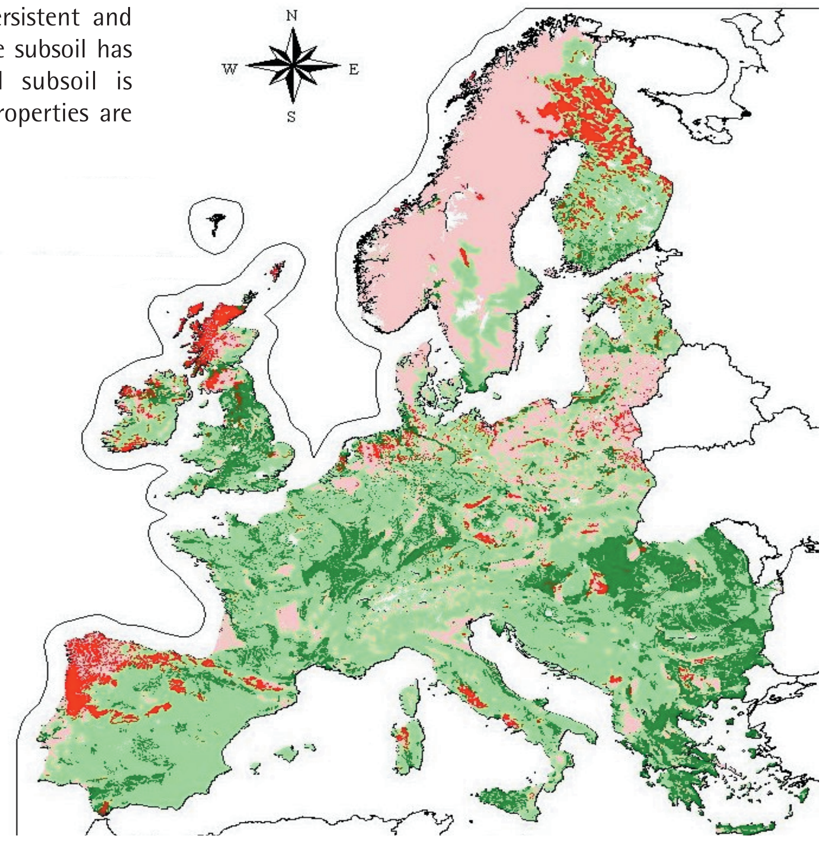
It is almost impossible to avoid topsoil compaction. On the other hand, tillage and natural processes can re-loosen the topsoil. Subsoil compaction is much more persistent and difficult to remove. Artificial loosening of the subsoil has proven to be disappointing. The loosened subsoil is recompacted very easily and many physical properties are strongly reduced.



Compaction leads to a deterioration in conditions for soil fauna (JJHVDA).

Areas degraded by soil compaction are increasing because wheel loads in agriculture are still increasing. Twenty years ago wheel loads of 50 kN (5000 kg) were considered very high. Nowadays wheel loads of up to 130 kN are used during the harvesting of sugar beet. Modern self-propelled slurry tankers with injection equipment with wheel loads of 90 – 120 kN are used in early spring on wet soils. Large tyres with an inflation pressure of about 200 kPa are needed to carry such high wheel loads. Even on moderate strong soil, compaction of up to 80 cm below the surface have been measured under such loads. The result is that the soil is increasingly compacted to ever-greater depth. The conclusion is that European soil is more threatened than ever (JJHVDA).

Subsoil compaction should be prevented instead of being repaired or compensated. Even on weak soils, relatively high wheel loads are possible by using large tyres with low inflation pressures or well-designed tracks. Subsoil compaction during ploughing can be prevented by using improved steering systems and adapted ploughs allowing the tractor to drive with all wheels on the untilled land. It is also possible to concentrate wheel loads on permanent traffic lanes and limit the compaction to these sacrificed wheel ways. By using gantries, the sacrificed area can be limited. However, these solutions are rarely used because of short-term economical constraints, lack of awareness, and negligence because the damage to the subsoil is not readily visible. Also the limited knowledge and data on soil strength under dynamic loading makes prevention of subsoil compaction difficult.



