REPORTS OF THE MINISTRY OF THE ENVIRONMENT 15en | 2016

Framework for assessing and reversing ecosystem degradation

Report of the Finnish restoration prioritization working group on the options and costs of meeting the Aichi biodiversity target of restoring at least 15 percent of degraded ecosystems in Finland

Janne S. Kotiaho, Saija Kuusela, Eini Nieminen, Jussi Päivinen and Atte Moilanen

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Helsinki 2016

MINISTRY OF THE ENVIRONMENT

Ympäristöministeriö
Miljöministeriet
Ministry of the Environment

REPORTS OF THE MINISTRY OF THE ENVIRONMENT 15en | 2016
Ministry Of the Environment
Department of the Natural Environment

Layout: Government Administration Unit, Publications
Cover Photo: Markku Meriluoto

The publication is available on the internet:
www.ym.fi/julkaisut

Helsinki 2016

ISBN 978-952-11-4603-9 (PDF)
ISSN 1796-170X (online)

PREFACE

On 10 February 2014, the Finnish Ministry of the Environment appointed a restoration prioritization working group. The aim of the working group was to create a framework for assessing and reversing ecosystem degradation and to establish criteria for prioritization of restoration measures, taking into account benefits, costs and the cost-efficiency of the measures in order to support the national implementation of Target 2 of the EU strategy for biodiversity: *"By 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems."*. While conducting the work, the working group was to consider national policies set out in the strategy and action plan for the conservation and sustainable use of biodiversity in Finland for 2012–2020. The working group was expected to specify the restoration need according to the national policies, draft a proposal for the restoration prioritization, and assess the overall costs of the proposal.

The term of the working group was from 10 February 2014 to 31 May 2015. The working group held 16 meetings, several smaller meetings for experts and one seminar. The work involved approximately 100 people.

Overall the working group was organised into a decision making group and three expert groups. The decision making group decided on the preparatory principles and provided consultancy for the expert groups. Expert groups were focused on forests, peatlands and cultural ecosystems. Outside the expert groups a few additional experts were consulted about inland waters, coastal areas, rocky outcrops and fell ecosystems. The expert groups assisted the decision making group and compiled data and analysed material on the current condition of ecosystems, restoration needs, responses of the ecosystem condition to restoration and the costs related to the restoration measures. The decision making group examined and analysed the material and drafted the proposal. There were 2 dissenting opinions and 3 additional remarks on the original proposition.

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This report is an abridged and revised English language edition of the original proposition of the Finnish restoration prioritization working group on the options and costs of restoring 15 percent of degraded ecosystems in Finland (Kotiaho et al. 2015a). The original report (246 pages) was published in Finnish.

Here we describe the procedures developed, other most relevant contents and a summary of the ecosystem-specific results. We acknowledge all of the authors of the original report and they have been named in Table 1. Members of the working group are listed in Appendix 1 of the original report (Kotiaho et al. 2015a). Authors of the current report Janne S. Kotiaho (chairman of the original working group), Saija Kuusela (member of the original working group), Eini Nieminen (assistant of the original working group), Jussi Päivinen (secretary of the original working group), and Atte Moilanen (scientific advisor of the original working group) are solely responsible for the contents of this report.

Kotiaho, J.S., Kuusela, S., Nieminen, E., Päivinen J., Moilanen A. 2016: Framework for assessing and reversing ecosystem degradation. Reports Of The Ministry Of The Environment 15en | 2016.

Table 1. Authors of the original report (Kotiaho et al. 2015a).

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Summary of key findings and propositions

Ecosystem and biosphere degradation ultimately caused by increasing human population size and per capita consumption, are among the greatest threats for biodiversity and ecosystem services and indeed for the future of humankind (e.g. Steffen et al. 2015). There are several global and EU-level strategies, incentives and agreements aiming to reverse the trend, one of the more ambitious ones being restoration of at least 15 percent of degraded ecosystems by 2020 (SCBD 2010; European Commission 2011). Although made with good intentions, the scheduling of the goal is overambitious (Kotiaho et al. 2015b), which is why in this work we adopted the year 2050 by which the implementation should be completed.

Even when we set a more realistic schedule at the outset, we still faced another major challenge: there were no broadly operable tools for empirical evaluation of the ecosystem condition and effectiveness of restoration measures in improving the ecosystem condition. This challenge was recognised by ARCADIS in the DG ENV study 'Priorities for the restoration of ecosystems and their services in the EU' (Lammerant et al. 2013). Similarly, Tittensor et al. (2014) concluded that they could not identify any indicators to measure the progress towards the target of restoring at least 15 percent of degraded ecosystems. It is worth noting that some highly sophisticated methods for optimal allocation of habitat restoration do exist (e.g. Noss et al. 2009; Wilson et al. 2011; Pouzols & Moilanen 2013), but these methods are comparatively data-hungry, require specialist skills in application, and their finesse may become lost in a process that unavoidably involves many stakeholders, limited time, and serious compromise to reach anything like the 15 percent restoration target.

Because humanity has nevertheless agreed on a quantitative 15 percent ecosystem restoration target, but we lack operable tools, we started by developing procedures i) to systematically estimate the magnitude of degradation from which the 15 percent can be calculated, ii) to evaluate the magnitude of improvement different restoration measures can offer, and iii) to prioritize restoration measures within and between ecosystem types. The procedure was developed from the perspective of real-world, limited time, operational feasibility while still retaining the ecologically most relevant components. While data was naturally used whenever available, all aspects of the procedure are also fully operable based on quantitative estimates or expert opinion.

The guiding principle adopted for the development of the procedure was to treat all ecosystems that are not in their natural state as degraded. However, it is worth emphasizing that the objective is not to reach the natural state of the ecosystems, but to reduce the degree of ecosystem degradation by restoration. In the prioritization of restoration measures, attention was paid to the cost-effectiveness of the measures from the point of view of biodiversity, and the effects of the measures on biodiversity and on key ecosystem services. In addition to the prioritization between the restoration measures, we paid attention to the risk of extinction classification of species and habitat types, ecosystem area, restoration costs, and the degree of degradation in the prioritization between ecosystems.

The Finnish restoration prioritization working group, which was composed of about 100 experts, collated an exceptionally extensive data across many terrestrial ecosystem types over the entire terrestrial area of Finland (c. 300 000 km^2) in a relatively short period of time (less than a year). On this data we applied the procedure we developed. The procedure enabled us to find the balanced and cost-effective restoration measure portfolios within each ecosystem type and to allocate resources effectively to those ecosystem types that provided highest benefits in terms of biodiversity and reduction of the degree of ecosystem degradation. To our knowledge, this report is the first to estimate the cost of meeting the 15 percent restoration target across all relevant terrestrial ecosystems in one country. Our work exemplifies that simultaneous prioritization within and among all ecosystem types is effective in delivering significant economic benefits. Indeed, if we focus on restoring 15 percent of one ecosystem type at a time, which is the *modus operandi* in many parts of the world, the overall cost of meeting the 15 percent restoration target is more than twice compared to the prioritization approach we have adopted here. More specifically, focusing on the restoration of each ecosystem type separately and reducing the degree of degradation in each by the 15 percent, it would in Finland cost 38 billion euros by 2050. However, with prioritization within and among all ecosystem types the overall cost of meeting the 15 percent restoration target in Finland could be reduced to 16 billion euros.

Rather than getting fixed on the 15 percent target, the working group decided to also provide additional options for decision makers. Thus, the working group gives alternative answers to the question of which ecosystem restoration measures to take, at which scale and in which ecosystem types, in order to meet the overall target for ecosystem restoration in Finland. None of the options should be viewed as an absolute proposition that should be applied as such, but the options are examples of potential prioritization schemes. Indeed, for the most effective outcome, the work should be revised if extensive on-the-ground operations are initiated under a known total budget. The benefit of the procedure used by the working group is that it makes the calculation and comparison of prioritization options relatively transparent.

This work is also a response to the invitation extended by target 2, action 5 of the EU biodiversity strategy (European Commission 2011), according to which Member States should assess the state of ecosystems and ecosystem services in their area. The procedure we developed could also be applied directly to the assessment of the state of ecosystem services included in the invitation given in the EU strategy. Furthermore, the work complies with the objective to develop procedures for assessing the net loss of biodiversity and ecosystem services as a result of projects and programmes, as laid down in action 7 in target 2. The procedure can also be used to assess the need for financing mechanisms, such as compensation schemes, and the costs for the current ecosystem restoration measures.

The work described in this report was assigned by the Finnish Ministry of the Environment. The original report was handed to the Ministry in June 2015. Below we detail all of the propositions of the working group, some of which are specific to the Finnish system. However, **we highlight with bold font the propositions that are globally most relevant**. In addition, based on our experience of the work, we drafted a few additional propositions for the international readership to help to plan and implement work towards meeting the global target of restoring 15 percent of the degraded ecosystems.

Original propositions of the working group:

1) The current ecosystem-specific conservation and action plans that have been approved by the Finnish Government must be completed in accordance with the decisions.

2) We need an analysis of the current ecosystem restoration programmes and mechanisms and their effects and effectiveness. We must also map the mechanisms and practices that degrade the state of ecosystems. We must assess the steering methods based on the results, and determine if they need to be changed.

3) **Cooperation and communication between administrative branches and sectors must be improved, and the steering methods for ecosystem restoration must be made harmonious. Cooperation models between regional operators must be improved.**

4) **We must minimize the negative effects of activities that degrade ecosystems by improving planning and examining the different elements of sustainability simultaneously.**

5) **We must start preparing a shift from ecosystem-specific action plans and conservation schemes to programmes aimed at restoring multiple ecosystems.** If Finland wants to achieve the ecosystem restoration targets, these programmes must be coordinated and provided with sufficient resources so as to ensure that all the elements of sustainability are taken into account.

6) **We must analyse alternative sources of funding and new operational models that could make the funding base of the ecosystem restoration work more diverse, such as market-based compensations.**

7) All follow-up work related to ecosystem restoration must include an assessment of the economic and societal effects of the restoration measures.

8) We must launch research and development projects to support ecosystem restoration and to produce more information. More information is needed, among other things, for the assessment of ecosystem service effects, climate change mitigation and adaptation, and about the interfaces and transitional zones between ecosystems.

9) **The selection of restoration measures targeted at improving the ecosystem condition should also consider the ability of the measures to simultaneously support local livelihoods, mitigate climate change and support adaptation to climate change.**

10) **We must promote international dialogue on best practices and the assessment of the state of ecosystems. The procedure developed by the working group must be promoted actively. The aim is to make the assessment methods used in different countries comparable with each other.**

Additional propositions for the international readership:

1. The realization of the savings and the benefits recorded in the prioritization plan requires long-term commitment and resources to ecosystem restoration.

2. If a net 15 percent restoration compared to the situation in 2010 is seriously pursued, then continued degradation of the landscape since 2010 must be accounted for in the calculation of the condition of the ecosystems.

3. In an optimal case also the broader economic and societal impacts including those to employment should be assessed. The Finnish working group was constrained to complete the work within a year, and with this constraint such assessments were not feasible.

4. Practical implementation of restoration measures should take place without delay to prevent further degradation and biodiversity loss.

5. The assessment of the ecosystem condition is the task of scientists and experts, and in the assessment face there should be no room for policy making. However, for a successful outcome, co-operation and engagement of relevant stakeholders is necessary during the prioritization, decision making and the practical implementation of restoration.

1 Global conventions as the premise for ecosystem restoration

Ecosystem and biosphere degradation caused by the human population size, per capita consumption and their increase are among the greatest threats for biodiversity and ecosystem services, and thus also for the future of humanity (e.g. Steffen et al. 2015). Intensive land-use has been globally acknowledged to cause serious compromises and threats for human well-being (MEA 2005; IPBES 2015). Ecosystem restoration has been seen as a necessary tool to mitigate global ecological threats, and several ambitious global, regional and national strategies, incentives and agreements have been set to ensure restoration of ecosystems and to help halt biodiversity loss and the consequent degradation of ecosystem services.

Some of the most influential international strategies and agreements considering ecosystem restoration include Aichi Target 15 of Strategic Plan for Biodiversity 2011–2020 (SCBD 2010) rearticulated in Goal 15 in the Sustainable Development Goals (UN 2015), the Bonn Challenge (2011), and the New York Declaration on Forests supported by the United Nations Secretary General's Climate Summit (2014). The goals of these strategies are to restore at least 15 percent of degraded ecosystems by 2020, to restore 150 million hectares of the world's deforested and degraded lands by 2020, and to restore in total 350 million hectares (3.5 million km^2, 2.35% of the world's land area) of degraded landscapes and forestlands by 2030, respectively.

In Finland ecosystem restoration and management for biodiversity have been studied and executed in different ecosystem types already for years (e.g. Toivanen & Kotiaho 2007a, b; Vanha-Majamaa et al. 2007; Haapalehto et al. 2010, 2104; Aapala et al. 2013; Similä & Junninen 2012; Halme et al. 2013; Komonen et al. 2014; Maanavilja et al. 2014; Noreika et al. 2015, 2016; Similä et al. 2014; Elo et al. 2015, 2016; Kareksela et al. 2015; Punttila et al. 2016). This work was originated because of the national adoption of the CBD Strategic Plan for Biodiversity 2011–2020 including the Aichi Target 15 (SCBD 2010) and the EU Biodiversity Strategy (European Commission 2011). National targets have been developed in the national strategy (The Finnish Government 2012) and action plan (Anonymous 2013a) for the conservation and sustainable use of biodiversity.

The Convention on Biological Diversity (CBD) and the targets set in the Strategic Plan for Biodiversity 2011–2020

The main targets set in the Convention on Biological Diversity (78/1994) are the conservation and sustainable use of biodiversity. The aim is to halt the degradation of biodiversity by 2020 at global, regional and national scales. The strategic plan and the so-called Aichi targets approved by the tenth meeting of the Conference of the Parties to the CBD in 2010 (SCBD 2010) are an international framework which the parties to the Convention implement.

The plan comprises 20 targets, and target 15 is the most important of these from the point of view of ecosystem restoration. It concerns degraded ecosystems, 15 percent of which should be restored by 2020:

Target 15: "*By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 percent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.*"

The rationale for target 15 (Anonymous 2010) states that the conservation, restoration and sustainable use of forests and peatlands are proven means to sequester carbon dioxide. Deforestation, wetland drainage and other land use changes lead to growing emissions of carbon dioxide and other greenhouse gases. Thus, the international target is related not only to the securing of biodiversity, but also to climate change mitigation and adaptation. When backed up by incentive politics, ecosystem restoration measures can simultaneously support local livelihoods, secure biodiversity and mitigate climate change (Venter et al. 2009; Anonymous 2010).

Our life insurance, our natural capital: an EU biodiversity strategy to 2020

On 3 May 2011, the European Commission published the communication "Our life insurance, our natural capital: an EU biodiversity strategy to 2020" (European Commission 2011). The European Council released its conclusions concerning the strategy in June 2011 and December 2011. The communication sets the following headline target to 2020: "*Halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss.*" The communication has the following vision: "*By 2050, European Union biodiversity and the ecosystem services it provides – its natural capital – are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided.*"

EU biodiversity strategy has several targets and Target 2 points out that numerous ecosystems and ecosystem services have been degraded, largely due to ecosystem fragmentation (which is caused by habitat loss and degradation). The target is aimed at maintaining and enhancing ecosystem services by restoring the degraded ecosystems through the integration of green infrastructure into land-use planning, for example. The target is considered to i) enhance the functional links between ecosystems and ii) contribute to climate change mitigation and adaptation. The key aim of target 2 is to restore 15 percent of the degraded ecosystems by 2020. Although target 2 does not state this directly, it is evident in the rest of the strategy that the targets should be compared to the 2010 level. Exact wording of the Target 2 of the EU biodiversity strategy is below (European Commission 2011).

Target 2: *"By 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems."*

Government Resolution on the Strategy for the Conservation and Sustainable Use of Biodiversity in Finland for the years 2012–2020, 'Saving Nature for People'

On December 20, 2012, the Finnish Government approved the resolution on the strategy for the conservation and sustainable use of biodiversity in Finland for the years 2012–2020 (The Finnish Government 2012). The strategic goals and targets in the resolution correspond to the issues covered by the Convention on Biological Diversity. The strategy aims to promote ecologically, economically, socially, and culturally sustainable utilization and development of biodiversity and natural resources in Finland, while also safeguarding biodiversity, the vital needs of future generations, and livelihoods that are based on natural resources. The Government resolution has 5 strategic goals and 20 specific targets related to these. In its resolution, the Finnish Government states that *"These guidelines have been defined with reference to conditions in Finland to comply with the goals defined at the CBD's COP 10 conference and the targets set in the EU's biodiversity strategy. They form a flexible framework capable of responding to Finland's national needs and priorities."* From the point of view of ecosystem restoration, the most important target is target 15 under strategic goal 4.

