Chapter 4
Regulatory Ecosystem Services and Supporting Ecosystem Functions

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Abstract This chapter provides the analysis and assessment of **ten regulatory and supporting ES**: *R1, air quality regulation; R2, water quality regulation; R3, erosion and natural hazard regulation; R4, water flow regulation; R5, local climate regulation; R6, global climate regulation/carbon sequestration; R7, biodiversity promotion; R8, life cycle maintenance/pollination; R9, pest and diseases control; and R10, maintenance of soil formation and composition.* All ES are described in the unified structure: definition and brief characteristics, methods used for identification and assessment, main types of landscape and ecosystems providing given ES, the importance of ES in terms of nature and landscape protection, and ES assessment for the territory of Slovakia. Spatial assessment is provided as a map of the landscape capacity for given ES provision. For all ES, short conclusions and overview of input data for further assessment of the ES capacity, demand and flow are also given.

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4.1 Air Quality Regulation (R1)

4.1.1 Definition and Brief Characteristics of ES

Burkhard and Maes (2017) identify *air pollution as one of the main environmental risks*, especially for urban areas, because of the high production and concentration of pollutants in the air. The source of air pollution comes mainly from anthropogenic activities and anthropogenic controlled ecosystems, which release pollutants into the atmosphere, and these can then be deposited elsewhere, also in pollution-sensitive ecosystems. For example, NH_3 and NO_2 emissions from livestock farming and the use of fertilizers (also used for ecosystem management) can lead to increased nitrogen deposition or direct intoxication of plants sensitive to this type of pollution (Sutton et al. 2011). Deposition of pollutants from the atmosphere in the soil and vegetation can significantly reduce their concentration in the air (Fowler et al. 2009) and thus reduce the adverse effects on human health and other ES (RoTAP 2012).

According to the UK National Ecosystem Assessment UK NEA, air quality regulation is a primary or intermediary regulatory service which affects atmospheric concentrations of air pollutants and their deposition in land and water. At the national level, the most important pollutants include particular matter, ozone, nitrogen oxides, ammonia and sulphur, deposition of which can lead to acidification of ecosystems and their eutrophication.

Ecosystems contribute to improving air quality by removing pollutants from the atmosphere: gases and solid particles are deposited on the ecosystem (especially plant) surfaces, and polluting gases enter the leaves through stomata. The extent of this removal depends on a number of factors, including air turbulence (higher vegetation has higher effectiveness), duration of foliage (evergreen trees are more effective) and stomatal processes (deposition may decrease under dry conditions – UKNEA 2011b).

Maintaining good air quality depends on the exchange of chemicals between ecosystems and the atmosphere through biogeochemical cycles. Soil, along with vegetation, emits compounds which contribute to the formation of secondary pollutants in the atmosphere, such as the emission of volatile organic carbon from plants, which contributes to the formation of ozone and aerosols in the ground layer of the atmosphere (Royal Society 2008).

Air quality regulation through ecosystems brings many benefits, including clean air for breathing, prevention of respiratory and skin diseases. Ecosystems affect air quality by emitting chemicals into the atmosphere (serving as a *source*) or extracting chemicals from the atmosphere – i.e. serve as *waste containers* for industrial emissions, for example sulphur compounds (Preston and Raudsepp-Hearne 2017). The removal of pollutants from the air is mainly performed by trees and other vegetation through dry deposition of substances which accumulate at the earth's surface (Burkhard and Maes 2017). The Spanish National Ecosystem Assessment (Santos-Martín et al. 2016) lists air quality regulation and climate regulation (57% of answers) as the most valuable benefits provided by ecosystems to maintain quality of life.

To conclude and summarize, *air quality regulation is the ES which mainly consists of attenuation/transformation of the effects of air pollution on ecosystems and people*.

4.1.2 Methods Used to Assess and Identify ES

Considering the physical-chemical nature of the processes associated with this ES, biophysical methods are mainly used for its assessment. The atmospheric gas flow, atmospheric/air-purifying capacity and pollutant level/content in the atmosphere are appropriate indicators for measuring air quality regulation. Burkhard and Maes (2017) present secondary (supporting) indicators important for air quality regulation: net primary production, disease prevention, regulation of ecosystem dynamics and stability of ecosystem processes, ability of ecosystem restoration, ecosystem diversity and interconnection promotion.

The mapping of ES air quality regulation according to Burkhard and Maes (2017) is based on three types of information: dry deposition rate (potential), air pollutant removal (real production) and human pollution exposure (demand). A good measure of this ES comes in the form of the cycle of pollutant removal through vegetation as a result of dry deposition and pollutant concentration. Consumption of this ES can be mapped based on population exposure and pollutant concentration above the limit set by legislation.

The Finnish national ES assessment (Jäpinen and Heliölä 2015) used a cascade model with four indicators: structure, function, benefit and value of ecosystem service provision. The following indicators are used in case of air quality regulation: green infrastructure in cities (structure), storage/absorption of small particles (function), improvement of air quality (benefit), health benefits from clean air and saved/avoided healthcare costs (value).

For the regulation of local climate and air quality, the national ES assessment in Germany (Albert et al. 2016) selected the indicators of the *extent of green areas in settlements* as the potential of ES provision. Germany has extensive environmental data available and considers the ES potential through assessing and planning at the regional and municipal level as part of landscape planning.

Modelling tools InVEST or ARIES need to be highlighted as comprehensive tools for ES assessment. Both models work in ArcGIS environment and are freely available. The primary input for these models is the land cover and land use maps, complemented by socio-economic and ecological parameters (carbon stock in soils, average annual rainfall). On the other hand, a simplified production matrix method is also used (Burkhard et al. 2014). Accordingly, air quality regulation is provided to the highest extent by forest ecosystems with an index of 5, while cities and densely populated areas have the highest consumption with an index of −5.

Another group of assessment methods is the economic methods of air quality regulation – according to Farber et al. (2006), contingent valuation method, cost savings or replacement costs methods could be used. For cost savings, the ES is valued on the basis of an estimate of costs which have not been incurred or the possibility of avoiding the costs associated with averting or mitigating the negative effects of the absence of the ES. The replacement cost method assesses the ES according to the cost of replacing this service.

The integrated ES assessment in the Czech Republic (CZ) is based on the assessment of the current ES status, including the regulation of air pollution from the *value transfer* method. In this way, the economic valuations of the given ES in many studies performed under comparable conditions were used, and the values were *transferred* in a new context in conditions of the CZ (Vačkář et al. 2014). The average economic value of ES air quality regulation by Frélichová et al. (2014) in the CZ is 266.33 EUR/ha.

4.1.3 The Main Types of Landscape and Ecosystems Which Provide ES

The national assessments of ecosystems and their services, together with the production matrix (Burkhard et al. 2014), confirm that the most widespread and important biotope on the European level providing ES air quality regulation is the forest ecosystems and another wooded land.

This also applies to Slovakia, where forest ecosystems are clearly the most important for air quality regulation. Other ecosystems are essentially of little significance from a nationwide perspective, but they can be significant locally. In the built-up areas, there is clearly the largest demand for this ES combined with its highest consumption. Forest ecosystems are therefore crucial both in terms of the quality of provision of this ES (Fig. 4.1) and in terms of the overall ecosystem area in Slovakia. It is important that all areas of Slovakia have a sufficient share of continuous forest stands, which is the case, in particular, in Central Slovakia. The southern parts of Western and Wastern Slovakia, which are dominated by arable land, are significantly poorer for the provision of this ES. It is essential to maintain/expand/restore urban parks and vegetation in cities, especially from a local point of view, so that these areas are as close as possible to the place of demand and consumption.

The area of forest stands in 2017 amounted to 1.9 mil. ha, i.e. more than 40% (38% based on the ecosystem map of Slovakia by Černecký et al. 2020) of the area of Slovakia (MPSR NLC 2018). Thanks to this fact, the forested landscape has the highest share in provision the air quality regulation. Among other functions, forest ecosystems play a key role in the deposition of pollutants from the air, and therefore their protection is crucial.

Fig. 4.1 Natural oak forest in SAC Mäsiarsky bok with old trees contributes significantly to air quality regulation. (Author: J. Černecký)

Ecosystems of good quality have a clearly positive effect on air quality, primarily through the absorption, storage and removal of pollutants. However, if the pollutant storage rate exceeds the critical thresholds, the opposite effect on the other ES may occur. Emissions in the atmosphere from ecosystems can even directly or indirectly deteriorate air quality (UK NEA).

4.1.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

As mentioned above, sufficient area, proper structure and quality, especially of woody vegetation, is necessary for sufficient provisioning of ES air quality regulation. At the same time, this ES also contributes to the value of protected areas in terms of providing basic conditions for the life of organisms, including humans. Polluted air causes annual damage to health and premature deaths in many cases. A

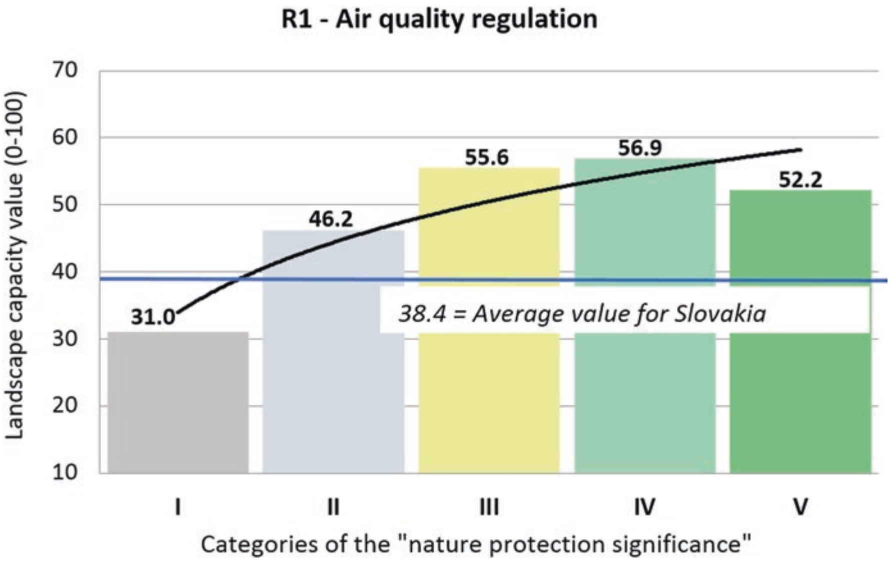


Fig. 4.2 The relationship between ecosystem service R1 and the significance of the territory of Slovakia in terms of nature and landscape protection

quality ecosystem included in protected areas contributes to the potential of a given area in terms of improving the conditions for life, and from the local point of view, it provides visitors of such a protected area with health benefits. The beneficial health effects of clean-air forest areas have been known for a long time and have been used for a long time in the form of treatments, thus increasing the credit and justification of individual protected areas with a high proportion of forest ecosystems. It should be noted that the most of protected areas in Slovakia has a majority of forest ecosystems, and it is therefore evident that in addition to the basic functions related to habitat and species protection, these areas also fulfil the function of ensuring/improving human health through production, regulation and purification of air for the Slovak population. The positive relationship between nature protection and the provision of the R1 regulatory service is also evident from Fig. 4.2, especially in categories III–V, where the capacity of the territory is highly above average.

Support for good-quality provision of ES air quality regulation is based mainly on the appropriate management of existing forest and woody areas in the landscape and in the planting of new green areas – especially in cities where demand for this service is the largest. Such measures are in most cases also supportive in terms of nature and landscape protection. The importance and function of this regulatory service in built-up areas needs to be emphasized – preserving and developing urban *green areas* will contribute to increasing air quality and the quality of life of inhabitants. Trees and other plants are involved in the removal of pollutants, which accumulate on the earth's surface due to dry deposition (Burkhard and Maes 2017). Urban green areas have many functions, but air quality improvement is one of the key ones. Therefore, green park areas and other areas with residential vegetation should be effectively protected.

4.1.5 ES Assessment for the Territory of Slovakia

Air purification and related microclimatic function is considered one of the important non-production functions and services of forest ecosystems. Čaboun et al. (2010) insert this function among the so-called atmospheric functions of the forest and consider the appropriate land use, good-quality forest structure and location of the area in terms of demand for this function, in particular, to be important factors of efficiency.

Various international assessments show that the most important provider of air quality regulation services is the forest ecosystems, which also applies for Slovakia. Especially important are forests with the natural species composition of trees (Fig. 4.3). In our conditions, it is possible to define the highest quality groups of forest habitats, which provide the ES air quality regulation – these include mainly oaks, hornbeams and scree forests. In terms of quantity, these include beech and fire-beech forests. In a smaller but qualitatively significant extent, the areas of

Fig. 4.3 A typical commercial forest dominated by European beech (*Fagus sylvatica*) is a good example of providing this ES in Slovakia. (Author: J. Černecký)

Table 4.1 Input data for capacity, demand and flow assessment of ES air quality regulation

Input data/ ES	R1: air quality regulation
Capacity	Map of current landscape structure – reclassification as appropriate for ES provision
	Species composition, structure and condition of forest areas and stands (classification, types of stands, age of forests)
	Biomass volume in the landscape – leaf area index (LAI 2018)
Demand	Air quality in the region – polluted areas, concentrations of main pollutants
	Population of the municipality/region
	Recreation areas, special demand areas
Flow	Real effect of vegetation – rate of improvement of air quality
	Number of residents within the effect of ES provision

non-forest woody vegetation in the landscape (small forests, groves, shrubs, riparian vegetation), orchards and city parks also contribute to the provision of this service.

In order to assess the capacity and real provision of this ES, it is necessary to use data on the natural and real state of forest areas and the use of non-forest areas (Table 4.1). The pilot assessment at the national level was conducted using the appropriate and available data – especially data on forest areas (ESFT, stand types, age) and the current landscape structure of Slovakia. As a supplementary indicator for the volume of biomass, the so-called leaf area index (LAI) was taken into account from the European RS Copernicus system database (available online: www.copernicus.eu/en). These data were subsequently reclassified in a similar way as in the case of other ES to the relative landscape capacity scale for the provision of ES air quality regulation. The assessment result is shown in Fig. 4.4.

Table 4.1 also shows the basic indicators which can be used for future expression of the level of demand for ES as well as its real use. Logically, the highest demand for this ES is in the built-up areas, where the production of this service is the lowest. The number of inhabitants living in a particular territory is a suitable indicator. Demand can be expressed, for example, by the need to regulate air quality (delimitation of polluted areas) or the existence of special types of territories requiring improvement of air quality (zones, protected areas, etc.).

The ES flow is conditional on its real use – i.e. the level of air quality improvement by ecosystems, the number of inhabitants living in the affected area and the like. Obtaining such data at the national level is likely to be problematic, so it will be appropriate to use certain substitute indicators, so-called proxy indicators. Albert et al. (2016), for example, mentions the following as appropriate indicators of demand and consumption: the population density, the extent of settlement and exposure to air pollutants and to the harmful effects of urbanized environments.

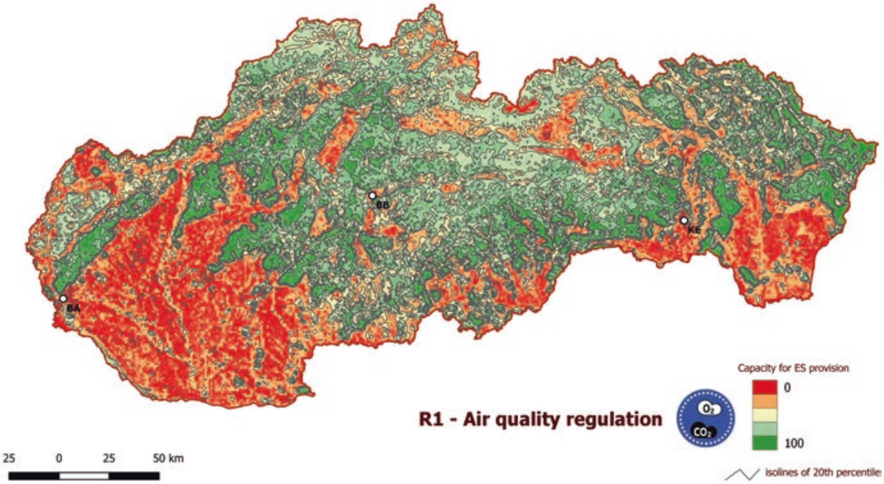


Fig. 4.4 Capacity of the landscape to provide ES air quality regulation

4.2 Water Quality Regulation (R2)

4.2.1 Definition and Brief Characteristics of ES

Water, as the basic prerequisite for life on Earth, provides a lot of different ES to people and at the same time supports the provision of all others ES (Coates et al. 2013). In addition to provisioning (drinking water and freshwater supply) and cultural services (recreation, healing), water represents a particularly important regulatory ecosystem service: for example, the correct timing and seasonal distribution of water supply and watercourses or water purification (in terms of water quality, including biological treatment as well as sediment storage, etc.) (Dudley and Stolton 2003; Bruijnzeel 2004; Brauman et al. 2007).

In order to define this ES and for its valuation, it is necessary to focus on what is understood by water quality. Water quality is often not exactly interpreted as the final ES. In this case, the connection between the provided ES and human well-being is particularly pronounced, as the water quality is highly perceived and highly valued by the public (Keeler et al. 2012).

In general, water quality may be seen as a set of several different biophysical parameters, which may affect the final provision of ES. These parameters can include, for example, the amount of nutrients (especially nitrogen and phosphorus), the acid-base balance, the presence/concentration of organic pollutants, pathogens, pesticides, industrial and pharmaceutical products, retained sediments, water colour, transparency or temperature (Smith et al. 2012).

Water purification for drinking and other purposes, as well as removing microbes and other toxins, is an important contribution to human health. The main components of ES water quality regulation identified based on the work by Smith et al. (2012) and UK NEA (2011) include, in particular, nitrate absorption, phosphorus absorption, regulation of pathogens and organic pollutants, sediment absorption and absorption of particulate organic carbon (POC), regulation of dissolved organic carbon (DOC), acidity balancing, water temperature balancing, pollutants dilution, prevention against the reproduction of harmful algae, the decomposition of organic pollutants, the intake of plant and microbial nutrients and the infiltration of pollutants into the soil and sediments. These processes contribute to the final ES, including the regulation of pollutants in other media, the provision of drinking water, fishing and recreation.

Given the number of subprocesses which make up this regulatory function, it is quite difficult to generalize the main factors of its functioning, as well as exactly capture the role of ecosystems. In general, however, ecosystems have the highest potential to regulate those water quality components which are bound to the sources of water collected in the river basin or the related water retention processes (Smith et al. 2012). They are therefore closely related to other regulatory ES, such as air quality and soil quality regulation, climate regulation and nutrient retention (UK NEA 2011).

4.2.2 Methods Used to Assess and Identify ES

The assessment of water quality regulation is quite challenging – the change in water quality affects several aspects of human well-being, and, moreover, benefits and/or costs can reach different groups of affected parties at different times and locations. Compared to other services, water quality regulation is thus much more complex. It cannot be assessed simply by one indicator or parameter, such as in the case of carbon sequestration (tons of captured CO_2). Similarly, the expression of marginal value may also be complicated, since any improvement in water quality by one degree can only affect the local level, and this value may vary depending on the spatial context and may have significantly decreasing marginal benefits (e.g. additional reduction of lake pollution by nutrients will bring only minimal additional benefits, and these benefits are also influenced by the state and proximity of other lakes). The time aspect can also play a very crucial role – current interventions can affect water quality for a relatively long period of time into the future, which complicates forecasting future values (Keeler et al. 2012).

Given the complexity of this ES, its assessment requires the use of an integrated approach and a combination of multiple assessment methods – in particular biophysical and economic methods. This approach makes it possible to capture the change in service provision in the case of, for example, changes in ecosystem management or land use, which can cause changes in water quality and thus influence the provision of ES and their value (Keeler et al. 2012).

Biophysical models link the changes in the landscape (ecosystems) with the change in water quality, as measured by, for example, the change in nutrient concentration, sediment deposition or input of chemical substances. Different models can be used for such assessment, such as SWAT (*Soil and Water Assessment Tool*) or InVEST. Outputs from these models can be expressed using the nutrients captured in the landscape or the loads at specific river basin endpoints. Similarly, biophysical assessment can be used to link water quality changes with the change in ES provision and goods, which directly affect human well-being.

In the case of aquatic ES, hydrological models and supporting indicators can also be used to capture complex interactions between different factors (climate, topography, geology, etc.). In their work, Grizzetti et al. (2016) divided these indicators on the basis of whether it is the ecosystem's potential/capacity to provide the given ES, the flow of the service or the social benefit.

Simpler methods of biophysical assessment focus on one or several key indicators. Pérez-Soba et al. (2015) mention the following as the most frequently used indicators: for example land use, hydrogeological properties, soil quality and vegetation properties – its spatial structure (canopy cover, biomass volume), naturalness, diversity and nutrient cycle. They are all included among the so-called proxy indicators which explain the operation and level of provision of the given ES only indirectly. Maes et al. (2014) and Czúcz et al. (2018) also stress the importance of qualitative indicators of water – organic carbon content, microbial activity, nutrient content and content of dissolved solids. The biophysical methods can also include the spreadsheet method/GIS-based approaches (Burkhard et al. 2012; Vihervaara et al. 2012).

Most of the national assessments of this ES also use biophysical indicators – the presence and quality of habitats significant for water purification (Denmark, Finland, Germany, Ireland, Luxembourg, United Kingdom) – or water quality indicators (Germany, Italy, Romania).

The aim of the economic assessment is then to reflect on how the change in the provision of ES will be reflected in its value and the benefits which people derive from it. To do this, different approaches can be used – a cost-based approach, whereby the estimation is focused either on the damage-cost avoided if the water quality is improved or on the costs associated with the increased health risk due to poor water quality. For the economic assessment, the so-called stated preference methods are used, where respondents directly answer the question of how much they would be willing to pay for some improvement in water quality. The third approach often includes the revealed preference methods, which, for example, compares respondents' willingness to pay for real estate near a good-quality water resource (Keeler et al. 2012; Grizzetti et al. 2015).

Various social assessment methods (usually combined with other assessment methods) can also be used to assess this regulatory ES, which also take into account social preferences attributed to, for example, drinking water (Perni et al. 2012).

4.2.3 The Main Types of Landscape and Ecosystems Which Provide ES

Water quality regulation is primarily linked to different types of aquatic ecosystems – i.e. lakes, rivers, marine and coastal waters, groundwater, freshwater and coastal wetlands, coastal areas and floodplains (Grizzetti et al. 2015). However, terrestrial ecosystems also play an important role, for example, in regulating the transfer of dispersed contaminants into the surface waters, particularly by infiltration and retention of pollutants in the soil (Smith et al. 2012). At the same time, in the case of watercourses, ecosystems in the upper parts of the basin have a major impact on water quality regulation (Fig. 4.5) – they dilute pollutants from point sources of pollution entering the aquatic ecosystems in lower parts of the basin in order to mitigate the impact of pollution on water resources (Smith et al. 2012). The main media for

Fig. 4.5 Important mountain watercourses usually have high water-purification capacity (TANAP, Javorová dolina). (Author: D. Kaisová)

the proper functioning of this regulatory ES include vegetation, soil and biota and wetland ecosystems (metabolic activity of plants and microorganisms).

