CHAPTER B.I.

Guidance and tools for effective restoration measures for species and habitats

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I.1 Introduction

*The Society for Ecological Restoration (SER; Gann et al. 2019) defines **ecological restoration** as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. It is distinct from **restoration ecology**, the science that supports the practice of ecological restoration, and from other forms of environmental repair in that it seeks to assist recovery of native ecosystems and ecosystem integrity, including semi-natural ecosystems with high nature value due to traditional human use (e.g. heathlands, flower-rich meadows, coppice woodland etc.). Ecological restoration measures have the goal of achieving substantial ecosystem recovery relative to an appropriate reference model, regardless of the time required to achieve recovery. Once recovery has been achieved, any ongoing interventions (e.g. ensuring continued disturbance regimes) would be considered **ecosystem maintenance or management**.*

Ecological restoration is part of a range of activities and interventions which can be implemented to achieve better ecological conditions and to reverse ecosystem degradation. Other activities include remediation and rehabilitation (see chapter 3).

The EU Birds and Habitats directives provide important targets for ecological restoration in Europe. Measures taken pursuant to the Habitats Directive (HD) shall be designed to maintain or restore, at favourable conservation status (FCS), natural habitats and species of wild fauna and flora, taking account of economic, social and cultural requirements as well as regional and local characteristics (HD Article 2 and 3). The concept of FCS includes requirements regarding the natural range, area, structure and functions of natural habitats and, regarding the natural range, area of habitat and population dynamics of species. Natural habitats are defined as terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural. In the context of ecological restoration the term natural habitat is synonymous with native ecosystem as used by the SER. Ecological restoration is paramount to achieve target 2 of the EU Biodiversity Strategy to 2020: Maintain and restore ecosystems and their services (*EU, 2011*).

The Biodiversity Strategy 2030 has an important role to play in the next decade, the UN Decade on Ecosystem Restoration. Ecosystem restoration is a spearhead in the new Biodiversity Strategy 2030. It mentions that significant areas of carbon-rich ecosystems are to be restored. Also, legally binding restoration targets are foreseen, a proposal will be developed during 2021. The targets and how to measure success are yet to be defined.

In order to cope with these challenges and dilemmas, successful restoration will largely depend on skilled ecological judgment and knowledge exchange between scientists and practitioners. Carefully considered criteria and use of tools can increase this success.

Citation

Chapter B.I: Decleer, K. & Bijlsma, R.J. (2021): Guidance and tools for effective restoration measures for species and habitats. In: Van der Sluis, T., Schmidt, A.M. (2021). E-BIND Handbook (Part B): Scientific support for successful implementation of the Natura 2000 network.

The whole document can be downloaded under ecologic.eu/book/scientific-support-for-successful-implementation-of-the-natura2000-network

Main challenges and dilemmas for **effective restoration** result from the following requirements:

- Proper understanding of ecosystem functioning, i.e. abiotic conditions and processes including natural hydrology, natural disturbances and natural gradients in nutrient availability.
- Proper understanding of species (meta)population functioning, i.e. dynamics, reproduction success, genetics, dispersal capacity, food resources, ecological traps, extinction debt.
- Understanding current ecosystem species composition and functioning regarding historical land use and pressures.
- Facilitating (re)colonization of characteristic flora, fauna and vegetation types following abiotic restoration and management.
- Improving ecological resilience regarding pressures and threats at the landscape level (e.g. fragmentation, acidification, nitrogen deposition, climate change).
- Avoiding and controlling the encroachment of invasive alien species.

In this chapter we provide introductory treatments of criteria, concepts and tools, based on principles and standards for the practice of ecological restoration agreed by the SER, in particular:

- **Standards of good practice** for planning and implementing ecological restoration projects (chapter I.2).
- An introduction to the concept of **restorative continuum** to help planners, funders, and implementers understand how nature-based solutions, green infrastructure, and a host of other interventions and activities relate to each other and lead to better conditions on the ground and improve biodiversity (chapter I.3).
- An introduction to the '**LESA-approach**' to facilitate the **selection of appropriate reference ecosystems**, to improve understanding of their ecosystem functioning and to detect desirable restoration measures (chapter I.4).
- An introduction to the **recovery wheel** as a tool helping to design and implement projects, but also for assessment and communication, helping to visually demonstrate how restoration is improving conditions on the ground and to measure effectiveness and outcomes over time (chapter I.5).
- An overview of some existing **science-practice collaboration networks on ecological restoration in Europe** and some helpful information platforms (chapter I.6).

I.2 Standards of good practice for planning and implementing ecological restoration projects

This chapter is largely based on a more comprehensive treatment by *Gann et al. (2019 section 3).*

I.2.1 Planning and design

- Stakeholder engagement should include relevant authorities, owners, managers and local community representatives at the initial planning and throughout the project lifespan.
- Baseline inventories are required to document extent and effects of degradation regarding key ecosystem attributes (and see § 1.5.1): physical conditions, species composition, structural diversity, ecosystem function, external exchanges and absence of threats.
- Identification of reference ecosystem(s) and reference models based on a confrontation of historical and current information: status of current abiotic conditions and pressures and biotic values (habitats, species) as well as their historical context and future threats. See chapter I.4 for details on using a landschape-ecological system analysis (LESA) for this purpose.

- Vision, targets, goals and objectives.* Clear and measurable targets (outcome of the project) goals (desired states of the ecosystems over the medium to long-term) and objectives (desired changes to reach project targets) based on a common understanding of the project vision.
- Analysing and prioritizing logistics and restoration measures, regarding limited resources, risk management, permissions etc.
- Restoration treatment prescription. Clearly stated treatment prescriptions, describing what, where and by whom treatments will be undertaken.

I.2.2 Implementation

- All treatments are undertaken in a manner that is responsive to natural processes and that fosters and protects potential for natural and assisted recovery.
- Adaptive management is applied, informed by the results of monitoring. This practice anticipates unexpected ecosystem responses and corrective changes in activities in accordance with the previous practice.
- Regular communication with stakeholders, preferably based on a communication plan.

I.2.3 Monitoring, documentation, evaluation and reporting

- Monitoring follows from specific targets, measurable goals and objectives identified during planning and design. Preferably methods should be easy-to-use and implemented through participatory processes.
- Documentation of treatment implementation and monitoring activities, including the assessment of treatment effectiveness (evaluation regarding targets, goals and objectives) and enabling adaptive management.
- Reporting and disseminating progress and evaluation results to key stakeholders and a broader public.

I.2.4 Post-implementation maintenance

- The management body is responsible for ongoing maintenance and carrying out post-completion monitoring. Comparison to an appropriate reference model should be ongoing, including surveillance and communication.

* Terms used according to *Gann et al. (2017)* Box 5: Hierarchy of terms used in project planning.

I.3 The restorative continuum concept

The Restorative Continuum (Figure I.1) includes a range of activities and interventions which can be implemented to achieve better ecological conditions and reverse ecosystem degradation and landscape fragmentation by:

- Reducing societal impacts.
- Improving ecological conditions (remediation).
- Repairing ecosystem functions (rehabilitation).
- Recovering native ecosystems (ecological restoration).

The continuum highlights the interconnections among these different activities, and the fact that the specific situation of the locality slated for restorative interventions will dictate which activities are best suited for the different landscape units. As one moves from left to right on the continuum, both ecological health and biodiversity outcomes, and the quality and quantity of ecosystem services, increase. It is also important to note that project-level ecological restoration can and does occur in urban landscapes, agricultural landscapes and elsewhere – it is not restricted to natural ecosystems in protected areas. However, an ecological restoration project or program should aspire to substantial recovery of the native biota and ecosystem functions (*Gann et al. 2019*).