Strategic goal 4, target 15: *"Ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced through conservation and restoration. Finland participates in global efforts to restore at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification. The impacts of the increased use of bioenergy on biodiversity and the nutrient and carbon cycles of forests have been assessed, and guidelines have been set to safeguard biodiversity. Urban biodiversity is enhanced through conservation measures, management measures and the provision of structures that promote biodiversity."*

2 What do we mean with ecosystem restoration and other relevant concepts?

The concepts related to ecosystem restoration can have several, slightly different meanings and definitions. In our interpretation the ultimate goal is to restore ecosystems with measures that enhance biodiversity in the area, secure the availability of ecosystem services for future generations, and contribute to climate change adaptation.

Restoration and rehabilitation

Restoration has the following definitions:
SER (2004): "*The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.*"

UNEP/CBD/SBSTTA/15/4 (2011): "*The process of actively managing the recovery of an ecosystem that has been degraded, damaged or destroyed.*"

IPBES (2015): "*Restoration is defined as any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state*" and "*rehabilitation is used to refer to restoration activities that may fall short of fully restoring the biotic community to its pre-degradation state.*"

EC Biodiversity Strategy Impact Assessment (2011): "*The return of an ecosystem to its original community structure, natural complement of species, and natural functions*".

This shows that "restoration" can be interpreted in many ways. The first three of the definitions quoted above are very similar and focus on assisting the recovery. The fourth definition, on the other hand, describes restoration as the return of an ecosystem to its original natural state or condition. There are two drawbacks in the fourth definition: i) recovery of an ecosystem essentially follows some natural successional trajectory, and the restoration activities by humans can only assist in this process; and ii) the requirement on returning all the way to the original natural state or condition is for most cases not feasible (Maron et al. 2012). The original natural state is necessary as a baseline for assessing the magnitude of damage, and while the target should be to the direction of the natural state baseline, the natural state or condition itself does not need to be the target. The latter is taken into account in the third definition that differentiates restoration from rehabilitation. In the third definition rehabilitation is used to refer to restoration activities that fall short of fully recovering the ecosystem to its pre-degradation or original natural state or condition and therefore restoration is only used when full recovery to the natural state is achieved or targeted.

In this report restoration is defined as follows: *Restoration includes all intentional activity that initiates or accelerates the recovery of an ecosystem towards its pre-degradation i.e. original natural condition*. This definition does not rely on the success of the selected restoration measures and it basically integrates the terms restoration and rehabilitation differentiated by IPBES (2015). At the same time the term allows us to include a wide array of methods which aim to enhance ecosystem recovery. In addition to more traditional restoration measures these methods encompass e.g. nature set-asides as well as enabling measures such as changes in legislation and management practices.

Degraded ecosystem and the pre-degradation condition

As we learnt earlier, different international and national conventions and strategies often include the target to restore at least 15 percent of the degraded ecosystems. To verify our success in meeting the target, we need to have a common understanding of the terms degraded ecosystem and pre-degradation condition.

Degraded land is defined as the state or condition of land which results from the persistent decline or loss in biodiversity and ecosystem functions and services that cannot fully recover unaided within decadal time scales (IPBES 2015). In this case inability to recover unaided must refer to i) crossing an ecological tipping point after which the ecosystem is unable to recover or to ii) business as usual land use and management that will prevent an ecosystem from recovering unless aided with a change or cessation of management.

The logical conclusion is that since we have noticed that ecosystems have degraded, we must have an idea of the pre-degradation state of the ecosystem. This leads us to an important question: what is the state or baseline against which we should compare the current condition? In the context of conservation and sustainable use of biodiversity, the state against which the current condition must be compared is the pre-degradation state or as we also call it here the natural state (Figure 1).

In scientific philosophical literature about conservation biology, natural state is one of the most debated concepts. The question is whether we can say that there is a natural state without humans (see, for example, Hunter 1996; Haila et al. 1997; Jackson & Hobbs 2009). The perspective and answer vary based on the extent to which humans are seen as a part of nature. Ultimately the fact is that humans are just another species and thus a part of nature. In strictly defined terms, this would mean that an environment that has been shaped by humans is in its natural state. However, it has been firmly established in international and national agreements, strategies and programmes that we do not consider current ecosystems to be in their natural state but rather we consider them to be degraded to different degrees. **In Finland, the pre-degradation state was defined as the state of the ecosystems that would be existent in the absence of human intervention.** The definition of degradation is then derived from the definition of the pre-degradation state; it is the difference between the current condition and the pre-degradation state (this is elaborated upon later).

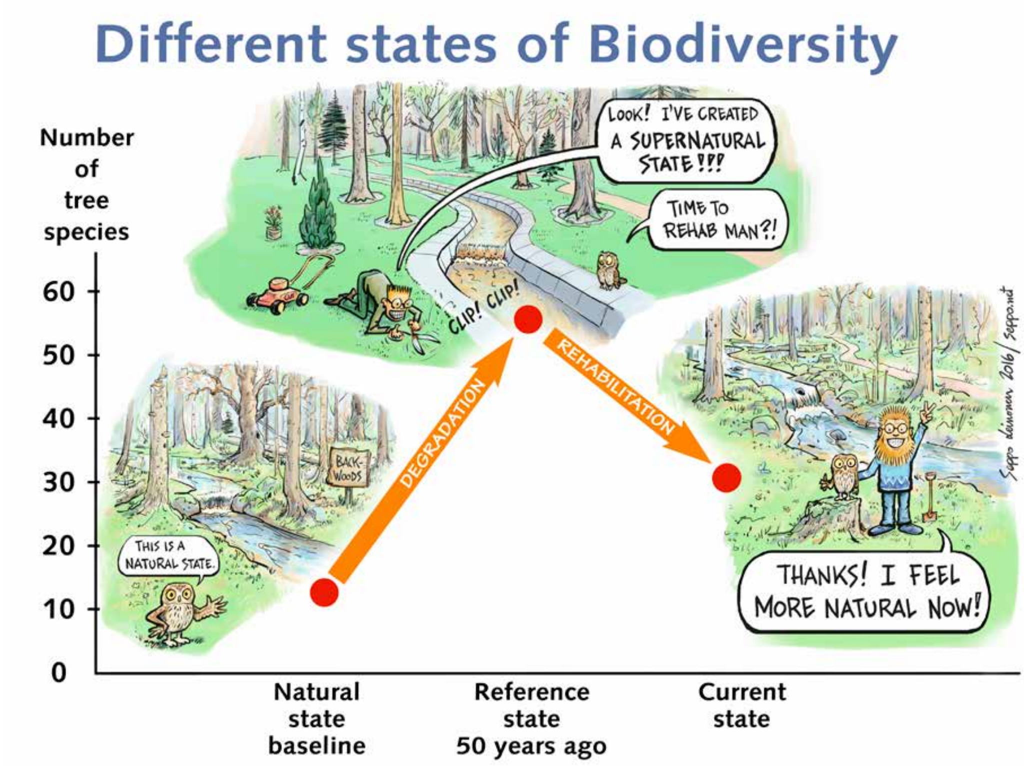

Figure 1. Different states of biodiversity. In the x-axis there are (from right to left) the current state, reference state 50 years ago and the natural state baseline. In the y-axis there is an indicator of biodiversity (number of tree species). Between the current state of the biodiversity and the reference state 50 years ago there appears to be a clear negative trend in the tree species diversity. However, when a natural state baseline is added, it immediately becomes clear that the negative trend we thought we were observing was an illusion created by the arbitrary choice of the reference state. In this hypothetical example, several alien tree species were introduced to the focal ecosystem in the past, some of which were successfully eradicated between the reference state and the current state. Natural state baseline anchors the observations and removes the ambiguity in the direction and magnitude of the change. The difference between an arbitrary year as a reference state and the natural state baseline may seem trivial but like the example here illustrates, in the context of assessing trends of biodiversity (or e.g. ecosystem services), it is far from it. Natural state baseline reflects the deviation from genuine sustainability and as a global standard would ensure the fairness and comparability of biodiversity and ecosystem service assessments across countries that are in different phases of economic development (Kotiaho et al. 2016b).

The aim of the work described in this text is to restore degraded ecosystems and to estimate the costs and amount of improvement achieved through the planned measures. Considering the requirements of the real world, attention should be paid to the following three aspects:

i) The selected pre-degradation state will always influence the assessment of the amount of degradation. In Finland, we compared the current condition with the pre-degradation state, which, in most cases, is the natural state. While this maximises the amount of degradation in the assessment, it does not require nor allow the making of subjective choices about the degree of human intervention permitted in the pre-degradation state. Had we chosen any state with some degree of human intervention as the pre-degradation state, our assessment on the amount of degradation would have been smaller but untruthful and subject to endless debate about the definitions of human-influenced reference states (see also UNEP 2003; Newbold et al. 2015; Kotiaho et al. 2016).

ii) As an exception to the rule, semi-natural grasslands have no natural state that would be free of human intervention, because these ecosystems have been shaped and maintained by human activities. These ecosystems cannot retain their current condition without constant human activities. Instead, their natural succession would slowly return the ecosystems towards their natural state. However, because people often consider the current condition of the semi-natural grassland ecosystems to be valuable, the pre-degradation state selected for these ecosystems was not their natural state. It is worth mentioning that this was a necessary political compromise during the work, but that strictly speaking these ecosystems are degraded.

iii) The natural or pre-degradation state used for determining the amount of ecosystem degradation does not have to be and usually is not the same as the target state of restoration (see, for example, Higgs et al. 2014; Kotiaho et al. 2016). This is an extremely important point to consider and reflect upon. The natural state baseline is necessary for assessing the magnitude of damage, but while the target should be defined in relation to the natural state baseline, the natural state itself need not be the target. The difference is that natural state derives from scientific research, while the target state is unavoidably a political decision that balances social, economic and ecological interests (UNEP 2003; Kotiaho et al. 2016). Nature reserves and set-asides are an exception to the rule, and the target in these areas can be and is restoration to the natural state.

Ecosystem and habitat

Ecosystem is one of the fundamental concepts in ecology. It refers to an area that is relatively uniform in terms of its environmental conditions, and the interdependent community of flora, fauna, fungi and microorganisms living in it. Ecosystem is the primary spatial level used in the CBD to discuss the safeguarding of biodiversity and ecosystem services on a global scale. Habitat, on the other hand, is the natural living and reproduction environment of the species. Each ecosystem is the habitat of numerous species, and the habitat of one species can include elements from one or more ecosystems. In this report, we use exclusively the concept of ecosystems or ecosystem types (see below), although the procedures we develop are applicable also to habitats and essentially to any spatial scale.

In principle, all ecosystems should be examined together, but for practical reasons the examination of Finnish ecosystems was first divided into the following main ecosystem types: forests, peatland, rocky outcrops, coastal ecosystems, fell area and cultural ecosystems, which encompass semi-natural grasslands (including grazed woodlands and wooded pastures), agricultural ecosystems and urban ecosystems. Open sea was not, and inland water ecosystems were only partially targeted by the working group. Of the targeted ecosystem types urban ecosystems were only partially covered.

Ecosystems were further divided into categories (sometimes called ecosystem types). For example, forests were further divided into the following types: herb-rich forests, herb-rich, mesic and sub-xeric heath forests, and xeric and barren heath forests. Peatlands were divided into spruce mires, pine mires, and bogs and open peatland (including fens and rich fens). In this report we use one forested ecosystem type, herb-rich forests, as an example illustrating the details of the work conducted for each of the ecosystem types.

Ecosystem services

The different species, or species diversity, in an area form the biotic component of an ecosystem. Ecosystem functions are the result of the joint functioning of the species, and there are no ecosystem functions without the species. Ecosystems produce a number of benefits for humans, and these benefits are known as ecosystem services (MEA 2005). Ecosystem services are divided into four categories: provisioning services, regulating services, cultural services and supporting services. According to estimates, the loss of ecosystems and ecosystem services would have immense detrimental effects on human economy and well-being, and once lost, ecosystem services are often difficult, if not impossible, to recover (Kniivilä et al. 2011; Costanza et al. 2014; Jäppinen & Heliölä 2015).

When we aim to increase the production of certain ecosystem services for economic purposes, the situation becomes problematic from the point of view of the conservation of biodiversity and the sustainable use of ecosystem services. This is because the enhanced production of specific ecosystem services (like wood provision) is likely to conflict with the target of preserving natural biodiversity (Bennett et al. 2009; Schröter et al. 2014). Changing the amount of an ecosystem service for the purpose of maximising economic benefit will inevitably affect the natural functions of the underlying ecosystem service (see also Döhrena & Haasea 2015). Enhancing the production of one ecosystem service at the expense of other ecosystem services and biodiversity will make such use of the service in question unsustainable.

Restoration measures portfolio

There is usually a variety of restoration measures available for each ecosystem. The measures range from traditional restoration and nature management measures to different levels of conservation (removal of human impacts). With the restoration measure portfolio, we mean the suite of measures determined by the expert working group that should be applied within each of the ecosystems. Restoration measure portfolios are ecosystem-specific: for example, measures targeted at peatlands differ from measures targeted at forests. Prioritization is an important element in the formation of the restoration measure portfolio, and it is based on certain criteria (to be specified further later on). Each of the measures in the portfolio will be applied on a specific proportion of the degraded area, and the portfolio as a whole has to be designed so that it is able to deliver the targeted 15 percent overall reduction in degradation.

Prioritization and cost-efficiency

The compilation of the ecosystem's restoration measure portfolio involves prioritization between the measures. This is because the measures are not equally valuable for biodiversity or ecosystem services and because the per-unit costs of the measures vary. Prioritization means that these differences are taken into account in the formation of a cost-effective portfolio. Cost-effectiveness is a central criterion used in the prioritization of measures alongside ecological effectiveness and contributions to ecosystem services. In addition to this, a realistic extent of area for the application of each measure needs to be determined. For example, the controlled burning of forests can bring notable biodiversity benefits, but due to practical restrictions it can only take place in a rather small area. Furthermore, different measures can complement each other by bringing benefits to (restoring) different components of biodiversity, which also should be taken into account in the prioritization. For example, the preservation or increasing of the amount of decaying wood benefits different species than controlled burning. An element of balance needs to be built in the restoration portfolio.

In this work cost-effectiveness and balance have primarily been examined from the perspective of biodiversity. Cost-effectiveness means the ratio of reduction in the degree of ecosystem degradation to the per-unit cost of the measure. In general, cost-effective measures are the preferred choice, because they yield better results with the same investment compared to less effective methods.

In addition to the restoration measures within an ecosystem, also the ecosystems are prioritized. The prioritization among ecosystems is based on an analysis identifying the ecosystems where reasonable investments bring the greatest reduction in the degree of ecosystem degradation. Investing more in these ecosystems enables achieving the 15 percent restoration target in a cost-effective way.

No Net Loss and applicability to biodiversity offsetting

If activities that degrade ecosystems are compensated for by restoration measures so that the overall state of the ecosystem is not degraded, the activities are not considered to cause ecosystem net loss. In addition to the assessment of ecosystem restoration, the procedure described in chapter 4 can be applied to the assessment of net loss resulting from any development project or initiative that damages and degrades ecosystems. Hence, the procedure outlined here is applicable also in the context of biodiversity offsetting (BBOP 2012; Bull et al. 2013; Quetier et al. 2012, 2013). Step 7 of the procedure that is specified in chapter 4 can be applied for assessing the damage with the same logic as it is used to assess the restoring effects of the measures. This enables calculating the degree of ecosystem degradation caused by the development project or initiative. For there to be no net loss, the compensating measures need to equal (or exceed) the degree of degradation. Thus, the need for compensation can be considered to be equivalent to the ecosystem restoration target. Applying the procedure to the compensation need enables calculating the costs for the compensation of ecosystem degradation with the help of the restoration measure portfolios. Interpreted the other way around, the same procedure also enables estimating the actual costs of ecosystem degradation.