Provisional map of inherent susceptibility of subsoil in Europe to compaction, based on soil properties alone. Further input data are required on climate and land use before vulnerability to compaction of subsoil in Europe can be inferred from the susceptibilities shown here. Some of the very high areas (red) correspond to peat soils that are not subjected to "normal" agricultural practices. However, it is worth including the peat heaths and forests of Europe as they are often used for forestry and can be compacted by heavy timber harvesting machines and off-road vehicles (RJ).

HYDRO-GEOLOGICAL RISKS refer to floods and landslides related to soil and land management.

A landslide is the down slope movement of terrain due to a failure of the material composing the landscape. Landslides may be induced by physical processes such as earthquakes or caused by human interference on slope stability. Landslides, mudflows and other mass movement events are both erosional and depositional events (EM).

When river banks are overtopped through rising flood waters, the results can be devastating. In the last decade Europe has experienced a number of unusually long-lasting rainfall events that produced severe floods, For example, in the Netherlands, Belgium, France and Germany (1993, 1995), the Czech Republic, Poland and Germany (1997), in northern Italy (1994, 2000) and in the UK (1998, 2000, 2004). The trend seems to be continuing.

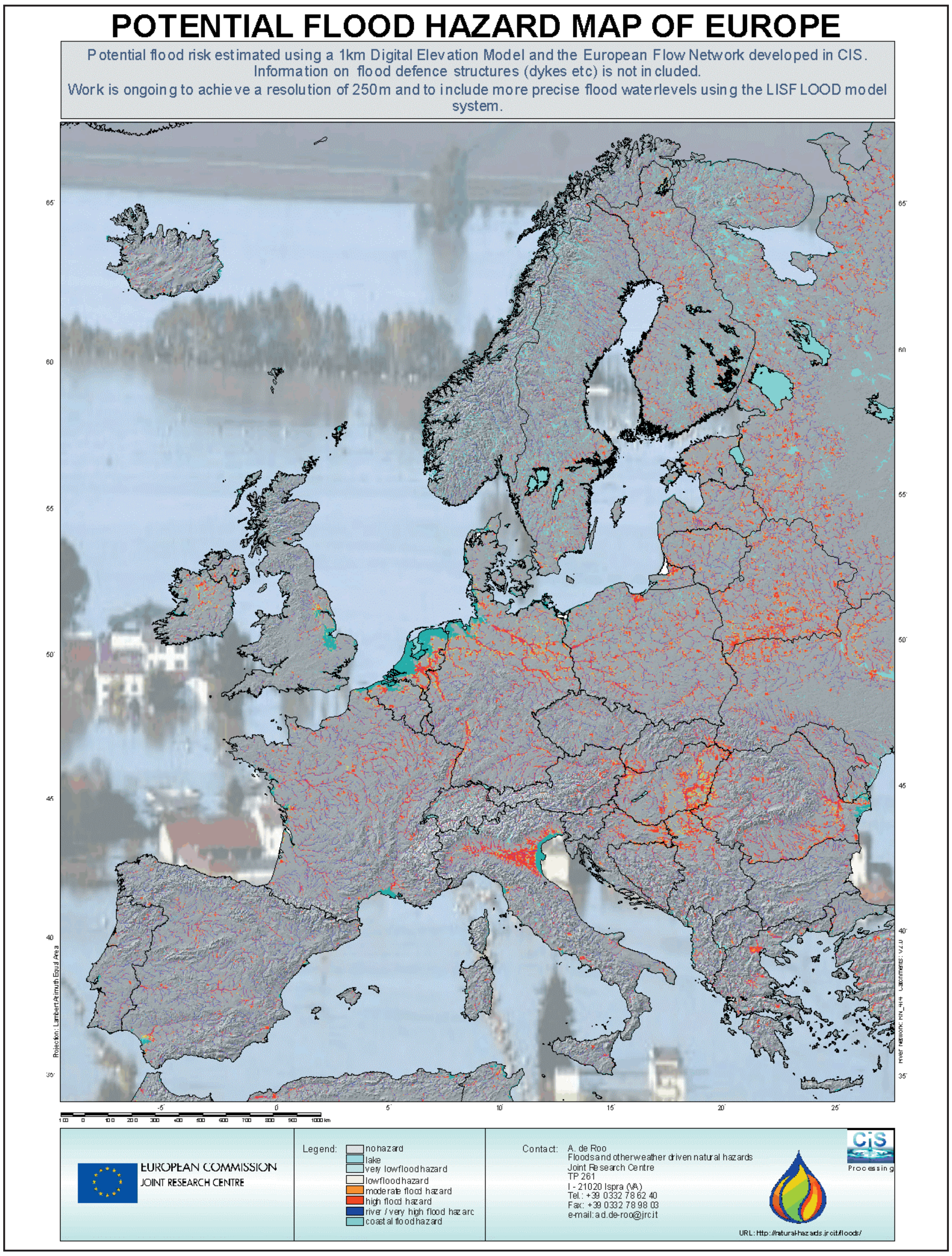
According to the World Meteorological Office review of the year 2001, the 24-months period ending in March 2001 was the wettest in the 236-year time series of precipitation in England and Wales. From October 2000 to March 2001, precipitation was also exceptional in the Bretagne (France), where the normal annual rainfall was exceeded by 20 to 40% in parts of the region. A third consecutive year of severe flooding occurred in Hungary and parts of Eastern Europe in March 2001 where the Tisza river reached its highest level since 1888 while two weeks of heavy rain during in June 2001 produced Poland's worst flood since 1997. In August 2002 devastating and costly floods in the Elbe and the Danube rivers were observed with further extreme precipitation and flooding in southern France, where almost half of the normal annual rainfall fell in just one day!