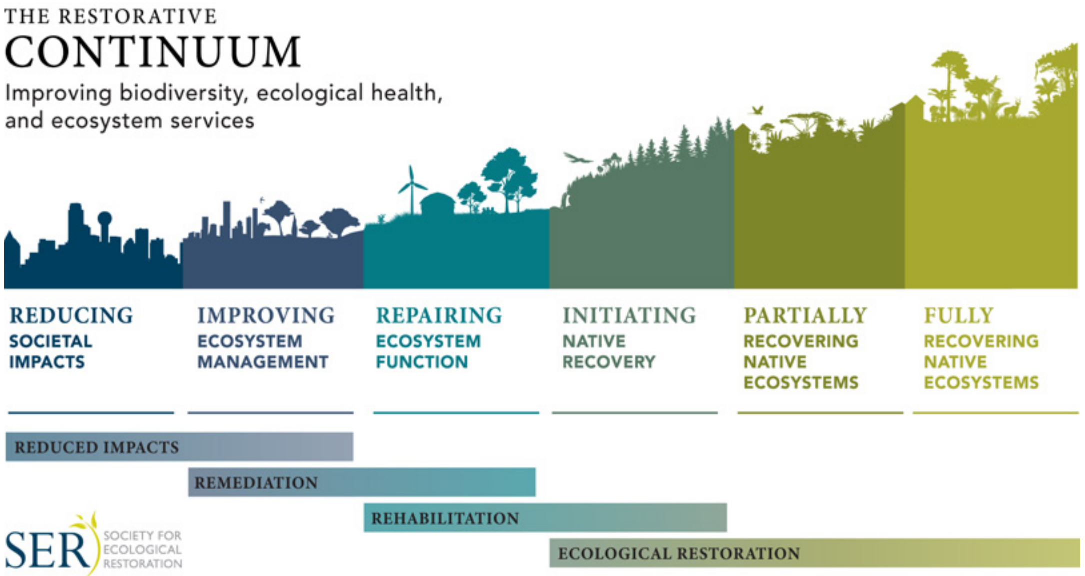


Figure I.1
The restorative continuum presented as overlapping activities to improve environmental conditions and reverse ecosystem degradation and landscape fragmentation (from *Gann et al. 2019*).

I.4 The 'LESA approach' to understand and prioritize reference ecosystem

I.4.1 A plea for a landscape-ecological approach to restoration

Ecological restoration not only gains cumulative value when applied at large scales (*Gann et al. 2019*, Principle 7) but requires analysis and understanding of ecosystem functioning at the landscape level, even when targeted at a local scale. This is because local conditions have been and are shaped by drivers operating at the landscape level and beyond, such as productivity gradients, regional hydrology and land use resulting in changed abiotic and biotic interactions and therefore changed perspectives on long-term viability of habitats and species. Selecting reference ecosystems and models for restoration (see § I.2) must take account of these historical drivers as well as future pressures and threats. Climate change makes local approaches to restore habitats and species even more ineffective if not obsolete.

The underpinning and communication of the selection of reference ecosystems requires a transparent analysis based on commonly available data sources. All the more important when semi-natural habitats or alternative natural habitats are involved. In Europe, the Habitats Directive requires "*to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated*" (Article 6.2). This adds to possible dilemmas in prioritizing targets for restoration in the case of opportunities for restoring long-term viable natural habitats, in particular if anticipated restoration is at the possible expense of one or more existing natural habitats or species indicative of less optimal or even adverse conditions.

I.4.2 The LESA pathway

The landscape-ecological system analysis (see the side box) was introduced as a tool to allow a transparent and verifiable analysis and evaluation of abiotic conditions, natural habitats and species in Dutch sites as a starting point for management plans including ecological restoration (*Van der Molen et al., 2011*). The landscape-ecological approach acknowledges the importance of regionally operating abiotic and biotic drivers of local diversity and viability of natural habitats and species. The LESA can be included in a procedure to prioritize natural habitats and species as targets for long-term viable development in Natura 2000 sites and to develop a management vision. This extended LESA is in line with SER principles and standards for selecting reference ecosystems (*Gann et al., 2019*).

The LESA approach was used for example in planning the restoration of raised bog remnants in the Netherlands. Historically, the orginal bogs covered large areas of the country including adjacent Germany and Belgium. Although all bog remnants are included in Natura 2000, these sites

The LESA approach

The LESA approach aims at a confrontation of abiotic and biotic patterns and trends at the landscape level and the subsequent evaluation of possible causes for observed changes, resulting in targets for restoration and management.

The analysis includes relationships between patterns in physical-geographic features (geology, geomorphology), soil types and hydrological processes at the landscape level on the one hand, and species composition and spatial distribution of habitats and species on the other hand. Historical distribution data and historical-geographic insights (e.g. on colonization and land use) are key components. Based on knowledge of ecological requirements of habitats and species and of species- and system-specific delays in response to environmental changes, observed biotic changes can be attributed (or hypothesized) to changes in abiotic factors and processes (e.g. groundwater tables, nitrogen deposition) often resulting from modified land use, and to changes in biotic interactions (e.g. invasive species, isolation due to fragmentation).

The extended LESA proceeds by evaluating the (ir) reversibility of changes and trends and the ecological and technical feasibility of restoration approaches, resulting in a vision on long-term viable targets for management and restoration (reference ecosystems or models). This pathway is summarized in Figure I.2.

Data and analyses used in this pathway can be illustrated for the Natura 2000-site Schoorlse Duinen, a c. 1700ha large coastal area in the Netherlands (Figure I.3) with mostly lime-poor dunes (management plan: *Meijer et al. 2016*). First, historical maps show changes in land use for the period 1850–1950 (Figure I.4), including the establishment of large pine plantations. Historical distribution data (1926, 1977) reveal that water tables were much higher during the early 20th century: the moisture-loving shrub Myrica gale virtually disappeared (Figure I.5). During the same period became strongly degraded and surrounded by well-drained agricultural landscapes. Ecohydrological landscape analyses provided insight into the current and historical landscape processes, such as hydrology and land use. This resulted not only in perspectives on improved rainwater retention and maintaining high water levels, but for some sites also on restoring gradients from the nutrient-poor, acid bog centres to the nutrient-richer and more buffered surrounding lagg-zones which are essential habitat for many species of bog ecosystems. Decades of research by the Dutch OBN Knowledge Network for Nature Restoration and Management (see chapter I.6) including several PhD studies resulted in full insight and guidance on the landscape ecology, restoration and management of raised bogs in the Netherlands (summarized in a textbook by *Jansen & Grootjans, 2019*).

We emphasize that, even in Natura 2000 sites, a LESA should not be restricted to designated Natura 2000 features (habitats and species) but should consider all historically and currently characteristic native ecosystems and species in the particular landscape as well as invasive, exotic species. This broader perspective is necessary to anticipate or avoid conflicting demands and to express responsibility for the regionally characteristic biodiversity. After all, the aim of the Habitats Directive is just "*to contribute towards ensuring biodiversity*" (Article 1).