3 Minimum requirements for conceptually sound ecosystem restoration

When beginning to implement the CBD Target 15 (SCBD 2010) in practice, the very first question one is faced with is what is meant with the *"restoration of at least 15 percent of degraded ecosystems"*? Understanding the extent of damage is the fundamental starting point to any repair process. From an ecological perspective, ecosystem degradation or improvement has a minimum of two dimensions: the extent of area that has become degraded or improved and the degree of the degradation, or its counterpart improvement, at any given location (fig. 2, 3) (Kotiaho et al. 2015a, b; Kotiaho & Moilanen 2015). Note that formally improvement needs to be calculated as the reduction in degree of degradation rather than improvement of the ecosystem condition but for textual simplicity we occasionally also use the term improvement.

It is important to recognize, that knowledge about the extent of the degraded area alone is not sufficient for providing a conceptually sound estimate of the degree of ecosystem degradation or improvement, because from an ecological perspective it makes a great deal of difference whether an ecosystem has been only slightly degraded or is almost completely lost. The existence of these two dimensions illustrated in Figures 2 and 3 has so far not been appreciated in the pertinent literature (e.g. Egoh et al. 2014) and it has been only partially acknowledged in the first attempt to operationalize the 15 percent restoration target (Lammerant et al. 2013). One can see from Figure 3 that the current extent of damage, which from now on will be called degree of degradation, at each location can be obtained by subtracting the current condition from the pre-degradation state.

So what are the problems if we do not take into account the two dimensions? To illustrate, Egoh et al. (2014) evaluated the options that exist for meeting the restoration target based on spatial conservation prioritization analysis across threatened habitats, species and ecosystem services in 27 Member States of the EU. They also explored how inclusion of restoration costs in different Member States influences the prioritization. Restoration planning that spans several countries or indeed the entire EU is called for because a lack of global international cooperation and coordination will unavoidably significantly reduce conservation outcomes (Pouzols et al. 2014). However, while the aims of Egoh et al. (2014) are commendable, there are conceptual and operational challenges compromising the conclusions of their study (Kotiaho & Moilanen 2015). The conceptual issue related to Figure 4 is the neglect of both the degree of degradation and the degree of improvement of the ecosystem condition expected due to restoration action (y-axis in Figures 2 and 3). The operational issue is the inclusion of inappropriately measured restoration costs into the analyses: Egoh et al. (2014) reviewed information about the financial resources required by each Member State from the European Commission's LIFE programme for restoration activities in Natura 2000 sites and estimated a mean per hectare restoration cost for each Member State. A mean cost that ignores the type of ecosystem restored and the effectiveness of the restoration measure will incorrectly prioritize cheap and inefficient rather than cost-effective restoration measures and areas. Thus, an approach such as in Egoh et al.

(2014) runs a risk of focusing restoration efforts towards areas where the improvement of ecosystem condition as a result of restoration is the smallest. In other words, it is not at all satisfactory to identify 15% of degraded land area where a minimal amount of restoration can be done for little or no cost. If restoration effort is minimal, the true net reduction in degradation will be close to zero rather than 15% or more.

To support EU Member States in the development of a strategic framework for setting priorities for ecosystem restoration, the European Commission prepared guidelines with the help of ARCADIS, in which a "*four-level model for ecosystem restoration*" was developed (Lammerant et al. 2013). Although it was a good first step, in its original form the model does not properly take into account the degree of ecosystem degradation or improvement and thus it does not on its own allow assessment of the success of achieving 15 percent net improvement or any other quantitative target (see also Tittensor et al. 2014). Moreover, even if a scientifically valid approach within the four-level model framework could be developed, in reality its operational implementation would be exceedingly difficult. This is primarily because for each focal ecosystem one would need to develop descriptors of the ecosystem condition at each of the four levels, and for each degraded component in each of the ecosystems, threshold values for moving between each of the levels should be determined. Attention will focus on operations that easily move areas from one subjectively defined degradation class to another.

In the next chapter we develop a ten-step procedure that is based on empirical continuous degraded components and in which there is no need for categorization or *a priori* target setting. This procedure fills a recently identified important gap in measuring progress towards restoration targets (Tittensor et al. 2014): there are no previous indicators to measure progress towards the CBD target 15.

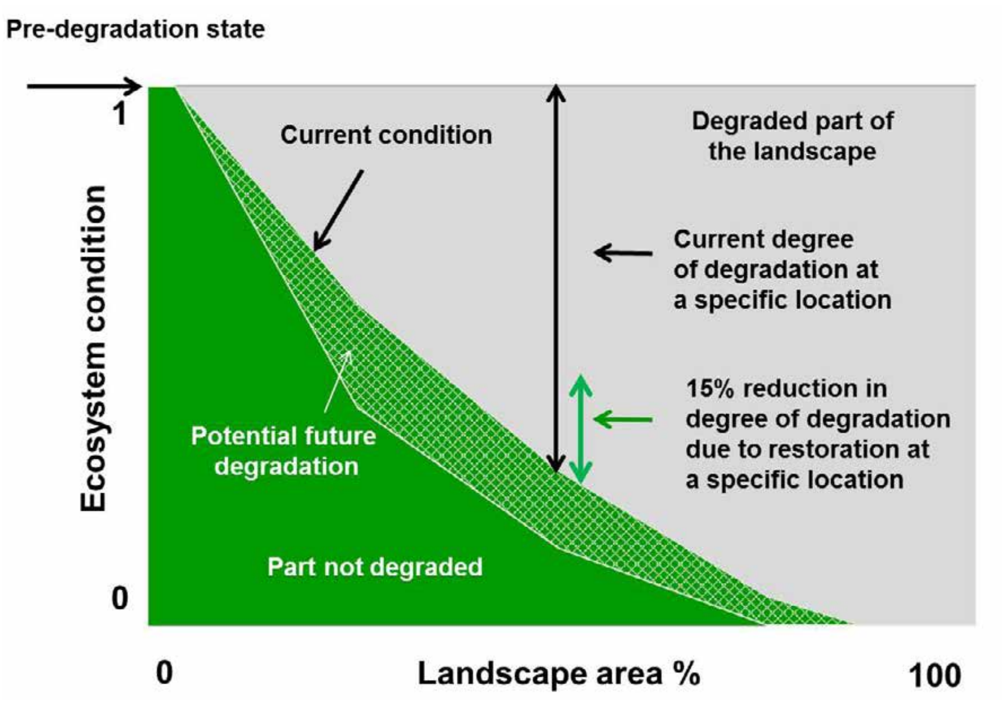

Figure 2. Conceptual illustration of the ecosystem condition (y-axis) before degradation (pre-degradation state), current condition, and the current degree of degradation at any specific location of the landscape (x-axis). In the schematic, land parcels of the hypothetical landscape have been ordered on the x-axis in a decreasing order of condition: high-quality areas on the left and highly degraded areas on the right. The grey area is the degraded part of the landscape and green area is what remains of the landscape after degradation. The overall degree of degradation is an aggregate of the extent of the degraded area (x-axis) and the current degree of degradation at each of the locations (y-axis).

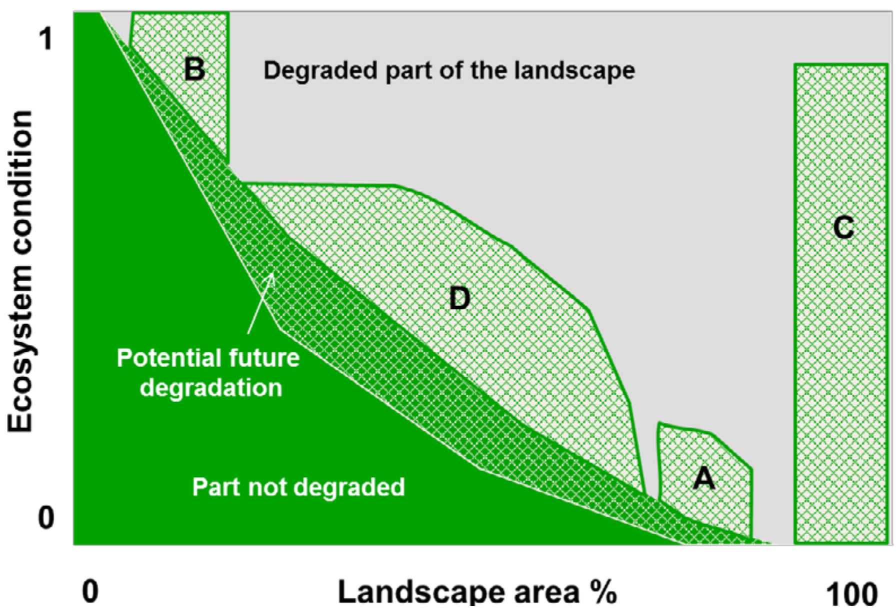

Figure 3. Conceptual options for restoration. On x-axis landscape area in decreasing order of condition and on y-axis ecosystem condition. Area of the degraded part covered by each restoration option A–D, i.e. combination of landscape area and improvement in ecosystem condition, represents the net reduction in overall landscape degradation the option delivers. Options A, B, and C focus on 15 percent of landscape area. Nevertheless, option A fails to deliver 15 percent net reduction in overall landscape degradation because the improvement of ecosystem condition is small. Option B fails since even complete restoration of 15 percent of landscape area that is only slightly degraded does not deliver 15 percent net reduction in overall landscape degradation. Option C does deliver 15 percent net reduction in overall landscape degradation, but the investment and effort required for nearly complete restoration of totally degraded sites is likely to be not only socially and economically unsustainable, but also biologically impossible. Option D does deliver the 15 percent net reduction, by significant partial restoration at sites spanning much more than 15 percent of total landscape area. To guarantee no net loss, restoration should also fully compensate for any potential further degradation.

4 Procedure for assessing and reversing ecosystem degradation

The past c. 30 years of restoration ecology research has accumulated a lot of knowledge (e.g. Suding 2011; Halme et al. 2013; Kareksela et al. 2013; Wiens & Hobbs 2015). Unfortunately, like many other academic disciplines, much of restoration ecology has advanced to a level of detail that makes it somewhat divorced from on-the-ground operational reality of ecological restoration practice. For example, highly sophisticated methods for optimal allocation of habitat restoration do exist (e.g. Noss et al. 2009; Wilson et al. 2011; Pouzols & Moilanen 2013), but these methods require ample human resources and they are extremely data-hungry. Given the schedule and the magnitude of the task, lower-dimensional approaches are operationally more feasible. Following the heuristic logic of Figure 2, we drafted the procedure that retains the ecologically most relevant components while having otherwise minimal data demands and complexity. Data is naturally used whenever available, although all aspects of the procedure are fully operable based on quantitative estimates and opinions of experts. The procedure is based on simplification and modification of prior work by Pouzols et al. (2012) and Pouzols and Moilanen (2013).

In Figure 4 we have sketched information flow of the procedure. Its basic idea is conformity and comparability between all ecosystem types, and consequently capacity to determine, how much each ecosystem type needs to be improved in relation to other ecosystem types when aiming at any given restoration net target effect or at some known level of funding. The procedure rests on the identification of quantitatively measurable continuous ecosystem components that are known to be associated with maintenance of biodiversity and ecosystem services (Halme et al. 2013; Pereira et al. 2013; Rayment et al. 2014). Contrary to some other restoration frameworks (e.g. Lammerant et al. 2013) there is no need for categorization or *a priori* target setting here. With the procedure we are able to i) measure the degree of ecosystem and ecosystem service degradation in different ecosystem types, ii) identify a balanced and cost-effective portfolio of restoration measures within each ecosystem type, and iii) prioritize restoration efforts among ecosystem types. The procedure enables simultaneous scrutiny over all ecosystem types.

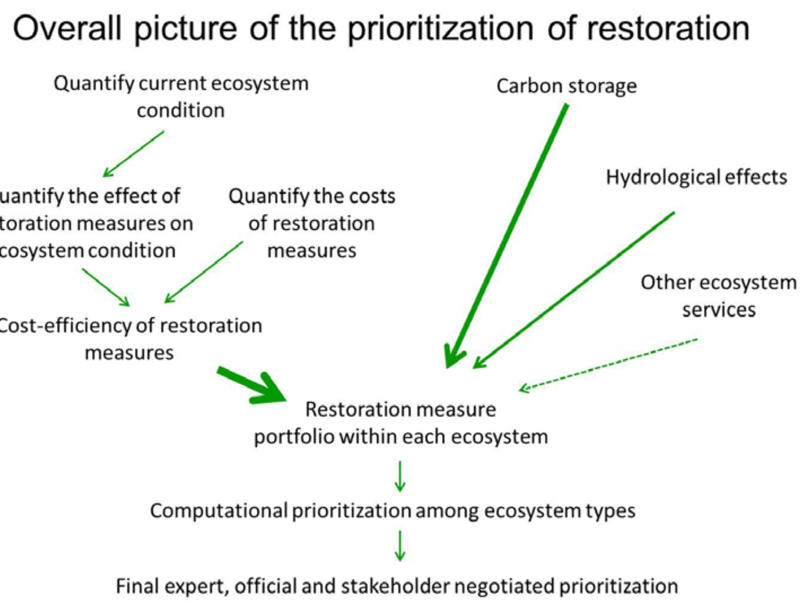

Figure 4. Overall outline of the procedure of the prioritization of restoration. The procedure can be divided into four main phases (columns in fig. 5): (i) defining the focal ecosystem categories, (ii) determining current ecosystem condition, (iii) determining effects and costs of alternative restoration measures and (iv) prioritizing restoration measures within and among ecosystems. The procedure can be further divided into ten steps that are illustrated in Figure 5 and which will next be described in detail.

Figure 5. The four phases (columns) and ten steps of the procedure for reversing ecosystem degradation by cost-effective restoration measures. Phase I) comprises the first two steps, which define focal ecosystems and identify ecological components (e.g., hydrology, amount of dead wood, etc.) that have degraded. Phase II) comprises steps 3–5, which determine the current condition of the ecosystems. Phase III) comprises steps 6–8 which determine the ecological effects and costs of alternative restoration measures. Phase IV) comprises the final two steps and launches into cost-effective and balanced prioritization of restoration measures within each ecosystem type and prioritization across ecosystem types.

Step 1. Decide focal ecosystem types and determine the area of each

1. Decide focal ecosystem categories. Categorization of ecosystems is somewhat artificial (Lamarck 1809) but in practice necessary, as it facilitates expert-driven identification of ecosystem-specific degraded components and potential restoration measures. Ecosystem categories used in international biodiversity strategies, such as the habitat types in the EU Habitats Directive classification (EU 1992), may provide a feasible shortcut to categorization. From here on, all the tasks specified are conducted separately for each ecosystem type.

2. Determine the total area of each ecosystem type. Divide the total area into the (variably) degraded part and the part that has not been degraded.

Step 2. Determine degraded components in each ecosystem type

1. For each of the ecosystem types identified in step 1, determine the main functional or structural components that may have degraded from the perspective of biodiversity and ecosystem services. Here it is essential to keep in mind that ecosystem services are not a biological phenomenon, but that by definition they are the ecosystem functions that humans value (MEA 2005), and there may be trade-offs between them and biodiversity (MEA 2005; Bennett et al. 2009; Schröter et al. 2014). Where trade-offs occur, we must not let biodiversity be compromised for ecosystem services. This is because if we do, we are not really imposing limits to ourselves (Meadows et al. 1972), but rather, we let economic and other benefits drive further unsustainable exploitation of our environment. That said, the procedure described here can be applied to biodiversity only, ecosystem services only, or both simultaneously, depending on the aims of the particular case.

2. Determine the area of the ecosystem that has been degraded by each of the components or their relevant combinations.

Step 3. Determine current and pre-degradation condition of each degraded component

1. Using empirical data and expert knowledge available, estimate the current mean condition of each degraded component in the ecosystem identified in step 2. The EU biodiversity strategy suggests that the current condition against which the targets should be compared is year 2010. Note that in many cases human activities may degrade ecosystems so rapidly that even large-scale restoration measures cannot compensate for this ongoing negative trend. Hence, if we take the target of reducing the degradation of ecosystems by 15 percent from the 2010 level literally, noting that the condition of ecosystems has degraded further since 2010, we should be taking more measures at the moment compared to the amount of work needed for reducing the degradation by 15 percent in 2010.

2. Specify the natural, pre-degradation state of each degraded ecosystem component identified in step 2. Note that the pre-degradation state needs to be based on ecology, not on societal value. It is also very important to keep in mind that the pre-degradation state is not a target; it is utilized to evaluate the current condition and to estimate and compare the amount of recovery of ecological value via alternative restoration measures. Targets for the desired amount of improvement are set separately (step 9).