Prolonged periods of moderate rainfall can lead to "*plain floods*" that build up over days and can affect large areas, whereas short-lasting but very intense rainfalls cause "*flash floods*", that can develop within a few hours only, are very localised, and because of their sudden development and violence represent a particular problem for civil protection.

According to climate modellers, the probability, frequency, duration, intensity (seriousness) of extreme weather events (extreme temperatures and rainfall) are increasing and will be more common in the future. If these weather features are combined with hilly landscapes, a lack of permanent and dense vegetation cover, inefficient land management practices and soils with unfavourable physical properties, then increased extreme soil moisture situations, be it either waterlogging or drought, may develop. The former will lead to higher surface runoff and flood events while the latter will cause crop failure, reduced drinking water supplies and a breakdown of soil properties. The impact of such events depends greatly on the **physical and hydro-physical properties of soils.**

The **main factors affecting soil moisture** are:

- the depth, thickness and sequence of various soil horizons within the soil profile between the surface and the groundwater table;
- the hydro-physical characteristics of these soil layers;
- the quantity, status, energy, relations, chemical composition and vertical or horizontal movement of soil moisture.



(ADR)

The main hydro-physical characteristics of soils include particle-size distribution, saturation percentage, bulk density, aggregate state and stability, porosity, pore-size distribution, water storage capacity, field capacity, wilting percentage, available moisture range, infiltration rate, permeability, saturated and unsaturated hydraulic conductivity. The values of these parameters for a large number of European soils are stored in the HYPRES database (see Page 99).

Floods and landslides are natural hazards intimately related to soil and land management. Floods and mass movements of soil cause erosion, pollution and loss of soil resources with often catastrophic impacts for human activities and lives, damage to buildings and infrastructures and loss of agricultural land. Floods can, in some cases, result from soil not performing its role of controlling the water cycle due to compaction or sealing.

Such events are occurring more frequently in areas with highly erodable soil, steep slopes and intense precipitation, such as the Alpine and the Mediterranean regions. In Italy more than 50% of the territory has been classified as having a high or very high hydro-geological risk, affecting 60% of the population or 34 million inhabitants. More than 15% of the territory and 26% of the population are subjected to a very high risk. The impacts on population and the economic damage are relevant. In Italy over the last 20 years, floods and landslides had an impact on more than 70 000 people and caused economic damage of at least 11 billion euro.