A LESA can benefit strongly from data and analyses already gathered to set favourable reference values (FRVs) for habitats (FRR: favourable reference range; FRA: favourable reference area) and species (FRR; FRP: favourable reference population) at the national level as required for Article 17 reporting. Guidelines for setting these FRVs are available from the Reference portal for reporting under Article 17 of the Habitats Directive and *Bijlsma et al. (2019)*. In using historical information for setting FRVs, the latter report considers the recent past, including about 50 years before the Directive came into force, and the historical past, up to the last two or three centuries, depending on occurrences of major (irreversible) impacts on distribution, population size or area.

species of wet, calcareous dune slacks in the outer dune zone strongly declined as well, such as Parnassia palustris (Figure I.6). The hydrology of the site is determined by an impermeable layer of clay and peat in the subsoil (Figure I.7), absent from the southern area which was part of a former estuary. Due to increased water extraction and evaporation by encroaching scrub and woodland, the water table dropped more than 1m between 1900 and 1980. This change is considered as partly irreversible and restoration measures focus on rewetting large and relatively deep dune slacks only, by cutting c. 140ha of pine forest and facilitating succession to deciduous woodland in another 250ha as well as by removing the vegetation and topsoil in formerly humid dune slacks (Figure I.8 and I.9). Nature values of the corresponding wet habitat types (H2190 Humid dune slacks, H2180 wet Wooded dunes, H3260 Water courses) are considered vulnerable and the restoration and management of these types has priority over measures for inherently dry habitats (such as H2130 Grey dunes, H2140 Decalcified fixed dunes with Empetrum and H2180 dry Wooded dunes) which are considered robust and are allowed to interfere and replace each other within limits.

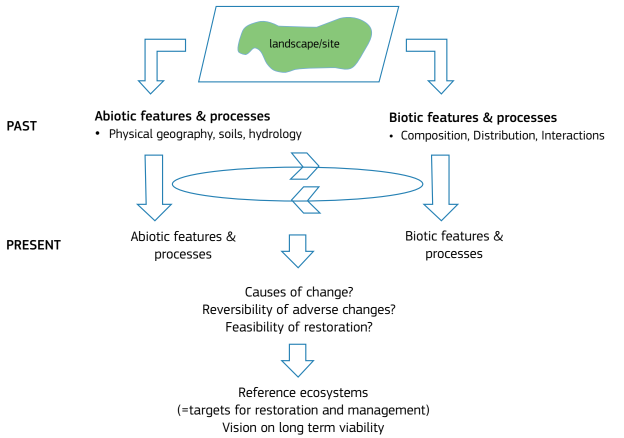


Figure I.2 (left)

Scheme of the LESA pathway showing the confrontation and analysis of historical and current patterns in abiotic and biotic features, followed by an analysis and evaluation of causes of changes and trends. This eventually results in a selection of reference ecosystems serving as targets for restoration and management (adapted from *Bijlsma et al. 2017*).

Figure I.3 (right)

Aerial photo (2018) of Natura 2000 site Schoorlse Duinen (yellow line). Grid: 2,5x2,5km.

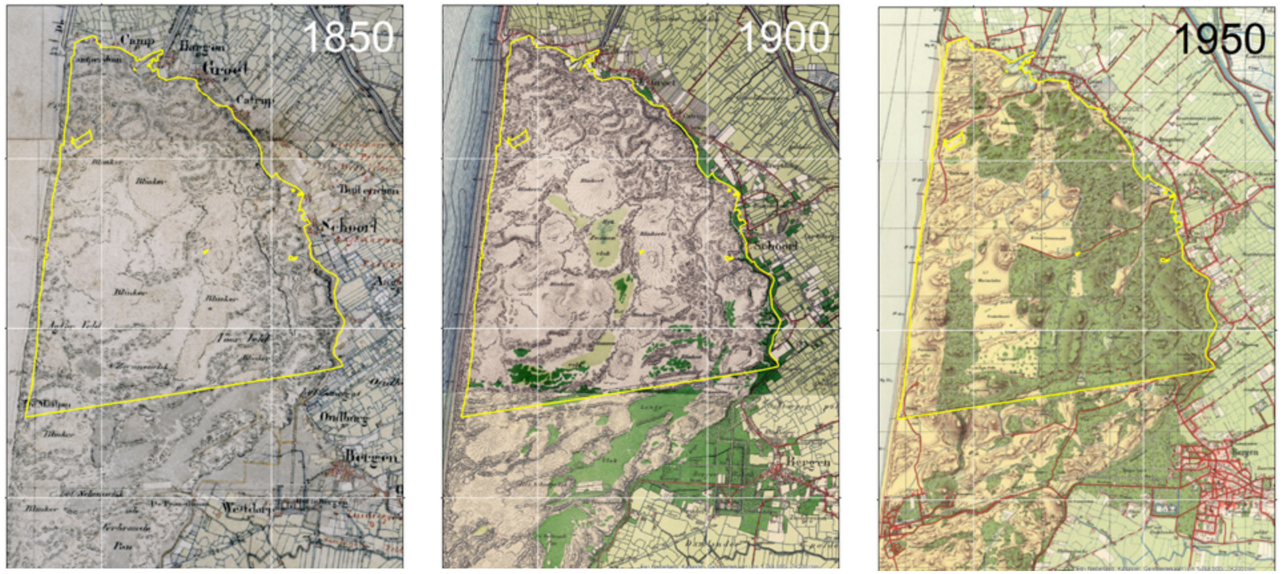
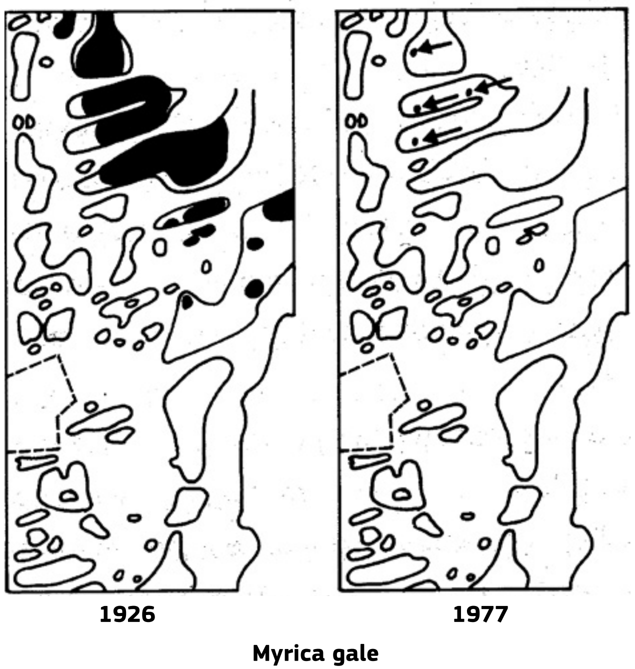


Figure I.4

Historical maps (1850, 1900, 1950) of Natura 2000 site Schoorlse Duinen (same clip as Figure 4.1).



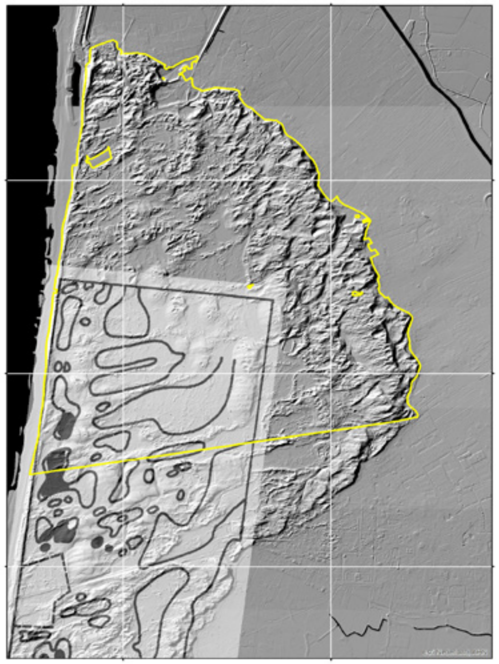


Figure I.5 (left)

Historical distribution (1926, 1977) of the shrub Myrica gale in the Schoorlse Duinen and adjacent dune area (compare Figure I.6) (from *Van Zadelhoff, 1981*)

Figure I.6 (right)

Historical distribution (1926) of the calcicolous Parnassia palustris georeferenced on an elevation map (hill shade) of the Schoorlse Duinen.