It is therefore evident that not only the aquatic and wetland ecosystems themselves are *carriers* of ES water quality regulation, but the overall quality of local and regional ecosystems is also important, in particular sufficient extent, the appropriate spatial structure and quality of key types of ecosystems. In particular, we can include the forest ecosystems, wetlands and riparian vegetation, as well as permanent grassland near the waters and in river valleys.

The importance of this regulatory ES is also evident in the higher altitude and windward areas, where major water quality problems are often related to the deposition of atmospheric pollutants (sulphur, nitrogen, metals) as well as the colour/transparency of water in relation to dissolved organic carbon (Smith et al. 2011).

4.2.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

Regulatory ES, including water quality regulation, are essential for nature and landscape protection. They create the conditions necessary to provide provisioning ES which bring direct benefits to people, such as crop production, availability of clean water and others, as well as cultural ES. However, compared to provisioning ecosystem services, changes in the provision of regulatory ES are reflected in a much longer time frame. There is, therefore, a risk that the deterioration of regulatory ES will not be seen immediately after the intensification of use of provisioning ES (Kumar 2010). Thus, the reduction in the ability of ecosystems to regulate water quality may be delayed. A frequent trade-off (i.e. provision of one type of ES at the expense of another service) is the more intensive use of provisioning ES at the expense of regulatory and cultural services (Rodríguez et al. 2006; Raudsepp-Hearne et al. 2010; Maes et al. 2012).

In the context of biodiversity protection, water quality regulation acts as a synergy – good water quality promotes water and water-related biodiversity at the same time (Smith et al. 2012). In a broader context, effective water quality regulation enables the healthy functioning of other ecosystems. On the other hand, in view of the close links between the different regulatory ES, deteriorated water quality may, for example, result in deterioration of soil quality and hence its ability to provide different soil-related ES (Smith et al. 2012). Water quality deterioration can have widespread ecological consequences – for example, water acidification, which has led to losses of biodiversity and fish stock over the past decades, which in turn has negatively affected the provision of recreational and provisioning ES (Smith et al. 2011).

According to the results of the assessment of this ES for the territory of Slovakia, the direct correlation between the capacity of the landscape and the significance of the territory in terms of nature and landscape protection is not as obvious as for some other regulatory ES. However, except for the highest degree of significance (V.), this correlation exists (Fig. 4.6) – particularly in degrees III–IV, there is the

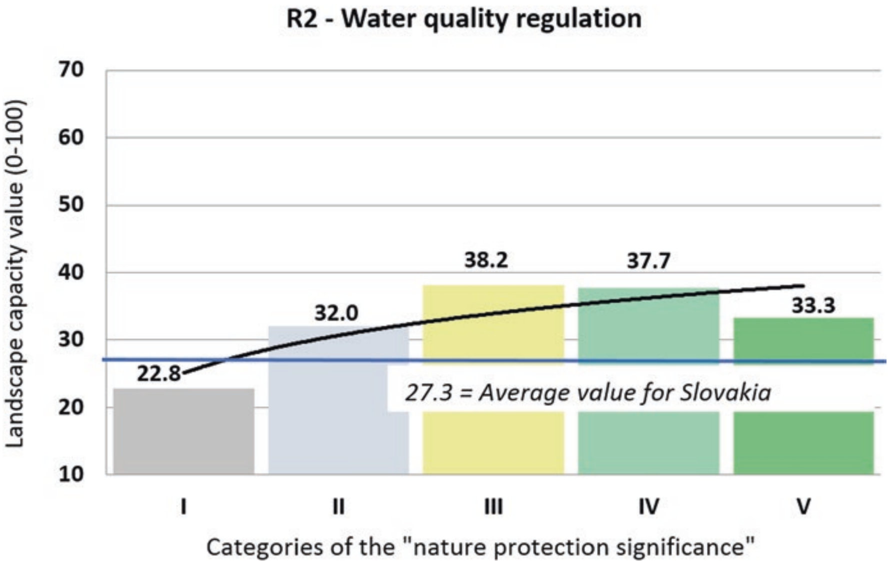


Fig. 4.6 The relationship between ecosystem service R2 and the significance of the territory of Slovakia in terms of nature and landscape protection

highest share of forest ecosystems, which are crucial for the provision of this ES, together with hydric ecosystems.

Maintaining aquatic ecosystems and especially wetlands is essential for the sustainable provision of water quality regulation (Fig. 4.7), both in terms of quantity and quality – not only inside but also outside of protected areas. This will necessitate focusing on the factors which are now most affecting the water quality, notably agriculture, industrial pollution and land use management (MEA 2005, Smith et al. 2012). In our conditions, we can also include residential development and the development of technical infrastructure (such as Žitný ostrov). Measures which can mitigate the impact of stress factors on water quality regulation include, for example, the development of buffer zones, which provide biological continuity between rivers and their riparian zones and, where possible, use green infrastructure, such as restoring coastal areas, wetlands and water retention areas that promote biodiversity and soil fertility and prevent flooding and droughts (European Commission 2012).

4.2.5 ES Assessment for the Territory of Slovakia

Hydric ES in Slovakia was studied, for example, by Bujnovský (2018), who estimated, among other things, the value of the regulatory ES on the example of the valuation of nitrogen retention in the aquatic environment – but only for the whole territory of Slovakia based on the value transfer from an analogous study (estimate of 3 million EUR per year). However, this is only a partial assessment, with the

Fig. 4.7 River Turiec with important aquatic habitats and flowering macrophytes (*Batrachion fluitans*). (Author: J. Černecký)

value being very low. Another specific assessment of this ES for Slovakia is not known. There are only partial studies assessing some aspects of water quality regulation, for example the ability of the soils to immobilize and transform risk chemical elements (Vilček 2014) or theoretical elaboration of water-protection function of forests (Čaboun et al. 2010; Konôpka 2012).

Považan et al. (2014a) propose to use the ecosystem infiltration capacity (e.g. water volume/surface area) as indicators of ES water regulation – volume per unit area/per time; water retention capacity (in mm/m^2) or water retention capacity by alluvial meadow (in mm/m). In the case of water purification, they present the nutrient capture by wetlands (tons or percent): water quality in aquatic ecosystems (sediments, turbidity, phosphorus, etc.). This represents the use of biophysical indicators, which are, however, more appropriate for the local to the regional level.

For a simple assessment, it is possible to use some of the methods which are used in foreign studies, for example models like InVEST or ESTIMAP, or the basic screening method of the so-called Burkhard matrix. Consequently, it is possible to follow up the biophysical assessment with an economic assessment.

For the initial assessment of the capacity of the landscape of Slovakia to provide ES water quality regulation, available data on the current land use, quantity and quality of vegetation focusing on forest areas as well as data on soils (absorption capacity) and relief (slope gradient) were used – see Table 4.2. The basic indicator used was the regulatory capacity of vegetation (the result of the R1 regulatory

Table 4.2 Input data for capacity, demand and flow assessment of ES water quality regulation

Input data/ ES	R2: water quality regulation
Capacity	The regulatory function of vegetation – result of ES R1 assessment
	Slope inclination – coefficient of runoff attenuation
	Soil absorption capacity
Demand	Water quality in the territory – contaminated areas, concentrations of main pollutants
	The population of the municipality/region in the demand areas
	Special areas of demand (water management, fishing, bathing, recreation)
Flow	The real effect of ecosystems – the rate of water quality improvement
	Number of residents within the effect of ES provision, the attendance of the affected areas

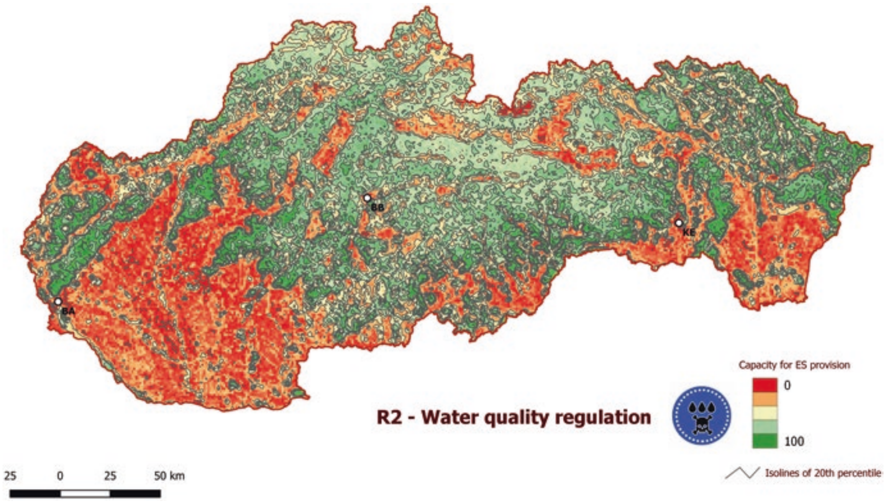


Fig. 4.8 Capacity of the landscape to provide ES water quality regulation

service assessment); the soil and relief correction coefficient was used to refine the input value. The values obtained were expressed in relative scale – the result of the assessment is shown in Fig. 4.8.

Together with the indicators for expressing the landscape's capacity, Table 4.2 also lists the indicators suitable for determining the level of ES demand and its real use. A suitable demand indicator is, for example, the need for water quality regulation – defining the polluted areas. The number of inhabitants living in a particular area (whether in polluted areas, but also, for example, in districts or in municipalities) is also important. Areas of demand also include areas of activities requiring clean water (recreational areas, watercourses and reservoirs, fishing grounds, etc.).

The real use of ES water quality regulation is determined by the quality of the water itself (watercourses, reservoirs and groundwater areas with good quality), an improvement over a certain period of time, the number of inhabitants living in such a territory, attendance and the like. Population density, spatial distribution of settlements, recreation or changes in the quality class of watercourses may be used as proxy proxy indicators similarly to ES R1.

4.3 Erosion and Natural Hazard Regulation (R3)

4.3.1 Definition and Brief Characteristics of ES

Erosion is a relief-forming process caused by the effects of exogenous processes, which lead to the removal of topsoil cover (usually topsoil), often faster than soil formation. The erosion processes occur mainly due to water and wind and can lead to a qualitative deterioration and loss of productivity, especially in agricultural areas, which can have serious consequences for the costs of agriculture and food. Analysis of erosion-sensitive areas allows decision-makers to anticipate this risk and implement erosion reduction measures which can be achieved through preventive land use and management (Becerra-Jurado et al. 2016).

The ES of protection of the territory against these adverse processes is based on the ability of the river basins to determine the surface water runoff in the landscape so as not to damage natural resources. Relief and land use method establish the basic framework for the regulation of processes associated with surface runoff and water retention. The condition of soil saturation leads to processes of surface erosion, gully erosion and slope gravity disturbances. Soil erosion is a natural and normal process – it is important to ensure that the soil runoff limits are not exceeded during land use (e.g. in the Universal Soil Loss Equation (USLE) model). This ES is indirectly related to other ecosystem land services, such as carbon sequestration, biomass production, water quality control, nutrient and contaminants filtering and their retention (Palm et al. 2014; Vilček 2014).

Several types of soil erosion are recognized – the basic types include surface water erosion, gully erosion and wind erosion. The specificity of the last one is that it is not so heavily connected to rainfall-runoff conditions and relief. It depends more on the soil characteristics (texture, structure, moisture regime), land-use methods and wind conditions.

The second group of processes associated with rainfall-runoff conditions in mountain and foothill areas includes *slope deformations – landslides* (geodynamic phenomena in the broader sense). It is a relatively fast gravitational transfer of slope masses (top layer of soil, debris and rocks along the so-called shear surface) from the source area along the slope, which results in the deformation of the original relief and the creation of a new form of relief (the landslide itself) usually composed of erosive, transport and accumulation part. Slope deformations have different causes and different characteristics, and therefore there are different types of landslides (available online: www.usgs.gov). Ensuring slope stability is quite complicated, which is related to the properties of the geological bedrock and slope inclination as passive factors and to the active action of rainfall, possibly to land use and technical human intervention in the country.

Relief-forming processes in the conditions of the alpine landscape are also associated with risks due to the movement of snow masses in the form of avalanches. The main *avalanche forming* factors include the height of the snow cover, the air temperature regime and the morphometric attributes of the relief. In addition to moving snow, avalanches have the ability to disrupt the vegetation and soil-substrate cover. Most often, the source parts of avalanches are at risk in this respect, so we use the potential avalanche formation model to identify and assess these. Avalanche disturbances also have a serious impact on the forest ecosystems of the subalpine and montane levels.

ES regulation of slope processes associated with the movement of material is clearly related to the rainfall-runoff regime in river basins and is limited by land use and the protective effect of vegetation, including types of ecosystems able to retain water in the landscape. The spatial structure of vegetation and its properties play an important role in soil protection and slope stabilization – for example plant roots help to stabilize the soil, minimizing soil degradation and also decreasing the sediment in watercourses and thus contributing to better water quality (Preston and Raudsepp-Hearne 2017).

To conclude, ES erosion and natural hazard regulation is understood as the *ability of ecosystems and landscape to regulate adverse relief processes* – especially to prevent and mitigate water and wind erosion, landslides and selected gravity processes and, to some extent, avalanche risk.

4.3.2 Methods Used to Assess and Identify ES

Relief processes associated with soil erosion, slope processes and avalanches are assessed on a long-term and global basis with the prevalence in the use of biophysical models based on natural environment parameters and landscape use factors.

The most commonly used indicators of soil erosion assessment include, in particular, the landscape use, relief (inclination), mapping of real processes (landslides and erosion occurrence), soil parameters (depth, texture, retention capacity) and vegetation characteristics – especially location, cover and spatial structure (Pérez-Soba et al. 2015; Czúcz et al. 2018).

In the national assessments of this ES, only the water erosion processes are virtually investigated within Europe. The properties of vegetation are almost always used in the calculations – the area of individual elements (especially forests and protective stands) and their spatial representation, to a lesser extent the properties of soils (Finland, Germany, Romania) and relief (Romania, UK). In Italy, the InVest model was also used to assess the territory's erosion protection (Giarratano et al. 2018). In the available national ES assessments, wind erosion, slope processes and avalanches were not considered at the national level.

Generally, the most widely used assessment method for ES erosion and natural hazard regulation is modelling – a wide range of models is used, mainly to calculate the *potential and actual water erosion* (Markov and Nedkov 2016). These include various modifications of the USLE, RUSLE (Revised Universal Soil Loss Equation) and USPED (Unit Stream Power-based Erosion Deposition) models in the GIS environment (for an overview see for example Šinka et al. 2013). The SSCRI modelling tool was developed for Slovakia's agricultural territory (Antal, 2005 – available online: www.podnemapy.sk/erozia/).

The calculation of potential and actual *wind erosion* is also mostly based on modelling, using models in the GIS environment (e.g. WEQ, Wind Erosion Equation; TEAM, Texas Tech Erosion Analysis Model; AUSLEM, Australian Land Erodibility Model – review by Grešová 2010). For Slovakia, it is possible to use the classification of the risk to the territory of Slovakia by wind erosion (overview in, e.g., Streďanský et al. 2005; Kobza et al. 2005, application within the portal available online: www.podnemapy.sk).

Minár and Tremboš (1994) present the method of determining *gully erosion* as a manifestation of concentrated surface runoff – it is based on the attributes of the relief slope, the slope length and the rock resistance factor. The authors also developed an empirical formula to determine the threat of gravitational *slope deformation* activation. A model for assessing the susceptibility of the area to landslides DYLAM (Pechoušková 2006). An antegrated assessment of natural threats was investigated by Šabo et al. 2012 and others.

The basic model for spatial identification of *formation of avalanches* used in Slovakia is the model of avalanche threats (Hreško 1998; Barka and Rybár 2003; Žiak 2012 and others).

4.3.3 The Main Types of Landscape and Ecosystems Which Provide ES

The most important type of country that provides the ES associated with the regulation of the effects of slope processes in Slovakia is represented by *forested parts of hills, highlands and mountainous areas*, while their real effect is determined by the local characteristics of the relief, climate and hydrological conditions (rainfall-runoff conditions). It is the vegetation cover that is the determining factor that can prevent most of these processes from occurring – the anti-erosion effect of vegetation is the most important (Fig. 4.9). The greatest effect comes from vegetation in the case of a suitable spatial structure (wood cover) and quality (species and age

Fig. 4.9 Forest ecosystems protect the steep slope against landslide and erosion and provide a rainfall retention function, thereby protecting property and health (Horná skala, Malachov). (Author: J. Černecký)

varied vegetation, with developed undergrowth), where it can be a direct limiting factor for such processes. When comparing the different types of forest stands, deciduous and mixed forests are clearly more favourable, while, for example, spruces are more susceptible to the appearance of processes due to their worse structure, lower stability and stand resistance.

On the other hand, in case of sudden events caused by extreme factors (extreme precipitation, slope stability erosion, earthquake), not even a very good and quality vegetation structure can guarantee the prevention of the occurrence of such an event – for example, catastrophic landslides or erosion phenomena occur periodically in forest areas. However, the most common cause of such events is the *unfavourable impact* of human activities in the area (construction, transport, mining of raw materials, deforestation, etc.).

A very good anti-erosion effect is also provided by permanent grassland – meadows of various types. That is why the resistant type of landscape is formed by the varied structures of the submontane agricultural landscape with a prevalence of grasslands and a high proportion of permanent vegetation, especially in the case of preservation of historical structures of the agricultural landscape (especially terraced and narrow-banded fields and meadows with a limit – Špulerová et al. 2017).

The most risk-prone types of landscape in terms of susceptibility and occurrence of erosion processes include the intensively used agricultural land with the dominance of large-scale arable land. It is in this type of territory that the most common manifestations of water and wind erosion occur. In these territories, the main ES caused by the occurrence of slope processes is, in particular, the protection and gradual restoration of soil productivity, in particular by respecting anti-erosion measures, appropriate forestry and agricultural practices and good agricultural practice and integrated nutrient provision management.

4.3.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

According to the assessment of the territory of the SR from the point of view of ES erosion and natural hazard regulation and other slope processes, the relationship between this ES and the significance of the area is clear in terms of nature and landscape protection, with a significant positive correlation (see Fig. 4.10). In the previous text, the importance of forests and extensively used agroforestry areas, which form the foundation and majority of the area of the protected nature areas in Slovakia, is emphasized.

In addition, the protection and management of protected areas create a prerequisite for regulation of slope processes by eliminating, limiting or conditioning human activities at various stages of protection which could trigger or accelerate the considered morphodynamic phenomena. The parts of the protected areas themselves or their ecosystems thus contribute to the elimination of the emergence and development of processes which could change the functioning conditions of the ecosystems concerned.

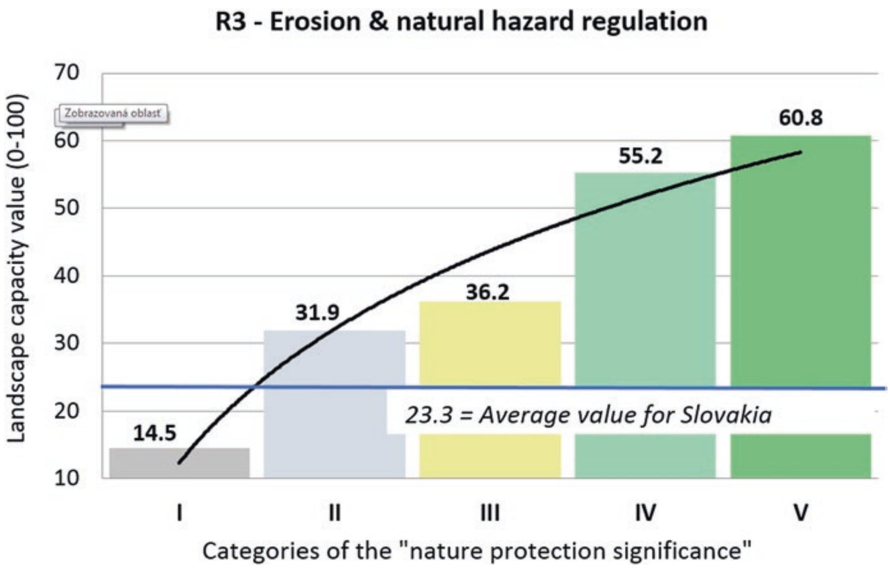


Fig. 4.10 The relationship between ecosystem service R3 and the significance of the territory of Slovakia in terms of nature and landscape protection

Fig. 4.11 Limits and ecotones in the traditional management of Hriňovské lazy create important elements for preventing soil erosion and landslide after torrential rains. (Author: F. Petrovič)

Such a *synergistic* effect also applies vice versa – the management of commercial activities of people focused on the prevention, elimination or mitigation of the effects of relief-forming processes is also a supporting factor for more effective nature protection. The protective measures include, in particular, finer and natural farming and agricultural methods (Fig. 4.11), which are now also strongly supported by the EU subsidy system (including, e.g., agri-environmental measures and agroforestry systems). Nevertheless, these measures in the current setting are not yet sufficient, and their implementation in practice lags behind the theoretical basis, while it is necessary to significantly change/set the schemes so that they can really contribute to the protection of nature in Slovakia and not vice versa.

On the other hand, some geomorphological processes can be closely linked to the development of important ecosystems and can be a forming active factor in their functioning. Avalanche ecosystems in the alpine environment of high mountains (Hreško and Bugár 1999; Fischer et al. 2012), wetland ecosystems in non-draining depressions of landslides, habitats in watercourse channels after flood events and so on are perceived as such. Many original disturbances like that are part of protected areas, in some cases, they were directly one of the main factors for their declaration.

4.3.5 ES Assessment for the Territory of Slovakia

Unlike most other ES, the issue of erosion and other slope movements is very well investigated and identified within the territory of Slovakia. When it comes to *water and wind erosion*, it is assessed regularly for agricultural land in the form of maps of potential and current water and wind erosion within the SSCRI Information

Service (available online: www.podnemapy.sk/default.aspx). Among other things, the portal provides the possibility of interactive modelling of current water erosion at the local level. According to the SEA (Enviroportál 2018) assessment in 2017, there was 38.6% of agricultural land (761.6 thous. ha) at risk from water erosion. While for the hilly landscape middle category of potential erosion (4–10 t/ha/year) is typical, for more rugged sub-mountainous and mountainous areas it is particularly the high threat (10–30 t/ha/year) and to a lesser extent extreme threat (above 30 t/ha/year). The area of soils potentially affected by wind erosion in Slovakia in 2017 amounted to 6.7% (131.6 thous. ha) of agricultural land. This type of erosion is associated with the lowland areas of Western, Southern and Eastern Slovakia. Water erosion on forest land is not assessed in this way, although several authors have processed maps of potential and actual water erosion of Slovakia according to the above-mentioned models, based on variously detailed data (Antal 2005; Gallay 2010 and others).