While the concept of natural state or pre-degradation state in ecology has often been problematized (Hunter 1996; Haila et al. 1997; Jackson & Hobbs 2009; Higgs 2014), conceptual or actual uncertainty about the natural state of an ecosystem is not an excuse for lack of action. It is a simple fact that a pre-degradation state is needed for each of the degraded components; otherwise the degree of degradation and thus the amount of restoration needed or degree of restoration success cannot be determined (for further discussion see section "Degraded ecosystem and the pre-degradation state" in Chapter 2 on pages 17-18).

Step 4. Determine the loss of ecosystem condition from each degraded component

Determine the fraction of the ecosystem's overall condition lost when the component has been completely degraded. This is needed for three reasons: i) different ecological components have different overall influence of ecosystem condition, ii) the current condition is often not completely degraded, iii) restoration does not usually lead to complete recovery (Maron et al. 2012). In most cases, the ecosystem condition is not zero even if there is a complete degradation of one of its components and the current condition is determined by a combination of a number of variably degraded components. It is important that these components are treated as continuous measures, both because this corresponds to the ecological reality that degradation is a continuous process and because the need to specify subjective thresholds is removed.

Step 5. Calculate overall ecosystem condition remaining

With the information gathered in the steps 3 and 4 we next calculate the (mean) ecosystem condition remaining at the current state. Assuming multiplicative effects of the components on ecosystem condition, the current condition remaining in ecosystem, R^E, can be calculated as

$$R^E = \prod_{n=1}^{N^E} \left(1 - L_n^E(1 - n_{curr}/n_{ref})\right)$$

in which N^E is the number of relevant components in the focal ecosystem E, and L_n^E is the loss of ecosystem condition if component n is completely degraded (step 4), and n_{curr} and n_{ref} are the state of component n in the current state and in the pre-degradation state, respectively (step 3). In the case there is a nonlinear relationship in how ecosystem condition changes with the change in condition of any component, the equation above can easily be expanded by a function $f\,(n_{curr}/n_{ref})$, which can model e.g. a threshold effect via a sigmoid function. Following from the equation above, when losses of ecosystem condition due to individual components are close to zero, the ecosystem condition remaining is close to one. Importantly, many degraded components can be measured by continuous variables and the current situation usually is only a partial degradation of the component. Also, even complete loss of a component might only cause partial loss of ecosystem condition - like a forest does not completely cease to be a forest even if there is zero dead wood remaining in it (for details see the worked out example on herb-rich forests in chapter 5).

It is worth mentioning, that subtracting the outcome from this model from one (i.e. 1-R^E) represents the minimum degree of degradation in the focal ecosystem. One should aim at including the components considered to be most important for the ecosystem condition and biodiversity, but there nevertheless are always likely to be also other degraded components that may have effects on biodiversity. Note also, that only components that have been degraded need to be included. This is because the above equation has been developed such that the contribution of components that have not been degraded will equal multiplication by 1 and therefore have no effect on the overall degree of degradation of the ecosystem while the number determined in step 4 takes care that the overall degree of degradation will not be biased by this feature.

Step 6. Determine potential restoration measures and their per unit costs

1. List all potential restoration measures which could plausibly be implemented to reduce degradation in the focal ecosystem. Consider both active and passive restoration measures (Benayas et al. 2009).

2. Estimate the per-unit cost of each of the measures (e.g. €/ha). In some cases, also the socio-economic benefits of restoration can be very clear (de Groot et al. 2013).

The costs of restoration will generally be realized immediately when implementing restoration measures. Some measures are conducted just once or at long intervals, but some others may need to be repeated annually (e.g., management of semi-natural grasslands). We calculated all the costs until 2050. Despite the fact that CBD Target 15 specifically sets the target for year 2020, 2050 is a well-justified choice, because biodiversity strategies often give targets for two years: 2020 and 2050. For example, the vision of the national biodiversity strategy of Finland is: *"The favourable status of biodiversity and ecosystem services will be ensured by 2050"* (The Finnish Government 2012). Moreover, it is clear that the scheduling of the CBD Target 15 is overly ambitious and impractical (Kotiaho et al. 2015b).

Step 7. Determine ecosystem condition and services gain from each restoration measure

1. Determine how much each restoration measure would recover the fractional loss of each degraded component. In other words, estimate how much any given restoration measure returns the ecosystem condition back towards the natural reference state. By adding the reduction of the degradation into the current condition of each component *n* and resolving again the equation in step 5, one is able to calculate the overall reduction of degradation (improvement) of the ecosystem as a difference between the before and after restoration condition of the ecosystem (i.e. $[(1–R^E_{Current\ condition}) – (1–R^E_{After\ restoration}]$ in which R^E is the current and after restoration condition remaining in ecosystem obtained with the equation in step 5). The difference from this equation is the reduction in degradation due to restoration. Relating this value to the original degree of degradation, one is able to obtain the overall percentage reduction in ecosystem degradation. Note that very seldom would any single restoration measure result in a complete recovery of the ecosystem (Benayas et al. 2009; Maron et al. 2012).

2. Assess the effect of each measure on ecosystem services of interest. In this work we did not specify the effect on ecosystem services at the same level of detail as the effect on biodiversity, although in principle it would have been possible and would have been done should we have had more time to complete the assessment. Simplifying, we assessed the effects of the restoration measures on the ecosystem services by estimating the direction of the effect (positive or negative) supplemented in some cases with an approximate categorization of the magnitude of effect (see chapter 5). In contrast to the costs that are relatively immediate, the ecosystem condition gain, i.e. benefits of restoration measures, will be realized more slowly. Like stated before, we aimed to develop an operational procedure that retains the ecologically most relevant components while having otherwise minimal data demands and complexity. Therefore, we simplified reality and assumed that the full estimated benefits of restoration would be realized by 2050 so that i) there is no need to independently evaluate the rate at which each of the ecosystem recovers following each restoration measure, and ii) the time scale of the costs and benefits is comparable.

Step 8. Determine cost-effectiveness of all restoration measures

Divide the aggregate benefit of each restoration measure (step 7) with its estimated per-unit cost (step 6).

Step 9. Form the restoration measure portfolio within each ecosystem type

Form the restoration measure portfolio for each ecosystem type, based on the cost-effectiveness of the biodiversity effects (step 8), ecological gains (step 7), and the effects on ecosystem services. Cost-effectiveness is the most important factor in the formation of the restoration measure portfolio. The second most important aspect is ecological gain and ecosystem services. Third, the portfolio needs to be balanced because of both ecological and operational reasons.

The balancing is an important part of developing restoration measure portfolios, as it has to be accounted for that different restoration measures may influence different species and different parts of ecosystem condition. This complementarity of effects was for reasons of operational feasibility not explicitly included in our quantitative prioritization process. Hence, the expert group that designed restoration measure portfolios for the ecosystem also dealt with a balancing of actions. The balancing of a portfolio is needed also for another reason. It is possible that a cost-efficient measure can only be applied to a small area (e.g. prescribed forest burning), or that a cost-efficient measure produces low absolute ecological gains (low ecological effects combined with very low price, like retention trees; see chapter 5). As a consequence, while allocation to the single most cost-efficient measure would seem to make sense, the reality is that ecological and operational questions require a broader, balanced portfolio of cost-efficient and feasible actions.

In the Finnish work, the foci for ecosystem services were carbon stocks, water effects (water balance and nutrient load), and other ecosystem services as a group. The allocation number in the right-hand column (see Table 9 on page 48) indicates the share of the degraded area that needs to be treated with each of the restoration measures in order to meet the target level of restoration. The measures were prioritized based on empirical data as stated above, but the share of each selected measure was further adjusted by experts in order to create the final balanced restoration measure portfolio.

Step 10. Prioritize among ecosystem types

Prioritization among ecosystem types follows after the formation of the restoration measure portfolios. Prioritization among ecosystems requires determining the order of priority between the ecosystems, which comprises several factors. Heuristically, it is desirable to, for example, account for the area of each ecosystem, species diversity and number of threatened species in each ecosystem, the degree of degradation of each ecosystem, and the costs and feasibility of restoration. These factors could be integrated in various ways; how this was done in Finland is described below.

Mathematically, division of resources between ecosystems was based on a priority index B_i which was calculated for each ecosystem type *i* as:

$$B_i = \frac{(k_1 SP_i + k_2 SPD_i + k_3 H_i + k_4 HD_i) \times f(A_i) \times \Delta_{Ai} \Delta_{hi} f^{'}(U_i)}{c_i}$$

where SP_i and H_i are number of threatened and near threatened species and habitat types in the national red lists respectively, and SPD_i and HD_i are the number of species and habitat types in bad and unfavourable status in the EU Species and Habitats Directives in each of the ecosystem type *i*. $k_1 - k_4$ are different weights for species and ecosystems. A_i is the extent of area of the ecosystem type *i* and f is a function that provides absolutely more but relatively less weight for large areas [$f(A_i) = A_i^{0.75}$]. Δ_{Ai} is the proportion of one unit area from the total area of the ecosystem type *i* and Δ_{hi} is the per unit area average improvement of the ecosystem condition in ecosystem type *i* due to the chosen area-weighted restoration measure portfolio – here improving more is better. U_i is the current condition of the ecosystem type *i* and $f^{'}$ is a function that provides more weight for more degraded ecosystem types (i.e. those with a greater extinction debt) [$f^{'}(U_i) = 0{,}25U_i^{-0.75}$, which is the slope of the canonical species-area curve]. Finally, c_i is the average cost of the area-weighted restoration measure portfolio – one would rather have the same benefits with lower cost. Since there are only benefits in the numerator and the cost is in the denominator, the priority index B_i is a cost-efficiency index.

The point of the first component of the equation is that the more species and habitats and the more endangered species and habitats an ecosystem has, the more relevant or urgent is its restoration. The species and habitat types used in the formula are based on the number of threatened and near threatened species, as defined in the national Red List (Rassi et al. 2010), and habitat types, as defined in the evaluation of threatened habitat types (Assessment of threatened habitat types in Finland, Raunio at al. 2008). The formula we used also takes the number of species and habitat types covered by the EU Habitats and Birds Directives into account (Anonymous 2013b, c). The risk of extinction of the species is not assessed at the level of Member States in the reporting on the Birds Directive. For this reason, we compiled a preliminary classification of the species listed in the Birds Directive, and assessed their risk of extinction levels (for more details see the original report Kotiaho et al. 2015a).

Species and habitat types were given different weights. In general, we considered the national Red List and the assessment of threatened habitat types (Assessment of threatened habitat types in Finland, Raunio et al. 2008) to be more relevant in the case of Finland, and we prioritized them over the species and habitat types listed in the EU Habitat and Bird Directives. In both materials, habitat types were prioritized over species, because ecosystem restoration is more focused on habitat types. Furthermore, we accounted for the different degrees of threats within the materials by applying different weights (for more details see the original report Kotiaho et al. 2015a).

After going through all the steps of the procedure, we can offer information on the cost-effectiveness of ecosystem restoration measures in each ecosystem type for decision-making and carry out the restoration prioritization among the ecosystems. Note that the quantitative prioritization arrived at through the procedure might create an "illusion of exactness," and it should be borne in mind that the procedure contains numerous simplifications, assumptions and assessments by experts, and that the collated data may include inaccurate or incorrect information. Nevertheless, the procedure compiles the best available information to support decision-making. It is important to clearly record all materials, assumptions and expert assessments when using the procedure as this ensures that the process is transparent, verifiable and repeatable.

5 Current condition of all terrestrial ecosystems in Finland and a detailed example for assessing and reversing ecosystem degradation in forests

Although the final restoration prioritization was made simultaneously over all ecosystems, Finland was initially divided into six main ecosystem types to facilitate the practical work for forests, peatland, rocky outcrops, coastal area, fell area, and cultural ecosystems including semi-natural grasslands, agricultural area and urban area. The ecosystem categories were based on the divide presented in the report commissioned by European Commission (Lammerant et al. 2013) and on the work by the Finnish Board on Ecological Restoration and its expert groups (see http://www.metsa.fi/web/en/finnishboardonecologicalrestoration). Inland water areas, which cover nearly 3.4 million hectares (approximately 8 percent of the total area of Finland), were not included in the work. Open sea was also not included as it is regulated through the EU Marine Framework Directive and thus via a different process.

Following the procedure explained in chapter 4, we calculated the degree of degradation for the degraded area in all the ecosystem types in Finland. In calculating the numbers in columns "Ecosystem condition lost/remaining" in Table 2, note that the extent of area that has not been degraded and the degree of degradation of the degraded area of each ecosystem type has been accounted for. Based on our results, if we focus solely on the extent of degraded area over all ecosystem types in Finland, 84 percent of the terrestrial area has been degraded to some degree. However, this number does not take into account the degree of degradation at each ecosystem type. When both dimensions are taken into account i.e. the extent of degraded area and the degree of degradation within each ecosystem, we find that the overall area-weighted average proportion of degree of degradation of Finnish ecosystems is 0.61. In other words, we have caused degradation to such an extent that we have lost on average 61% of the ecosystem condition in Finland.

Table 2. The main ecosystem types used in the Finnish restoration prioritization work, their total area, extent of degraded area and combination of the extent of degraded area and the degree of degradation (proportions of ecosystem condition remaining/lost). The proportions ecosystem condition remaining and lost take into account the degree of degradation of the degraded area as well as the area that is not degraded. The simple proportion of degraded area from the total area is 0.84, but when the second dimension i.e. the degree of degradation in each ecosystem is also accounted for, the total degree of degradation i.e. area-weighted overall ecosystem condition that has been lost is 61 percent.

Ecosystem type	Total area (km^2)	Degraded area (km^2)	Ecosystem condition remaining (proportion)	Ecosystem condition lost (proportion)
Forests	153 535	135 933	0.32	0.68
Peatland	88 500	61 130	0.57	0.43
Semi-natural grasslands	1 000	998	0.08	0.92
Agricultural area	23 602	23 602	0.04	0.96
Urban area	8 100	8 100	0.27	0.73
Fell area	13 000	11 440	0.56	0.44
Coastal area	1 708	1 708	0.32	0.68
Rocky outcrops	1 569	113	0.99	0.01
TOTAL	291 014	243 025 (0.84)	Area-weighted average 0.39	Area-weighted average 0.61

Next, we will follow the procedure introduced in chapter 4 step by step for one forest ecosystem type, herb-rich forests. But before that, we will present some background information of Finnish forests.

Background information of Finnish forests

The total area covered by forest land in Finland is approximately 20 million hectares (definition of forest land: the average annual growth of trees is over 1 m^3/ha over a period of one hundred years). 61.0 percent of the total area is privately owned, 25.4 percent is state-owned, 8.2 percent is owned by companies, and 5.4 percent by others (incl. municipalities and parishes) (Peltola 2014). Approximately 90 percent of the forest land in Finland (this estimate includes only mineral soils which is c. 15 million hectares) is used for wood production, and the share of controlled wood production is about seven percent of this area. Thus, approximately 10 percent of Finnish forest land is excluded from management for wood production. However, area excluded from wood production is not evenly distributed and in Southern Finland, the percentage is as little as 2.9, while in Northern Finland, it is approximately 20 percent (National Forest Inventory NFI 11).

Forest biodiversity is attempted to be maintained by both legislative and voluntary means. The most important acts from the point of view of forest biodiversity are the Nature Conservation Act, the Forest Act and the Wilderness Act. Protected areas include national parks and strict nature reserves, as well as areas covered by various conservation programmes (Table 3). The ecological condition of protected areas is improved through active restoration and nature management measures. In 2010–2014, measures were undertaken on 16 300 hectares of state-owned land and on 1 300 hectares of privately-owned protected areas. The most important voluntary means include forest certificates (FSC and PEFC), recommendations for good forest management, and the Forest Biodiversity Programme for Southern Finland METSO.