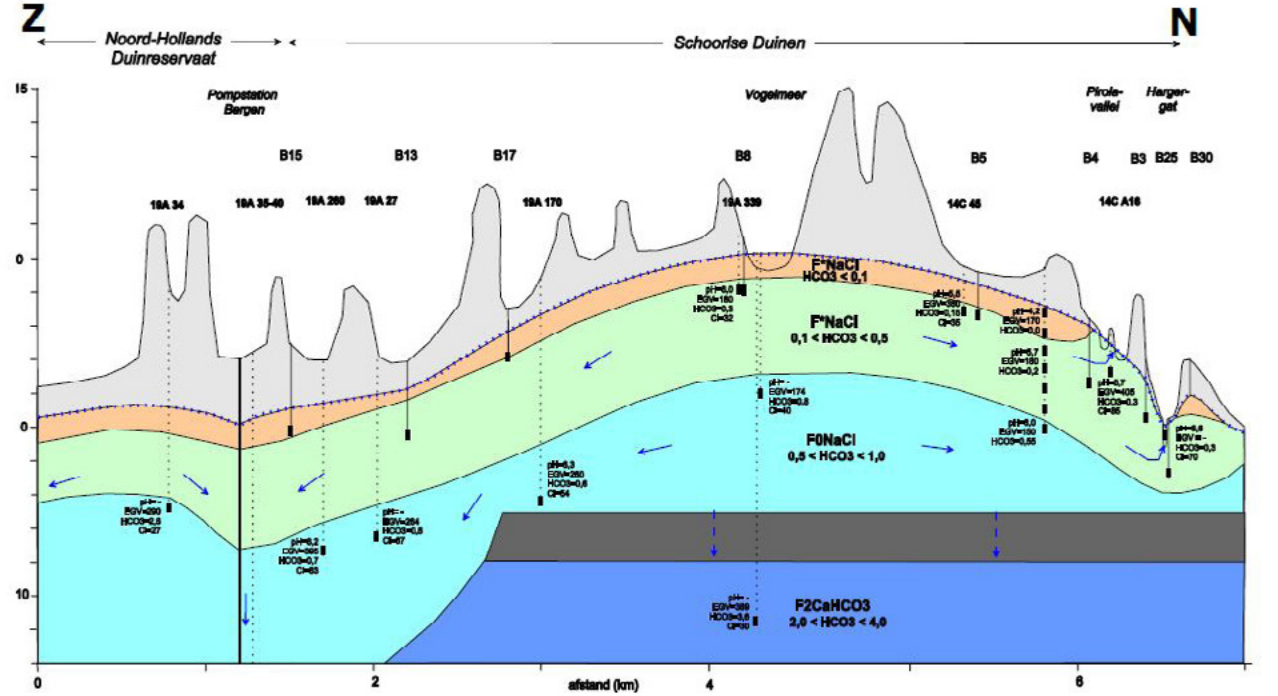


Figure I.7

Geohydrological (north-south) cross-section of the Schoorlse Duinen site and adjacent dune area and the impermeable layer of clay and peat (from *Meijer et al. 2016*).

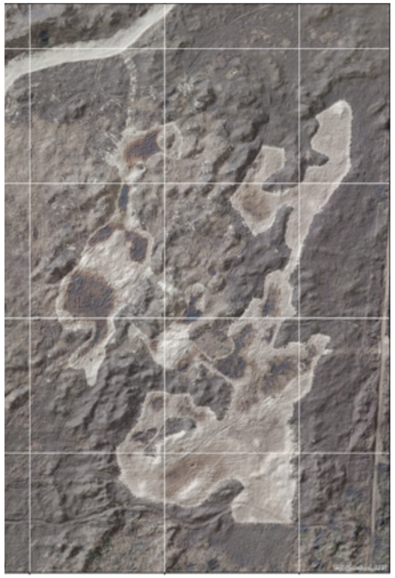


Figure I.8 (left)

Aerial photo (2018) of restoration measures in formerly humid dune slacks within the historical distribution of Myrica gale (compare Figure I.5). Grid: 100x100 m.

Figure I.9 (right)

Field photo of the same restoration measures as in Figure I.9 (photo: R.J. Bijlsma, June 2018).

I.5 Introduction to the 'recovery wheel'

I.5.1 Recovery wheel and five-star rating system for ecological goals*

To help managers, practitioners, and regulatory authorities identify a project's ecological targets and goals and track progress, we present tools for progressively evaluating the degree of native ecosystem recovery over time relative to the reference model – the recovery wheel (Figure I.10) and a five-star rating system (Table I.1). These tools are based on the premise that managers, practitioners, and regulatory authorities either are required or would like to report progress from a baseline condition to a higher level. Indicators are used to describe the state of recovery. (see chapter A.III Data Access).

In the example of fig. I.10, the first wheel represents the baseline condition of each attribute as assessed during the baseline inventory stage of the project. The second wheel depicts a 10-year-old restoration project, where over half its attributes have attained a 4-star condition. Practitioners familiar with the project goals, objectives, site-specific indicators, and recovery levels

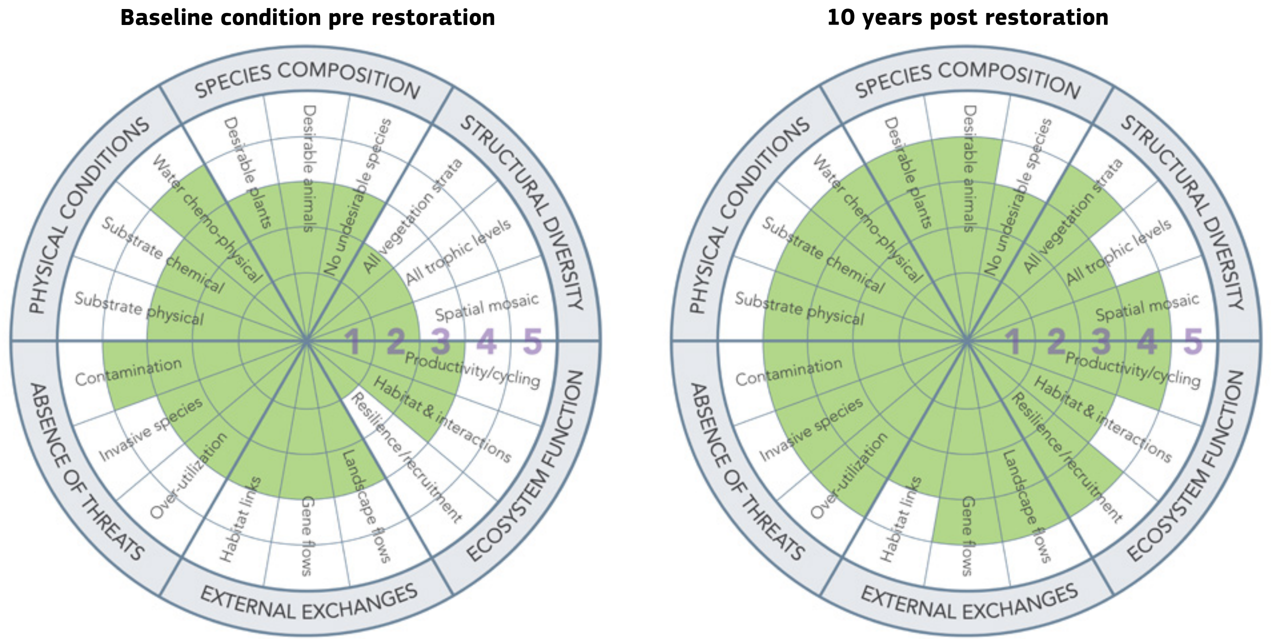


Figure I.10
Recovery wheel – A tool for conveying progress of recovery over time of ecosystem attributes (compared to those of the reference model) (from *Gann et al. 2019*).