Slope deformations are inventoried and assessed for the territory of Slovakia within the competence of the State Geological Institute of Dionýz Štúr (SGIDŠ) in Bratislava, which operates a database of slope deformations (available online: www.apl.geology.sk/geofond/zosuvy/) and Atlas of Slope Stability Map of the SR (available online: www.geology.sk/geoinfoportal/). There are 21,190 slope deformations registered in Slovakia, and these occupy an area of 257.5 thous. ha, which represents 5.25% of the territory of Slovakia. The largest number comes from landslides with registered number of 19,104, accounting for 90.2% of all registered slope deformations. The expansion of slope deformations is associated mainly to areas built by Paleogene rocks and Mesozoic klippen belt and Paleogene of the outer flysch belt. Approximately, 12% of the total number of landslides in Slovakia is active.

Slope deformations represent a phenomenon which significantly affects the state and effective use of land. It acts as a constant threat where buildings are located without adequate measures and repeatedly causes damage to the land, line and other structures, underground and overground utility networks, as well as agricultural and forest land. The landslide risk in some regions of Slovakia is also currently increasing due to the intensified direction of construction activity from flat and slightly inclined areas to sloping and more exposed areas. This trend is particularly evident in the villages of mountainous regions of Slovakia. It is caused not only by the lack of suitable building plots in flatlands but often also by the targeted placement of buildings on slopes due to the attractiveness of the environment. The classification of *avalanche risk* in the mountains of SR is realized through the portal of the Mountain Rescue Service (available online: www.laviny.sk) and the GIS portal of the alpine environment of the SR (available online: www.avalanche.sk). Similar to other alpine areas, avalanche processes are associated with the alpine, subalpine and supra-montane zones in Slovakia. Their disturbing modes according to Bebi et al. (2009) perform bidirectional interactions in which avalanches affect the structure and composition of the forest and avalanches affect the structure and composition of the forest. The occurrence of avalanches is associated only to the high mountains of the Carpathians, predominantly above the top boundary of the forest. The creation of detailed avalanche maps of Slovak mountains is currently under work by, for example, Žiak (2012).

The occurrence of individual types of geomorphological processes and susceptibility to them is elaborated relatively in detail in Slovakia. However, a comprehensive assessment of slope processes and, in particular, the degree of protection against their effects (which represents the ecosystem service itself) is not yet present – although it was methodically investigated and applied in the model area by, for example, Šabo et al. 2012.

For the purposes of the ES catalogue of Slovakia, the calculation of ES water erosion regulation was performed as a pilot assessment based on several available and created documents (see Table 4.3 for a list of background maps). The result is not presented in the *classical* form of the intensity of potential or actual water erosion – the capacity of the landscape is expressed as the protective effect of vegetation and ecosystems against the processes of erosion and other geodynamic phenomena (such as the difference between potential and actual erosion intensity). All the important factors of the erosion susceptibility of the area – the relief (the inclinations of the relief, the shape and the length of the slopes), the precipitation intensity, the soil characteristics and the nature of the use of vegetation and ecosystems – were included in the calculation.

It is logical that the highest protective effect of vegetation is typical for rugged sub-mountainous and mountainous areas with a high-water erosion susceptibility (Fig. 4.12) – mostly wooded and grassed areas. The moderate effect of vegetation is typical in lowland hills and lower mountain ranges, and low effect in flatlands (due to the fact that potential erosion is low in these areas).

Table 4.3 Input data for capacity, demand and flow assessment of ES erosion and natural hazard regulation

Input data/ ES	R3: ES erosion and natural hazard regulation
Capacity	Land use – CLS types
	Nature of vegetation – structure and quality of forest habitats (alternative C-factor)
	Relief – inclination, segmentation and length of slopes (alternative LS factor)
	Erosion susceptibility of soil (alternative K factor)
	Precipitation intensity (alternative R factor)
Demand	Potential water erosion and susceptibility to other processes (wind erosion, landslides, avalanches)
	Integrated assessment of the territory to adverse geomorphological processes
	Number of inhabitants of municipalities/areas in areas prone to assessed processes
	Definition of particularly sensitive areas – urbanized areas, recreational areas
Flow	Real effect of ecosystems – the measure of the protective effect of vegetation for individual processes
	Integrated flow assessment – ES utilization rate for all assessed processes
	The number of inhabitants within the ES reach – population protection

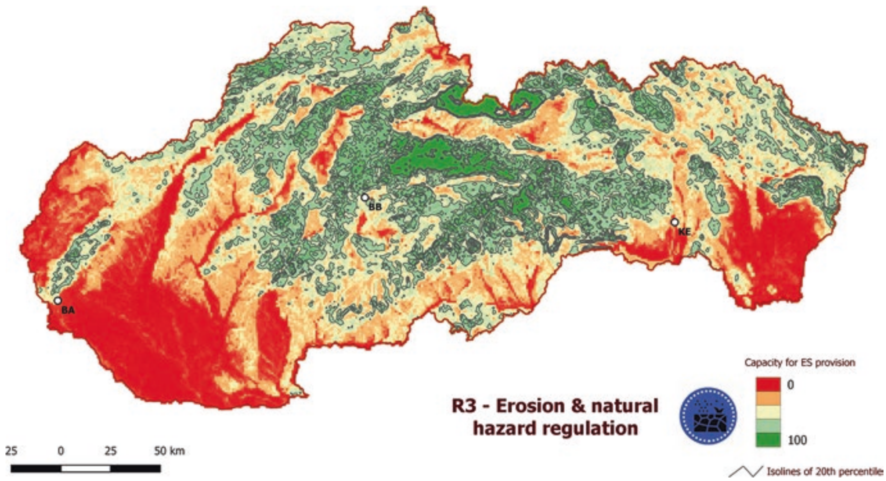


Fig. 4.12 Capacity of the landscape to provide ES erosion and natural hazard regulation

Table 4.3 also shows the indicators proposed or appropriate for determining the level of demand for a given ES and its real use. For the ES demand, it is appropriate to express the need for regulation of slope processes, based mainly on the definition of vulnerable territories and the determination of the population living in such territories. The territory of demand can also include sensitive areas (urbanized areas, recreational areas) characterized by the number of affected inhabitants.

The real use of ES erosion and natural hazard regulation can be assessed by expressing the real effect of vegetation and ecosystems in vulnerable territories as well as some integration of action in relation to other processes (not only erosion but also landslides and avalanches). It is also possible to express the number of inhabitants living in the territory with a real positive effect of the ES.

In the absence of the necessary data, proxy indicators can be used (e.g. population density, spatial projection of settlements and other activities).

4.4 Water Flow Regulation (R4)

4.4.1 Definition and Brief Characteristics of ES

Floods are complex events which are difficult to predict, with many factors contributing to their occurrence. Water retention capacity in river basins is therefore particularly important for flood risk reduction. Another important prerequisite for landscape protection is the infiltration capacity of the soil and the presence of habitats with high-water retention capacity. These habitats should be given particular attention. As floods can have a devastating effect in the landscape, the monetary and social benefits of adequate water flow regulation are enormous (Becerra-Jurado et al. 2016).

The assessed ES water flow regulation expresses the *river basin's ability to regulate water runoff during extreme rainfall events* so as to avoid flooding in the context of exceeding N-years flow rates and minimizing the duration of a flood event. With extreme flows in watercourse channels, there also exists a threat of waterlogging and flooding due to high groundwater levels.

Supporting natural water flow regime in river basins through natural ecosystems provides people with many benefits – for example by mitigating droughts and extreme flood events, mitigating extreme minimum and maximum watercourse flows and providing natural water supplies for utility purposes. Changes in landscape cover and land use can affect the timing and extent of flow, flood discharges and saturation of watered alluvial layers. Flood mitigation factors or water regime adjustments also include soil permeability, the presence of alluvia and wetlands, which may also reduce the need to build technical infrastructure (Preston and Raudsepp-Hearne 2017).

Based on the Millennium Ecosystem Assessment (MEA 2005), ES water flow regulation can be defined as the impact of ecosystems on the timing and extent of water runoff, floods and refilling of groundwater collectors, primarily in terms of ecosystem or landscape potential to collect and retain water.

ES water flow regulation can be comprehensively understood as an *ecosystem and landscape ability to regulate outflow processes* – especially to mitigate extreme volumes of surface runoff and flood discharges. It is suitable to assess different spatial levels – from defined micro-basins and reference profiles on watercourses through larger river basins to national levels. It is also appropriate to assess the real significance of the ES with the emphasis on the distribution of inhabitants with regard to the areas prone to the occurrence of flood events.

4.4.2 Methods Used to Assess and Identify ES

Similar to the case of erosion and other slope processes, biophysical methods and indicators are used in the assessment of runoff conditions and flood risk. The simpler methods include the use of various indicators and mapping methods; the more complex approaches include the use of various complex computational models.

A summary of indicators applied in various world studies is provided by, for example, Pérez-Soba, Harrison et al. (2015) and Czúcz et al. (2018). They highlight the indicators of land use (spatial structure of use, share of greenery), relief (inclination, size and shape of the basins), hydrological parameters (runoff, flow rates, occurrence of floods), soil parameters (retention capacity, permeability) and ecosystem properties (spatial structure of vegetation – coverage, distribution). Maes et al. (2014) also emphasize the importance of river floodplains and their threats and the proportion of water elements and wetlands in vulnerable territories.

The assessment of this ES has been largely carried out in the framework of national ES assessments in European countries. The most commonly used indicators include the area of water retention ecosystems and runoff mitigation (Finland, Germany, Ireland, Luxembourg, Romania). Some countries have also used models for water retention and water runoff from the river basins (Germany, Romania, United Kingdom).

More complex computational models for the calculation of surface runoff volumes in micro-basins and the interpretation of landscape properties with respect to their regulation are represented by, for example, HEC-HMS (Hydrological Modelling System) and HEC-RAS (River Analysis System) models. HEC-HMS serves to simulate the rainfall-runoff process, to calculate the volume of direct runoff volume from the area and to simulate peak flows on the basis of N-year precipitation (model description, e.g. Kadlec 2010; Jeníček 2009). HEC-RAS is a one-dimensional hydraulic model designed for flow modelling in river systems (e.g. capacity calculations of selected watercourse profiles – e.g. Černý (2012) and website of Hydrologic Engineering Centre USACE – available online: www.hec.usace.army.mil/).

The assessment of runoff conditions and flood risk is also investigated by several Slovak authors. Solín (2011) created a methodology not only to determine the hydrological balance but also to identify runoff genesis in the context of land use changes. An important contribution to ES assessment is the generation of integrated flood risk assessment models in basins (Solín et al. 2016; Solín 2017). For the processing of flood maps and watercourse risks, water depths and water flow rates for floods with a repetition time of 5, 10, 50, 100 and 1000 years have been specified.

An alternative calculation of the potential and real direct surface runoff from the basins and in the reference profiles is provided by the method of runoff curves (so-called CN curves), which has been prepared down to the level of micro-basins with the use of ArcGIS superstructures or other GIS systems – more details can be found in works by, for example, Smelík (2016), Šinka et al. (2013), Kaletová and Šinka (2012) and Gallay (2010).

4.4.3 The Main Types of Landscape and Ecosystems Which Provide ES

The ES water flow regulation needs to be assessed in the spatial context of hydrological systems of rivers and streams, which form the backbone of almost all types of socio-economic activities from urbanization, communication networks, agriculture and so on. Hydrological regulatory functions are similar to those of the previous ES, directed at the mitigation of erosion processes – the essence of which is the ability of a landscape and ecosystems to retain surface runoff, reduce its volume (which is also done by water consumption by ecosystems), slow down runoff processes and transform them as much as possible into subsurface levels of soil and subsoil.

The specific feature is that runoff processes and floods are manifested through the hydrological network of watercourses and their offshore systems; therefore, the status of aquatic ecosystems is crucial for this ES. The natural and well-functioning watercourses, their valleys and wetlands carry the key regulatory function – this includes the dynamic ecosystems which can best transform flood waves and high-water levels into lower parts of the basin. Unfortunately, such watercourses are limited in Slovakia to virtually only mountain basins, as they almost completely retreated from the structural basins and lowlands due to anthropogenic adaptations and commercial land use. This is particularly true in the case of wetland ecosystems, which were also of great importance in the lowlands, not only in terms of regulatory function but also in balancing the landscape's moisture deficit during the growing season (Fig. 4.13).

Forest ecosystems are the most important area element in the landscape with a water flow regulation function. Forests and permanent vegetation in the landscape (groves, line stands of woods) are key elements for rainfall transformation and runoff regime. Similar to the anti-erosion function, the appropriate spatial structure (especially the total biomass volume) and the quality of the stands are important. It is true that species and age-diverse stands with developed scrub and herbaceous undergrowth are more stable and more suitable in terms of runoff transformation and balancing. The problem is that disturbing the stability (especially of non-native) of forest stands in the mountainous areas of Slovakia, the frequent occurrence of calamities and the subsequent large-scale harvesting over the last 10–15 years reached an almost *catastrophic* extent, which largely undermines the fulfilment of forest regulatory functions.

In addition to watercourses, their shoreline vegetation and perennial permanent vegetation, permanent grassland is also important in the agricultural landscape. These permanent grasslands fulfil hydrological functions in addition to their anti-erosion functions. As with other regulatory functions, diversified land use patterns

Fig. 4.13 Flood areas in the ecosystem help significantly in flood protection (wetland near the village of Rad on the Východoslovenská nížina lowland). (Author: J. Hreško)

of mosaic nature, which mainly form the submontane agricultural land with preserved small-scale historical structures, have a high value in this respect.

On the contrary, ecosystems negatively affecting the fulfilment of regulatory hydrological ES include the intensively used agricultural and urbanized areas – with a predominance of settlements, technical elements and large-scale fields. Such a landscape is characterized by a changed hydrological regime not only of the agricultural landscape itself but also of the unsatisfactory state of watercourses and other hydric elements. Water management measures are also part of the land reclamation and amelioration measures – their main objective was to improve the state of the landscape in terms of increasing water availability and productivity (building of water reservoirs and other sources, irrigation, hydro-melioration channels, etc.) and protection against the undesirable effects of natural processes (watercourses modification, water flow). Unfortunately, in the second half of the twentieth century, a number of modification and interventions in the landscape were implemented, which had a considerable negative impact on the functioning of natural processes and mechanisms ensuring the fulfilment of hydrological regulatory functions. Technical buildings in the landscape require care and maintenance, which is often not the case for water structures. Therefore, instead of performing their original purpose, water management structures are severely limited in their function, and their construction has rather disrupted regulatory relations and processes, especially in the lowland and basin landscapes. While the large water management structures like dams and embankments can prevent floods in the lower basin areas, they even such structures are not able to prevent the occurrence of floods and flood damage in higher parts of the river basin. It is in these areas where floods are particularly frequent in case of poor landscape state and inadequate ways not only of urbanization but also of agriculture and forestry.

4.4.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

As with most regulatory services, a landscape with well-functioning regulation of hydric processes is in line with the performance of natural protection functions. When assessing the relationship between the landscape's capacity to fulfil this ES and the significance of the territory of Slovakia in terms of nature and landscape protection, there is no direct correlation or positive correlation (see Fig. 4.14). This is probably due to the fact that the assessment is focused on sub-basins, not the ecosystem types themselves, and at the same time this ES is important and present not only in mountain areas (direct transformation and deceleration of runoff conditions) but also in lowland areas (flood prevention, water management etc.).

When assessing the landscape's hydric functions in relation to nature protection, it should be however emphasized that the method of landscape management and the implementation of possible water management adjustments are essential. It is

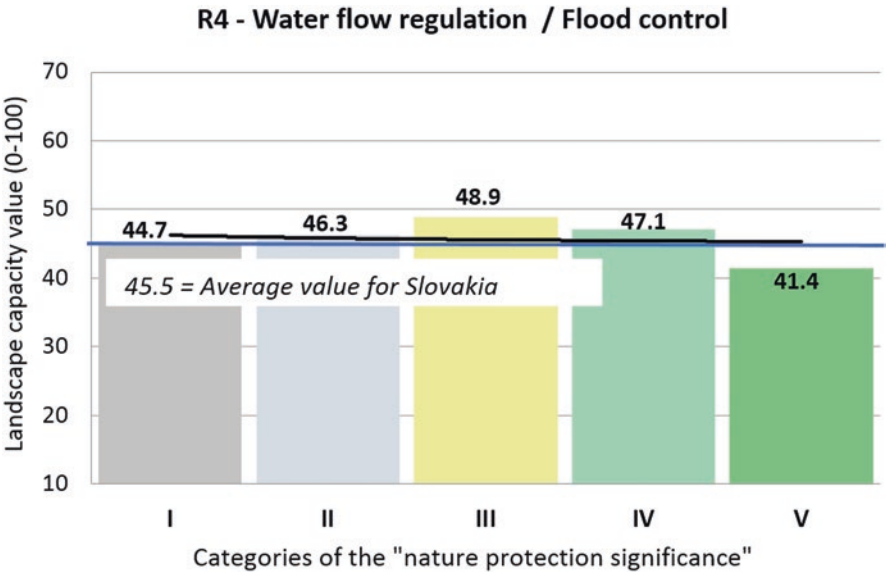


Fig. 4.14 The relationship between ecosystem service R4 and the significance of the territory of Slovakia in terms of nature and landscape protection

essentially a long-term dispute between the advocates of *nature-based* and *technical* solutions and measures.

Nature-based hydrological measures and river basin management are based on the preference of nation-wide measures to change the way the landscape is managed. It is a return to small-scale and diversified forms of agriculture, revitalization and renaturation of hydric ecosystems, planting of woody vegetation, local anti-erosion and flood control measures, natural forestry measures, small-scale and selective forest management and the like. Such measures are in line with most other landscape regulatory and support functions and services, including nature conservation. Reciprocally, effective protection and management of protected areas of nature is in line with such a concept of hydrological functions of the landscape.

Hydrotechnical solutions and measures are mainly represented by *hard* interventions in the landscape – building reservoirs, polders and flood-protection dams and regulating and straightening watercourses. Although these provide immediate solutions and can improve flood protection for large territories, they have negative consequences in terms of other ecosystem functions and landscape services – in many cases being very significant and irreversible, including nature and landscape protection. For that reason, such interventions are absolutely inappropriate in protected areas – and their implementation in other territories should be clearly justified by the inability to protect the territory by other means.

4.4.5 ES Assessment for the Territory of Slovakia

Extreme hydrological processes in river basins leading to periodic floods of local to regional extent are quite frequent in the territory of Slovakia. Their importance is increasing in the current climate context, so it is logical that relatively high attention is paid to mapping and assessing vulnerable territories both in the government area and in science and research.

The flood-threatened areas are very accurately expressed in the flood maps – the flood hazard map and the flood risk map of the watercourses of Slovakia. Maps are prepared, maintained and updated by the Slovak Water Management Company, š.p. as a tool to *reduce the adverse effects of floods on human health, the environment, cultural heritage and economic activity by reducing the extent of flooding, reducing vulnerability and mitigating the negative consequences of floods* (available online: www.mpompr.svp.sk). The maps show the territories threatened by various floods (Q_5 to Q_{1000}) and the data on the potentially adverse effects of possible floods on the population and the economy. They were created by simulating steady uneven water flow through a mathematical hydrodynamic model.

The long-term classification of the Slovak basins is performed also by the Geographical Institute of SAS. The basic classification of runoff regulation in river basins is provided by the results of the regional hydrogeography of Slovakia (Solín 2003, 2011). In addition, Solín et al. (2016) created five classes of the Slovak river basins according to flood risks, which can form the basis for assessing the need for ES regulation of runoff conditions.

Both of these and most of the other approaches assessing the territory of Slovakia are focused on mapping, or flood risk assessment, which in the ES context represents a demand-side and not a capacity to provide this ES. Therefore, for the purposes of the ES catalogue of Slovakia, the calculation of ES water flow regulation was carried out as the landscape's capacity to provide this ES, which is a kind of *prevention* against the possible emergence of undesirable phenomena.

The map was compiled on the basis of available relevant documents (see Table 4.4 for a list of background maps). It represents a combination of two basic factors – the favourability of *local conditions* in terms of runoff regulation represented by the quantity and quality of the vegetation cover and soils (the expression of the so-called CN-curve based on vegetation and soil data) and the characteristics of the micro-basins in terms of transformation of runoff conditions (size, average slope, vegetation coverage). The result is provided in a form of the *relative scale of regulatory functions of the landscape and the micro-basins*.

The landscape's highest capacity to provide this ES is not typical for mountain areas but for larger valleys of watercourses, water reservoirs and lowland landscape with sufficient representation of forests or water elements (Fig. 4.15). The above-average protective capacity is shown by less rugged forested mountains, while low to very low capacity of the landscape is documented for deforested hills and rugged river basins with lower representation of forests. For a large part of the territory of

Table 4.4 Input data for capacity, demand and flow assessment of ES water flow regulation

Input data/ ES	R4: water flow regulation
Capacity	Landscape use – CLS types
	Nature of vegetation – structure and quality of forest habitats (alternative C-factor)
	Soils – permeability classes
	Relief – average slope of micro-basins
	Structure of vegetation – the average value of CN-curve for micro-basin
Demand	Classification of micro-basins according to flow volumes/peak flood discharges
	Micro-basin classification according to flood risks
	Number of inhabitants of municipalities/areas in flood-threatened areas
	Definition of particularly sensitive areas – urbanized areas, residential and technical buildings, agricultural areas
Flow	The real effect of ecosystems – real protective effect according to micro-basins
	Degree of real ES action during real floods
	Number of residents within the reach of the ES – protection of citizens, prevention of financial losses

Fig. 4.15 Riparian forest and shore plants near the Danube (Patince) as an important element of water retention in the landscape, also providing flood protection function. (Author: D. Štefunková)

Slovakia, the average capacity of the landscape is typical for the regulation of runoff processes (Fig. 4.16).