The decline and loss of ecosystem condition and biodiversity in managed forests is attempted to be reduced or decelerated with nature management measures, such as leaving a few retention trees (see e.g. Roberge et al. 2013) and dead trees in the forest at the final felling and by leaving some broad-leaved trees during the thinning (for some results see e.g. Laita et al. 2010; Timonen et al. 2011a, b: Juutinen & Kotiaho 2011; Selonen et al. 2011; Selonen & Kotiaho 2013; Olden et al. 2014). Around 95 percent of Finnish forests are certified, which means that almost all the managed forests are treated with nature management measures targeted for decelerating the biodiversity loss, and the implementation and quality of the measures is monitored. In forests, the various measures aimed at reducing the threat to species have been more successful than in other ecosystems, but despite some deceleration, measures have not been enough to halt the decline and loss of ecosystem condition and biodiversity and new innovations are needed (Halme & Kotiaho 2013). In general, changes related to the forest management in forest ecosystems are the primary source of threat for almost 700 species. Important wooded habitat types for threatened species are herb-rich forests, mature forests and esker forests. (Rassi et al. 2010.) Forest regeneration by planting, thinning and other commercial management activities aimed at intensification of the wood production result into monotonous, even-aged forest structure with very low diversity of tree species, and are also the most important reason why many Finnish forested habitat types have become threatened (Raunio et al. 2008). The drastic reduction of the amount and quality of decaying wood, in particular, has affected and continues to threaten the habitat types and species in the forested ecosystems (Raunio et al. 2008; Rassi et al. 2010).

Table 3. Strict forest reserves and set-asides (area in hectares) in state-owned and privately-owned land.

Ecosystem	State-owned protected areas	Privately-owned protected areas	Total
Herb-rich forests	7 919	5 623	13 542
Herb-rich, mesic and sub-xeric heath forests	1 204 578	32 213	1 236 791
Xeric and barren heath forests	233 702	3 572	237 274
TOTAL/hectares	1 446 199	41 408	1 487 607

A detailed example of the procedure

Step 1. Decide focal ecosystem types and determine the area of each

Forests included to the work of forest expert group were wooded mineral soils classified as productive forest land, currently covering altogether about 15 million hectares in Finland. Wooded mires and bogs, such as spruce mires, were included in the work of the peatland expert group. Similarly, grazed woodlands and wooded pastures were included in the work of the cultural ecosystems working group, and poorly productive wooded rocks in rocky outcrops, and mountain birch forests in the fell area.

For the procedure, forests were divided into three focal ecosystem types: 1) herb-rich forests, 2) herb-rich, mesic and sub-xeric heath forests and 3) xeric and barren heath forests (Table 4). Despite their relatively small area, herb-rich forests were treated as a separate ecosystem type, due to their importance for many threatened species and habitat types (Raunio et al. 2008; Rassi et al. 2010). Inevitably, within the given time frame, the division into ecosystems had to be made very coarse. Given more time and human resources, the division could have been much more refined.

The calculation of total area and degraded ecosystem areas was based on the National Forest Inventory (NFI 10 in 2004–2008; area of mineral soil within the forest land; including both managed and protected forests). The assessment of the extent of the degraded area is based on age categories: in herb-rich forests, stands under 100-years-old were classified as degraded, while the age limits for mesic and sub-xeric heath forests and the most barren heath forests were 120 years and 140 years, respectively. Forests older than this were considered to be mature and free from degradation from the point of view of stand structural characteristics that indicate the ecosystem's natural state or condition.

We selected this artificial definition method based on age because the assessment of the degraded area turned out to be difficult with other methods. Mature managed forests are more likely to have stand structural characteristics that indicate the ecosystem's natural state, such as coarse woody debris and large trees (see, for example, Siitonen et al. 2000). However, it is worth noting that the age alone does not determine the natural state of the forest. Most forests in Finland, including the mature ones, have some history of forest management that has affected the natural state of the stand structure. Therefore, mature managed forests might not have, for example, very large broad-leaved trees and mature protected forests might be unnaturally dense (Lilja & Kuuluvainen 2005). Furthermore, the age-based examination of natural state does not address young successional stages, which can be beneficial for biodiversity (Kouki et al. 2001; Junninen et al. 2006; Kouki 2013), or small-scale dynamics (Kuuluvainen & Aakala 2011). From here on, the example focuses exclusively on herb-rich forests, the estimated degraded area of which is 96.5 percent of the total area (Table 4).

Table 4. Division into forest ecosystems, and the total and degraded areas of the ecosystem types.

Ecosystem	Total area		Degraded area	
	ha	%*	ha	%**
Herb-rich forests	367,300	2.4	354,500	96.5
Herb-rich, mesic and sub-xeric heath forests	14,318,200	93.3	12,664,600	88.5
Xeric and barren heath forests	668,000	4.4	574,200	86.0

* The percentage of the ecosystem within the total area of mineral soil forest land (see text for more details).
** The percentage of degraded area within the total area of the forest ecosystem.

Step 2. Determine degraded components in herb-rich forests

After lengthy discussions and comparison of options, we identified three primary components or structural characteristics to indicate the degradation of herb-rich forests (Table 5): 1) reduced number or density of large trees (with a diameter of ≥40 cm), 2) reduced amount of decaying wood, and 3) reduced volume of broad-leaved trees. The selected components have a verified significant effect on the risk of extinction classification status of species and habitat types in forests. The current volumes of large trees, decaying wood and broad-leaved trees and changes in these can be calculated from the data in Finnish National Forest Inventory (NFI), which was one of the reasons why we chose these particular components.

Step 3. Determine current and pre-degradation condition of each degraded component

We carried out literature reviews and based on these made an assessment and specified the pre-degradation condition for the selected components (Table 5). Note that all ecosystems that are not in their natural state should be considered degraded. The assessment of the number of large trees is based on a study on boreal forests (Nilsson et al. 2003), according to which the average density of large living trees with a minimum diameter of 40 cm was 20 trees per hectare – more in lush areas and less in barren areas. The amount of decaying wood in herb-rich forests was assessed based on three studies, weighing the results by the number of forest stands examined in each particular study (Sippola et al. 1998; Siitonen et al. 2001; Kuuluvainen et al. 2014; Tuomas Aakala/University of Helsinki, oral statement). The volume of broad-leaved trees in pre-degradation state herb-rich forests is based on an expert assessment of the forest expert group.

Step 4. Determine the loss of ecosystem condition from each degraded component

The loss of ecosystem condition if the component was completely degraded i.e. missing was estimated to be at least 0.4 for each of the components, meaning that the complete loss of the component would reduce the ecological condition of the forest by at least 40 percent (Table 5). The volume of broad-leaved trees was given more weight due to their importance for biodiversity. The weights given were based on expert assessments. Large trees are important for epiphytes (e.g. Selonen et al. 2011; Olden et al. 2014) as well as for birds of prey and they also affect the microclimate of the area. Furthermore, there would be no large dead trees without large living trees. 20–25 percent or about 4000–5000 of all species living in Finnish forests are dependent on coarse woody debris (Siitonen 2001). The reduced amount of coarse woody debris is the most common cause for and threat associated with threatened species in forests (Rassi et al. 2010). Furthermore, decaying wood affects the circulation of nutrients (including large dead trees and stumps as long-term nitrogen stocks) and forest regeneration, stand structure, and the formation of carbon stocks in natural forests. Furthermore, decaying wood has major indirect effects in the ecosystem for example as a provider of shelter. The assessment of the importance of broad-leaved trees was based on material in Linder et al. (1997).

Step 5. Calculate overall ecosystem condition remaining and lost

We applied the equation explained in step 5 in chapter 4 (pages 28–29) and calculated the total ecosystem condition remaining and degree of degradation or loss of ecosystem condition of the herb-rich forests, and found that the loss was 56 percent (Table 5). Note, that in this model the degradation of the ecological condition represents the minimum degree of degradation. Despite the fact that we included the components we considered to be most important for the ecosystem condition and biodiversity, there nevertheless are also other degraded components that may have negative effects on biodiversity.

Table 5. Degraded components in herb-rich forests (step 2), their pre-degradation state and current condition (step 3), loss multiplier (step 4), and the calculated total degree of degradation (step 5; for technical details see chapter 4). Loss multiplier of 0.4 is equivalent to the 40 percent of loss of the ecological condition of the ecosystem if the component was completely missing.

Ecosystem	Degraded component	Pre-degradation state	Current condition	Loss multiplier	Degree of degradation (%)
Herb-rich forests	Large trees (per hectare)	30	10.1	0.4	56.1
	Decaying wood (m^3/ha)	100	7.0	0.4	
	Broad-leaved trees (m^3/ha)	100	92.0	0.6	

Step 6. Determine potential restoration measures and their per unit costs

During the work, we identified a total of 13 potential restoration measures that could be used for the improvement of the ecological condition of forests, and for which adequate data was available so that they could be used as part of the quantitative analysis. Eight of these measures were applicable in herb-rich forests (Table 6). Most of these measures are intended for managed forests. Details of the measures and the formation of the costs are provided below and the costs for each measure are tabulated in Table 7.

In addition to the above measures included into the procedure, we listed many other measures that do not influence the selected ecosystem components, or for which we did not have sufficient information on their costs or effects. In the case of herb-rich forests, examples of such measures include the favouring of broad-leaved trees in forest management, preservation of broad-leaved trees in thinning and felling, and landscape planning for the purpose of improving the connectivity of herb-rich forests. The measures were listed because they can inform any follow-up work and the practical restoration work.

Table 6. Restoration measures included in the quantitative procedure for reversing ecosystem degradation in herb-rich forests.

Measure	Description
Permanent preservation of living retention trees 10 m³/ha	Measure in managed forests: leaving living retention trees at the final felling at a density of 10 m³/ha, and preserving these trees in each subsequent felling.
Preservation of dead trees at felling	Measure in managed forests: preserving dead trees (incl. individual recent windfalls, but excluding large wind-fallen areas) at all stages of felling.
Fixed-term conservation contracts on areas larger than the statutory minimum	Using environmental subsidy agreements to preserve areas that are larger than the areas specified by the Forest Act and the Nature Conservation Act.
Biodiversity focus at the level of estate	Measure in managed forests: leaving 5 percent of the estate's forest land outside felling and treating another 5 percent with nature management measures.
Protective strips around water bodies and wetlands	Measure in managed forests: the minimum width of a protective strip is 10 m around water bodies with an area of > 5 ha and 5 m around small water bodies and wetlands with an area of < 0.5 ha; low-growing trees are preserved on the protective strip, and the soil on the strip is not prepared.
Establishment of new reserves	Establishing new herb-rich forest reserves.
Forest management that takes the characteristics of herb-rich forests into account	Measure in managed forests: comprises uneven-aged forest management, the increasing of broad-leaved trees, and the preservation of valuable individual trees and dead trees.
Active management of herb-rich forests in protected and managed forests	The aim of the nature management measures is to create a herb-rich forest that is dominated by broad-leaved trees, with some amount of decaying wood and large trees; the measure includes, among other things, the removal of planted spruce.

Detailed descriptions of the selected restoration measures and their costs

Here we provide detailed information about the restoration measures and their costs. The estimated costs of the restoration measures are in Table 9 (page 48). In general, we added consultancy costs only to the costs of the measures that we did not consider feasible without consultation. We only added administrative costs to the measures related to the establishment of reserves and the fixed-term agreements.

Permanent preservation of living retention trees 10 m³/ha

The preservation of living retention trees at all stages of the felling cycle produces large living and dead trees in managed forests. The preferred retention trees are broad-leaved trees, particularly large aspen and great sallow. This measure would result in the density of the retention trees to exceed the current recommendation. This is a particularly vital measure because the density of living retention trees has decreased in the privately-owned clearcutting areas in Finland since the early 2000s (Peltola 2014).

The cost for this measure is made up of the value of the non-felled retention trees. The average stumpage price for retention trees (EUR 33/m³) also covers less valuable trees and pulpwood. Furthermore, 5 percent of the costs are allocated to consultancy at approximately 20-year intervals, which is the average time between changes of forest stand ownership.

Preservation of dead trees at felling

This measure involves preserving existing dead trees in forest regeneration and management and when harvesting wood for energy. Operators harvesting wood both for energy and as industrial round-wood must avoid harvesting dry standing trees or damaged stem-wood for energy (see Äijälä et al. 2010). The aim is to change the treatment and harvesting methods to enable, for example, the preservation of standing dead trees and coarse woody debris with a careful planning of harvester's driving routes and by preserving dead forest stands. Coarse woody debris makes up more than 70 percent of all large dead trees in the forest land (large dead tree within the meaning of the NFI: diameter ≥ 10 cm, length ≥ 1.3 m) (NFI 10; Korhonen et al. 2013). As much as over 80 percent of existing coarse woody debris might be destroyed and lost during regeneration logging and soil preparation. However, a majority of all large decaying trees, up to 80 percent, is located in forests to be felled, and most of these are large stumps from regeneration felling (Berglund 2012).

Fixed-term conservation contracts on areas larger than the statutory minimum

In Finland, the Nature Conservation Act (1996) protects certain small habitat types (often called woodland key habitats, WKHs (Timonen et al. 2011a, b)) that are in their natural or semi-natural state. These habitat types may not be altered in a way that would change the characteristics of the habitat type. The Forest Act (2014, section 10) similarly specifies and protects habitats of special importance, which must remain in their natural or semi-natural state and be clearly distinguishable from the surrounding forest nature. Landowners have the statutory duty to preserve the characteristic features of these ecosystems and their natural structural characteristics in accordance with the minimum requirements laid down in the act. On wooded sites, landowners may preserve, for example, a 0.5-hectare or a smaller area of the natural site that is in the best condition and fell the remaining area. However, the METSO programme enables making temporary agreements to protect larger areas than the statutory habitat types and ecosystems. A site can be protected, for example, with a 10-year environmental subsidy agreement that focuses on the habitats of special importance, as specified in the Forest Act.

Biodiversity focus at the level of estate

In this voluntary measure in managed forests, 5 percent of the forest land belonging to the estate is preserved. Another 5 percent is treated with nature management measures, such as increasing or preserving decaying wood or uneven-aged forest management. The FSC-certified estates of over 20 hectares are an example of this measure (FSC Finland 2011).

The costs for this measure are made up of the lost income from the 5 percent non-felled area that is not covered by forestry operations. We took only the value of the trees at the moment of implementation into account in the cost estimate; we did not, for example, calculate an interest on the lost income. It is relatively difficult to estimate the costs for the 5 percent area of the forest that is subject to nature management measures, because the measures vary greatly. Retention trees and decaying wood are examples of components that increase costs. We estimated the costs on the basis of the costs incurred by applying the FSC criteria. In addition to the expert assessment, the cost estimate was based on a report by Indufor (2014), the thesis by Rantanen (2014), as well as interviews with operators. The expert assessment played a major role. The costs include consultation costs of 5 percent.

Protective strips around water bodies and wetlands
In this measure in managed forests, a protective strip with a minimum width of 10 metres is left around water bodies that are larger than 5 hectares. A protective strip with a minimum width of 5 metres is left around water systems that are smaller than 0.5 hectares and around wetlands. Felling is allowed on the protective strip, but low-growing trees must be preserved and the soil may not be prepared.

The costs for leaving protective strips are made up of more detailed planning costs. These costs are difficult to estimate. The estimate is based on research on the costs incurred by PEFC certification. In addition to the expert assessment, the cost estimate was based on a report by Indufor (2014), the thesis by Rantanen (2014), as well as interviews with operators. The expert assessment played a major role. The costs include consultation costs of 5 percent.

Establishment of new reserves
This measure covers the permanent nature reserves established under the Nature Conservation Act. These include privately-owned nature reserves, estates and parcels of land sold to the state for protective purposes, nature reserves established on state-owned land, and soil replacements. Of the current measures, the permanent preservation of forests is mainly used within the METSO programme that is based on the voluntary measures by landowners. The programme is targeted at forests that already have conservation values, such as decaying wood, large trees and broad-leaved trees. These components improve as forests grow older, which is why the establishment of nature reserves has a major effect on ecosystem condition. The effect is particularly great on lush sites, such as herb-rich forests.

In the permanent protection measure, the landowner is compensated for the financial value of the trees and, if the land is sold to the state, for the value of the soil. New reserves should mainly be established south of Lapland, because the degradation of forests has been the most severe in Southern Finland. Thus, we based most of the cost estimates on prices valid in Southern Finland. The costs for establishing a reserve include administrative costs, such as costs incurred by property formation. The administrative costs were estimated to be the same on all types of sites, and the percentage of administrative costs applied was 20 percent of the total establishment costs. In addition to this, a 100 Euro production-related loss per hectare was included in the costs for herb-rich forest reserves (Matti Heikurainen, Ministry of Agriculture and Forestry, oral statement). However, this estimate will probably turn out to be too high over the long term. The annual revenue from privately managed forests amounts to approximately 100 Euro per hectare (Peltola 2014). Even though this measure has a major effect on ecosystem condition, the cost-effectiveness appears low due to the high price of densely wooded sites and the wood production losses associated with it.