* Paragraph 5.1 is largely based on *Gann et al.* (2019 section 2 principle 5)

achieved to date can shade the segments for each sub-attribute after formal or informal evaluation. Note: Sub-attribute labels can be added or modified to best represent a particular project.

Importantly, the 5-star system serves to evaluate the progression of an ecosystem along a trajectory of ecological recovery relative to the reference model. It is not generally intended to evaluate the success of a restoration project against the full range of its goals (for example, social goals can be evaluated using a different tool), the individual performance of practitioners, or to make comparisons between different project sites. Rather, managers are encouraged to use the 5-star rating system to identify their project's ecological targets and goals relative to the six key attributes and to provide a monitoring framework.* The idea is to show progress over time, which can be highly encouraging, even if full recovery is not possible. The 5-star system is most informative when applied at the scale of an individual project or site. It provides a generic framework only, requiring users to develop indicators and a monitoring metric specific to the ecosystem and sub-attributes identified.

Number of stars	**Summary of recovery outcome** (Relative to the appropriate reference model)
★	Ongoing deterioration prevented. Substrates remediated (physically and chemically). Some level of native biota present; future recruitment niches not negated by biotic or abiotic characteristics. Future improvements for all attributes planned and future site management secured.
★★	Threats from adjacent areas starting to be managed or mitigated. Site has a small subset of characteristic native species and low threat from undesirable species onsite. Improved connectivity arranged with adjacent property holders.
★★★	Adjacent threats being managed or mitigated and very low threat from undesirable species onsite. A moderate subset of characteristic native species is established and some evidence of ecosystem function commencing. Improved connectivity in evidence.
★★★★	A substantial subset of characteristic biota present (representing all species groupings), providing evidence of a developing community structure and commencement of ecosystem processes. Improved connectivity established and surrounding threats being managed or mitigated.
★★★★★	Establishment of a characteristic assemblage of biota to a point where structural and trophic complexity to a level of very high similarity to the reference ecosystem is likely to develop with minimal further restoration interventions. Appropriate cross-boundary flows are enabled and commencing, and resilience is restored with return of appropriate disturbance regimes. Long term management arrangements in place.

Table I.1
Summary of generic standards for 1–5 star recovery levels. See Table I.2 for more detailed generic standards for each of the six key ecosystem attributes (from *Gann et al. 2019*).

* Although the five-star rating system is qualitative, and not intended as a substitute for formal quantitative monitoring, it can be adapted for monitoring by developing objective guidelines around the definition of each star. The Recovery Wheel can then be used to develop response ratios (comparison of values of a variable at the restoration site to the reference model) that are commonly employed to measure restoration success.

Attribute	★	★★	★★★	★★★★	★★★★★
Absence of threats	Further deterioration discontinued, and site has tenure and management secured.	Threats from adjacent areas beginning to be managed or mitigated.	All adjacent threats managed or mitigated to a low extent.	All adjacent threats managed or mitigated to an intermediate extent.	All threats managed or mitigated to high extent.
Physical conditions	Gross physical and chemical problems remediated (e.g., nutrient, pH, salinity, contamination or other damage to soil or water.	Substrate chemical and physical properties on track to stabilize within natural range.	Substrate stabilized within natural range and supporting growth of characteristic native biota.	Substrate securely maintaining conditions suitable for ongoing growth and recruitment of characteristic native biota.	Substrate exhibiting physical and chemical characteristics highly similar to that of the reference ecosystem with evidence they can indefinitely sustain species and processes.
Species composition	Colonizing native species (e.g., ~2% of species in the reference ecosystem). Moderate onsite threat from nonnative invasive or undesirable species. No threat to regeneration niches or future successions.	A small subset of characteristic native species establishing (e.g., ~10% of reference). Low onsite threat from nonnative invasive or undesirable species.	A subset of key native species (e.g., ~25% of reference) establishing over substantial proportions of the site. Very low onsite threat from undesirable species.	Substantial diversity of characteristic native biota (e.g. ~60% of reference) present on the site and representing a wide diversity of species groups. No onsite threat from undesirable species.	High diversity of characteristic native species (e.g., >80% of reference) across the site, with high similarity to the reference ecosystem; improved potential for colonization of more species over time.
Structural diversity	One or fewer biological strata present and no spatial patterning or community trophic complexity relative to reference ecosystem.	More strata present but low spatial patterning and trophic complexity, relative to reference ecosystem	Most strata present and some spatial patterning and trophic complexity relative to reference site.	All strata present. Spatial patterning evident and substantial trophic complexity developing, relative to the reference ecosystem.	All strata present and spatial patterning and trophic complexity high. Further complexity and spatial patterning able to self-organize to highly resemble reference ecosystem.
Ecosystem function	Substrates and hydrology are at a foundational stage only, capable of future development of functions similar to the reference.	Substrates and hydrology show increased potential for a wider range of functions including nutrient cycling, and provision of habitats/ resources for other species.	Evidence of functions commencing – e.g., nutrient cycling, water filtration and provision of habitat resources for a range of species.	Substantial evidence of key functions and processes commencing including reproduction, dispersal and recruitment of species.	Considerable evidence of functions and processes on a secure trajectory towards reference and evidence of ecosystem resilience likely after reinstatement of appropriate disturbance regimes.
	Potential for exchanges (e.g. of species, genes, water, fire) with surrounding landscape or aquatic environment identified.	Connectivity for enhanced positive (and minimized negative) exchanges arranged through cooperation with stakeholders. Linkages being reinstated.	Positive exchanges between site and external environment starting to be evident (e.g., more species, flows etc.).	High level of positive exchanges with other natural areas established; control of pest species and undesirable disturbances.	Evidence that external exchanges are highly similar to reference, and long-term integrated management arrangements with broader landscape in place and operative.

Table I.2

Sample 1–5 star recovery scale interpreted in the context of the six key ecosystem attributes used to measure progress along a trajectory of recovery. This 5-star scale represents a gradient from very low to very high similarity to the reference model. It provides a generic framework only, requiring users to develop indicators and a monitoring metric specific to the ecosystem and sub-attributes identified (from *Gann et al. 2019*).

I.5.2 Connecting the recovery wheel to EU habitats directive reporting

The recovery scale interpreted in the context of the six key ecosystem attributes can contribute greatly in drawing up management plans of Natura 2000 sites regarding degraded habitat types and habitats for species. Moreover, this approach can easily be connected with several aspects of EU Habitats Directive reporting.

At the site level, Standard Data Forms (SDF) require for habitat types assessments of Representativity (A excellent, B good, C significant), degree of conservation of structure (I excellent, II structure well conserved, III average or partially degraded structure), degree of conservation of functions (I excellent prospects, II good prospects, III average or unfavourable prospects) and of restoration possibilities (I easy, II restoration possible with an average effort, III restoration difficult or impossible) which directly relate respectively to the key ecosystem attributes species composition, physical conditions & structural diversity and ecosystem functions whereas restoration possibilities relate to decisions from the planning and design of restoration at site level. For species the SDF likewise requires assessments for the Degree of conservation of the features of the habitat important for the species and restoration possibilities.