Table 4.4 also includes useful indicators for determining the level of demand for this ES and its real use. Demand for ES can be assessed on the basis of the above-mentioned sources (flood risk maps, or classification by micro-basins). It is also

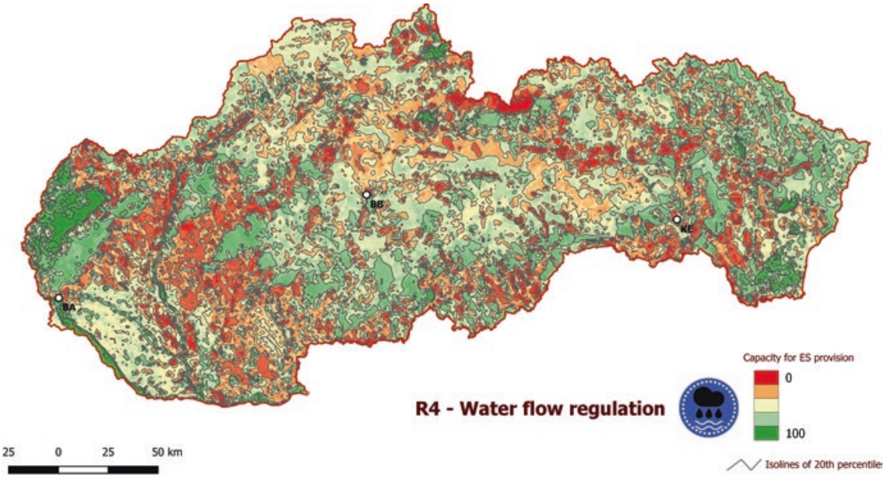


Fig. 4.16 Capacity of the landscape to provide ES water flow regulation

important to specify the number of inhabitants living in vulnerable territories and potential economic damage.

The real use of ES water flow regulation should be assessed on the basis of the real effect of ecosystems and the landscape during real or modelled floods – for example in the form of a flood-protected area, the number of protected residents or the value of avoided economic damage in territories with a real positive ES effect. As in the case of the previous ES, in the absence of the necessary data, proxy indicators may be used, for example, population density, spatial projection of settlements and other activities.

4.5 Local Climate Regulation (R5)

4.5.1 Definition and Brief Characteristics of ES

Local weather and climate are determined by the complex interaction of regional and global circulation characteristics with local topography, vegetation, as well as the configuration of water bodies (De Groot et al. 2002). According to Smith et al. (2012), ecosystems provide shelter from heat, UV radiation, wind and precipitation;

they regulate local temperature, the occurrence of droughts and the amount of precipitation.

Ecosystems regulate our climate at different levels. In cities and their surroundings, tree vegetation or urban forests provide shade during hot summer days and through evapotranspiration cool the surrounding environment, bringing benefits in terms of cost savings or reduced ozone production (Burkhard and Maes 2017). Evapotranspiration is the process of water intake by leaves, its conversion to water vapour and the consequent emission of water vapour into the atmosphere (Georgi and Dimitriou 2010). The conversion of water in leaves into water vapour cools the leaf and by releasing the vapour into the atmosphere through stomata also cools the surrounding microclimate (Hunter et al. 2012). Therefore, this physical phenomenon plays an important role in the water cycle and at the same time contributes to the provision of ES by vegetation.

First, providing shade with tree vegetation means changing the radiation balance which has two basic effects on humans. Plants capture part of the incident shortwave radiation, which increases the temperature on the Earth's surface, leaving the air temperature below the vegetation low. Second, reducing the effect of direct radiation on the human body reduces its physiological burden. These two effects of ES regulation of microclimatic conditions increase people's comfort during hot summer days (Ali-Toudert and Mayer 2007; Lee et al. 2013).

The shade provided by tree vegetation in cities has, in addition to temperature reduction, a positive effect on buildings – trees growing near buildings reduce their temperature during the summer days, thereby saving the cost of cooling them/air conditioning (Nakaohkubo and Hoyano 2011; Berry et al. 2013).

Based on the above definitions, the regulation of local climatic conditions can be characterized as the ability of ecosystems to regulate temperature and provide shade, to support the evapotranspiration process, to regulate the amount of incident solar radiation and to some extent regulate the spatial distribution of other microclimatic factors (e.g. wind, precipitation) and dampen the effects of some related processes (e.g. pollutants, dust, noise). In particular, these co-acting factors provide a local temperature reduction during days with high daily temperatures.

4.5.2 Methods Used to Assess and Identify ES

Biophysical methods in particular, but to some extent economic and sociocultural methods too, are used to assess this ES.

The basic and simplified assessment method (not only for this) of ES is the use of the so-called production matrix according to Burkhard et al. (2014), which expresses the relative potential, supply and demand for ES for the main types of ecosystems, or forms of landscape use. The regulation of local climatic conditions is provided to the highest extent by the index 5 forest and shrubby ecosystems, with the highest consumption and thus the deficit coming with index −5 built-up urban parts.

According to assessment work done by Pérez-Soba, Harrison et al. (2015) and Czúcz et al. (2018), the most used indicators of the assessment of this ES include, in addition to the characteristics of landscape use, in particular the climatic parameters (temperatures, precipitation, evapotranspiration, shading, wind, surface reflectance), spatial structure of vegetation (spatial distribution, cover, biomass volume), vegetation quality, representation and the nature of settlement vegetation (quantity, quality).

Local climate regulation has been assessed in national ES studies, for example in Germany and Romania. The indicators used for this EC included the volume of biomass, population density and the proportion of green areas in settlements (Germany) or meteorological data (temperatures, precipitation) and population distribution (Romania).

Based on the study of expert works, the following indicators, in particular, can be used for the biophysical assessment of the ES local climate regulation: temperature regulation, incident radiation regulation, shading and evapotranspiration. These indicators are mentioned in the vast majority of scientific papers in relation to the urban environment, in which they are easier to measure and assess, especially in relation to human health, and are more interesting because of the direct effect at the site of action. All four indicators of regulation of local climate conditions are interconnected and linked. In his work, Takács et al. (2014) support the findings made in recent decades that have shown air temperature reduction due to tree vegetation at the local level, especially during the day. The average air temperature below the tree canopy was, on average, 1–4 °C lower compared to the ambient air temperature. Hunter et al. (2012) state that the *tree canopy* can reflect, absorb or transmit incoming solar radiation depending on the type of vegetation, stands density, woody plants size, etc. The transmission of solar radiation through the *tree cover* in the summertime ranges from 4% to 30% and in winter from 40% to 80% (Shashua-Bar et al. 2010; Konarska et al. 2013).

From the point of view of ES provision, the quantifiable vegetation attribute, *leaf area index* (LEA), used in its assessment (Lee and Park 2008; Georgi and Dimitriou 2010) is important. Software tools such as FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) can be used to assess the leaf area, using the current Landsat satellite images or Copernicus data.

Sociocultural methods can also be used for the purpose of assessing this ES – for example the contingent valuation method, which involves a direct determination of people's willingness to pay or accept compensation for a change in ES within a hypothetical market (Farber et al. 2006). Identifying the diversity of views on the well-being based on ES cultural value (Fernando et al. 2013) has shown that people living in the countryside combine their well-being with provisioning ES (food, cattle, fishing) and, conversely, people living in cities prefer (value highly) regulatory ES, in particular regulation of microclimate and air regulation. Promoting green infrastructure was an important part of the ES's assessment in Italy (Capotorti et al. 2015).

From the economical methods, the following methods are suitable, in particular: cost-saving methods (which would arise in case of failure of the given ES – e.g. costs of air conditioning or heating, etc.) and method of benefit transfer from other territories.

Fig. 4.17 Wetland habitat contributes significantly to the local climate regulation of – Šúr Site of Community Importance. (Author: J. Černecký)

4.5.3 The Main Types of Landscape and Ecosystems Which Provide ES

Based on analysed works and assessment of ecosystem capacity and landscape of Slovakia, the following may be considered as the main types of landscapes/ecosystems regulating the local climate: forests and other elements of permanent vegetation, wetlands (peat bogs, marshes and other wetlands – Fig. 4.17), water bodies, watercourses and shore vegetation, to a limited extent also grasslands – meadows and pastures and subalpine and alpine communities.

The regulation of local climatic conditions within Slovakia is mainly provided by forest ecosystems, to a lesser extent by non-forest communities and potentially also by agricultural land. To assess microclimatic conditions, it is necessary to consider the quantitative representation of individual types of ecosystems in Slovakia, not only their quality.

In terms of regulation of the local climate, forest ecosystems also dominate this ES, both in terms of quality of provision and quantitative representation. The area of grassland and herbal habitats plays an important role because, due to its significant presence, it can be considered as the second most important category of ecosystems after forest ecosystems after considering consumption/demand. If only the quality of provided ES is taken into account, peat bogs, marshes and raised bogs are also important. Other ecosystems are less involved in the creation of this ES.

On the contrary, demand for this ES is significantly higher than production in built-up areas, especially in residential areas.

4.5.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

The importance of nature and landscape protection for the regulation of the local climate is quite notable. The prerequisite for ES provision is the condition and dynamics of ecosystems, the nutrient cycle and the connection with other ecosystems. These conditions can be ensured by protecting them, maintaining a favourable ecosystem status and managing them in protected areas (Fig. 4.18). Protected areas most often include large-scale continuous forest ecosystems, which are key to regulation and co-creation of the local climate at the national level.

Green elements in urbanized environments improve the environment, i.e. they increase human comfort through the provision of several ES, but mainly by local climate regulation. With the current negative trend of increasing temperature extremes in the summer months, caused by climate change and resulting weather extremes, the regulation of local climatic conditions is very important, as well as an easily identified function of ecosystems by the general population. An example of this is the seeking of shade during hot days under the tree canopy which, through physical phenomena, reduce temperature, reduce incident radiation and cool the air in the surrounding environment. Paradoxically, landlocked countries like Slovakia are hit by increasing average annual temperatures the most. This is evidenced by measurements in recent years when the Czech Republic and Slovakia have recorded some of the highest increases in average annual temperatures among all EU Member States.

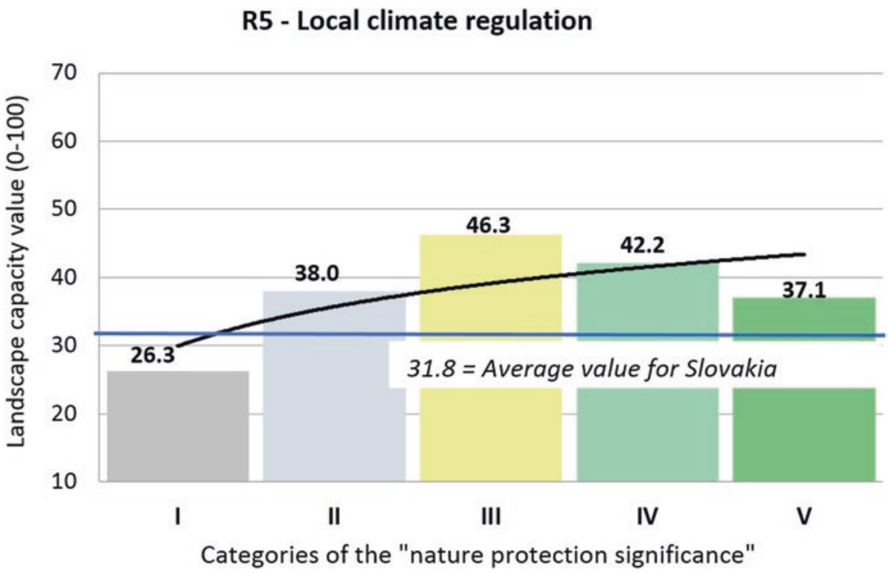


Fig. 4.18 The relationship between ecosystem service R5 and the significance of the territory of Slovakia in terms of nature and landscape protection

The creation, protection and maintenance of permanent vegetation elements in towns and villages in Slovakia, such as city parks, forest parks, orchards, tree alleys, gardens and woody plants planted in housing estates, together with water elements, represent elements of the concept of *green infrastructure* and TSES. The aim of these is to interconnect the natural/semi-natural areas or ecosystems in the urban environment. The importance of building green infrastructure elements is obvious and justified, so this measure is part of the updated Adaptation Strategy of SR to climate change 2018.

In urban areas, it is necessary to support the provision of ES by establishment and maintenance of a wide range of woody and herbaceous vegetation in parks and forest parks, preventing any harvesting of woody plants or tree alleys along roads, watercourses and housing estates, since uniform and *sterile* semi-natural ecosystems do not provide ES in full scale and degrade over time.

Nature protection objectives often focus on achieving a favourable state of habitats and species located in protected areas. However, the implementation of the measures to improve/maintain the status does not only have an effect on the subject of protection but also the provision of an accompanying ES, which is essentially a contribution not only for nature protection but also for residents in the form of improved local climatic conditions.

4.5.5 ES Assessment for the Territory of Slovakia

Ecosystem functions aimed at regulation of the local climate are inherently local and therefore often not understood and assessed at the national level. In addition, its assessment often uses parameters similar to those of the ES global climate regulation, and it can be stated that these two ES also significantly intersect in the assessment with regard to the types of ecosystems providing the service and also with regard to the assessment of potential, provision and demand.

The assessment of the territory of Slovakia in terms of the potential or provision of this ES is not implemented, although the key role of vegetation and especially of forests is evident. The importance of the so-called atmospheric (or climatic) functions of the forest is also mentioned by Čaboun et al. (2010) or in other assessments of non-production forest functions. Climatic functions of vegetation in urban, especially city environment (Fig. 4.19), are investigated by, for example, Supuka (1998). However, a comprehensive assessment of the territory of Slovakia has not yet been prepared.

For the pilot assessment of the capacity of Slovakia's territory from the point of view of this ES (see Table 4.5), we used data on the regulatory function of vegetation (based on the state of forest stands and the use of non-forest areas), which were also used in the R1 regulatory service. The basic classification of the area was subsequently refined with the use of two indicators – the coefficient of climatic conditions (temperature ratios, amount of solar radiation) and the vegetation efficiency coefficient (based on the combination of indicators NDVI (normalized difference vegetation index) and FAPAR). These two indicators were obtained from the database of the European system RS Copernicus (available online: www.copernicus.eu/en).

Fig. 4.19 City parks provide regulation of climatic conditions in cities. (Author: J. Černecký)

Table 4.5 Input data for capacity, demand and flow assessment of ES local climate regulation

Input data/ ES	R5: local climate regulation
Capacity	Map of current landscape structure – reclassification as appropriate for ES provision
	Species composition and structure of forest stands (classification, types of stands, age of stands)
	Climatic data – global solar radiation and avg. temperature of the growing season
	FAPAR (Fraction of Absorbed Photosynthetically Active Radiation – an indicator of photosynthetic activity of vegetation)
	NDVI (normalized difference vegetation index)
Demand	Climatic classification of the territory – areas with the highest temperatures and sunlight, insufficiently provided with moisture
	Classification by population of municipality/region
	Special areas of demand – residential areas, city centres, recreational areas,
Flow	Real effect of vegetation – improvement of local climate parameters (temperatures, radiation, shade, air humidity)
	Number of residents within reach of ES

Both indicators implicitly express the representation of vegetation and photosynthetic activity (NDVI, FAPAR).

The calculated data was reclassified in a similar way as in the case of the other ES into the scale of the landscape's relative capacity to provide ES local climate regulation. The assessment result is shown in Fig. 4.20.

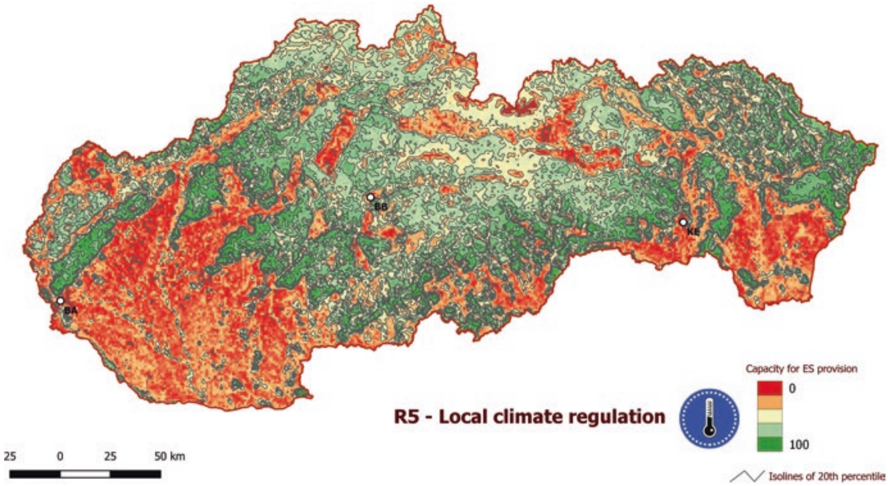


Fig. 4.20 Capacity of the landscape to provide ES local climate regulation

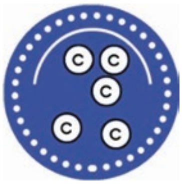
The best habitats in terms of provision of regulation of local climatic conditions are natural forest stands and forests in good condition (species composition, age structure) – however, the quality of such high-quality forests is decreasing in Slovakia, as evidenced by the value of satellite vegetation indices. To a lesser extent, this ES is provided by non-forest ecosystems – a mosaic agricultural landscape with sufficient representation of permanent vegetation, watercourses and areas, grasslands and in some cases orchards. Intensively used agricultural land, especially arable land, is hardly involved in the provision of this ES. In urbanized areas, the role of the settlement vegetation, especially of larger parks, is irreplaceable – at the national level; however, their significance is almost unregistered due to their small size.

Table 4.5 also includes the basic indicators which can be used for future expression of the level of ES demand as well as its real use. As is the case with air quality, the highest demand for this ES is in built-up areas – a suitable indicator comes in the form of the number of inhabitants living in a particular territory. Although city parks, tree alleys or gardens and orchards are involved in the provision of this ES within cities, the demand for this ES largely exceeds its provision. Demand can be expressed also by the need for regulation of microclimate (definition of exposed areas in terms of temperature and solar radiation) or the existence of special types of territories requiring this method of regulation (residential areas, facility areas in cities, etc.).

The ES flow is conditioned by its real use – i.e. the degree of improvement of climate conditions due to ecosystems, the number of inhabitants living in the affected area and so on. Obtaining such data at the national level can be problematic, so proxy indicators can be used – for example population density, the spatial extent of settlement, overall values of solar radiation, extreme summer temperatures and the like.

4.6 Global Climate Regulation/Carbon Sequestration (R6)

4.6.1 Definition and Brief Characteristics of ES



The main role of global climate regulation through ecosystems is to maintain liveable climate and thus maintain a favourable chemical and physical composition of the atmosphere for human beings. Natural forest ecosystems and wetland ecosystems as well as maritime/coastal areas maintain suitable atmospheric conditions for life on Earth and regulate climate at global level (Maes et al. 2015). The biodiversity information system in Europe (BISE 2019) identifies global climate regulation as one of the most important ES on a global and European level, as European inland ecosystems represent a stock of 7–12% of *pure* carbon from anthropogenically produced carbon emissions, according to measurements from 1995.

ES experts and other authors agree in their publications on the basic functions or on the primary indicators which contribute to the production of this ES or support global climate regulation partially. Mooney et al. (2009) state that ES global climate regulation is mainly aimed at the issues of greenhouse gases, so the carbon storage, carbon sequestration and greenhouse gas regulation are the primary indicators of this service. However, secondary indicators play an important role in the global climate regulation, such as above-ground and underground biomass, landcover, carbon deposited in soil, nutrient flow and soil characteristics. Burkhard and Maes (2018) identify the basic and supporting ecosystem functions to maintain the global climate regulation service. Primary functions include *net primary production, carbon storage* and *conservation carbon stock*. Supporting ecosystem functions are defined by the regulation of ecosystem dynamics, ecosystem stabilization processes, ecosystem resilience, the development of complex ecological networks and the development of ecosystem diversity/habitat quality.

Carbon sequestration is a natural process which significantly contributes to climate regulation by capturing and long-term storage of atmospheric CO_2 in the soil (CO_2 being the major greenhouse gas) (Luyssaert et al. 2007). Carbon sequestration involves the transfer of atmospheric CO_2 into long-life *reserves*, i.e. carbon stock and its safe storage, so it does not immediately return to the cycle (Lal 2004). Pure primary production represents the net amount of carbon assimilated by green plants/vegetation (within a given time period).

The total land-related organic carbon reserves (in soil and vegetation) are estimated at 3500 Pg C, and most of it (up to 75%) is stored in the soil. It is almost five times the amount than the amount of carbon in the atmosphere. The carbon deposited in the soil comes mainly from dead organic material. The main factors influencing the state of soil organic carbon reserves are the landcover consisting of inland ecosystems and their habitats, land management and local climatic conditions. Land use change and management practices can lead to carbon flow imbalance (Burkhard and Maes 2017).

Increasing the area of wooded land in the UK has contributed to improving climate regulation through higher carbon sequestration while improving ES associated with timber production. The projected changes in emissions (within the business-as-usual scenario) resulting from land use and forestry changes in the next 10 years will change the net carbon stock to the source of its production. The effects of failure to provide this ES would be particularly pronounced in urban areas and would make the climate stress worse for a large number of people (UK NEA 2011).

In summary, according to MEA (2005) – global climate regulation is the *final ES* which provides climate regulation through biogeochemical and biophysical processes in such a way as to avoid adverse effects on humanity and biodiversity.

4.6.2 Methods Used to Assess and Identify ES

Global climate regulation such as ES is often indicated by carbon sequestration or net primary production, probably as a result of the great attention paid to climate change (Maes et al. 2015). Net primary production is the basis of this ES but also of many other ES and is, therefore, the most frequently mapped indicator (Burkhard and Maes 2017).

Biophysical methods for assessing this ES are based on soil *carbon pools*. This indicator mainly affects the process of sequestration and net primary production as a potential for carbon pool creation (Haberl et al. 2007). In the framework of biophysical methods of ES assessment, the InVEST and ARIES modelling tools need to be highlighted. Both models work in ArcGIS environment and are freely available. The primary input to these models includes the land cover and land use maps, complemented by the socio-economic and ecological parameters (soil carbon pools, average annual precipitation).

A study from Northern Germany (Maes et al. 2018) for the assessment of this ES applied quantitative indicators derived from Corine Land Cover categories such as annual gross primary production, net primary production, soil organic carbon and carbon pool compared to qualitative indicators.

Another way of ES assessment includes the use of the production matrix. For example, according to Burkhard (2014), each ecosystem-provided ES is rated on a scale of 1–5 (low to very high benefit), and ES consumption is rated on a scale from −1 to −5 (low to very high demand). Value 0 is attributed to services and ecosystems which do not produce or consume the ecosystem service. Burkhard's production matrix index values show that wetland habitats and forest habitats have the highest provision index for ES global climate regulation. The demand/consumption index is the largest in cities and densely populated areas.

Cascade model for the assessment of ES global climate regulation was used in the national ES assessment in Finland (Jäpinen and Heliölä 2015). The following indicators were assessed: (1) habitats with carbon pools, forests, wetlands, inland water bodies, farms and urban areas (structure); (2) carbon balance, sequestration rate (function); (3) climate regulation and stabilization (benefit); and (4) avoided costs of negative climatic consequences, actual/used value of stable climatic conditions (value). This ES was similarly assessed in Luxembourg (Kleeschulte and Ruf 2016), where they used the capacity indicator (modelled carbon pools per mapped unit), the ES balance/flow indicator (carbon storage per mapped unit) and the ES benefit indicator – carbon sequestration value in dollars per tonne.