Forest management that takes the characteristics of herb-rich forests into account
Herb-rich forests range from xeric, sun-exposed esker forests to humid, fern-rich forests in demanding microclimates. When determining the characteristics of managed herb-rich forests, attention should be paid to the natural requirements of species, taking into account not only the sufficiency of retention trees and decaying wood, but also the characteristic features of the site, such as the shrub layer. The measure used in managed herb-rich forests is a special felling scheme that enables uneven-aged forest management on a case-by-case basis, felling small clearings or strips, increasing the share of broad-leaved trees, and preserving valuable individual trees and dead trees. The aim of the measure is to preserve some non-treated areas for the purpose of conserving the shrub layer and broad-leaved tree stands that comprise several species. The measure is applied to various kinds of nature management felling that aim to enhance biodiversity, the living conditions of game or the landscape (Äijälä et al. 2014).

The costs for this measure are made up of the rise in harvesting costs, increased working hours, retention of valuable individual trees, value loss in tree stands, and harvesting losses. The measure is repeated approximately every 20 years. The price varies greatly between the implementation level and the landowner category. The cost estimate used for the procedure is based on the management of state-owned, managed herb-rich forests. Consultancy costs of 5 percent were included.

Active management of herb-rich forests in protected and managed forests

The aim of this measure is to increase the share of broad-leaved trees in herb-rich forests and to secure variation in the stand structure. In practice, this often means removing or reducing the number of planted spruce from nature reserves or preventing the natural proliferation of spruce. Furthermore, ring-barking spruce can be used as the means to produce decaying wood, where appropriate. Nature management felling is an active management measure in managed herb-rich forests. The number of retention trees is notably higher than usual in a felling that aims to preserve biodiversity, and the aim of the felling is to preserve the characteristic shrub layer of the herb-rich forest and to preserve large trees and broad-leaved trees. In practice, this measure is typically implemented as state-subsidised nature management projects under the METSO programme (Vesanto & Ruutiainen 2012). This measure is more effective in preserving the biodiversity of the site than *forest management that takes the characteristics of herb-rich forests into account.*

The costs for this measure vary greatly between sites, the variation can be thousands of euros per hectare. Clearing a stand of spruce saplings can be extremely costly, whereas the removal of mature spruce can yield notable sales proceeds. In the most expensive scenario, the manual work in herb-rich forest reserves (including clearing, piling up the material that was removed etc.) can cost 8 000 Euros per hectare, and in the most economical scenario, the measure can yield the same amount in proceeds. In the nature management projects under the METSO programme, the costs varied between EUR 2 733 and 8 577 (Kurppa & Saaristo 2012). The maximum clearing price was EUR 1 500/ha, and we used this figure as the basis of our cost estimate. A planning cost of 150 Euro/ha is included in the costs, and the estimate is based on a 10–20-year interval between the management measures. In general, the active management of herb-rich forests is expensive, and its cost-effectiveness is low. The differences between the measures used in protected and managed forests make the determination of costs difficult.

Step 7. Determine ecosystem condition and services gain from each restoration measure

In order to develop an operational procedure that retains the ecologically most relevant components while having otherwise minimal data demands and complexity we simplified reality and assumed that the full estimated benefits of restoration would be realized by 2050 so that there is no need to independently evaluate the rate at which each of the ecosystems recover following each restoration measure. The expert working groups were specifically advised to work from the assumption that the benefits would be realized in full by 2050. Not following this simple rule of procedure may have the following effects. In some cases, the benefits from the restoration measures are less than what they would be, if the rule was followed. However, it is also possible from the explanation provided below that the costs of some measures are less than what they should be as it appears that to achieve a long-term effect on herb-rich forest condition some measures should have been repeated in time. Whether these effects cancel each other out is unknown, but the cost-efficiency of the restoration measures targeted to forests may be influenced, and thus also the rank of forests compared to the other ecosystems may be affected.

For the herb-rich forests, the assessment of the ecosystem condition gains from the restoration measures was primarily based on their effects on the degraded forest components by 2050 (Table 7). The chosen time frame affects the effects the measure will have on the degraded components. The forest expert group considered 2050 to be appropriate as the end time of the effect assessment period, because 2020 would have been too soon, and 2100 would have made part of the short-term benefits yielded by the restoration measures unmeasurable due to processes such as decomposition. Note, however, that ephemeral benefits from a measure could have been considered in the procedure simply by repeating the measure at appropriate time intervals and appropriate area of the ecosystem. This could have been calculated e.g. by the average number of hectares that would have needed to be treated with this measure every year in the given ecosystem in order to have the effect remain constant over time.

With regard to the degraded components examined, some of the restoration measures might increase the biodiversity of the sites beyond what it was in the pre-degradation state. Thus, ecosystem restoration was allowed, in some cases in the herb-rich forest example, be greater than one hundred percent (Table 7). Note however, that in principle it is not possible to increase the naturalness of "a natural state" and in fact the increase of species diversity or abundance of endangered species above the natural state of an ecosystem should actually be considered as degradation.

Table 7. Effects of the restoration measures on degraded components of the herb-rich forests and in the overall reduction in the degree of degradation in the condition of the ecosystem by 2050.

Ecosystem	Measure	Degraded components			Reduction in the degree of degradation %
		Large trees (pcs/ha)	Decaying wood (m^3/ha)	Broad-leaved trees (m^3/ha)	
Herb-rich forests	Permanent preservation of living retention trees 10 m^3/ha	3	3	1	6.4
	Preservation of dead trees at felling	-	9*	-	4.5
	Fixed-term conservation contracts on areas larger than the statutory minimum	14	20	6	36.6
	Biodiversity focus at the level of estate	2	9	5	10.2
	Protective strips around water bodies and wetlands	-	-	1	0.5
	Establishment of new reserves	20	93	8	100.2
	Forest management that takes the characteristics of herb-rich forests into account	2	5	20	16.0
	Active management of herb-rich forests in protected and managed forests	2	4	35	23.2

*The present mean density of decaying wood is 11 m^3/ha in managed forests that are at their felling stage, and 2 m^3/ha in sapling stands (NFI 11).

Permanent preservation of living retention trees 10 m^3/ha

Retention trees make the crown structure of the forest more diverse at all successional stages. They provide organisms with shelter, nutrition, nesting places and/or appropriate habitats. We estimated the current density of living retention trees that are left to be 4 m^3/ha, based on the density of retention trees found in the monitoring of nature quality from 2013 (2.6 m^3/ha) and the density of living trees in regeneration areas (6 m^3/ha) found in NFI 11 in 2009–2012 (Ylitalo 2013). Living trees in regeneration areas comprise retention trees and the trees in valuable ecosystems that are preserved at felling (such as woodland key habitats, WKHs). We estimated that by leaving 10 m^3/ha retention trees will increase the density by 6 m^3/ha. This volume was divided equally between large trees and dead trees (3 m^3/ha for both components). We estimated that the current measures already increase the number of broad-leaved trees, which means that the new measure can only slightly increase the number of broad-leaved trees in herb-rich forests.

Preservation of dead trees at felling

The expert assessment was based on the results of NFI 11 (2009–2013) concerning the number of dead trees at different successional stages. We calculated the net loss of decaying wood by comparing the amount of decaying wood in production forests with the amount of decaying wood in forests and sapling stands at their regeneration age. All measures related to the harvesting of wood as industrial round-wood and energy and to soil preparation have already been taken in sapling stands, but the amount of decaying wood has not lowered as a result of decomposition yet. The amount of decaying wood in sapling stands is the sum of the lost dead trees and the new dead trees produced during or after felling. At the national level, 39 percent of dead trees in forests at their regeneration stage are located in sapling stands. This percentage was the lowest in herb-rich forests (at 18 percent).

Fixed-term conservation contracts on areas larger than the statutory minimum

This measure yields similar ecological benefits as permanent protection agreements if the contract is renewed constantly. The fixed-term conservation contracts are safe from felling for 10 years at a time. 90 percent of the agreements are renewed after the first 10-year period, as is evidenced by past experience of the METSO programme. Nevertheless, there are no guarantee about the continuation of agreements and indeed due to recent government budged cuts in the funding of the METSO programme, it is clear that some agreements cannot be renewed. Also, the temporary sites discussed here are subject to the Forest Damages Prevention Act, which means that damaged trees, as specified in the act, might have to be removed from them. Due to these effects, we estimated the improvement of the ecological condition due to this measure to be lower compared to permanent reserves. The costs of this measure are relatively high and depend on the frequency by which agreements are renewed. It is difficult to assess the long-term effects of the measures due to factors such as legislative amendments. Thus, we estimated the effects of the measures on components other than decaying wood to be 70 percent of the effects of establishing a permanent nature reserve.

Biodiversity focus at the level of estate

The specific effects of this measure are difficult to assess because there is not enough information available. We assumed the ecological effect on the non-felled 5 percent to be similar to the establishment of nature reserves, although the actual effect depends on the type of the non-felled areas. We expected biodiversity to improve also in areas subject to nature management measures. Because of the shortage of information, we simplified the effect assessment, estimating that the effects equalled 10 percent of the effects of the establishment of reserves, based on the fact that biodiversity measures are targeted to 10 percent of the estate's area. The number is probably too high, considering the fact that the nature management measures may vary and their effects are likely to differ from the effects of conservation. Furthermore, the sites covered by the measures might not be permanent.

Protective strips around water bodies and wetlands
This measure does not affect the degraded components examined, except for the number of broad-leaved trees. However, the measure has positive effects on the state of water bodies, and the strip can serve as the habitat for game. We took the possible removal of trees into account in the effect assessment. If some trees were left on the protective strip, the measure would also affect the degraded components included in the study.

Establishment of new reserves
This measure involves establishing new reserves on sites with structural characteristics that are important for biodiversity: decaying wood, large trees and broad-leaved trees. Usually, permanently preserved sites that can be included in the METSO programme are mature dense forests that have not been managed for a long while. We expect the amounts of structural characteristics examined to eventually correspond to the pre-degradation state, which is why we estimated the effects of the establishment of nature reserves by calculating the difference between the pre-degradation state and the current state. This produced a large increase in the ecosystem condition.

Forest management that takes the characteristics of herb-rich forests into account
The component-specific effectiveness figures of the measures are based on expert assessments. We estimated the effect with the assumption that the herb-rich forest would no longer undergo the most common regeneration process: clear-felling, mechanized scarification and the planting of spruce.

Active management of herb-rich forests in protected and managed forests
The effects are based on an assessment by experts. We estimated the ecological effects of the measures to be mainly seen in the increased number of broad-leaved trees. Because this is an active measure, we expected it to increase the broad-leaved tree volume more than *forest management that takes the characteristics of herb-rich forests into account.* With regard to decaying wood, the assessment is based on the management of herb-rich forest reserves, which has produced on average 3.7 m^3/ha of decaying wood. The trees may also grow large, although this is not the primary target of the measure.

Ecosystem service effects of the restoration measures
We divided ecosystem services into the following categories: carbon stocking, water balance, load on water bodies (Table 9), game, natural products, wood biomass, cultural services (recreation, well-being and tourism) and supportive services (Table 8). The assessment of ecosystem service effects was aided by external specialists. Carbon and water-related services were considered to be the most important ecosystem services for the work, because they contribute to climate change mitigation and adaptation. Long-term carbon balance includes the sequestration of carbon, as well as the carbon stock in trees and forest land. In the final assessment, the carbon stock was graded on a scale from -100 to +500, for the purpose of shedding light on the differences in scale between the measures. Water balance includes the regulation of water and the maintenance of water reserves (including protection against floods), as well as the solids and nutrient load on water bodies.

Other ecosystem services were graded on a scale from -2 to +2. The ecosystem services related to game were given more weight if the measure influenced several game species. The natural products covered by the assessment were berries (blueberry, lingonberry and raspberry) and fungi (bolete, chanterelles and other edible mushrooms). Wood biomass includes saw timber trees and pulpwood, slow-grown trees for carpentry, firewood (for households) and energy wood. The category "other ecosystem services" includes cultural services: outdoor activities and recreation, nature tourism and travel, well-being and health, teaching and studying, along with aesthetic and landscape values. This category also includes supportive services, such as the maintenance of biodiversity and the ecosystem's ability to recover. Note that some restoration measures can simultaneously have positive effects on one and negative effects on another service.

The selection of the restoration measure portfolios (see below for further details) was based on the following ecosystem services: carbon stock, water balance, load on water bodies and other ecosystem services as a whole.

Table 8. The effects of restoration measures on ecosystem services in herb-rich forest. Effects on carbon stock, water balance and load on water bodies are in Table 9 (example of a restoration measure portfolio).

Ecosystem	Measure	Effect on the ecosystem service				
		Game	Natural products	Wood biomass	Well-being, recreation and tourism	Supportive services
Herb-rich forests	Permanent preservation of living retention trees 10 m³/ha	0	0	-1	1	1
	Preservation of dead trees at felling	0	0	0	0	1
	Fixed-term conservation contracts on areas larger than the statutory minimum	1	1	-1	1	1
	Biodiversity focus at the level of estate	2	1	-1	1	2
	Protective strips around water bodies and wetlands	1	1	0	0	0
	Establishment of new reserves	2	1	-2	2	2
	Forest management that takes the characteristics of herb-rich forests into account	1	1	-1	1	2
	Active management of herb-rich forests in protected and managed forests	1	1	0	1	1

The *Establishment of new reserves* had the greatest positive effect on all ecosystem services except for the wood production. Based on the assessment, *Fixed-term conservation contracts on areas larger than the statutory minimum* and *Biodiversity focus at the level of estate* have the second greatest positive effects on ecosystem services. *Permanent preservation of living retention trees* and *Preservation of dead trees at felling* were estimated to have only minor effects on ecosystem services.

The amount of wood retained on the site correlates with the amount of carbon the site can sequestrate and store. The carbon stock in soil can also be improved by increasing the unharvested area and reducing soil preparation in the harvested area.

Forests retain water and nutrients, which means that the water body effects of the measures were positive on sites where the area of retained tree stands was the greatest and the soil was disturbed as little as possible.

With regard to game, all the other herb-rich forest restoration measures except for the *Preservation of dead trees at felling* were considered to have positive effects. *Retention trees* benefit game species (Lindén et al. 2014; Suomen metsäkanalintukantojen hoitosuunnitelma 2014). The coverage and layers of the forest provide shelter and food for game. Herb-rich forest restoration measures also benefit fish spawning grounds, since a major part of all herb-rich forests are located along brooks.

Most of the measures were considered to have positive effects on natural products. Based on the assessment, *Permanent preservation of living retention trees* and *Preservation of dead trees at felling* had no effects on natural products. Berries and mushrooms thrive in wooded areas; on the other hand, felling might benefit raspberries and lingonberries.

Most of the measures were considered to have negative effects on wood biomass, and the effects were the greatest in areas with the most retention trees. Based on the assessment, *Preservation of dead trees at felling*, *Protective strips around water bodies and wetlands* and *Active management of herb-rich forests* had no effects on wood biomass production.

With regard to cultural services, we estimated the measures that keep the landscape wooded to have positive effects; *Establishment of new reserves, Fixed-term conservation contracts on areas larger than the statutory minimum* and *Biodiversity focus at the level of estate.* Furthermore, *retention trees* are important elements in the landscape. With regard to the *Preservation of dead trees*, individual large trees might look handsome, but a tangle of coarse woody debris might hamper the outdoor use of the area by blocking bicycle and walking routes. However, guidance and education play a major role in shaping people's attitudes towards decaying wood (see, for example, Gundersen & Frivold 2011; Hauru et al. 2014).

In relation to the supportive services, most of the measures aimed at preserving tree stands were considered to have positive effects on the maintenance of biodiversity and adaptation to climate change. *Preservation of dead trees at felling* has another positive effect: stumps and decaying wood fix nitrogen, which makes them on-site nitrogen stocks. *Protective strips* were not considered to have an effect on supportive services.

Step 8. Determine cost-effectiveness of all restoration measures

Cost-effectiveness of the restoration measures is obtained by simply dividing the aggregate benefit of each restoration measure (step 7) with its estimated per-unit cost (step 6) and the cost-efficiency is tabulated in Table 9.

Step 9. Form the restoration measure portfolio within each ecosystem type

Our selection of the restoration measure portfolio was based on cost-effectiveness, improvement in the ecological condition and the effects on ecosystem services. We also examined the potential area that could be treated with the measure.