At the national (biogeographic) level Article 17-reporting can benefit from concepts underlying the 5-star recovery scale and recovery wheel, in particular regarding the conservation status parameters habitats for the species (Annex B Species) and structure and functions (Annex D Habitat types) as well as future prospects (both Habitat types and Species). The reporting formats emphasize assessments based on short-term and long-term trends which require proper monitoring (see § I.2.3 and Chapter A.1, on monitoring).

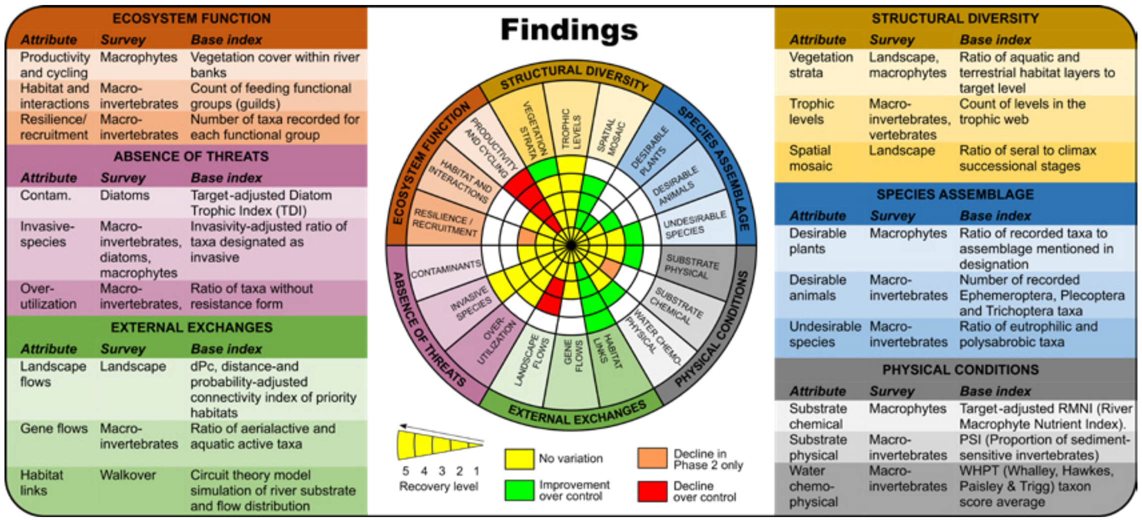


Figure I.11

Use of the recovery wheel in practice

In the UK the Recovery Wheel concept was tested to detect recovery trends in a river restoration project (*Fioratti, 2017*). A set of 6 key attributes and 18 sub-attributes were selected to assess recovery trends relative to an unrestored control site. For each attribute appropriate metrics were defined. The metrics are based on a combination of biotic and landscape indicators integrated in a comprehensive sampling protocol, designed to be cost-effective and reliable.

For each indicator the results were scored on a 1 to 5 scale of increasing recovery. In this case the results were presented in one wheel only, with the use of different colours to indicate positive, negative or no change relative to the control. Also, change over time was assessed with a phase 1 (results after 2 years) and a phase 2 (results after 1 year). Achievement of complete recovery is evaluated with a comparison of the metric to a set threshold or range delimited by a lower and an upper value. Lower recovery stages are assigned as a function of the distance of the reading from the threshold or range.

For example, the indicator 'desirable animals' improved with one level 2 years after the restoration. The indicator 'chemical quality of the substrate', based on a River Macrophyte Nutrient Index, declined in the first year with one level, but improved again with one level after the 2nd year. The results for the indicator 'invasive species' showed no difference after restoration. For the attribute 'productivity' the indicator 'vegetation cover' was used and the results showed a decline with 5 levels after restoration.

It is envisaged that the identification of suitable quantitative indices and an affordable and flexible sampling protocol for the recovery wheel will expand substantially the scope and potential of this innovative tool for science-informed and target-based ecosystem restoration.

I.6 Science-practice collaboration networks in Europe and information platforms

Successful interaction and knowledge transfer between researchers, policymakers and practitioners is essential to foster cost-effective restoration of ecosystems. While many nature conservation agencies and NGOs employ staff with a proper scientific education and background, it is often not evident for them to keep track of the latest insights related to specific and often complex matters in restoration ecology and ecosystem functioning. For a given situation, specific knowledge may be lacking that is essential to assess bottlenecks for successful restoration and to plan appropriate measures. Nor is it evident for them to set up time-consuming field experiments to test hypotheses according to robust scientific methods and techniques. Restoring conditions for the recovery of endangered species is another illustration of why expert involvement may be necessary at project level. Researchers can also help in the training of practitioners (or 'training of the trainers'), in setting up or executing baseline or follow-up monitoring of restoration projects, in reporting and in validation of data and results in scientific publications in order to internationally share information and promote cross-border collaboration. Scientists can also help in the underpinning of restoration priorities at different geographic scales.

English is the universal language for communication between researchers, but in multilingual Europe, language is often a barrier for successful knowledge exchange and collaboration at the local level. Having science-practice collaboration platforms and networks in the local language is a huge benefit, especially for practitioners and volunteers. Involvement of local scientists also builds more sustainable networks as they are more familiar with the local actors and the local ecosystem conditions and functioning, which may vary between different European regions. A good understanding of the local legal and cultural context is important as well.

In the rapidly evolving field of restoration ecology and conservation biology, science-practice collaboration is of uttermost importance. Unfortunately, actively bridging the 'gap' between science and practice is still undervalued, as made evident by the limited efforts of the science and nature administration bodies at national and European level. A more active government support across the policy domains of 'science' and 'practice' could guarantee the long-term sustainability of capacity building, especially if some funding is available for facilitating applied research and training by scientists and for active dissemination of best-practice information through digital platforms, field courses, workshops, conferences and publications. The Dutch OBN Knowledge Network (see box) is an excellent example that deserves emulation in other European countries.

In several European countries national science-practice collaboration networks developed spontaneously and gradually over the last one or two decades. Some merely operate at European or even global level, are dedicated to ecological restoration in general, also include ecosystem

The Dutch Knowledge Network for Restoration and Management of Nature (OBN)

Based on: Giulia Variara, 2019 (compilation & editing). www.natuurkennis.nl/Uploaded_files/Publicaties/obn-english-2019-2.14f730.pdf

Organisation and financing

The OBN Knowledge Network includes

- researchers from institutes and universities,
- site managers and private land owners,
- representatives from consultancies and NGOs
- representatives from governmental bodies such as provinces and water boards.

The objective is to closely cooperate in the restoration of ecosystems and nature reserves in all major Dutch landscapes.

Since 2006 the network formulates a mission statement and knowledge agenda each 4 to 5 years which is leading in all activities. Nine landscape-based '**Expert Teams**' are working on the development, dissemination and implementation of knowledge on restoration and rehabilitation of ecosystems, on issues regarding Natura 2000 and the EU Water Framework Directive, as well as on the conservation of individual species. Atmospheric nitrogen deposition, climate change, sea level rise, coastal defence, flood risks and agricultural practise are main environmental concerns.