According to Frélichová et al. (2014), the carbon sequestration or carbon pools represent the biophysical method for assessing/valuing global climate regulation. Much more options for the assessment of this ES come from *economic methods*: avoided cost, benefit transfer, contingent valuation, emissions trading scheme, marginal abatement cost, direct market valuation and the social cost of carbon. The average economic value of ES climate regulation for the Czech Republic according to this study was set at EUR 4015.78/ha.

4.6.3 The Main Types of Landscape and Ecosystems Which Provide ES

Based on the above-presented approaches and methods of ES assessment and identification and in accordance with the production matrix by Burkhard (2014), the following can be considered the main types of landscape/ecosystem which provide global climate regulation: forests and other wooded landscape; peat bogs, marshes and other wetlands; meadows and pastures and alpine vegetation, subalpine shrubs, raised bogs and inland surface waters and riparian vegetation.

Forest ecosystems cover a large part of Europe, and their share in global climate regulation is, therefore, most prominent. Trees and other woody vegetation process and store large amounts of carbon through their assimilation organs. Larger reserves of organic carbon are further produced only by peat bogs. Meadows and pastures, alpine vegetation and riparian vegetation contribute to the ES supply at a lower level in terms of area and vegetation but are important in terms of quantity.

In terms of preliminary analyses of the provision of ES, habitats with a large area are more significant in Slovakia, as they provide the ES on a considerable area, as opposed to habitats, which are the most significant in terms of the quality of ES provision, but their area is negligible. In terms of both quality and quantity, the provision of this ES is dominated by forest ecosystems, which also have a high potential, as well as the value of the provision of this ES and, at the same time, high quantity. Peatbogs are included in the category of high quality. In case of arable land ecosystem, when taking into account the area within Slovakia, consumption of this ES is expected to be significantly higher than its production by this ecosystem. The built-up area also does not produce this ES, while ES consumption is obvious and to a high degree.

4.6.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

Ecosystems are highly involved in carbon sequestration and storage, as well as in the production of new biomass as key indicators of global climate regulation. Carbon sequestration by above-ground biomass and its storage in soil reduce the rate of CO_2 increase in the atmosphere, which, along with other greenhouse gases, affects the processes of global warming and climate change on Earth. Based on this, it can be stated that ecosystems, especially ecosystems in a favourable state, mitigate the effects of global warming on biodiversity, such as increasing average annual temperature, shifting of vegetation belts, wind calamities and related calamities caused by bark beetle insects, drying out of aquatic and wetland habitats and decreasing level of groundwater, shorter periods of permanent snow cover in the mountains, spread of invasive and expansive species, etc.

In Slovakia, most importance of the carbon sequestration and net primary production is attributed to forest ecosystems (more than 38% of the SR area). For the practical protection and conservation of forest habitats in Slovakia, several national parks, protected areas, nature reserves and special areas of conservation were declared. Particular attention should be paid to the protection of Natura 2000 areas under which forest habitats of European importance are protected – including, for example, NNR and SAC Svrčinník (Fig. 4.21). In terms of quantity, it is the large-scale protected areas which have the greatest benefit, namely, the most widely represented habitats in them – Ls5.1 beech and fir-beech forests and Lk1 lowland and submontane hay meadows. Despite the relatively common occurrence within Slovakia, the habitats just mentioned playing a key role in maintaining and keeping global climate regulation. The continuous large-scale areas of the Ls5.1 and Lk1 habitats are the most important in terms of the provision of this ES and are mainly located in the national parks of Slovakia.

In case of this ES, it is also necessary to emphasize the value and benefit of primaeval forests and primaeval forest remains, which represent a prime example of the maximum benefit of global climate regulation and are among the best carbon pools of all the ecosystems. The most qualitatively significant carbon pools in the form of deposited organic residues in Slovakia are provided by peatbog habitats, for the protection, of which several small-scale protected areas such as NR Rojkovské rašelinisko peatbog, NNR Rakšianske rašelinisko peatbog (Fig. 4.23) and others have been declared. The positive relationship of this ES and the significance of the territory of Slovakia in terms of nature and landscape protection is also apparent from Fig. 4.22 (Fig. 4.23).

Seeing the protected areas as a basic tool for the protection of biodiversity in Slovakia can be enriched by one of the most significant benefits provided by these areas with the application of the ES concept. Therefore, in economic terms, consumers in protected areas are no longer represented by only the habitats and species but also by people as one of the main consumers. In this case, this is associated with ES essential for survival and key for the adaptation to the current and incoming climate change. Changing the view of the nature and benefits of protected areas is

Fig. 4.21 Primeval forest remains of natural spruces in NNR Svrčinník represent a carbon pool. (Author: J. Černecký)

essential and very important in terms of future scenarios for the development of not only biodiversity but also the survival and quality of life of humans themselves.

4.6.5 ES Assessment for the Territory of Slovakia

The assessment of the ES global climate regulation/carbon sequestration by a market prices method was described by Považan et al. (2014b). They specifically describe two ways of calculating carbon stock in both above- and below-ground biomass and underline the need to develop clearer benchmarks for this indicator for different types of forest ecosystems and recommend taking into account the impact of climate change on carbon storage. The peatbogs are the most important carbon pools, but their massive drainage during the collectivization in Slovakia caused their degradation and vanishing of habitats. Restoring and protecting peatbogs is key to

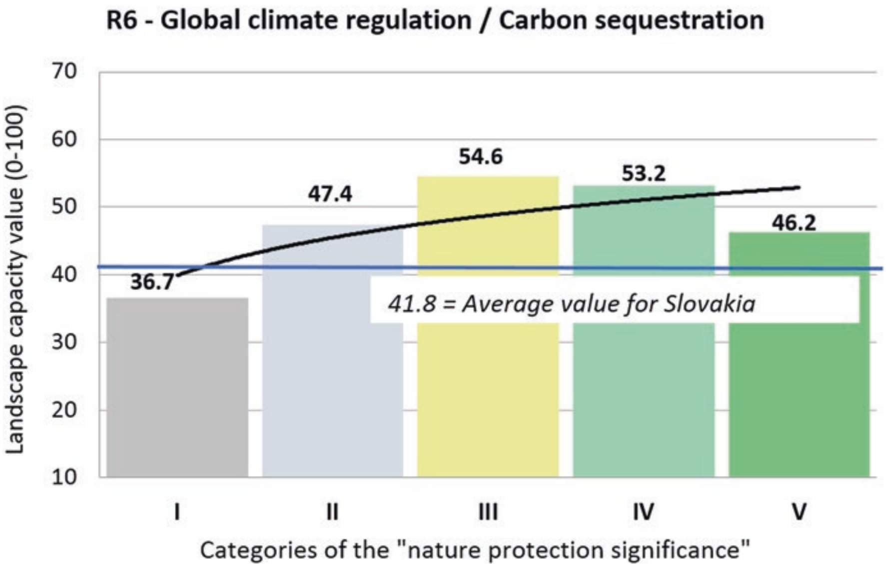


Fig. 4.22 The relationship between ecosystem service R6 and the significance of the territory of Slovakia in terms of nature and landscape protection

mitigating climate change; even though they are considered small-scale habitats, they are important in terms of the quality of provision of this ES at the local level.

ES assessment through biophysical indicator – a measurement of organic carbon in the surface layer of the soil – is investigated in Slovakia by Skalský et al. (2017). Carbon stocks in agricultural soils in Slovakia can be estimated on the basis of NPPC-SSCRI data. In the past, a map of organic matter content in soils of the SR was prepared (Bielek in Granec et al. 1999).

Despite these approaches, the comprehensive assessment of the ES global climate regulation/carbon sequestration in Slovakia is not performed. The assessment should be based on three aspects: capacity, demand and real production/consumption of this service. As mentioned above, *forest and selected non-forest ecosystems are important in terms of ES provisioning capacity*. The *peatbogs* have the highest quality for provision of this ES, but their area is very small to fundamentally affect the overall value at the national level. The need to protect them is that much greater. Therefore, as with most other regulatory services, forest ecosystems must be given the greatest importance.

For the pilot assessment of the Slovak territory's capacity, we also used the data on the regulatory function of vegetation assessed under the R1 regulatory service as the basis for this ES. The coefficient used to refine this value was the FAPAR indicator expressing the rate of photosynthetic activity of vegetation and was obtained from the source RS Copernicus (available online: www.copernicus.eu/en). The second aspect of the provision of this ES (carbon retention rate in soils) was expressed by the capacity of the soil to accumulate carbon, based on the organic matter content

Fig. 4.23 In terms of quality, peatbog retains the most carbon compared to other types of habitats (National Nature Reserve Rakšianske rašelinisko). (Author: J. Černecký)

in the soil subtypes and the depth of the soil cover. The overall capacity of vegetation and soils for carbon capture and storage was then expressed in a relative scale of landscape capacity to provide this ES – the assessment result is shown in Fig. 4.24.

As is the case with the previous ES, the best quality habitats for the provision of this ES are forest areas of good quality (species composition, age structure), but the non-forest ecosystems are also important – already mentioned *wetlands* (with a very low occurrence), production meadows and pastures – significant carbon supply is also saved in the top quality agricultural soils (deep soils with good-quality humus layer and high organic content).

Table 4.6 also shows the basic indicators which can be used for future expression of the level of ES demand as well as its real use. In this case, it is not easy to establish demand indicators – it could even be said that the need for global climate regulation is the same throughout Slovakia. However, if we want to distinguish some areas, then densely built-up areas and places of consumption can be rightly considered to be places of increased demand – i.e. intensively used agricultural areas.

From the point of view of the real production/flow of this ES, it is clear that there are much more ecosystems with only the average value of the provision of global climate regulation than the potential. In order to increase the provision and quality

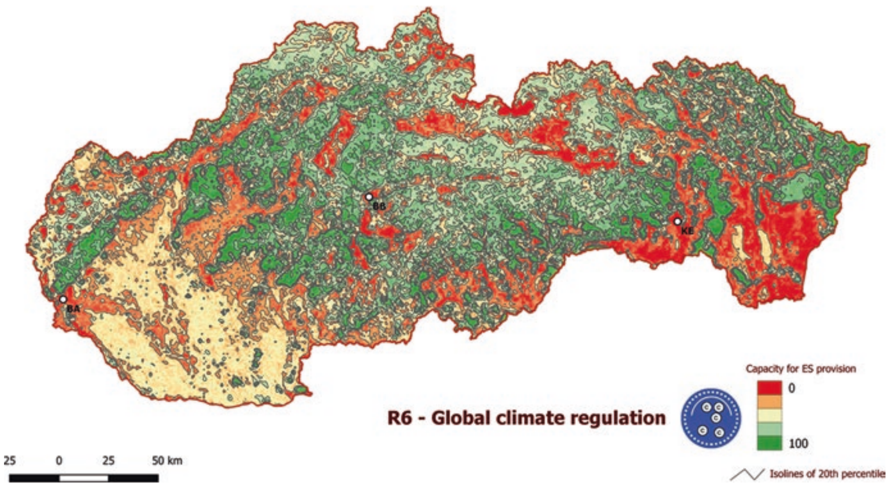


Fig. 4.24 Capacity of the landscape to provide ES global climate regulation

Table 4.6 Input data for capacity, demand and flow assessment of ES global climate regulation/carbon sequestration

Input data/ES	R6: global climate regulation
Capacity	Map of current landscape structure – reclassification as appropriate for ES provision
	Species composition and structure of forest areas (classification, forest types, forest age)
	FAPAR (Fraction of Absorbed Photosynthetically Active Radiation – an indicator of photosynthetic activity of vegetation)
	Soil classification based on organic matter content and soil depth
Demand	Special areas of demand – residential areas, places of carbon consumption (agricultural land)
	Classification by population of municipality/region
Flow	Real ES provision – carbon storage in vegetation and soils
	Number of residents within the real effect of ES

of this ES, it is necessary to improve the status of watercourses, reduce the size and intensity of forest interventions, increase the age of the forests and substantially protect peatbog and wetlands. The last should be done in places where they are already protected and try to revitalize the wetlands in places from which they vanished, as their size in relation to other ecosystems is extremely small. In agricultural areas, it is also appropriate to limit deep ploughing, which contributes to the release of carbon from the soils.

4.7 Biodiversity Promotion (R7)

4.7.1 Definition and Brief Characteristics of ES

Biodiversity expresses the diversity and variability of living organisms and ecosystems. Different organisms, species and communities differ in their properties and functional characteristics, as well as in the share within ecological processes. Species and ecosystem diversity promotion as the ES is seen as a result of complex interactions between biotic and abiotic environmental components, which support species life cycles. Among these are the conservation of habitats and species, the preservation of key habitats for animal husbandry, as well as the conservation of genetic diversity, and the promotion of cultivated and farmed species in nurseries, arboretums, breeding ponds, etc. It is very difficult to accurately describe the importance of all species biodiversity for humans. Approximately 40% of the global economy is estimated to be based on biological products and biological processes. Biodiversity promotion was initially specified in the ES classification as a separate supporting service group (Kumar 2010; MEA 2005); in other classifications, it has already been included in regulatory services (Haines-Young and Potschin 2013).

The main importance of the ES *biodiversity promotion* is to ensure the proper functioning of ecosystems, which also affects the provision of other major services (Becerra-Jurado et al. 2016). Ecosystems themselves contribute to biodiversity promotion by providing living space and refuges to different species of plants and animals; by providing them with food and shelter opportunities, space for plant and animal reproduction, space for migration or spreading within the landscape (seed dispersal by insects, birds and other animals) and biotopes for pollinators; and by participating in the nutrient cycle and the like. In fact, with a few exceptions, we could consider most of the ES to be the benefits gained from maintaining and promoting biodiversity. Maintaining the diversity of nature as a whole – especially the number of plant and animal species, their regional and local populations and genetically modified variants – is one of the basic tasks of not only for nature conservation, science and culture but also for economic activities (Čaboun et al. 2010).

Higher biodiversity increases the potential of terrestrial, freshwater and marine ecosystems to provide different benefits to society, such as soil formation, pollination, erosion and other natural hazards regulation, regulation of air and water quality or provision of materials, as well as space for education, inspiration, or physical use of nature and landscape. Higher biodiversity promotes the functioning of all ecosystems and also contributes to maintaining ecological stability (see Fig. 4.25).

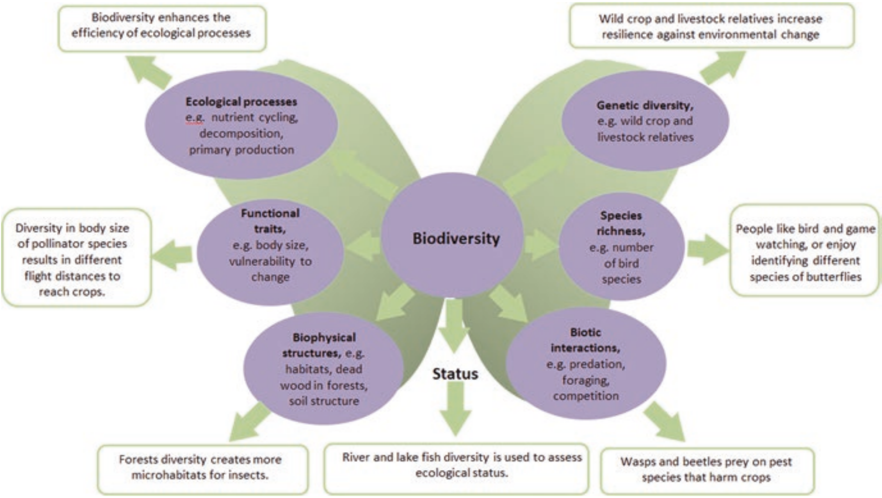


Fig. 4.25 The diverse role of biodiversity in promoting the provision of ecosystem services and assessing the ecosystem status. (Source: Maes et al. 2013)

4.7.2 Methods Used to Assess and Identify ES

In biodiversity promotion, the need to protect and preserve the biodiversity of individual species and habitats is of interest to science research since its inception. The species and ecosystem diversity itself can be expressed using different diversity indices (Jurko 1990; Loh and Harmon 2005; Pielou 1975). The ecological status of the landscape and the importance of the bio-component in the landscape are characterized by, for example, *ecosozological characteristics of the gene pool* (a rarity, endangerment, endemites, protected plants), *degree of ecological stability threats* and so on (Barančok and Barančoková 2015; Halada et al. 2011; Špulerová 2007). The assessment of this ES was preceded by the theory of ecosystem functions, which began to develop more intensively in the second half of the twentieth century. According to Kontriš (1978), the vegetation function is the highest category expressing the aggregate real or potential use of the effects of vegetation, which participates in the creation of ecosystems and the creation of ecological conditions of the environment, aimed at meeting the economic and social needs of society. De Groot (1992) defines ecosystem functions as *the ability of natural processes and components to deliver goods and services which directly or indirectly satisfy people's needs*. Mapping of habitats and their characteristics (such as functional properties, ecosystem structure) is a determining indicator for ES assessment (Lavorel et al. 2011).

The capacity of current ecosystems to support species and ecosystem diversity has been assessed using a variety of methods, most commonly biophysical assessment, participatory methods and economic expression of ecosystem value.

Biophysical assessment was mostly based on habitat mapping, the determination of ecosystem basic state and proper indicator selection. Such an assessment has been used in several national ES assessments:

- In Flanders, on the basis of selected criteria (a rarity, biological quality, vulnerability and ecosystem resilience), five classes of ecosystem assessments were distinguished, from the built-up area (no value) to very valuable areas (Stevens et al. 2015).
- Biodiversity indicators were assessed relatively in detail on a five-degree scale as part of the national assessment in Bulgaria at different levels: for plant biodiversity (cover and type of vegetation layer – using aerial and satellite images, habitat type, number of protected species), animal diversity (number of protected species), habitat diversity (share of natural habitats, fragmentation of green infrastructure) and spread of invasive species (Vranic et al. 2016).
- For the ES national assessment in Ireland, the design of indicators was based on the international CICES classification and on the European ES assessment methodology (European Commission 2014b). The following indicators have been proposed as indicators for this ES: High Nature Value (HNV) areas and ecological status of aquatic ecosystems (Parker et al. 2016).
- A similar approach has been selected for the national ES assessment in Luxembourg, where capacity indicators have been proposed for this ES (capacity indicator – habitat quality, area for biodiversity support (European areas with HNV) – and balance indicators flow indicator – number of species, biodiversity indicators, weighted index of the Birds Directive per unit area) (Becerra-Jurado et al. 2016). A map of ecosystems with habitat values has been included in the assessment because the authors assume that only healthy ecosystems are capable of sustainably providing this type of service.
- The MAES methodology was also applied to the national ES assessment in Italy – the following were proposed as indicators for the assessment: ecosystem status, degree of naturalness/hemerobia, nature conservation status, difference between real and potential vegetation, fragmentation of ecosystems and limiting indicators for achieving favourable habitat status (Capotorti et al. 2015).
- Indicator design in Finland was based on a cascade model, and important ES were assessed from four different aspects: structural (habitat area and status), functional (shelter and food possibilities, measured by reproduction success), utility (population vitality) and value (cost savings for revitalization and other management measures) (Jäppinen and Heliölä 2015).
- Practical assessment of forest quality at the landscape level is investigated by authors Dudley et al. (2012), who proposed the presence of rare and endangered species as the indicator for the *biodiversity and genetic resource protection* service.

Participative methods for ES biodiversity promotion were used by several authors. Burkhard et al. (2012, 2014) developed a matrix for the Corine Land Cover (CLC) categories and 29 ES grouped into four basic categories, based on MEA (2005). Based on expert estimates, they set the capacity to provide the ES on a five-degree scale (from no relevant capacity to very high relevant capacity). A similar assessment tool has been applied in several case studies based on expert estimation and public participation (Bezák and Bezáková 2014; Vihervaara et al. 2010). Expert assessment, combined with various spatial data (analytical maps) grouped into themes (instead of exclusively using landscape structure data), was used in the *GreenFrame* method developed in Finland to determine the ES capacity, especially for green infrastructure (Kopperoinen et al. 2014).

Another option for ES assessment is the visual modelling of scenarios, based on predicting the landscape's development in case of certain pressures affecting the landscape. As part of the behavioural research, these scenarios can be subsequently assessed and commented on by local stakeholders in order to select an optimal model of development of the assessed territory. This approach was applied to the national ES assessment in Denmark, using the following indicators of biodiversity change for seven assessed scenarios: coverage of landscapes important for the protection of rare species, habitat continuity and their structure. Three scenarios were aimed at promoting species and ecosystem diversity (Termansen et al. 2017).

Economic approaches present another option for assessing this ES. The ES monetary value based on their ecological value has been investigated in the Czech Republic (Seják et al. 2010). The ecological value of natural and semi-natural habitats mapped within the NATURA2000 system was calculated on the basis of expert scoring according to eight defined criteria (Seják and Dejmal 2003). Subsequently, the authors derived the initial monetary value by analysing the effectiveness of actual revitalization measures. In Finland, researchers also tried to express the annual value of forest ecosystems based on the assessment of the loss of biodiversity, expressed by the need to create habitats for 650 endangered species (Matero and Saastamoinen 2007).

4.7.3 The Main Types of Landscape and Ecosystems Which Provide ES

Ecosystems providing ES biodiversity promotion in Slovakia can be assessed from two points of view. From the point of view of quantity, the most common are forest habitats which cover about 40% of the country's territory – but they are altered to varying degrees by humans, which negatively affects the capacity to provide ES R7. The best-preserved good-quality habitats provide this ES in full, but their area is often negligible from a national perspective.

In terms of conservation of species and ecosystem diversity, the most endangered and rare habitats deserve the greatest attention, including calcareous marshes with great fen-sedge and *Caricion davallianae* species, oligotrophic to mesotrophic waters with benthic vegetation of *Charophyta*, active and degraded raised bogs with natural regeneration (Fig. 4.26) and, in general, biotopes associated with sands, peatbogs, alpine environment and xerothermic habitats. In addition, attention should

Fig. 4.26 Active raised bogs are very rare in Slovakia, they are a habitat of many rare and endangered species – Orava region, Rudné – Suchá Hora. (Author: J. Špulerová)

be paid to other European and national habitats which can contribute to biodiversity conservation (Černecký et al. 2020).

In terms of the assessment of this ES, it is important to distinguish habitats and the degree of their naturalness (natural, semi-natural and anthropogenic) as well as taking into account the status of habitats and species of European importance based on the EU Habitats Directive (Article 17) and the Birds Directive (Article 12). The assessment results are available online at www.biomonitoring.sk. The distinction and detailed description of plant species typical for individual habitat categories are contained in the Catalogue of Habitats of Slovakia (Stanová and Valachovič 2002). Other publications describing and assessing the status of habitats and species include, for example, Monitoring of Plants and Habitats of European Importance in the Slovak Republic (Šefferová Stanová and Galvánková 2015) and Monitoring of Animals of European Importance in the SR (Janák et al. 2015).