In addition to the overtly ambitious scheduling of the Aichi Target 15 (Kotiaho et al. 2015b), also the percentage target itself is challenging. Therefore, the decision making group decided to compile an alternative restoration measure portfolio also for a 1 percent target. In addition, based on allocation of resources in the 15 percent restoration measure portfolio the working group calculated the costs for alternative targets at 3, 5 and 7.5 percent restoration (see section "alternative targets" in chapter 6). However, it is important to note that the procedure is not dependent on any particular *a priori* target setting as it can be applied to evaluate the optimal level of each ecosystem improvement in relation to other ecosystems at any given target or resource level.

The formation of the restoration measure portfolio was initiated by mechanically calculating the allocation of the measures on the basis of their cost-effectiveness only. In balancing of the 15% restoration measure portfolio, we were forced to bias the allocation towards measures that are expensive but provide significant ecological benefits, because otherwise the target would not have been met. We also took the potential area where the measure can realistically be implemented into account. For example, *Protective strips around water bodies and wetlands* (with a minimum width of 5 metres) cover only 1.5 percent of the degraded area, which means that we cannot allocate more areas for this measure. The restoration measure portfolio column in Table 9 shows the proportion of the degraded ecosystem area that should be treated with each measure in order to achieve either the 15 or the 1 percent restoration target. Note that this means that all of the measures in a given portfolio need to be applied in their respective proportion in order for the target to be met. It is notable that the effects, costs and allocation can vary orders of magnitude between restoration measure alternatives. This demonstrates that the estimation of effects and costs was a worthwhile effort.

Table 9. Measures in herb-rich forests, costs of the measures per hectare (EUR/ha) for 2016–2050, benefits of the measures in percentage (the reduction in the degree of degradation), the cost-effectiveness of the measures (%/EUR), effect of the measure on the carbon stock (tonnes/ha), water balance (on a scale from -3 to +3), on the load on water bodies (on a scale from -3 to +3), and on other ecosystem services (positive or negative overall effect on all the ecosystem services included in the study), and the restoration measure portfolio for the 15 and 1 percent restoration targets. The number in the restoration measure portfolio column indicates the fraction (%) of the degraded ecosystem area that should be treated with each of the measures in order to achieve the target.

Herb-rich forests				Ecosystem services				Restoration measure portfolio	
Measure	Cost 2016–2050 EUR/ha	Benefit %	Cost-effectiveness %/EUR	Carbon stock	Water balance	Load on water bodies	Other ecosystem services	15% target	1%target
Forest management that takes the characteristics of herb-rich forests into account	1890	16.0	0.009	100	0	1	4	4.0	0.3
Permanent preservation of living retention trees 10 m³/ha	210	6.4	0.032	10	0	0	1	13.0	0.9
Preservation of dead trees at felling	65	4.5	0.075	10	0	0	1	27.0	1.8
Fixed-term conservation contracts on areas larger than the statutory minimum	7 800	28.6	0.003	100	1	1	3	4.0	0.3
Biodiversity focus at the level of estate	210	10.2	0.051	100	2	2	5	25.0	1.7
Protective strips around water bodies and wetlands	32	0.5	0.016	0	1	1	2	0.5	0.3
Establishment of new reserves	10 700	100.2	0.015	500	3	3	5	7.0	0.5
Active management of herb-rich forests in protected and managed forests	1 650	23.3	0.016	0	0	0	4	8.0	0.4

At the end, we adjusted the restoration measure portfolio on the basis of its ecosystem service effects. In the examination of the ecosystem services, we gave more weight to measures with the most positive ecosystem service effects, and less to those with negative effects. Our primary attention was on carbon stocks, then on the effects on water bodies and, finally, on other ecosystem services. The *Establishment of new reserves*, in particular, was given more weight because of its positive effects on ecosystem services.

The restoration measure portfolio for the 1 percent target was initially constructed based on the cost-effectiveness similarly to the restoration measure portfolio for the 15 percent target. In this target we did not need to give more weight to measures that we had emphasised in the 15 percent restoration measure portfolio for the purpose of achieving the significant improvements implied by the 15 percent target. This means that reducing the target from 15 percent to 1 percent provides more options for the implementation and the outcome can be reached with more cost-efficient measures reducing the relative per unit cost of improvement.

Because restoration, nature management and conservation are complementary processes, we decided to include all the measures in the portfolio, even if in small proportions, which will also add flexibility to on-the-ground implementation. As a result, the measures will probably influence different degraded components. Had we completely excluded some measures from the portfolio, we would have also needed to examine their complementary nature to ensure that all the prioritized measures would not be targeted at the same degraded component.

We allocated most of the area in herb-rich forests for the measures *Preservation of dead trees at felling, Biodiversity focus at the level of estate* and *Permanent preservation of living retention trees 10* m^3*/ha*, because these measures are cost-effective and they can be applied to large forest areas. We allocated large areas for the *Establishment of new reserves* because of the great (and permanent) ecological benefits and ecosystem service effects of the measure.

Step 10. Prioritize among ecosystem types

Prioritization among ecosystem types follows after the formation of the restoration measure portfolios. Prioritization among ecosystems requires determining the order of priority between the ecosystems, which comprises several factors explained in detail in chapter 4. In the next chapter we will provide the results from the among ecosystem prioritization.

6 Restoration options and their costs

After forming the restoration measure portfolio for each ecosystem type, we moved on to consider all ecosystem types simultaneously. In prioritized options, the resources among the ecosystem types are allocated in proportion to the cost-efficiency index B_i of each ecosystem type (for details of the index see step 10 in chapter 4). For the 15 percent and 1 percent targets, we compiled four options for restoration that would reduce the degree of degradation the targeted amount by 2050. The restoration prioritization options are: 1) *Equal reduction of the degree of degradation*. The degree of degradation of each ecosystem will be reduced the same amount. This means that there is no prioritization between ecosystem types, but the condition of each ecosystem type is increased the targeted amount (Table 10). 2) *At any cost*. This option contains prioritization among ecosystem types. However, in this option we consider only the benefits for biodiversity and ecosystem services. Costs are not yet included in this prioritization (Table 11). 3) *Complete computational prioritization*. This option is identical to the *At any cost* option, but now also the costs of restoration measures are taken into account (Table 12). 4) *Adjusted prioritization*. This option is the complete computational prioritization adjusted and balanced by the expertise of the working group in the final negotiations (Table 13).

The total cost and the allocation of restoration resources to each ecosystem type differ significantly between the options. The reduction in the degree of degradation for each ecosystem type varies except in option 1, in which there is no prioritization between ecosystem types but in each ecosystem type the reduction of the degree of degradation is either 15 percent or 1 percent. In forest and fell ecosystems, some of the restoration measures can be implemented on overlapping areas and thus in these ecosystem types the area needed to be restored can be over 100 percent (e.g. 125 percent and 192 percent, respectively, in Table 10). In all the other ecosystems different restoration measure combinations were formed and thus spatial overlap in restoration measures is not possible and the area needed to be restored is always 100 percent or less. Note that in agricultural ecosystems no combination of the restoration measures allowed achievement of the 15 percent target. The maximum potential reduction in the degree of degradation of agricultural ecosystems is only about 2.5 percent.

Option 1: Equal reduction of the degree of degradation

In the first option, the degree of degradation of each ecosystem type will be reduced the same amount i.e. by 15 percent or 1 percent. Note that this does not mean that the extent of area to be restored in each ecosystem type would be 15 percent and 1 percent but that the overall reduction of degradation is 15 percent or 1 percent for each ecosystem type. This is because ecosystem degradation has a minimum of two dimensions: the extent of area that has become degraded and the magnitude of the degradation at any given location (see chapter 3). Equal reduction of the degree of degradation is based only on the information gathered until step 9 of the procedure (chapter 4): there is prioritization of the restoration measures within each ecosystem type, but there is no prioritization between ecosystem types (step 10 omitted).

When the fact that each restoration measure is only partially able to reduce the degree of degradation at any given area (see Table 7 in chapter 5) is understood, it becomes clear why for instance in the herb-rich forests 88 percent of the degraded area needs to be restored in order to meet the 15 percent target (Table 10). Given the inability to meet the 15 percent target in the agricultural ecosystems we provide the total cost of the measures also without the agricultural ecosystems (Table 10). Compared to the between ecosystem types prioritized restoration options (see below), equal reduction of the degree of degradation comes out as a remarkably expensive way to improve the condition of Finnish ecosystems.

Table 10. Restoration option 1: Equal reduction of the degree of degradation. In this option, each ecosystem is examined separately, and there is no prioritization between ecosystem types.

Ecosystem	The extent of restoration area and its share of the degraded area, when the objective is a 15% or a 1% reduction of the degree of degradation.				Total costs of the measures in EUR and the per-hectare cost EUR/ha when the objective is a 15% or a 1% reduction in the degree of degradation in 2016–2050			
	15%		1%		15%		1%	
	ha	%	ha	%	Millions of EUR	EUR/ ha	Millions of EUR	EUR/ ha
Herb-rich forests	313 733	88.5	21 979	6.2	484.3	1 544	34.0	1 547
Herb-rich, mesic and sub-xeric heath forests	12 360 650	97.6	485 054	3.8	18 510.7	1 498	629.2	1 297
Xeric and barren heath forests	717 750	125.0	37 725	6.6	684.7	954	51.3	1 359
Spruce mires	236 002	18.3	15 556	1.2	1 052.0	4 458	70.1	4 509
Pine mires and bogs	657 189	19.6	43 813	1.3	1 852.8	2 819	123.5	2 819
Open peatland	304 752	23.9	21 783	1.7	457.5	1 501	33.4	1 535
Semi-natural grasslands	25 900	26.4	1 806	1.8	935.0	36 101	72.	40 264
Agricultural ecosystems	2 210 934	90.0	1 290 238	52.5	14 273.7	6 456	10 772.9	8 350
Urban ecosystems	-	-	-	-	-	-	-	-
Inland water	-	-	-	-	-	-	-	-
Coastal ecosystems	2 585	13.5	172	0.9	185.6	71 803	12.6	73 498
Rocky outcrops	2 878	25.6	242	2.1	21.1	7 338	1.3	5 274
Fell area	2 196 480	192.0	80 080	7.0	28.6	13	1.3	17
TOTAL	19 028 853		1 998 448		38 486.2		11 802.4	
TOTAL in one year	543 682		57 099		1 099.6		337.2	
TOTAL without agricultural ecosystems	16 817 919		708 219		24 212.5		1 029.5	
TOTAL in one year without agricultural ecosystems	480 512		20235		691.8		29.4	

Option 2: At any cost

In the second option, prioritization among ecosystems types is made, but costs are not accounted for (see formula in chapter 4, step 10: the divisor c_i is excluded). Prioritization among ecosystem types means that the degree of degradation is not going to be reduced by the same amount in all of the ecosystem types. Option 2 was compiled as we wanted to see how the restoration effort should be allocated if we only took into consideration factors that are important for the biodiversity and ecosystem services. Although the costs for each ecosystem type were not taken into consideration in step 10, to some extent they nevertheless contribute to the prioritization as they are considered already in step 9. In step 9 the cost-effectiveness of different restoration measures was used to compile the restoration measure portfolio for each ecosystem type.

Table 11. Restoration option 2: At any cost. In contrast to the option 1, prioritization among ecosystem types means that the degree of degradation is not going to be reduced by the same amount in each of the ecosystem types even though the overall reduction of degree of degradation remains the same. The aim here is to favour ecosystems that are capable of delivering highest ecological benefits without caring for the costs.

Ecosystem	The extent of restoration area and its share of the degraded area, when the objective is a 15% or a 1% reduction of the degree of degradation.				Total costs of the measures in EUR and the per-hectare cost EUR/ha when the objective is a 15% or a 1% reduction in the degree of degradation in 2016–2050			
	15%		1%		15%		1%	
	ha	%	ha	%	Millions of EUR	EUR/ha	Millions of EUR	EUR/ha
Herb-rich forests	440 217	124.2	10 628	3.0	1 571.3	3 569	37.9	3 569
Herb-rich, mesic and sub-xeric heath forests	3 743 475	29.6	16 148	0.1	4 855.6	1 297	20.9	1 297
Xeric and barren heath forests	714 243	124.4	28 746	5.0	970.8	1 359	39.1	1 359
Spruce mires	962 556	74.8	6 654	0.5	4 738.3	4 923	20.9	3 146
Pine mires and bogs	1 067 928	31.6	4 275	0.1	2 298.0	2 152	9.6	2 243
Open peatland	1 373 865	99.7	11 603	0.8	1 986.5	1 446	18.9	1 626
Semi-natural grassland	97 696	99.7	3 133	3.2	3 933.6	40 264	126.2	40 264
Agricultural ecosystems	79 087	3.5	2 867	0.1	406.6	5 141	17.0	5 944
Urban ecosystems	-	-	-	-	-	-	-	-
Inland water	-	-	-	-	-	-	-	-
Coastal ecosystems	26 112	99.7	2 206	8.4	1 952.0	74 755	143.9	65 242
Rocky outcrops	11 240	99.8	5 502	48.9	82.5	7 341	20.1	3 660
Fell area	2 177 888	190.4	1 398 626	122.3	24.9	11	16.2	12
TOTAL	10 694 308		1 490 389		22 820.0		470.8	
TOTAL per year	305 552		42 583		652.0		13.5	

Prioritization among ecosystem types changes significantly the share of each ecosystem type to be restored (Table 11). For example, in option 1, 88 percent of the degraded herb-rich forest area needed to be restored in order to meet the 15 percent target. With the prioritization in option 2, the area of degraded herb-rich forests needed to be restored increased to more than 120 percent (Table 11). Also the share of semi-natural grasslands which are very important from the perspective of biodiversity has increased from about 26 percent to over 99 percent. Simultaneously, if we focus on the somewhat less diverse forest ecosystem types like herb-rich, mesic and sub-xeric heath forests, we see that with the selected restoration measure portfolio, the degraded area needed to be restored has decreased from more than 97 percent to less than 30 percent.

It is notable that even though in this option the costs were not considered in the between ecosystem prioritization stage, the overall cost decreased significantly compared to the option 1. This is due to the fact that there is large variation in the benefits to be obtained across ecosystem types and that the most expensive ecosystem type to be restored (agricultural ecosystems) coincidentally happens to provide comparatively very limited benefits. In this option, the large reduction of the cost is coincidental and results from the prioritization diverting more effort into ecosystem types that provide higher ecological benefits.

Option 3: Complete computational prioritization

In the third option, prioritization among ecosystems is done based on the full procedure (see chapter 4). This option is otherwise identical to the option 2, but ecosystem-specific mean costs (c_i) are also accounted for. As with option 2, the degree of degradation is again reduced by variable amounts in different ecosystems. While the overall reduction of degree of degradation remains the same, it is accounted for that in some ecosystems significant restoration is cheaper than in others.

Accounting for costs results in a very different result from the previous. For example, while the area needed to be restored in herb-rich forests did not change for the 15 percent restoration target, the area to be restored of semi-natural grasslands decreased from 99 percent to 14 percent (Table 12). This happens because the restoration costs of semi-natural grasslands are extremely high compared to almost any other ecosystem. These costs are high because of the continuous need for management of semi-natural grasslands (grazing and/or mowing). Our focus on a longer timeframe (until 2050) reveals the excessive but quite real cost of this management and pinpoints the importance of considering cost-efficiency across different ecosystem types and over a longer period of time. The very large difference in the total cost between the 15 percent and 1 percent targets is due to the fell ecosystems being very inexpensive to be restored and nearly all of the ecosystem condition improvement at the 1 percent target can be covered from this one ecosystem type only. However, while this is a cost-effective resolution, it is not satisfactory from the perspective of the overall target and hence we also completed the adjusted prioritization below.

Table 12. Restoration option 3: Complete computational prioritization. Taking the costs into account significantly lowers the total costs compared to options 1 and 2, above.