This photograph shows the power of a large flood in the Ossola Valley of northwest Italy. A torrential and prolonged rain storm in 2000 completely destroyed one of the main highways between Italy and Switzerland (RJ).

The main objective of efficient **soil moisture control** is to *increase the water storage within the soil in a form that is available to plants* without any unfavourable environmental consequences. Such measures should:

- reduce evaporation, surface runoff and filtration losses of water (atmospheric precipitation and irrigation);
- increase the available moisture range of the soil (to help infiltration into the soil, increase the water storage capacity, reduce the immobile moisture content);
- improve drainage conditions of the soil profile (reduce over-saturation and waterlogging).

It is important to stress that most of these measures are also important elements of **water conservation and environment protection.** What is good for the soil is good for the land.

Salinisation

SALINISATION is the accumulation of soluble salts of sodium, magnesium and calcium in soil to the extent that soil fertility is severely reduced.

Salt affected soil often exhibits a white or grey salt crust on the ground. The pH of the soil is around 8.5 and the salt interferes with the growth of all but the most specially adapted plants (ED).

Salinisation, also known as alkalisation or sodification, is often associated with irrigated areas where low rainfall, high evapotranspiration rates or soil textural characteristics impede the washing out of the salts which subsequently build-up in the soil surface layers. Irrigation with high salt content waters dramatically worsens the problem.

In coastal areas, salinisation can be associated with the over exploitation of groundwater caused by the demands of growing urbanisation, industry and agriculture. Over extraction of groundwater can lower the normal water table and lead to the intrusion of marine water. Natural disasters in coastal areas, such as tsunamis, can cause severe salinisation problems with several years of low fertility of the affected soil before recovery.

In Nordic countries, the de-icing of roads with salts can lead to localised salinisation.

Salinity is one of the most widespread soil degradation processes on the Earth. According to some estimates, the total area of salt affected soil is about one billion hectares. They occur mainly in the arid–semiarid regions of Asia, Australia and South America. In Europe, salt affected soil occurs in the Caspian Basin, the Ukraine, the Carpathian Basin and the on the Iberian Peninsula. Soil salinity affects an estimated 1 million hectares in the European Union, mainly in the Mediterranean countries, and is a major cause of desertification. In Spain 3% of the 3.5 million hectares of irrigated land is severely affected, reducing markedly its agricultural potential while another 15 % is under serious risk.

Salt affected soil can be divided into five main groups:

- Saline soil (Solonchak) with high amount of water soluble soils.
- Alkaline soil (Solonetz), high alkalinity and high exchangeable sodium percentage (ESP).
- Magnesium soil: high magnesium content in the soil solution.
- Gypsiferous soil: strong gypsum or calcium sulphate ($CaSO_4$) accumulation.
- Acid sulphate soil: highly acidic iron or aluminium sulphate accumulation.

In Europe, the first two groups are the most significant (see Page 16 and the section in the Atlas on the major soil types of Europe for more details on saline soil).

The factors that determine the accumulation of salt in a soil are as follows:

- source of salt (local weathering, surface and subsurface waters, human activities);
- transporting agents accumulating salts from large areas to smaller deposits as well as from thick geological strata to thinner horizons (usually water, wind);
- limited vertical or horizontal drainage conditions;
- driving force for movement of solution, usually relief (surface runoff), hydraulic gradient (groundwater flow), suction (capillary transport) or concentration gradient (diffusion);
- negative water balance (evapotranspiration greater than precipitation).

Two main types of salt accumulation in soil can be distinguished in Europe:

- Continental salt accumulation due to intense weathering and arid climate or due to hydro-geological conditions (e.g. closed evaporative basins).
- Human induced salt accumulation due to improper land use (e.g. irrigation, fertilizer application).