Other anthropogenic ecosystems which create elements of green infrastructure and create habitats for many animal species, thus contributing to biodiversity promotion, are important mainly in urbanized or intensively used agricultural landscape.

4.7.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

The main benefit of this ES is the improvement of the conditions for maintaining the gene pool of plants and animals, creating suitable habitats, proper food and shelter opportunities for species migration, which is in line with the interests of nature and landscape protection in Slovakia. This ES, therefore, promotes the protection of nature and landscape the most prominent as it is directly aimed at promoting species and ecosystem diversity. This fact is clearly evident from Fig. 4.27, which shows the relationship between the landscape's capacity for provision of this ES and the significance of the territory in terms of nature and landscape protection.

From the viewpoint of ecosystem and species diversity protection as well as ecological stability and variability of the whole landscape of Slovakia, the most important tool is the existing network of protected areas (national network of protected areas, areas belonging to the European system of protected areas NATURA 2000 and internationally important areas identified under various international conventions) as well as biocentres and biocorridors of ecological networks from local to national level. The subject of protection of protected areas is precisely to enable/maintain the natural development of ecosystems as such; with respecting the values created by traditional forms of farming, the result of which comes in the form of rare communities of established non-forest habitats contributing to increased biodiversity. The established system of protected areas provides a precondition for promoting ecosystem stability at the national level. However, the mere fact that a

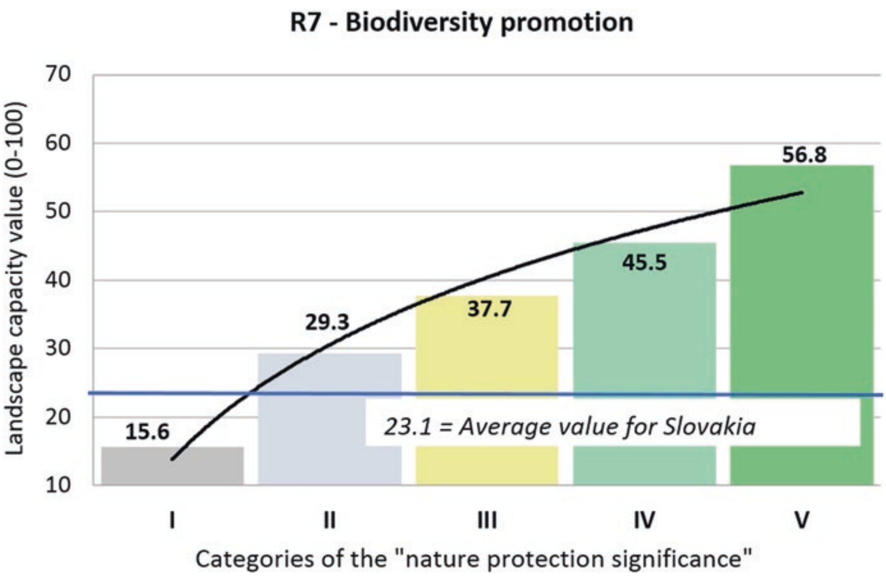


Fig. 4.27 The relationship between ecosystem service R7 and the significance of the territory of Slovakia in terms of nature and landscape protection

territory is declared protected will not prevent the continuing trend of biodiversity loss (Schröter et al. 2019). Therefore, it is important that individual protected areas have prepared and approved management programs and that individual measures to revitalize and maintain a favourable habitat and species status are implemented in practice.

Elements of the territorial system of ecological stability (ecological networks) are not covered by a special level of protection unless they are part of protected areas, but their creation and maintenance are of public interest. Act no. 543/2002 on Nature and Landscape Protection (National Council of the Slovak Republic 2002) in its Article 3 par. 3 states that, where entrepreneurs and legal persons intend to carry out activities in the landscape which may threaten or undermine the territorial system of ecological stability, they are also obliged to propose measures which contribute to its creation and maintenance. Priority for habitat care should be focused on habitats in protected areas, but in order to maintain the stability and balanced provision of the ES, which will help the landscape's adaptive capacity, attention should also be paid to habitats and ecosystems outside protected areas, with some regulation of their use. In order to promote and preserve biodiversity, it is important to apply the principles of sustainable agriculture and forestry practices in real life, which would also increase the benefits of ecosystems for people in the regions.

Biodiversity is threatened by changes in land use, which poses a significant risk to human society's well-being. The main trend is the increasing intensity of conventional agriculture and forestry, leading to a decline in biodiversity. The decline in traditional farming has resulted in the abandonment and reduction of semi-natural high natural value habitats (Keenleyside and Tucker 2010; Lieskovský et al. 2015). Biodiversity is also threatened by the exploitation and harvesting of natural resources, pollution of the environment and its components, as well as the spread of invasive species.

4.7.5 ES Assessment for the Territory of Slovakia

Research focusing on the assessment of the promotion of species and ecosystem diversity directly as an ecosystem service is quite rare in Slovakia. The current work rather presents the option for assessment of selected ES in case study areas. For territories with the traditional agricultural landscape, the following indicators were used (Špulerová et al. 2014): the importance of habitats (habitat of national or European importance), favourable habitat status and presence of protected and endangered species. The case study of the Trnava functional city area for the assessment of the joint ES biodiversity promotion, life cycle and pest control support used the GreenFrame method, based on expert assessment and synthesis of thematic layers (Mederly et al. 2017).

The proper understanding of this ES was preceded by an assessment of vegetation functions (forest function, non-forest woody or urban vegetation function), while diversity promotion was ranked among natural biotic functions (Brodová 2008; Kontriš 1978; Papánek 1978; Sláviková 1987). Ecological functions of the forest have been investigated in the most detailed way. The key criterion of the basic decision-making system for the assessment of the functional efficiency of forest ecosystems (in the landscape in various ecological-functional and socio-economic conditions) comes in the form of forest structure (nature-based/slightly altered/greatly altered species, age and space creating optimal trophic conditions for plants). The presence of protected areas, occurrence of rare and endangered species, occurrence of endemic species, seasonal species concentration, degree of environmental degradation and land use were other criteria used (Čaboun et al. 2010).

The capacity of current ecosystems for biodiversity promotion as well as the occurrence of genetically important species can be expressed, in particular, through the following indicators: the presence of significant and rare species (Fig. 4.28), or habitats. The need to preserve the diversity of species and ecosystems is evident

Fig. 4.28 Ecosystems provide space for rare species and their preservation – mountain Apollo (Parnassius apollo). (Author: J. Černecký)

Table 4.7 Input data for capacity, demand and flow assessment of ES biodiversity promotion

Input data/ ES	R7: biodiversity promotion
Capacity	The occurrence of priority and important habitats – map of ecosystems of Slovakia
	Naturalness of habitats (comparison of real forest and non-forest vegetation with potential natural vegetation)
	Significance of the territory in terms of nature and landscape protection – synthesis of territorial nature protection of SR
	Spatial structure of the territory – diversity of the landscape (number of ecosystem types per 1 km^2)
	Habitat status – according to SNC SR data
	Current landscape structure – additional data for territory classification
Demand	Current landscape structure – categorization by demand for this ES (mainly intensively used agricultural areas, forest monocultures)
	State of ecosystems – ecosystems disturbed or in a bad state
	Spatial projection of ecological network – territories with a deficit of significant elements and disturbed ecological stability
Flow	European and nationally significant habitats in a good state – real occurrence
	Locations of occurrence of protected and endangered species, indication species and the like – verified and real occurrence
	Small-scale structures of the agricultural landscape (mosaics) or other important CLS categories
	Ecological network and green infrastructure functional elements

particularly among the experts, who have a greater need to preserve biodiversity for future generations as they are more thoroughly aware of rare and endangered species, as well as their specific requirements and threat factors. Thus, demand can be spatially differentiated, by the real provision of the ES on the basis of ecosystem status, by environmental quality, by the representation of rare and nature-based habitats and so on.

Although it is not realistic to incorporate all the necessary data for the pilot assessment of Slovakia in terms of this ES, the input data are sufficiently representative (Table 4.7). The assessment was based on the *map of ecosystems of Slovakia* (Černecký et al. 2020), created from several available environmental data (especially SNC SR data on habitats and their status, occurrence of protected and endangered species, other data from biotic monitoring, data on forest structure and age, agricultural land use, basic topographic layers). Another input came from the naturalness of vegetation indices, assessed on the basis of comparison of real vegetation and potential natural vegetation. The significance of the territory in terms of nature and landscape protection formed another input – it was expressed on the basis of a combination of different types of protected areas in Slovakia. The biodiversity of the area was assessed as an indicator of the occurrence of the number of different types of ecosystems within a spatial unit of 1 km^2.

The total capacity of the area in terms of promoting species and ecosystem diversity was expressed as a combination of the above-mentioned layers in the relative scale of the landscape's capacity to provide this ES – the assessment result is shown in Fig. 4.29.

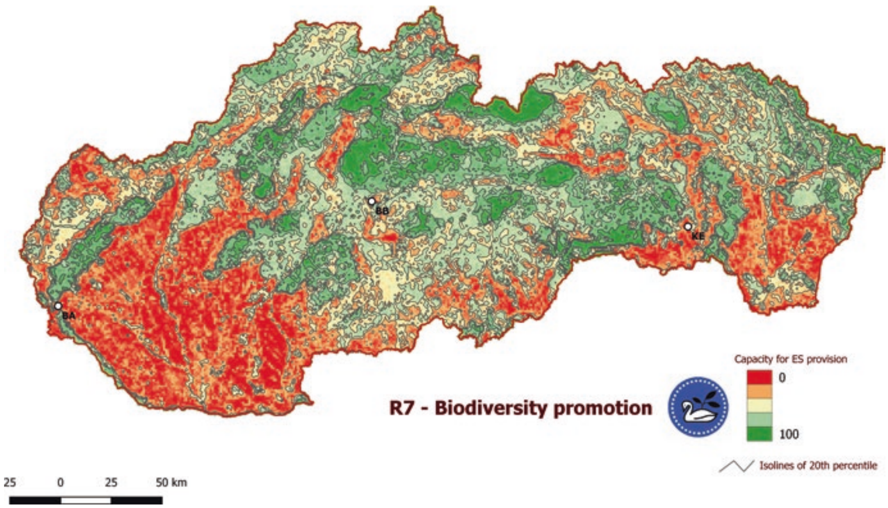


Fig. 4.29 Capacity of the landscape to provide ES biodiversity promotion

The spatial projection of the significance of the territory of Slovakia in terms of biodiversity promotion is logical and obvious – the highest level is typical for part of the mountain and sub-mountain areas, which are mostly forested and belong to the system of protected areas. On the contrary, the lowest level of significance is typical for large agricultural and urbanized areas in the lowlands, partly in the intra-mountain basins of Slovakia. It is these territories which include significant *islands* of biodiversity, which should form the basis for possible further measures to revitalize the landscape.

Table 4.7 also shows the basic indicators which can be used for future expression of the level of ES demand as well as its real use. In this case, the fundamental question is whether biodiversity support is primarily a priority in protected areas or it applies in the entire agricultural and forestry landscape or even in urbanized areas.

From the real production/flow of this ES point of view, it is necessary to focus on the real and verified occurrence and status of important habitats and gene pool sites, on the effect of management and renaturation measures in the landscape or on the functionality of ecological networks in agricultural and urbanized landscapes.

4.8 Life Cycle Maintenance/Pollination (R8)

4.8.1 Definition and Brief Characteristics of ES

The promotion of life cycles and processes includes the promotion of pollen distribution (pollination) as well as the promotion of plant reproduction conditions (seed dispersal), which may include bees, birds, bats, butterflies, flies, flightless animals or wind (Burkhard et al. 2014). Plant pollination is an inevitable and economically important ES which impacts the preservation and promotion of the biodiversity of most wild plants and the fertility, quality and stability of crop production (Kizeková et al. 2016). Based on the Global Pollination Assessment prepared by experts from the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), it is estimated that more than a third of plant production depends on pollinators and approximately 75% of all crops benefit to various extent from pollination by animals, including most vegetables, fruits or spices (Potts et al. 2016). In addition to the effects of pollination on crop production, feed crops for animals or the products of natural ecosystems (e.g. forest fruits), ornamental plant species (e.g. orchids), also benefit or depend on this ES (Schröter et al. 2019).

The abundance and diversity of pollinators in many ecosystems around the world is declining mainly due to the widespread intensification of agriculture, which is mainly linked to excessive use of chemicals, pesticides and monoculture cultivation and the effects of climate change (Benelli et al. 2017). Many studies have shown that the abundance and species diversity of pollinators, as well as pollination intensity, decreases with distance from natural or nature-based habitats (Garibaldi et al. 2011; Ricketts et al. 2008) as they are extensively dependent on habitat options for nesting and flower sources that cannot be found within arable land (Fig. 4.30). The disruption and fragmentation of many natural habitats results mainly from urbanization and increasing intensification of agriculture (Vanbergen et al. 2013).

In response to these negative pressures, various tools and possible approaches are being developed to reverse this state. A diverse array of original pollinators can

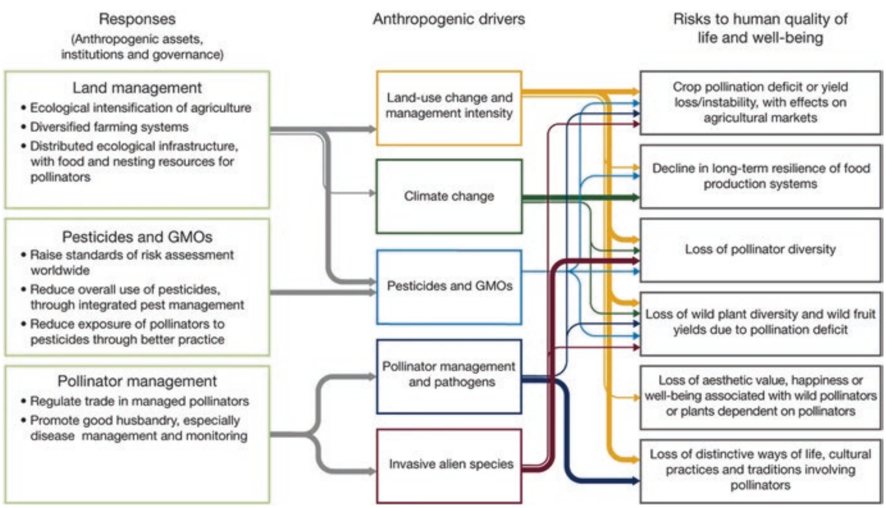


Fig. 4.30 Driving forces, risks and consequences associated with pollinator decline. (Source: Potts et al. 2016)

stabilize population variability between individual years and mitigate the decline in biodiversity of specific pollinator species (Ricketts et al. 2008; Tscharntke et al. 2005). In changing environmental conditions, these species can play an important role in maintaining the ecosystem's resilience (Schröter et al. 2019). Since pollination is representing an ES on which people are dependent through a link to food production, it has often been cited as an example of the economic value of ES (Hanley et al. 2015).

Crop pollination is largely dependent on beekeeping, but bees are often threatened by the combined effect of parasites, diseases and pesticides (Vanbergen et al. 2013). People are sometimes not even very aware of the pollination activity of bees until they see the consequences or evidence directly. People take it rather for granted, and it only becomes apparent when there is a catastrophe associated with the death of bees.

4.8.2 Methods Used to Assess and Identify ES

The first pollination valuations were published already in the 1940s. These assessments preceded the ES concept by nearly 40 years. The publications were not motivated by the protection of pollinators but by the interest in maximizing crop yields. In addition, these valuations focused mainly on honey bees in Europe and North America. Initially, the value was calculated as the total economic value of all crops, the yields of which, albeit minimal, were increased by insect pollinators. This value was the basis for all national assessments up to 1987 and the global assessments up to 2009. In 1987, O'Grady proposed a methodology for the *economic value of insect pollination* to overcome the problems associated with assessment methodology. This methodology includes a crop-specific pollination coefficient, usually based on the crop's biological properties and field research. According to this coefficient, the loss of economic benefits can be calculated if all bees suddenly disappear (Melathopoulos et al. 2015).

Other methods for pollinators assessment include (1) *replacement value* method, where the pollination costs are exchanged for human labour (Muth and Thurman 19951995); (2) *conditional valuation* method based on willingness to pay for the protection of wild pollinators (Mwebaze et al. 2010); or (3) *field services processes* method, which applies to parts of the landscape, its diversity, abundance and yields (Olschewski et al. 2006; Ricketts et al. 2004). All these methods have their limits and limitations, especially in view of the specificities of the territory under investigation and data availability. The environmental component of *pollination* service is represented by the abundance and diversity of pollinators, with the status indicator represented by the number and effectiveness of pollinating species, and the crop dependence on natural pollinators determines the efficiency (UNEP WCMC 2011).

An overview of the research and methods of ES valuation was prepared by Frélichová et al. (2014); economic methods of assessment were mainly used for pollination: benefit transfer and the insect pollination economic value.

Biophysical methods based on mapping or modelling of landscape structure, biodiversity and other natural indicators are also used to assess this ES. The modern modelling tools for ES assessment today include one of the InVEST models focused on the pollinator abundance and crop pollination (Tallis et al. 2011). The primary function of the model is to identify the nesting of wild bees and bumblebees in the landscape based on an embedded raster layer with landscape features and its properties which affect the behaviour of wild bees and bumblebees, supplemented by the list of pollinator species in the landscape and their characteristics, such as the nesting index in the cavities or in the ground, its rate of activity and the range of species to floral resources. The result of the modelling forms a map of the probable occurrence of wild bees with regard to the availability of nesting and flower sources from the surrounding area, which may be helpful, for example, in optimizing agriculture, and can be taken into account in the overall landscape management.

Various indicators are often used to assess this ES:

- In Germany, the proposed ES indicators were divided by supply (share of natural and semi-natural habitats in agricultural land) and demand (representation of pollination-dependant crops) (Albert et al. 2016). In another study, indicators such as the average yield of fruit trees, the density of bees, the proportion of extensively used habitats suitable for pollinator pasture, the distance between crops and pollinators and the area of agricultural crops dependant on pollination were monitored (Rabe et al. 2016).
- The pollination value in Finland was expressed by four indicators: (1) the economic value of pollination based on farmers' incomes for the most economically important crops, such as rapeseed, tomatoes, fruit and berries, as well as wild species; (2) health values by nutrients needed, for example vitamins or phytosterol, which reduces blood cholesterol concentration; (3) the value of the species themselves, which are dependent on the ecological function of pollination; and (4) the social value which affects some popular recreational activities, such as forest fruit harvesting and gardening (Jäppinen and Heliölä 2015).
- Ecosystem potential for ES pollination has been identified in Israel by assessment of two indicators: (1) food resources based on habitat assessment and monitoring (relative abundance of nectar-producing flowers and their flowering period) and (2) nesting possibilities for wild bees based on expert ecosystem assessment (Lotan et al. 2018).
- The national ES assessment in Luxembourg was based on the CICES international classification and the European ES assessment methodology (European Commission 2014a), where capacity indicators (pollination probability expressed by pollinator density) and balance indicators (percentage of pollinated crops expressed as % of area unit) were proposed for this ES (Becerra-Jurado et al. 2016).
- Five key indicators have been proposed for the spatial model to assess ES pollination in Europe (Zulian et al. 2013): (1) suitable nesting sites, (2) availability map of floral resources, (3) spatial range of pollinators, (4) species-specific

parameters in relation to temperature and solar radiation and (5) environmental factors limiting the nesting of pollinators.
- For the ES assessment in Romania, the following indicators were proposed for pollination: (1) structural, area of cultivated rapeseed and productive fruit orchards; (2) functional, abundance of pollinators; (3) evaluating, assessment of pollination deficit expressed by area of crops dependent on pollination; (4) utilitarian, number of beekeepers; and (5) value setting, value of honey produced (NEPA 2017).

4.8.3 The Main Types of Landscape and Ecosystems Which Provide ES

The distribution of the benefits of pollination around the world is very uneven and different in various types of ecosystems, sometimes even within agricultural regions of the same country.

The landscape of Slovakia provides suitable conditions for pollinators and beekeeping. There are widespread forests, which are the original home of bees and form a good-quality bee fodder. In particular, a less influenced landscape with more natural habitats, with the presence of species with a good supply of pollen and nectar, provides suitable conditions for pollinator populations. In particular, forest and scrub habitats are important in terms of pollination quality, as well as orchards. In terms of quantity, these habitats are important: beech and fir-beech forests, lime-oak forests and oak – hornbeam forests. Of the large non-forest areas, these include lowland and submontane hay meadows; other ecosystems of flowering meadows are also important (Fig. 4.31).

Species with a very good supply of pollen and nectar include woody plants such as black locust (*Robinia pseudoacacia*), willows (*Salix purpurea, S. fragilis, S. caprea*), cherries (*Cerasus vulgaris*) even nectarous shrubs like red raspberry (*Rubus idaeus*), currant (*Ribes* sp.), blackthorn (*Prunus spinosa*) and common hazel (*Corylus avellana*). In PG, the following are involved in the high honey-bearing potential: Dutch clover (*Trifolium repens, T. pratense, T. montanum, Medicago lupulina*), dandelion (*Taraxacum officinale*), meadow geranium (*Geranium pratense*), creeping thistle (*Cirsium arvense, C. oleraceum*), common heather (*Calluna vulgaris*), eyebright (*Euphrasia rostkoviana*) and oregano (*Origanum vulgare*). In the case of riparian habitats, these are mainly the stands of white butterbur (*Petasites albus, P. hybridus*), in succession or ruderal communities, for example rosebay willowherb (*Chamerion angustifolium*), honey clover (*Melilotus alba, M. officinalis*) and others.

Fig. 4.31 Species-rich Molinia meadows with flowering Siberian iris (*Iris sibirica*) offer suitable habitats for pollinators. (Author: J. Černecký)

4.8.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

Pollination of plants by pollinators contributes to the preservation and promotion of the biodiversity of most wild plants and to the overall functioning of ecosystems (Boyd and Banzhaf 2007; Fisher et al. 2009), as the pollinators are significant for more than 80% of wild plants in temperate climate (Potts et al. 2016). Pollinators find more suitable habitats in the semi-natural habitats, which are part of protected areas with a higher degree of protection against the use and application of chemicals and the like. In keeping the rules which apply to the landscape according to its degree of protection (National Council of the Slovak Republic 2002), nature protection contributes to creating more appropriate conditions for pollinators and preserving the biodiversity of the landscape.