Site managers, together with policy makers and researchers identify knowledge gaps to enable cost-efficient and effective nature restoration and management measures. A permanent secretary overlooks the activities of the expert teams and research projects, supported by an advisory board. OBN research projects ('**case studies**') are being allocated via calls for tenders to research institutes. Results are communicated in reports, brochures, newsletters, a website, publications in scientific journals and more… …popular nature magazines, interactive workshops management issues or purely focus on particular ecosystem types or species groups. Some networks and platforms share information for free, other expert groups can be involved with some financial compensation.

In the following overview a (non-limitative) list of the most relevant existing networks and platforms in Europe is presented with brief information and web links. In view of the existing policy targets, the sense of urgency to tackle the biodiversity and climate crisis and the many challenges in ecosystem restoration, more national and/or European funding of these groups would enable a boost in the highly-needed, sustainable and multidisciplinary science-practice collaboration with, in the end, more cost-effective ecosystem restoration and recovery of endangered species populations at both national and European scale.

I.6.1 Umbrella networks active in the field of ecological restoration

SER Europe (European Chapter of the Society for Ecological Restoration)
chapter.ser.org/europe; contact: info@ser-europe.org

The SER is a global network of restoration experts and enthusiasts, connecting and educating the restoration community by:

- biennial European conferences where researchers, practitioners, policy makers and students come together to exchange ideas, showcase their work, forge new alliances and participate in discussions and field trips. Example: sere2021.org
- biennial world conferences on ecological restoration
- promoting and co-organising regional workshops and conferences
- promoting and co-organising 'summer schools' and other training and educational events
- SER's peer-reviewed journal 'Restoration Ecology', which highlights advances in restoration science
- a global Restoration Resource Center: www.ser-rrc.org
- a European Knowledge Base on Ecological Restoration: chapter.ser.org/europe/knowledge-base/overview
- Reports and publications: www.ser.org/page/SERDocuments; chapter.ser.org/europe/publications/special-issues-conference-books
- promoting other reference publications: chapter.ser.org/europe/publications/recommended-books-and-reports

and field trainings. Within the OBN Knowledge Network field workshops are an important way of knowledge exchange. During these workshops research outputs and experiences with management techniques are being shared and discussed.

The network is financed by the Dutch National and Provincial governments. In 2018 the network received an operational grant of 1,948,000 euro in total. 1,188,000 euro was spend to pay for research projects (normally 6–8 yrs per project); 253,800 euro for the functioning of the expert groups; 215,680 euro for knowledge distribution (communication, publications, newsletter, symposia, website) and 290,520 euro for the coordination (secretariat staff etc.). Some income is acquired by subscriptions to attend workshops and field trainings.

The Expert Teams
The set-up of eight Expert Teams has been based on the various landscapes that occur in the Netherlands: Brook Valleys, Dry Sandy Areas, Wet Sandy Areas, Dunes and Coastal Areas, Colline Areas, Fen and Sea Clay Areas, Riverine Areas and Agricultural and Rural Areas. An additional expert group on fauna is established to provide advice to the Expert Teams on fauna aspects.

The Expert Teams form the core vehicle of the OBN Knowledge Network. These teams formulate research questions aimed at solving (long-term) management problems. They also supervise research projects and disseminate knowledge by means of reports, scientific papers, brochures, expert reviews, lectures, field symposiums, and a Nature Portal (via internet).

In all landscapes, changes in land use, desiccation, eutrophication, atmospheric nitrogen deposition, acidification, often biased by uncoordinated nature policies and nature management, still have a huge impact on habitats and species, causing a drastic deterioration …
… of the once very rich cultural-historical and land-

» active collaboration and networking with regional restoration networks and partners who subscribe to the quality standards and values of SER Europe, such as:

→ **REVER: the French restoration experts network**. REVER or "*Le Réseau d'Échanges et de Valorisation en Écologie de la Restauration*" has pretty much the same goals as SER Europe, but is restricted to France. They organize national conferences and other activities that link the French restoration community. In 2014 REVER became affiliated member of SER Europe. More information about REVER: www.reseau-rever.org (website in French). Contact person: Prof. Dr. Elise Buisson, elise.buisson@univ-avignon.fr.

→ **FBER: the Finnish Board on Ecological Restoration** is a national collaborative group consisting of managers, scientists, and experts working with habitat restoration and the management of cultural habitats. The group supports restoration and nature management actions both on state-owned and private land. Four expert groups work under the Steering Group: Peatland Restoration Expert Group, Forest Restoration Expert Group, Freshwater Habitats Restoration Expert Group and Semi-Natural Grassland Expert Group. The Restoration Board together with the expert groups e.g. prepares restoration handbooks and organizes seminars. The Restoration Board is coordinated by Metsähallitus and Finnish Environment Institute. Link to the Finnish web pages: www.metsa.fi/en/nature-and-heritage/habitats. Contact person: Jussi Päivinen, jussi.paivinen@metsa.fi.

→ **SIRF: the Italian Society of Forest Restoration** is based in the Department of Agriculture, Forestry, Nature and Energy (DAFNE) of Tuscia University (Italy). SIRF was established in 2012 and aims at: (1) showing the illegal or incorrect actions in forest systems, chief causes of forests and environmental degradation; (2) promoting the application of the principles of forestry and environmental restoration; (3) promoting biodiversity conservation and sustainable management of forest resources; (4) supporting the improvement of the quality of the forest and agricultural landscape. SIRF participates in research projects, provides consultancy, training and education and (co-)organizes meetings and conferences. SIRF became an affiliated member of SER Europe in 2015. Contact person: Prof. Dr. Bartolomeo Schirone, schirone@unitus.it.

→ **AEET: Asociación Española de Ecología Terrestre**. The Spanish Association for Terrestrial Ecology (AEET) is the largest ecological society in Spain and a member of the European Ecological Federation. Its working group on Ecological Restoration has promoted knowledge exchange on issues related to this topic over the last decade. Contact person: Josu D. Alday, osucham@gmail.com, www.aeet.org/Restauracion_Ecologica_133_p.htm.

scape values and the originally high biodiversity. Especially in the dune and coastal areas and along the main river systems, safety aspects and drinking water production often set special preconditions to nature management.

Case studies

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In this section some results are presented which give an overview of topics concerning restoration and rehabilitation of important ecosystems in the Dutch landscapes.

CASE STUDY 'Nitrogen deposition': Forest biodiversity on mineral-poor soils in dry sandy areas
This OBN project focused on the possible relationships between biodiversity loss and nitrogen deposition together with the inevitably associated acidification. It is known that nitrogen deposition affects the amino acid composition of plants. Acidified forests in particular are sensitive to amino-acid problems due to nitrogen deposition.

The results of this study show that the nitrogen deposition and the acidification cause shortages of plant mineral nutrients, compromising amino acid production in plants, which in turn affects the fauna communities leading to an advanced degradation of forest ecosystem quality. Two scientifically realistic ...
... restoration pathways are shown: the first is to have

→ **OBN: Dutch Knowledge Network for Restoration and Management of Nature**. The Dutch OBN Knowledge Network for Nature Restoration and Management is an independent and innovative platform where policymakers, site managers and scientists cooperate in the management and restoration of natural areas. Science and nature management jointly look for the most effective approaches to enhance sustainable conservation of important ecosystems in the Dutch landscapes (see box). More information: www.natuurkennis.nl/english/obn-knowledge-network/knowledge-network/knowledge-network-for-restoration-and-management-of-nature-in-the-netherlands. Brochure with more information about OBN: dt.natuurkennis.nl/uploads/OBN_English_Brochure_2016.pdf (English). Website in Dutch: www.natuurkennis.nl. Contact person: Wim Wiersinga (w.wiersinga@vbne.nl) or Mark Brunsveld (m.brunsveld@vbne.nl).