The Carpathian Basin in Hungary is a good example of the first case. Surface runoff, seepage and groundwater transport soluble weathering products from a large water catchment area to the lowest part of the basin where subsurface waters, enriched with sodium, calcium and magnesium carbonate (salts), accumulate in a thick continuous aquifer. In poorly drained, low lying areas, capillary flow transports high amounts of water soluble salts from the shallow, stagnant groundwater to the overlying soil horizons. Due to the chemistry of the soil solution (strongly alkaline), the sodium is the dominant element in the migrating waters. High sodium saturation of heavy-textured soil with large amount of expanding clay minerals results in unfavourable soil properties and limits their fertility, productivity and agricultural utility.

Salinity as an environmental stress and limiting factor for agriculture.

The accumulation of salts, particularly sodium salts, are one the main *physiological* threats to ecosystems. Salt prevents, limits or disturbs the normal metabolism, water quality and nutrient uptake of plants and soil biota. When water containing a large amount of dissolved salt is brought into contact with a plant cell, the protoplasmic lining will shrink. This action, known as plasmolysis, increases with the concentration of the salt solution. The cell then collapses. In addition, sodium salts can be both caustic (corrosive) and toxic (poisonous) to organic tissue. The nature of the salt, the plant species and even the individuality of the plant (e.g. structure and depth of the root system) determine the concentration of soil-salt levels at which a crop or plants will succumb. Examples of plants and crops with a high tolerance to salt include bermuda grass, cotton, date palm, peas, rape and sugar beet while apples, lemons, oranges, potatoes and most clovers have a very low tolerance.

One of the main characteristics of salt affected soils is their temporal variability. Prolonged rainfall can lead to a temporary leaching of salt from the surface layers. In many salt affected areas, small ponds are dug to drain the saline water from the soil thus allowing limited agriculture on other parts of the land. The white deposits on the bank of the pond are evaporated salt crystals (EM).

Salinization processes are near to irreversible in the case of heavy-textured soils with high levels of swelling clay. Although a combination of efficient drainage and flushing of the soil by water is often used, the leaching of salts from the profile is rarely effective

Because the reclamation, improvement and management of salt affected soils necessitates complex and expensive technologies, all efforts must be taken for the efficient prevention of these harmful processes. Permanent care and proper control actions are required. Adequate soil and water conservation practices, based on a comprehensive soil or land degradation assessment, can provide an "*early warning system*" that provides possibilities for efficient salinity (or alkalinity) control, the prevention of these environmental stresses and their undesirable ecological, economical and social consequences.

What is salinity?

Salinity is the degree to which water contains dissolved salts. Salinity is usually expressed in parts per thousand or grams per thousand grams. Normal seawater has a salinity of 33 parts per thousand. This rises to 40 parts per thousand in the Red Sea.

Soil salinisation in coastal areas affected by tsunami tidal waves

One of the long term effects of tsunami waves is the deposition of salty seawater on large flooded areas with consequent salinisation of soils. Depending on the climatic conditions, these effects can be temporary and the soils may recover rapidly by washing out the infiltrated salt deposits through heavy rainfall. In more arid or sub-humid areas the salinisation effects can on the other hand last for several years. Depending on the type of crops cultivated in the area and their resistance to salinisation there can be serious consequences on long term agricultural production and food security in the affected area.

The 9 magnitude earthquake that occurred at 00.58 UTC on 26th December 2004 at the interface between the India and Burma plates off the west coast of Northern Sumatra, Indonesia, triggered massive tsunamis that affected several countries throughout south and south east Asia (India, Bangladesh, Mynamar, Sri Lanka, Indonesia, Maldives and Thailand) as well as in East Africa (Somalia, Kenya, and Tanzania). The total inundated zone is estimated at ca. 60 000 sq. km. Soils of these areas have been affected by erosion and scouring that modifies the topography, land leveling and the elimination of bunds (for paddy fields), soil fertility losses when upper layer is washed away, deposition of salted sediment, salt infiltration and trash and debris accumulation. Recovery of the affected areas will require several years in some areas lacking sufficient rainfall for rapid outwash of accumulated salts and will be an additional burden to the local population.