Slovakia is a country with a strong agricultural tradition, while the production of pollinated crops is important for local and regional agriculture. In Slovakia, protection of pollinators is a common agenda of both the Ministry of Environment and Agriculture, who jointly adopt the measures to protect the pollinators. Slovakia is a member of an informal pollination coalition initiated by the Netherlands in December 2016 during the 13th Convention on Biological Diversity in Mexico (MoE SR 2017). The aim of the initiative is to jointly implement national strategies to include new approaches, such as green belts to improve the natural habitat of pollinators; innovations and practices which include promoting bee-friendly farming practices; as well as new partnerships to protect all important pollinators, by supporting diversified farming systems and through the protection, management and

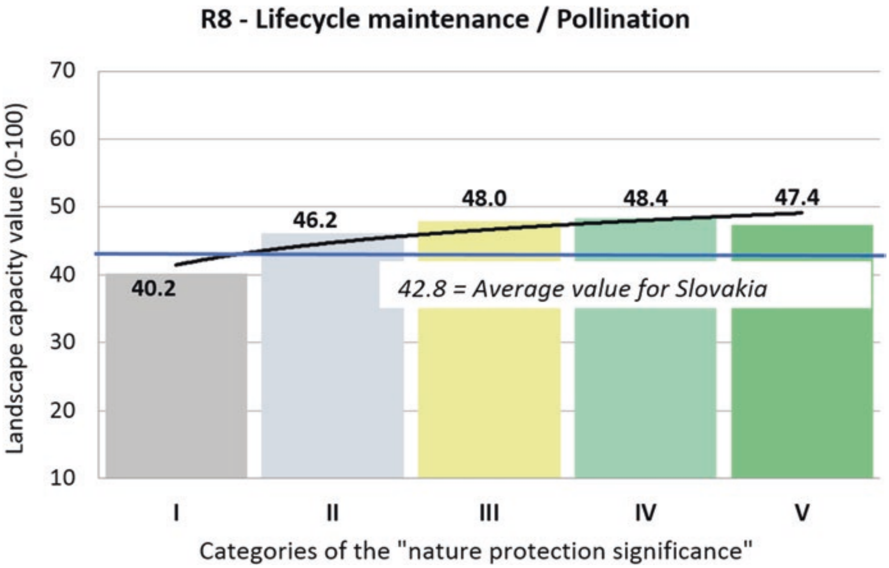


Fig. 4.32 The relationship between ecosystem service R8 and the significance of the territory of Slovakia in terms of nature and landscape protection

restoration of natural habitats in order to increase their extent and connectivity for pollinators.

Specific decisions on how to best ensure ES pollination depend on local circumstances and conditions. In countries where intensive agriculture dominates, measures such as methods of organic agriculture and planting of tree alleys providing floral resources have the largest impact (Schröter et al. 2019).

The fact that the agricultural landscape has its importance in terms of support for pollination can be documented by the *slightly positive* relationship between the significance of the territory in terms of nature and landscape protection and the capacity of Slovakia's landscape to provide this ES (Fig. 4.32). This relationship can be interpreted that there is no clear difference between individual categories of significance of territory in terms of nature and landscape protection – unlike the case of most other supporting and regulatory services, landscape pollination capacity is fairly evenly distributed among all categories.

4.8.5 ES Assessment for the Territory of Slovakia

In Slovakia, the landscape's capacity to provide ES pollination was assessed only in selected model areas using participative methods based on expert estimates for the provisioning capacity of this ES (Bezák and Bezáková 2014; Špulerová et al. 2018). To express plant nectar and pollen reserves within different plant communities,

Fig. 4.33 Gladiolus imbricatus is an attractive wildflower for various types of pollinators. (Author: J. Černecký)

Jurko (1990) suggested calculating the nectar potential, which expresses the percentage of species with pollen and nectar reserves within the overall species composition. The proportion of nectar-producing plants (Fig. 4.33) and nectar reserves within each community is merely an indicative figure, as actual reserves are conditioned by the spatial and physiognomic structure of the plant species and their coverage throughout the community and also by the vegetation phase over a period of time.

The distinction between capacity (supply), demand and the real status of providing pollination is very complex. Potential habitats for pollinators, as well as the abundance and number of pollinator species, can be used to determine the landscape's capacity for pollination support. This can be expressed using a qualitative scale or biophysical units/indicators, such as nesting possibilities density, potential abundance of pollinators and number of bee colonies.

In terms of landscape research and the benefits provided by pollinators for the society, it is also important to examine the environmental factors which affect their

Table 4.8 Input data for capacity, demand and flow assessment of ES life cycle maintenance/pollination

Input data/ ES	R8: ES life cycle maintenance/pollination
Capacity	Current landscape structure – favourability of CLS categories for pollinators (reclassification)
	Naturalness of habitats (comparison of real forest and non-forest vegetation with natural potential vegetation) – occurrence of important habitats
	Spatial structure of the territory – diversity of the landscape (number of ecosystem types per 1 km^2) – expressing conditions for the occurrence of pollinators
	Other suitable indicators:
	Data on the use of agricultural land – crops, agricultural land management
	Degree of nature protection, management of protected areas, habitat status
Demand	Current landscape structure – categorization by demand for this ES (especially intensively used agricultural areas and territories with lack of potential and real ES provision)
	Areas of cultivation of special crops and cultures with the need for pollination
	Areas with a deficit of ecologically important elements and disturbed ecological stability – the need to support natural elements
Flow	Small-scale structures of the agricultural landscape (mosaics) or other important categories of agricultural use in terms of honey-bearing potential – real occurrence
	Semi-natural and diverse forest ecosystems, special forest honey-bearing plants – real occurrence
	Occurrence and classification of stress factors – pollution and environmental threat, socio-economic activities – limiting factor of providing this ES

distribution, health and final production. For the pilot assessment of the capacity of the territory of Slovakia, we used the available data, which are sufficiently representative for this ES (Table 4.8). The basic layer was *a map of the current land use* with several categories of agricultural land and forests, which was subsequently reclassified in terms of suitability for pollinators. The assessment was mainly based on the *map of ecosystems of Slovakia* (Černecký et al. 2020), created from several available environmental data (especially SNC SR data on habitats and their status, occurrence of protected and endangered species, other data from biotic monitoring, data on forest structure and age, agricultural land use, basic topographic layers). Another input came from the *naturalness of vegetation*, assessed on the basis of comparison of real vegetation and natural potential vegetation. Spatial structure of the territory in terms of ES promotion was assessed similarly to that of the ES biodiversity promotion with the indicator *biodiversity of the area* based on the occurrence of the number of different types of ecosystems within a spatial unit of 1 km^2.

The overall capacity of the area in terms of supporting life cycles and processes and pollination was expressed as a combination of the above-mentioned layers in a relative scale of the landscape's capacity to provide this ES – the result of the assessment is shown in Fig. 4.34. Unlike most other regulatory and supporting services, the spatial interpretation of individual landscape capacity categories in this ES is not so obvious. Although the highest values are achieved in larger forest and mountain

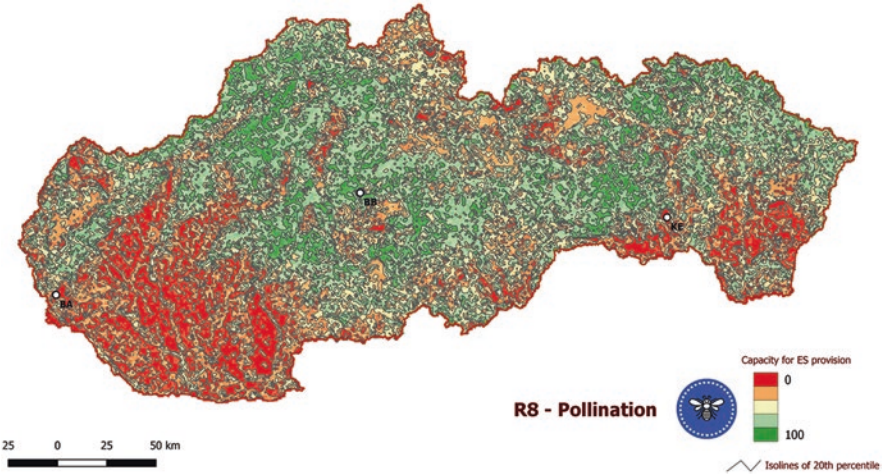


Fig. 4.34 Capacity of the landscape to provide ES life cycle maintenance/Pollination

complexes, the overall picture is like a mosaic, and perhaps with the exception of the larger areas of the southern Slovak lowlands, all categories of landscape capacities are evenly balanced. This shows the importance of the agricultural land for provisioning of this ES.

Demand for pollination can be expressed by the necessary amount of pollinators and pollinated area (achieving the *desired* value, taking into account the area, population and ecosystem status). Demand for pollination services is the result of farmers' decisions to grow crops that are dependent on pollination (Lautenbach et al. 2011), or the amount and spatial distribution of crops, garden and wild plants requiring pollination (Burkhard et al. 2014).

In terms of comparison of demand and real provision of this ES, it is necessary to say that the greatest demand is typical for lowland areas with dominant agricultural production, with many crops being dependant on pollination. The most favourable situation in terms of demand and production is mainly in Northern and Central Slovakia with a high proportion of forest and permanent grassland habitats, where the production of this ES is clearly exceeded by demand. In particular, agricultural and forest habitats are among the most important consumers of this ES, and therefore the agricultural sector is largely dependent on it. This is particularly evident in the region of Western Slovakia, with the demand being higher than the production of this ES from a national perspective. This deficit is mainly offset by beekeepers with their colonies. In regions where demand exceeds the production of this ES, there also exists a need to increase the presence of semi-natural ecosystems which provide suitable habitats for pollinators and also there is a need for creation of the suitable conditions to support beekeepers and eliminate factors that cause mortality or decrease of numbers of beehives.

4.9 Pest and Disease Control (R9)

4.9.1 Definition and Brief Characteristics of ES

Pest and disease control expresses the *ability of ecosystems to regulate pests and diseases through genetic variations of plants and animals*, thereby contributing to improving the ability of ecosystem resistance and mitigating the risk of spreading of diseases/pests and invasive/non-native species (Burkhard et al. 2014). The structure of the landscape influences local diversity and ecosystem processes, including mutual interactions of species and habitats, characterized by the different dynamics of these communities. The species can be associated with certain communities but can also move between different communities, both natural and anthropogenic (Tscharntke et al. 2005).

While the plant biodiversity is involved through energy and nutrient flows in regulatory functions of natural ecosystems, this form of control is gradually disappearing from the landscape as a result of agricultural intensification associated with environmental pollution, biodiversity loss, synantropization, habitat degradation and the creation of artificial ecosystems that are unstable and requiring constant human intervention and cause increased economic burden (Rusch et al. 2016). In addition to the intensification of agriculture, the prevalence and spread of diseases and pests is also influenced by human population growth, accidental introduction of pests and pathogens, land management and the impact of farming on wildlife. Intensively used agroecosystems are deprived of the natural regulatory capacity to support their own soil fertility and pest control, so costly external inputs need to be supplied to crops. These interventions can reduce the quality of life due to reduced soil, water and food quality if these are contaminated with pesticides and/or nitrates. Commercial preparation of seedbed and mechanized planting has replaced natural seed dispersal methods. Chemical pesticides have replaced the natural processes of control of weed, insects and pathogen populations; genetic manipulation replaces the natural processes of plant evolution and selection. At present and in the future, changes in climatic and hydrological conditions will increasingly affect the spread of diseases and pests. Changes in ecosystems can directly affect the number of human pathogens and can alter a number of disease transmitters (e.g. mosquitoes), as well as affect the incidence of pests and diseases of crop and cattle. In terms of landscape management, increasing the exchange of species between agroecosystems and semi-natural ecosystems can have both positive and undesirable interactions (Fig. 4.35).

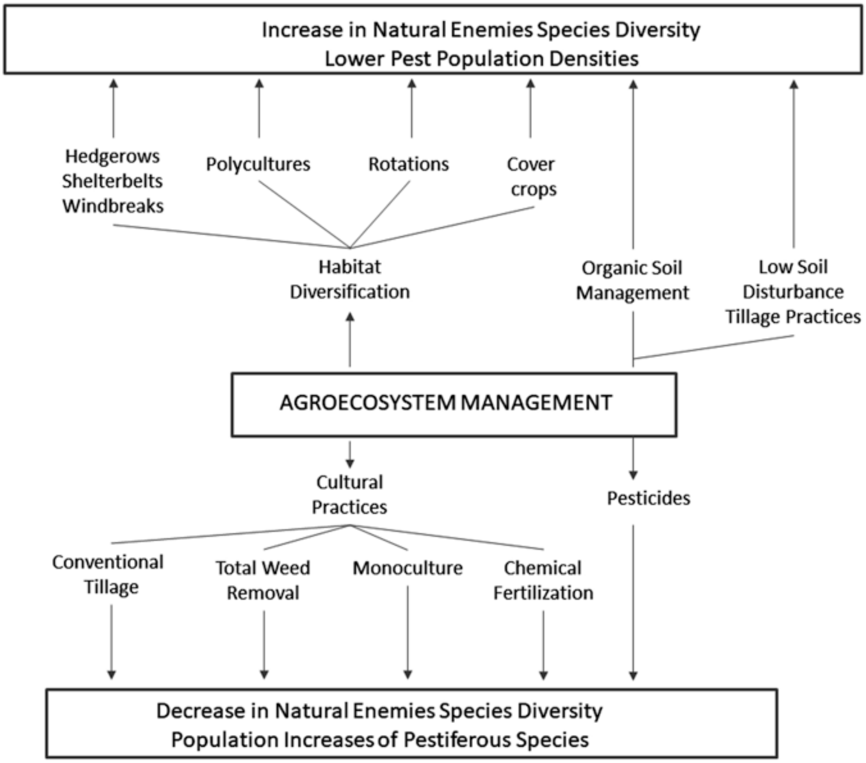


Fig. 4.35 Impact of agroecosystem management and related cultural practices on the biodiversity of natural enemies and the number of insect pests. (Source: Altieri 1999)

Similarly, for forest ecosystems, areas of planted monocultures are characterized by reduced stability and ability of these ecosystems for restoration, as manifested by, for example, in calamities. One of the most extensive ones in recent years was the windstorm in 2004, which affected the territories of the Vysoké and Nízke Tatry, Horehronie, Orava, Kysuce and Spiš (Kunca et al. 2014).

Original habitats and species can be also negatively affected by *non-native invasive plant or animal species*, which do not have their original area of distribution in Slovakia and have the potential to spread rapidly. In the case of their mass distribution, they significantly change the habitat character, threaten the native plant species and create homogeneous monocenoses. Some of them, such as the giant hogweed (*Heracleum mantegazzianum*) or common ragweed (*Ambrosia artemisiifolia*), are the causes of human health problems such as allergies and skin diseases.

4.9.2 Methods Used to Assess and Identify ES

As with other regulatory services, it is sometimes difficult to distinguish between the potential and the actual flows/contribution of ecosystems to the provision of a given ES. Therefore, service flow indicators have been proposed for some ES, including pest and disease control, to prevent the emergence and spread of pests and diseases, in proportion to capacity. Of course, the magnitude and effects of prevented events are difficult to measure in most cases, and the identification of definite location for the demand for a particular ES may be problematic (Burkhard et al. 2014).

Many studies provide examples of the assessment of this ES based on biophysical indicators, for example:

- Status indicator (service rate): number and effectiveness of pest control species
- Performance indicator (service sustainability): reduction of crop pests, human and animal diseases (UNEP WCMC 2011)
- Forest interactions with other habitats (list of functions, species); effects caused by forest change (benefits and loss of functions) – practical assessment of forest quality at the landscape level (Dudley et al. 2012)
- Density of small-scale structures on agricultural land or in special crops – national ES assessment in Germany (Grunewald et al. 2016)

Frélichová et al. (2014) have prepared an overview of research and methods of ES valuation, and for this ES, the following methods are used: biophysical assessment prepared in the form of a review (summary of data/indicators using biophysical metrics) or economic assessment methods (benefit transfer, contingent valuation). The benefit transfer method represents the application of values in monetary terms, with the values obtained by research for specific studies and applied to another, similar study. The contingent valuation method is used to determine the value of an ecosystem by identifying how much respondents are willing to pay for certain ecosystem benefits or services.

In another study (Farber et al. 2006), two methods have been proposed for the economic assessment of the ES: avoided cost – and production approach. When using the avoided cost method, the value derived from research is the cost of preventing or reducing environmental risk. The production approach assessment is based on the values of indirect benefits which could be caused by pests and diseases on agricultural production.

As is the case with other ES, the *GreenFrame method* was also used for this ES, based on a wide range of spatial data set (analytical maps) grouped into themes in combination with expert assessment (Kopperoinen et al. 2014).

4.9.3 The Main Types of Landscape and Ecosystems Which Provide ES

Considering the potential for the provision of this service, the natural and semi-natural habitats in the neighbourhood of agroecosystems or other anthropogenic areas are particularly important. Several studies of interspecies relations show that the diversity and abundance of beneficial species of herbivorous insects and predators, and thus the regulatory function of ecosystems, are higher, for example in ecotone communities, extensive orchards, natural grassland and mosaic-cultivated fields than in an intensively farmed large-scale agricultural landscape (Altieri 2004; Andow 1991; Collins et al. 1996; Offenberg 2015). These habitats located at the frontier of arable land plots can contribute to the control of pests and diseases of farm animals and plants, to the reduction of disease transmitters, human pathogens and the like.

The greatest benefit of this ES is visible in areas where supply and demand are in an approximate balance, i.e., for example, in a *diversified agricultural or urbanized landscape* with sufficient ecosystem representation which offer habitats for many animal species, thus creating a potential for promoting natural pest control (Schröter et al. 2019). With an increasing number of enemies, it is believed that biological pest control is also increasing.

It is therefore obvious that the spatial distribution of areas with a higher capacity for provision of this ES will be very closely correlated with the occurrence of the areas suitable for the provision of ES biodiversity promotion. Nature and nature-based ecosystems with proper status have the highest ability to participate in pest and disease control, and their functionality decreases with the disturbed state.

4.9.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

Natural and semi-natural habitats in landscape used by humans perform a balancing function by creating the conditions and space for nesting of relevant bird species, the space for the protection of small animals and the conditions for activity of pollinators, thus contributing to mitigating the risk of spreading diseases/pests and invasive/non-native species. They attenuate the negative effects of anthropogenic activity in the landscape and its components, thus contributing, in particular, to increasing the stability of the landscape and improving the ability of ecosystem restoration. Habitats of national or European importance are often small-scale protected areas in the midst of an intensively used agricultural landscape, thus largely fulfilling the function of pest and disease control. These protected areas and their protection zones (declared/non-declared) are subject to a higher level of territorial protection, which sets the conditions for the practical protection of the landscape and eliminates negative activities, affecting the habitat status, such as the

Fig. 4.36 Traditional agricultural mosaics with a diversified land structure and the presence of non-forest woody vegetation on the plot boundaries significantly contribute to pest and disease control (Hlboké nad Váhom). (Author: J. Špulerová)

application of chemical and fertilization. In this way, it ensures the conditions for better fulfilment of this ES in the landscape.

The effectiveness of this ES can be enhanced by *supporting the management of landscape diversity*, preservation and establishment of elements of ecological interest (Fig. 4.36), by creating bio-belts (increasing the stability of the landscape and the ecosystems themselves). This can also be helped by highlighting the importance of biodiversity (predators, antagonist parasites, soil microflora and microfauna) in providing crop protection and soil fertility *and developing agroecological technologies and systems*, which emphasize the conservation/regeneration of biodiversity, soil, water and other resources. Such measures are urgently needed to meet the growing range of socio-economic and environmental challenges and to enhance the ecosystems provide habitats for pest and disease control. Thus, it can be stated that the relationship of this ecological function with the principles of nature and landscape protection is complementary and mutually supportive (see Fig. 4.37).

For the prospective restoration of ecosystems with the aim to improve the quality of this ES, it would be necessary to *improve the condition of forest ecosystems*, as a significant part of forests is threatened by calamities due to deteriorated health. Similarly, it is appropriate to promote an increase in the presence of semi-natural habitats within the agricultural landscape, with these habitats then serving as refuges, and to eliminate any danger to these habitats from the spreading of non-native

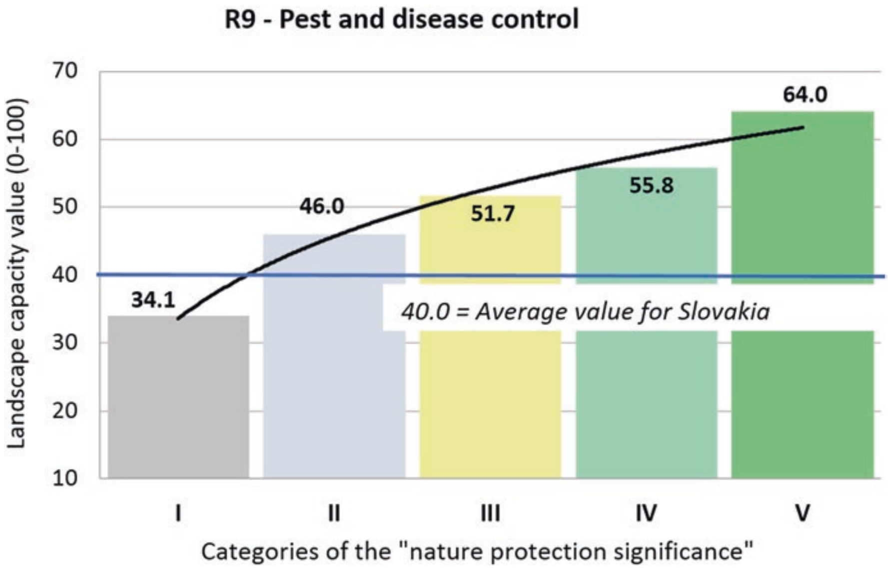


Fig. 4.37 The relationship between ecosystem service R9 and the significance of the territory of Slovakia in terms of nature and landscape protection

invasive species, as well as to promote a territorial geo-diversity (including abiotic environment) and diversity of land use.

4.9.5 ES Assessment for the Territory of Slovakia

So far, the practical assessment of this ES in Slovakia is rare. The joint ES – biodiversity, life cycles and pest control promotion – was assessed in a case study of the Trnava City functional area using the *GreenFrame* method, with the use of expert assessment and qualitative assessment of multiple map layers (Mederly et al. 2017).

Similar to the ES R7 assessment, the determinant factor here is the type of ecosystems and their status, as well as the selected positive and negative factors of the environment (Fig. 4.38). The pilot assessment of the capacity of the territory of Slovakia in terms of ES pest and disease control followed the ES R7 biodiversity promotion – as the data for the landscape's real state of health are not available, input indicators were selected from this ES. However, it should be noted that these are closely related ecosystem functions and services, the principles of which have a common basis in a favourable ecosystem state.

The main input into the assessment included the layers of naturalness of vegetation and habitat status in terms of quality and management. The spatial landscape structure was assessed by the diversity of the landscape based on the number of different types of ecosystems within the spatial unit of 1 km^2 (Table 4.9). The total capacity of the territory for the regulation of pests and diseases was expressed as a combination of these layers – the result of the assessment is shown in Fig. 4.39.