→ **Netzwerk Renaturierung – German Restoration Network (GRN)**. The German Restoration Network (GRN) was founded in 2016 at the Freising Conference of the Society for Ecological Restoration Europe. The GRN has members coming from universities as well as from restoration practice in Germany, Austria and Switzerland. A special feature of the network is the high and still increasing proportion of practitioners working in nature conservation authorities, NGOs, planning agencies or wild plant propagation companies. Learning from practical experiences and solving future challenges in ecological restoration is a focus of GRN. Website: renaweb.standortsanalyse.net. Contact person: Sabine.Tischew@hs-anhalt.de.

→ **CIEEM: the UK Chartered Institute of Ecology and Environmental Management**. CIEEM is the leading professional membership body representing and supporting ecologists and environmental managers in the UK, Ireland and abroad. CIEEM was formed in 1991 as the Institute of Ecology and Environmental Management. From small beginnings, it has grown into an increasingly influential professional body – setting standards, sharing knowledge and providing sound advice to governments on all aspects of ecological and natural environmental management practice. Website: cieem.net. Contact person for the Restoration and Habitat Creation Interest Group of CIEEM: j.mitchley@reading.ac.uk.

→ **Rede Portuguesa de Restauro Ecológico**: The Portugese Network for Ecological Restoration was created in 2019 and signed a memorandum of understanding with SER Europe on 02/08/2019 at the Faculty of Science of the University of Lisbon, at the occasion of the Congress of the European Ecology Federation. Contact person: Alice Nunes, amanunes@fc.ul.pt or rede.portuguesa.restauro@gmail.com.

a further reduction of nitrogen deposition and the second is to lift the mineral deficiency of trees by replenishing the system with minerals.

CASE STUDY Dune and Coastal Area: Grazing management related to fauna communities restoration in dry dune grasslands
This project investigated if and how grazing management can affect the fauna communities of open coastal dune habitats (H2130, H2140, H2150) in order to restore the biodiversity of this important landscape.

The study of differences between grazed and ungrazed plots along the whole Dutch coastline shows that grazing in general has a positive effect on fauna communities of dry open dune habitat. A low grazing pressure is preferable in calcium-rich dunes since it facilitates rabbits, characteristic butterfly species and other flower-visiting insects and has little effect on soil fauna. In calcium-poor dunes grazing decreases N-availability, which is necessary to temper plant growth. The high grazing pressure seems beneficial for the number of characteristic breeding birds, but detrimental to soil fauna, butterflies and other flower-visiting insects.

CASE STUDY Wetlands: Water level fluctuations in peatlands: relation between hydrology, ecosystem, dynamics and Natura 2000 habitat types
This research considered the ecological benefits and drawbacks of the re-establishment of fluctuating water levels as a management tool in different Natura 2000 habitat types to support water and nature management authorities in decision-making. The potential drawbacks of temporary lowered surface water levels, and related lowered water tables in the peat soil, seem to be more important than the potential benefits, overall at the expense of the development of protected brown moss vegetation in rich fens. Desiccation of the topsoil in rich fens should be avoided. In …
… contrast to drought, periods of inundation with

Eurosite
Eurosite is the network for Europe's natural site managers, bringing together non-governmental and governmental organisations, as well as individuals and organisations. Founded in 1989, the network has grown to include members across Europe. The mission of Eurosite is to provide opportunities for practitioners to network and exchange experience on practical nature management. Eurosite organizes and participates in many educational events, such as conferences, workshops, trainings and research projects. Website: www.eurosite.org.

I.6.2 Thematic Expert Networks

SPECIES

- Planta Europe Network: www.plantaeuropa.com
- BatLife Europe: www.batlife-europe.info
- European Mammal Foundation: www.european-mammals.org
- BirdLife International: www.birdlife.org/europe-and-central-asia
- International Wader Study Group: www.waderstudygroup.org/publications
- Reptile Amphibian Conservation Europe: www.arc-trust.org/news/the-race-is-on
- Societas Europaea Herpetologica: www.seh-herpetology.org
- Buglife-The Invertebrate Conservation Trust: www.buglife.org.uk; www.buglife.org.uk/resources/habitat-management
- Butterfly Conservation Europe: www.bc-europe.eu
- European Red List Species: www.iucnredlist.org/search?query=Europe&searchType=species
- European Committee for Conservation of Bryophytes: eccbbryo.nhmus.hu
- European Network on Invasive Alien Species: www.nobanis.org

ECOSYSTEMS

- International Mire Conservation Group: www.imcg.net/pages/home.php
- Wetlands International: europe.wetlands.org
- European Centre for River Restoration: www.ecrr.org
- Alliance for freshwater life: allianceforfreshwaterlife.org
- European Pond Conservation Network: www.europeanponds.org

base-rich water in summer can be favorable. The Ca- and Fe-contents of peat soils of and surface water turned out to strongly determine the responses to water table fluctuations in the peat soil.

CASE STUDY Dry Sandy Areas: Heathland recovery by incorporating extensive farmland
In the Netherlands, heathland natural areas harbour several Natura 2000 protected habitat types (H2310; H2330; H3160; H4010; H4030; H5130; H6230). Characteristic fauna species of these ecosystems are still in decline. One cause is the loss of land use gradients in the remaining heathland landscape. In the past, extensive agricultural fields linked the heathlands including fields near the villages; nowadays, this situation is rare. The project investigated the contribution of reinstated relatively nutrient-rich and dynamic habitats to the biodiversity of heathland landscapes.

The results show that in order to restore the faunal biodiversity, heathland management should incorporate extensive farmland management schemes.

CASE STUDY Colline Areas: Restoration and expansion of unimproved downland in Southern Limburg
The unimproved downland in Southern Limburg (with loess and calcareous soils) provides habitat for many species of Natura 2000 types H6210 (calcareous grasslands) and H6230 (matgrass swards). The biodiversity in this landscape is declining with increased availability of nitrogen as a major cause. In addition, fragmentation and isolation have emerged as major bottlenecks.

The project studied measures to reduce habitat fragmentation and investigated possibilities to restore unimproved downland on former arable land. ...

- Eurasian Dry Grassland Group: edgg.org
- European Heathland Working Group: contact Geert.Deblust@inbo.be
- Foundation for European Forest Research: www.fefr.org/portal
- European Forest Institute: www.efi.int
- Wild Europe: www.wildeurope.org
- Rewilding Europe: rewildingeurope.com
- European High Nature Value Farming Network: www.hnvlink.eu
- Coastal & Marine Union: www.eucc.net

I.6.3 Other knowledge platforms

Endangered Landscapes Programme: www.conservationevidence.com and www.restorationevidence.org

LIFE-Nature: ec.europa.eu/environment/archives/life/publications/lifepublications/lifefocus/nat.htm

Natura2000 Communication Platform: ec.europa.eu/environment/nature/natura2000/platform/knowledge_exchange

European Nature Information System (EUNIS): eunis.eea.europa.eu

Biodiversity Information System for Europe (BISE): biodiversity.europa.eu

Eionet Portal: www.eionet.europa.eu/etcs/etc-bd

Ramsar Convention: ramsar.org/resources/ramsar-sites-management-toolkit

Water Information System for Europe (WISE): water.europa.eu

Agreement on the Conservation of African-Eurasian Migratory Waterbirds: www.unep-aewa.org

Flemish Nature Information System: www.ecopedia.be (in Dutch)

... The study demonstrates that it is possible to recreate species-rich downland on improved grassland sites. It is important to investigate the soil chemistry, variation in soil type and presence of special features and to adapt the restoration plan in accordance with these findings.

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