Fig. 4.38 A healthy and resilient ecosystem (in good state) can eliminate pests (including spruce bark beetle) by itself and prevent property damage. (Author: J. Černecký)

Table 4.9 Input data for capacity, demand and flow assessment of ES pest and disease control

Input data/ES	R9: pest and disease control
Capacity	The naturalness of habitats (comparison of real forest and non-forest vegetation with natural potential vegetation)
	Spatial landscape structure – diversity of the landscape (number of ecosystem types per 1 km^2)
	Habitat status – according to SNC SR data
	Current landscape structure – additional data for territory classification
Demand	Current landscape structure – categorization by demand for this ES (populated areas, ruderal areas, intensively used agricultural areas, forest monocultures)
	State of ecosystems – ecosystems disturbed or in a bad state
	Environmental quality – damaged or disturbed areas (air quality, environmental hygiene, etc.)
	The occurrence of invasive species, allergens and the like
	Population distribution – densely populated areas, areas with increased occurrence of allergies, etc.
Flow	Habitat classification (forest and non-forest) – significant habitats, the occurrence of indication species and the like
	Small-scale structures of agricultural land (mosaics) or other CLS categories
	Areas with a real implementation of agri-environmental measures

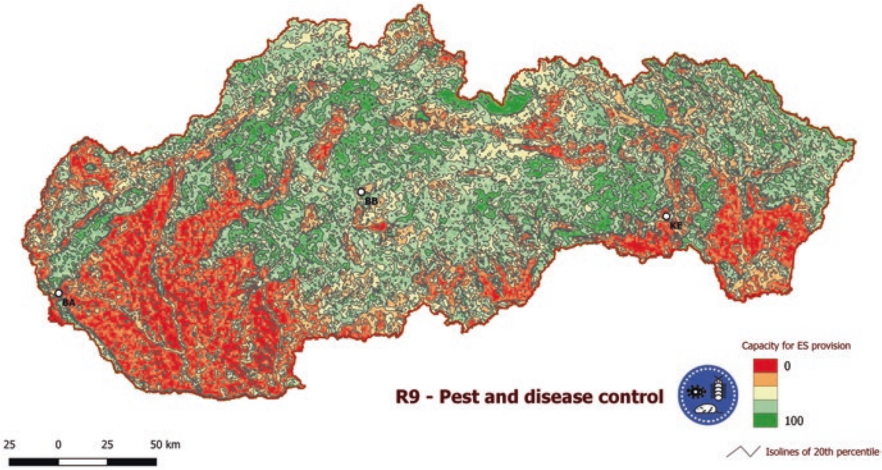


Fig. 4.39 Capacity of the landscape to provide ES pest and disease control

The spatial projection of the significance of Slovakia's territory from the point of view of this ES (Fig. 4.39) is very similar to that of ES biodiversity promotion, although the resulting image is more mosaic. The highest capacity is typical for mountains and sub-mountain areas, while the lowest capacity is documented in large agricultural and urban areas of Slovakia. The basis for the reconstruction of the biodiversity and regulatory functions of the landscape in these areas should come from the already mentioned *islands* of biodiversity and higher ecological quality, which are mainly bound to hydric and forest ecosystems.

The largest demand for this ES is obvious in settlements with mainly anthropogenic ecosystems and in areas of lowlands and basins with intensive agricultural activity, which are characterized by the low share of non-forest habitats and by being unstable. An important consumer of this ES is the agricultural land itself and thus the agricultural sector, which requires additional energy and constant human intervention to ensure the landscape stability and for prevention of the spread of pests and diseases. In regions where demand for this ES exceeds the production, it is necessary to increase the proportion of ecosystems which produce this service (e.g. a greater share of forest ecosystems) and to increase the functional biodiversity of agroecosystems (through the creation of multifunctional field margins – bio-belts on the arable land). Such practices are mainly applied in areas of organic farming which are supported by the Rural Development Program as part of the pillar II.

In the first pillar of the Common Agricultural Policy in relation to the conservation of biodiversity, the promotion of direct *greening* payments, linked to the implementation of the following procedures, contributes to such conservation: diversification of crops, permanent grassland maintenance and ecological focus areas (EFA). In ecological focus areas larger than 15 ha, a minimum of 5% of the area needs to be set apart for the following elements: fallow land; terraces; landscape features such as a solitary trees, row trees, small woods and hedges; buffer zones; areas with fast-growing species, with intermediate crops or green cover; or areas with nitrogen-binding crops. However, it should be noted that such a share is still insufficient in terms of maintaining ecosystems and hence the quality of the provision of this ES.

4.10 Maintenance of Soil Formation and Composition (R10)

4.10.1 Definition and Brief Characteristics of ES

Soil is the top layer of the weathered bedrock of the earth's crust containing water, air and living organisms. It is divided into horizontal layers with specific physical, chemical and biological properties. Individual layers have different ecological functions and functions related to human activities (Article 1 of the Principles of State Soil Policy of the SR, approved in 2001). The soil belongs to the essential component of the landscape necessary for life development and thus ecosystems. The above-mentioned document declares that soil is a common "wealth" of the citizens of the state and the heritage for future generations. It is an essential and non-renewable natural resource and forms an integral part of Earth's ecosystems. It is and will remain the basis of Slovakia's environmental, ecological, economic and social potential and must, therefore, be carefully protected from damage and unjustified reduction in its area and volume.

Soils represent complex ecosystems which consist of living and inanimate matter with lots of interconnections between them. The diversity and abundance of life in the soil is greater than in any other ecosystem. A small volume of soil can contain billions of different organisms that play a crucial role in soil quality to support plant growth. In addition to its participation in various biogeochemical cycles and nutrient exchange, the soil provides many other important ES (Schröter et al. 2019).

Soil formation is a long-term process of weathering of the bedrock and accumulation of organic particles. The soil environment is part of the main nutrient cycle in the environment – these being essential for life processes of organisms (e.g. N, S, P, C). Nutrients are decomposed and recycled in this process, changing forms, becoming available to plants and animals and for the ecosystem cycle. Biological fertility of soil is an important attribute of total soil fertility. The beneficial effects of soil organisms on the fertility of agricultural land are clear and obvious (available online: www.agroporadenstvo.sk). Soil processes such as the nutrient cycle, water cycle and biological activity promote soil formation and thus contribute to the development of soil properties and the provision of soil natural capital reserves. ES maintenance of soil formation is also dependent on the bedrock, climate, vegetation, time and territory in which they are located (Dominati et al. 2010).

Fertile and healthy soil is necessary for *ecosystem functioning and for food production*. Also, undisturbed soils can store and retain large amounts of carbon, which in turn has a beneficial effect on climate regulation. Soils are essential because they perform a number of essential functions in the landscape, such as nutrient cycle, water regulation, habitat protection and biodiversity, filtering and mitigating, as well as the stability of the area itself. The presence of dead biomass (necromass) is considered a good indicator of the ability of soil to perform these basic functions. In this context, the function of necrophages, invertebrates and organisms ensuring decomposition of organic material is very important. They are actively involved in interactions which develop in the soil between physical, chemical and biological processes. A comprehensive analysis of invertebrate activities shows that they can be seen as the best indicators of soil quality and at the same time should be considered as a resource to be managed to improve the provision of ES by agroecosystems (Lavelle et al. 2006). For example, Pavlík et al. (2015) experimentally followed the decomposition of various size wood fractions with saprophytic fungi – such fungi can be used for quicker decomposition of waste/unused dendromass and thus a faster intake of nutrients to forest land. Neher et al. (2012) explain the rate of decomposition of woody material by macrofauna (e.g. arthropods).

Due to the processes associated with pedogenesis, carbon is deposited in the topsoil layer, and the overall physical properties of the soil are improved. Significant benefits can be achieved with the proper functioning of processes associated with pedogenesis and the maintenance of soil quality – for example, this includes the need to reduce exogenous agricultural inputs (Becerra-Jurado et al. 2016).

The most important and most valued soil function is the provision of the substrate for plant growth. Almost all food production and a substantial portion of the raw materials and energy recovered is provided by plants growing on the soil. The importance of soil is still understood and assessed today especially in the context of agroecosystems**,** which provide for agricultural production of crops. However, as mentioned above, its quality is also equally important for the growth of other plants and woody biomass, as well as for several regulatory and supporting services (storage and distribution of carbon and other chemicals, regulation of runoff conditions and erosion processes, filtration and water purification, ensuring conditions for soil biodiversity, etc.). Soil properties are therefore very important not only for the functioning of the agricultural landscape ecosystems but also for other types of ecosystems which provide other ecosystem functions and related services for humans.

Soil quality regulation is a primary ecosystem function which plays a key role in providing regulatory services through storage and decomposition of organic substances, mediating the exchange of gases into the atmosphere, storing, decomposing and transforming materials, such as nutrients and contaminants, and regulating water flows. These supporting functions are largely related to the role of ecosystems in soil quality regulation and contribute significantly to other final ecosystem services, such as climate regulation, detoxification and purification as well as crop production and other products (e.g. fibres), growth of trees and others vegetation and peat formation (UK NEA 2011).

Simply put, in the context of ecosystem functions and services, we understand ES maintenance of soil formation and composition as the creation and maintenance of favourable conditions for the long-term provision of non-production soil functions.

4.10.2 Methods Used to Assess and Identify ES

ES Maintenance of soil formation and composition, in its essence, is a *strictly* scientific domain, so the biophysical methods are dominant in its assessment.

According to Pérez-Soba, Harrison et al. (2015) and Czúcz et al. (2018), the most important indicators for this ES include:

- Physical properties of soil: carbon stock, water capacity, soil structure
- Biological parameters: organic matter content, soil nutrients, biological recovery, above-ground biomass
- Process of pedogenetic processes: mineralization, decomposition, nutrient cycle
- Character of soil-forming bedrock

Other suitable indicators include, for example, land use management (agricultural production, forestry, urbanization activities), environmental pollution (soil, surface and groundwater contamination) and the share of organic farming (Maes et al. 2014).

Most of the national or regional assessments of the soil-related ES focus on its production characteristics and are predominantly assessed in terms of agroecosystems. According to Schröter et al. (2019), one of the assessment approaches includes the integration of the current understanding of soil-related processes into appropriate models to describe the dynamics of soil functions and related indicators. These models are usually designed for specific soil-related processes, such as carbon dynamics in soil, water flow in soil, soil compaction or greenhouse gas emissions. Change of soil functions corresponds to change of these properties, which in turn are influenced by land management practices. Another approach to soil assessment is to characterize the soil as a specific combination of its functional properties. What is traditionally known as *soil type* can be translated into a combination of functional properties (e.g. bulk density, organic carbon content, functional soil biota diversity).

The maintenance of soil formation and composition was investigated in more detail in the national assessment of, for example, Finland (Jäppinen and Heliolä 2015) and Great Britain (UK NEA 2011). In both cases, biophysical proxy indicators were used, namely, the functional diversity of soil organisms, nutrient cycle (Finland) or soil carbon, soil chemistry and heavy metal soil pollution (UK).

To a lesser extent, economic (monetary) methods are also used for the assessment of this ES (Frélichová et al. 2014) – it is possible to financially quantify the value of carbon or nutrients stored in the soil. Sandhu et al. (2010), on the other hand, assesses the soil on the basis of the market value of the earthworm-aerated topsoil layer and the mineralization estimates based on the market value of nitrogen that would otherwise have to be supplied externally to the soil. It is a *price-substitution* method which quantifies selected ecosystem functions and economically reflects the situation, where these functions would have to be artificially replaced. Colombo et al. (2006), in turn, followed the *willingness to pay for the ES* method to estimate the average price for a specific erosion regulation project, depending on its quality. Bond et al. (2011) estimated the value of soil from the cost of irrigation, which prevents erosion and loss of nitrogen.

Non-production functions and a system of qualitative and financial assessment of agricultural soils in Slovakia were investigated by Vilček (2014). In particular, he used biophysical assessment methods based on a number of indicators expressing the capacity of the soil to accumulate water (field water capacity), immobilize risk elements (sorption potential and content of risk elements), immobilize organic pollutants (C content and humus quality, clay content, soil depth, precipitation) and transform organic pollutants (C content and humus quality, clay content, air temperature). He also prepared a so-called soil environmental potential index (SEPI), as well as the financial expression of the main soil environmental functions.

For the ES soil formation itself, analytical indicators are the most important of this system – the content and quality of the organic soil component, clay content, soil depth, water capacity and soil sorption potential.

4.10.3 The Main Types of Landscape and Ecosystems Which Provide ES

For the proper functioning of the soil ecosystem, a healthy environment is necessary, without the presence of any serious negative factors (pollution and damage to the environment, intensive land use influencing natural processes and soil regime). That is why *nature and nature-based ecosystems* provide a suitable environment for the creation and circulation of nutrients and support for the main ecosystem functions associated with the soil environment (Fig. 4.40). These ecosystems include, in particular, *forest areas and grassland ecosystems* of large size, where space and time are provided for these processes to stay uninterrupted.

The reservoir of nutrients and their transformation media for the transfer to the soils is represented by *watercourses, water bodies and wetlands* – in this respect, they are very important for natural ecosystems with good ecological status. On the other hand, intensively used ecosystems (especially agroecosystems but also commercially used forest stands) are typically affecting the natural regime and the flow of nutrients – the use of natural resources, the disruption of natural cycles and the input of additional energy. The natural biological activity of the soil has been replaced by industrial fertilizers, chemicals and mechanization which have changed the chemical and physical properties of the soil, its biological activity and the like. The totally altered soil environment and the related disrupted main soil functions are present in urbanized ecosystems, where anthropogenic processes dominate.

Fig. 4.40 Decomposers – invertebrates involved in the decomposition of dead plant biomass, soil formation and sanitation activities for ecosystem cleaning. (Author: J. Černecký)

Approximately 12 mil. ha of soil is threatened annually in the world due to its desertification and degradation (Schröter et al. 2019).

On the other hand, proper management practices, especially in agroecosystems, can support the soil's biological fertility and gradually improve its physical-chemical properties. Soil environmental functions are increasingly taking on an economic as well as ethical and moral dimension. Assessment and valuation of the soil's capacity to perform vital tasks can significantly help in its necessary protection, especially in the case of thoughtless land take or anthropic interventions in the landscape (Vilček 2014).

4.10.4 Importance of ES in Terms of Nature and Landscape Protection in Slovakia

As specified in the assessment of ES *biomass for food production*, modern agriculture (and in part also the forestry) has become a threat to the proper functioning of ecosystems and thus to the fulfilment of non-production ecosystem functions and soil-related services. Therefore, intensive agriculture is perceived as a negative factor in relation to nature and landscape protection.

On the other hand, the promotion of non-production soil functions is generally consistent with the main objectives of nature and landscape protection. A well-functioning soil environment provides a number of non-production functions which directly or indirectly support the ecosystem's natural protection function. Similarly, it is clear that active nature protection, including the promotion of ecological and

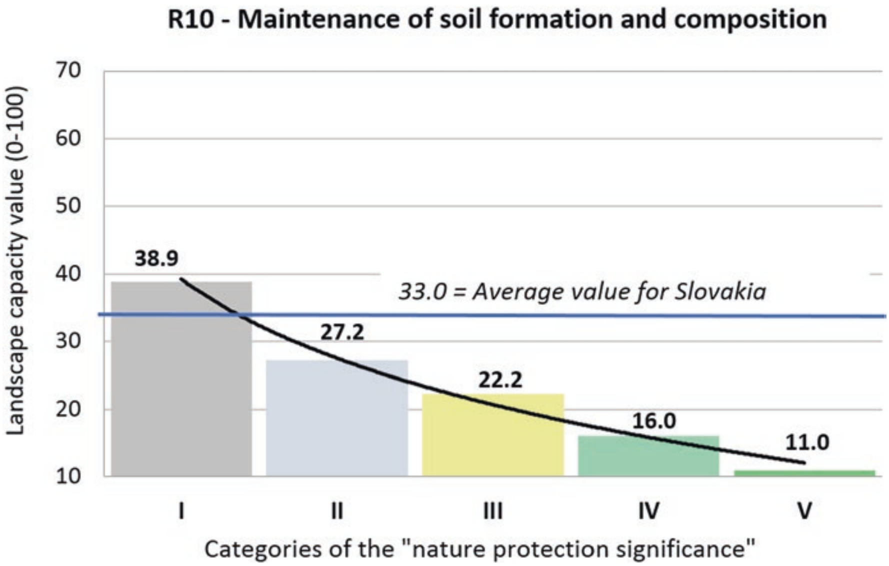


Fig. 4.41 The relationship between ecosystem service R10 and the significance of the territory of Slovakia in terms of nature and landscape protection

non-production functions of the landscape, is also in line with ES maintenance of soil formation and composition. Nevertheless, the current relationship between the landscape's capacity for provision of this ES and significance of the territory in terms of nature and landscape protection is characterized by a negative correlation (see Fig. 4.41) – this is mainly the result of the low capacity of mountain soils to fulfil this function due to their unfavourable physical and partly chemical conditions.

Management of soils and the promotion of their non-production functions should be an important priority for the agricultural sector, at the same level as the production function of agricultural and forestry landscape. This fact has been largely reflected in European sectoral policies – a system is in place to support the non-production functions and services of the rural landscape (Fig. 4.42) in the form of subsidy schemes.

The current *Rural Development Program 2014–2020* also focuses on sustainable management, restoration, conservation and enhancement of ecosystems, promotion of resource efficiency and support for the transition to a low-carbon climate-resilient economy. Direct support from the resources of the European Agricultural Fund for Rural Development (EAFRD) can be used, for example, for organic farming or for agri-environment-climate measures. The resources of the state budget can be used as direct support, for example, for climate and environment-friendly farming practices (available online: www.apa.sk). The purpose of these subsidies is thus indirectly to support several regulatory ES (anti-erosion, water management, soil protection) and supporting functions of the agricultural landscape (in particular, biodiversity promotion, pest and disease protection, support of soil fertility), to

Fig. 4.42 Agroforestry landscape in the Stará Turá region. (Author: D. Štefunková)

some extent support for cultural ES (agrotourism and recreation, preserving historical structures in the agricultural landscape).

4.10.5 ES Assessment for the Territory of Slovakia

The capacity of Slovakia's agricultural soils to perform environmental functions was expressed by Vilček (2014) with the so-called soil environmental potential index (for more details please see previous text). The total index was created as a combination of four sub-indices, which take the value from 1 (very high capacity) to 5 (very low capacity), and is also expressed in a point scale of 20–100 points. The average point value reflecting the capacity of Slovakia's agricultural land to provide environmental functions is 55.3 points. This highest average point value was achieved by agricultural land in the Nitra Region (72 points) and Šaľa District (82 points). The lowest average point value was recorded in the Prešov Region (48 points) and in the district of Košice 1 (42 points) and Gelnica (41 points). This index can serve as a spatial indicator expressing the heterogeneity of the capacity of Slovakia's agricultural land to provide selected environmental functions.

As this assessment is only valid for agricultural land and is more focused on hygiene functions (and there is no other assessment available for the territory of

Table 4.10 Input data for capacity, demand and flow assessment of ES maintenance of soil formation and composition

Input data/ ES	R10: maintenance of soil formation and composition
Capacity	Soil production potential (agricultural and forest soils)
	Soil filtration capacity
	Climatic conditions (especially the moisture balance)
	Relief – slope inclination
Demand	Intensively used agricultural (partly also forested) areas with depletion of nutrients and carbon
	Degraded and contaminated areas with infertile or hygienically harmful soils
	Disturbed ecosystems or ecosystems in a bad state
Flow	Territories with favourable soil characteristics (based on pedological surveys and analyses)
	Undisturbed areas with balanced use of soil resources (agroforestry areas)
	Territories with a practical implementation of agri-environmental measures and with the improvement of soil properties in a natural way

Slovakia), it is necessary to look for other indicators to express the capacity (potential) of the landscape to fulfil the supporting function of improving the formation and natural composition of the soil.

The pilot assessment of the capacity of the territory of Slovakia in terms of this supporting function followed the assessment of ES P1 biomass production – agricultural crops, where the productivity (fertility) of the soil was assessed in particular. This assessment was also taken as a basis for this ES, supplemented by filtering and buffering capacity of soils and correction coefficients expressing properties of relief (slope inclination) and climate (moisture balance). It is a simplified assessment of the total capacity of the area in terms of supporting pedogenesis and soil fertility (Table 4.10). The result was expressed as a combination of the above-mentioned layers in a relative scale – spatial differentiation is shown in Fig. 4.43.

From the resulting map, it is evident that lowland areas with favourable soil properties (depth, nutrient content, flat relief, suitable climate) have the largest capacity, while the lowest capacity is achieved by mountain areas with low capacity to support pedogenesis and related processes. However, sub-mountain and transitional areas with average landscape capacities are also important – with lightly disturbed environment and lower anthropogenic pressures (Fig. 4.42) than in the case of intensively exploited areas, which have a relatively good preconditions for a significant fulfilment of this ecosystem function.

Demand for ES maintenance of soil formation and composition is determined by the intensity of use and the state of the environment – the greatest demand is present in areas with the largest pressure to use the soil's production function (intensively used agricultural and forestry areas) or in areas with disturbed environment (degraded and contaminated areas, disturbed ecosystems).

The real use (flow) of this ES is, in turn, given either by the natural processes improving or promoting important soil characteristics and fertility or by appropriate

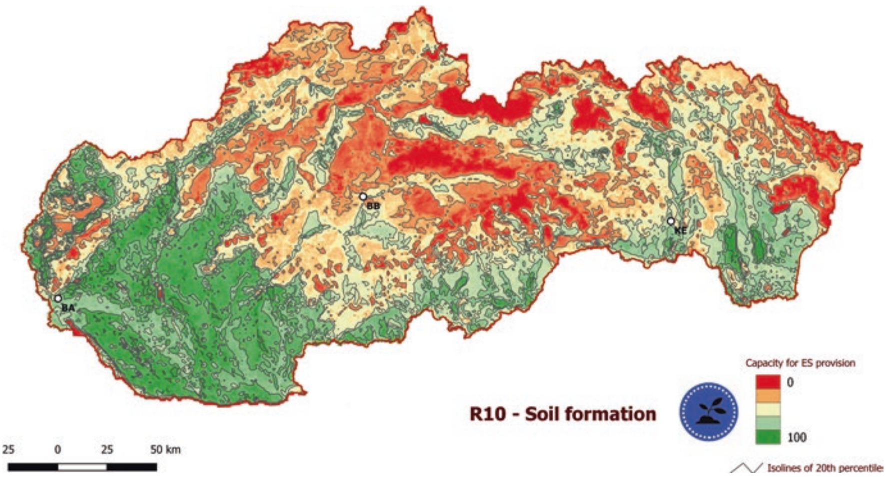


Fig. 4.43 Capacity of the landscape to provide ES maintenance of soil formation and composition

use and management of (in particular) the agricultural landscape. However, such indicators are likely to be very difficult to obtain at the national level.

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