Ecosystem	The extent of restoration area and its share of the degraded area, when the objective is a 15% or a 1% reduction of the degree of degradation.				Total costs of the measures in EUR and the per-hectare cost EUR/ ha when the objective is a 15% or a 1% reduction in the degree of degradation in 2016–2050			
	15%		1%		15%		1%	
	ha	%	ha	%	Millions of EUR	EUR/ ha	Millions of EUR	EUR/ ha
Herb-rich forests	441 294	124.5	40	0	1 575.1	3 569	0.1	3 569
Herb-rich, mesic and sub-xeric heath forests	5 983 884	47.2	169	0	7 761.6	1 297	0.2	1 297
Xeric and barren heath forests	712 485	124.1	287	0	968.4	1 359	0.4	1 359
Spruce mires	503 321	39.1	38	0	2 018.0	4 009	0.09	2 356
Pine mires and bogs	1 145 924	33.9	38	0	1 869.0	1 631	0.06	1 490
Open peatland	1 372 355	99.6	146	0	1 993.2	1 452	0.1	837
Semi-natural grassland	13 975	14.3	1	0	562.7	40 264	0.04	40 264
Agricultural ecosystems	43 333	1.8	8	0	172.2	3 973	0.03	4 083
Urban ecosystems	-	-	-	-	-	-	-	-
Inland water	-	-	-	-	-	-	-	-
Coastal ecosystems	12 807	48.9	1	0	945.5	73 825	0.03	55 185
Rocky outcrops	11 158	99.1	19	0.2	81.9	7 341	0.04	2 191
Fell area	2 198 448	192.2	1 638 513	143.2	25.1	11	19.0	12
TOTAL	12 438 980		1 639 260		17 972.5		20.1	
TOTAL per year	355 399		46 836		513.5		0.6	

Option 4: Adjusted prioritization

Option 4, adjusted prioritization, is perhaps the most sensible and realistic one among the four options presented here. It is otherwise equivalent to option 3, but the working group adjusted it based on the following criteria. The working group decided to decrease the share of rocky outcrops to be restored because the degree of degradation of rocky outcrops is generally very low (0.01; see Table 2 on on page 34) in Finland. Similarly, the relatively speaking very low cost of restoration of the fell ecosystems (reducing the grazing pressure from reindeer) resulted in very high cost-effectiveness of restoration measures leading to a disproportionally large extent of area to be restored. Hence, the share of fell area restored was decided to be decreased into about a third of that in the option 3 (Table 13). The third ecosystem type to be decreased in priority was pine mires and bogs. These are relatively cheap to restore, but their biodiversity is generally not as threatened as that of e.g. spruce mires (see e.g. Raunio et al. 2008, Rassi et al. 2010). Thus, 200 000 hectares of pine mires and bogs to be restored was exchanged to much more expensive and biodiverse spruce mires. In contrast, semi-natural grasslands are remarkably important from the perspective of biodiversity (e.g. Rassi et al. 2010), and their extent of the area to be restored was increased despite the extremely high restoration costs (see Table 10). Additionally, current area of semi-natural grasslands under management (about 30 000 hectares, Kemppainen & Lehtomaa 2009) and areas already planned to be included into management schemes (about 60 000 hectares under management by 2020, Kemppainen & Lehtomaa 2009) were taken into account in this option.

The agricultural ecosystems were also left out from this option, in addition to the urban ecosystems and inland waters that were excluded from options 1–3 as well due to lack of data. This was because the restoration measure options for the agricultural areas are much more limited than for the other ecosystem types, and as a result they produce low ecological benefits and with high price. In option 4, all the peatland ecosystem types and semi-natural grasslands receive the largest shares to be restored (Table 13).

Table 13. Option 4: Adjusted prioritization.

Ecosystem	The extent of restoration area and its share of the degraded area, when the objective is a 15% or a 1% reduction of the degree of degradation.				Total costs of the measures in EUR and the per-hectare cost EUR/ ha when the objective is a 15% or a 1% reduction in the degree of degradation in 2016–2050			
	15%		1%		15%		1%	
	ha	%	ha	%	Millions of EUR	EUR/ ha	Millions of EUR	EUR/ ha
Herb-rich forests	91 050	25.7	5 738	1.6	325.0	3 569	18.8	3 282
Herb-rich, mesic and sub-xeric heath forests	1 190 925	9.4	73 205	0.6	1 544.7	1 297	90.9	1 242
Xeric and barren heath forests	136 850	23.8	8 712	1.5	186.0	1 359	10.9	1 253
Spruce mires	845 604	65.7	52 179	4.1	3 917.3	4 632	117.5	2 252
Pine mires and bogs	2 340 429	69.2	93 023	2.8	5 672.1	2 424	171.2	1 840
Open peatland	1 019 474	74.0	113 277	8.2	1 234.6	1 211	42.5	375
Semi-natural grassland	60 004	61.2	30 001	30.6	2 416.0	40 264	1 207.9	40 262
Agricultural ecosystems	-	-	-	-	-		-	-
Urban ecosystems	-	-	-	-	-	-	-	-
Inland water	-	-	-	-	-	-	-	-
Coastal ecosystems	3 758	14.4	204	0.8	257.7	68 563	14.5	71 164
Rocky outcrops	864	7.7	140	1.2	6.6	7 619	0.1	919
Fell area	399 762	34.9	24 674	2.2	4.6	11	0.4	16
TOTAL	6 088 720		401 152		15 564.5		1 674.8	
TOTAL per year	173 963		11 461		444.7		47.9	

Alternative targets – letting go of the 15 percent target

Option 4 had the same 15 and 1 percent targets as the other three options. However, the targets could also be different. To illustrate, this section first presents an alternative 3 percent target (Table 14) with a twist that the overall cost of the option is fixed to the cost of the 1 percent adjusted prioritization described above in Table 13. This option was calculated to illustrate the power of radical prioritization in reaping much more benefits than options that balance the resources rather evenly among the ecosystem types (see Bottrill et al. 2008; Gilbert 2011; Kotiaho & Halme 2014).

In option 4, we agreed (via negotiation) to keep the area of semi-natural grassland at 30 000 hectares in the case of the 1 percent adjusted prioritization. However, because the management of semi-natural grassland is very expensive, here in the 3 percent target the hectares of semi-natural grassland were not fixed (Table 14). This option serves well as an illustration of what can be achieved with the same resource, if the focus of the prioritization is skewed more strongly towards cost-effectiveness. Reducing the area of diverse but very expensive semi-natural grassland by 25 000 hectares makes much resources available for other ecosystems, which means notable increases in the total area of ecosystems that can be restored: from little less than 0.5 million hectares in the 1 percent target to nearly 1.5 million hectares in the 3 percent target (Table 14). Choosing ecosystems with even higher cost-effectiveness could yield even higher reduction percentages of degradation with the same resources. However, when choosing between ecosystems, it should be borne in mind that one ecosystem can only receive elevated attention at the expense of other ecosystems or by increasing the overall amount of resources (Bottrill et al. 2008; Gilbert 2011; Kotiaho & Halme 2014). The comparison between the 1 and 3 percent targets above is a tangible example of this; even when the amount of resources remained the same, restoring semi-natural grassland at the expense of other ecosystems resulted in a million-hectare negative effect (trade-off) on the other ecosystems.

Second, we present options for prioritization in the case of a 5 or 7.5 percent restoration target (Table 15). In these two options, we followed the relative shares of ecosystems obtained in the 15 percent adjusted prioritization option (Table 13), with the exception that the fell area was forced to stay at one third of the degraded area. Utilizing the 15 percent prioritization was a shortcut and only adopted because there was not enough time to construct the restoration measure portfolios for more than the 15 percent and 1 percent options. Ideally the portfolios should be constructed for each target separately. Naturally, the costs are higher in prioritization models where the target for the reduction of the degree of ecosystem degradation is 5 or 7.5 percent (Table 15) compared to the 1 percent options. Finally, it should be noted that all of the prioritizations presented here are to be treated as examples: the work should be revised if extensive on-the-ground operations are initiated under a known total budget.

Table 14. Alternative prioritization when the costs are standardised to the 1 percent option presented in Table 13. Here the 1 percent option of Table 13 is replicated for the ease of comparison.

Ecosystem	The extent of restoration area and its share of the degraded area				Total costs for the measures in EUR and the per-hectare costs in EUR/ha			
	3%		1%		3%		1%	
	ha	%	ha	%	Millions of EUR	EUR/ha	Millions of EUR	EUR/ha
Herb-rich forests	16 530	4.7	5 738	1.6	59.0	3 569	18.8	3 282
Herb-rich, mesic and sub-xeric heath forests	215 321	1.7	73 205	0.6	279.3	1 297	90.9	1 242
Xeric and barren heath forests	24 838	4.3	8 712	1.5	33.8	1 359	10.9	1 253
Spruce mires	153 863	12.0	52 179	4.1	362.5	4 632	117.5	2 252
Pine mires and bogs	423 222	12.5	93 023	2.8	515.4	2 424	171.2	1 840
Open peatland	184 919	13.4	113 277	8.2	187.5	1 211	42.5	375
Semi-natural grassland	4 835	4.9	30 001	30.6	194.7	40 264	1 207.9	40 262
Agricultural ecosystems	-	-	-	-	-	-	-	-
Urban ecosystems	-	-	-	-	-	-	-	-
Inland water	-	-	-	-	-	-	-	-
Coastal ecosystems	683	2.6	204	0.8	37.7	68 563	14.5	71 164
Rocky outcrops	157	1.4	140	1.2	0.4	7 619	0.1	919
Fell area	393 714	34.4	24 674	2.2	4.6	11	0.4	16
TOTAL	1 418 082		401 152		1 674.7		1 674.8	
TOTAL per year	40 517		11 461		47.9		47.9	

Table 15. Alternative prioritization with the 5 and 7.5 percent targets.

Ecosystem	The extent of restoration area and its share of the degraded area				Total costs for the measures in EUR and the per-hectare costs in EUR/ha			
	7.5%		5%		7.5%		5%	
	ha	%	ha	%	Millions of EUR	EUR/ha	Millions of EUR	EUR/ha
Herb-rich forests	43 729	12.3	28 316	8.0	156.1	3 569	101.1	3 569
Herb-rich, mesic and sub-xeric heath forests	575 229	5.0	370 566	3.0	746.1	1 297	480.7	1 297
Xeric and barren heath forests	66 311	12.0	42 578	7.0	90.1	1 359	57.9	1 359
Spruce mires	403 690	31.4	262 903	20.4	1 188.4	2 944	633.2	2 408
Pine mires and bogs	1 115 875	33.0	731 365	21.6	1 401.4	1 256	905.4	1 238
Open peatland	483 101	35.1	323 003	23.4	499.0	1 033	327.5	1 014
Semi-natural grassland	17 207	17.6	5 574	5.7	692.8	40 263	224.4	40 266
Agricultural ecosystems	-	-	-	-	-	-	-	-
Urban ecosystems	-	-	-	-	-	-	-	-
Inland water	-	-	-	-	-	-	-	-
Coastal ecosystems	1 786	6.8	1 171	4.5	120.3	67 359	64.6	55 191
Rocky outcrops	413	3.7	268	2.4	1.1	2 657	0.7	2 665
Fell area	395 055	34.5	397 228	34.7	4.6	12	4.6	12
TOTAL	3 102 395		2 162 974		4 900.0		2 800.0	
TOTAL per year	88 640		61 799		140.0		80.0	

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DOCUMENTATION PAGE

Publisher	Ministry of the Environment Department of the Natural Environment	*Date* April 2016
Author(s)	Janne S. Kotiaho, Saija Kuusela, Eini Nieminen, Jussi Päivinen and Atte Moilanen	
Title of publication	**Framework for assessing and reversing ecosystem degradation – Report of the Finnish restoration prioritization working group on the options and costs of meeting the Aichi biodiversity target of restoring at least 15 percent of degraded ecosystems in Finland**	
Publication series and number	Reports Of The Ministry Of The Environment 15en | 2016	

Abstract

This report is an abridged and revised English language edition of the original proposition of the Finnish restoration prioritization working group on the options and costs of restoring 15 percent of degraded ecosystems in Finland.

We start with the key findings and the original propositions of the working group. Based on the experiences from Finland, we also provide a few new propositions for the international readership to help to plan and implement work towards meeting the global target of restoring 15 percent of the degraded ecosystems.

In the beginning of the report, we describe the conceptual background of the work, i.e. that ecosystem degradation or improvement has a minimum of two components: the extent of area that has become degraded or restored and the magnitude of the degradation, or its counterpart improvement, at any given location. We then describe the procedure that we developed to systematically measure the magnitude of degradation from which the 15 percent can be calculated and the magnitude of improvement that different restoration measures can offer. The guiding principle adopted for the development of the procedure was to treat all ecosystems that are not in their natural state as degraded. However, it is worth emphasizing that the objective is not to reach the natural state of the ecosystems, but to reduce the degree of ecosystem degradation by restoration.

With an example from herb-rich forests, we show how we prioritized restoration measures within an ecosystem. The prioritization was based on the effects of restoration measures on biodiversity and on the costs of the measures. We also considered the effect of restoration measures on some key ecosystem services. In addition to the restoration measures within each ecosystem, we also conducted prioritization among ecosystems. The prioritization among ecosystems is based on an analysis identifying the ecosystems where reasonable investments bring the greatest reduction in the degree of ecosystem degradation. The procedure thus enabled us to find the balanced and cost-effective restoration measure portfolios within each ecosystem type and to allocate resources effectively to those ecosystem types that provided highest benefits in terms of biodiversity and reduction of the degree of ecosystem degradation.

To our knowledge, this report is the first to estimate the cost of meeting the 15 percent restoration target across all relevant terrestrial ecosystems in one country. Our work exemplifies that simultaneous prioritization among all major terrestrial ecosystems greatly reduces the overall cost of meeting the 15 percent restoration target. Indeed, if we focus on restoring 15 per cent of one ecosystem type at a time, which is the *modus operandi* in many parts of the world, the overall cost of meeting the 15 percent restoration target is more than twice compared to the prioritization approach we have adopted here.

Rather than getting fixed on the 15 percent target, we also decided to provide additional options for decision makers. Thus, the report gives alternative answers to the question of which ecosystem restoration measures to take, at which scale and in which ecosystem types, in order to meet the overall target for ecosystem restoration in Finland.

Keywords	biodiversity, Convention on Biological Diversity (CBD), cost-effectiveness, degradation, ecosystem, prioritization, restoration, target, 15 percent			
Financier/ commissioner	Ministry of the Environment			
	ISBN 978-952-11-4603-9 (PDF)		ISSN 1796-170X (online)	
	No. of pages 65	*Language* English	*Restrictions* For public use	
For sale at/ distributor	The publication is available on the internet: www.ym.fi/julkaisut			
Financier of publication	Ministry of the Environment			
Printing place and year	Helsinki 2016			

KUVAILULEHTI

Julkaisija	Ympäristöministeriö Luontoympäristöosasto	*Julkaisuaika* Huhtikuu 2016
Tekijä(t)	Janne S. Kotiaho, Saija Kuusela, Eini Nieminen, Jussi Päivinen ja Atte Moilanen	
Julkaisun nimi	**Framework for assessing and reversing ecosystem degradation – Report of the Finnish restoration prioritization working group on the options and costs of meeting the Aichi biodiversity target of restoring at least 15 percent of degraded ecosystems in Finland** (Kehys ekosysteemien heikentymisen suunnan kääntämiselle ja arvioinnille – Suomalaisen elinympäristöjen tilan edistämisen työryhmän raportti kustannuksista ja vaihtoehdoista luonnon monimuotoisuuden Aichi-tavoitteiden saavuttamisessa eli ennallistettaessa vähintään 15 prosenttia Suomen heikentyneistä ekosysteemeistä)	
Julkaisusarjan nimi ja numero	Ympäristöministeriön raportteja 15en | 2016	
Tiivistelmä	Tämä raportti on lyhennetty ja uusittu englanninkielinen versio alkuperäisestä suomalaisen elinympäristöjen tilan edistämisen työryhmän alkuperäisestä esityksestä, jossa esitetään vaihtoehtoja ja kustannuksia ennallistettaessa 15 prosenttia heikentyneistä ekosysteemeistä Suomessa. Aloitamme työryhmän tärkeimmistä havainnoista ja alkuperäisistä esityksistä. Perustuen Suomessa saatuihin kokemuksiin teemme myös muutamia uusia esityksiä kansainväliselle lukijakunnalle auttaaksemme heitä suunnittelemaan ja toteuttamaan työtä, jonka tarkoituksena on täyttää maailmanlaajuinen tavoite ennallistaa 15 prosenttia heikentyneistä ekosysteemeistä. Raportin alussa kuvailemme työn konseptuaalista taustaa, eli sitä, että ekosysteemin heikentymisellä tai toipumisella on vähintään kaksi komponenttia: heikentyneen tai ennallistetun alueen laajuus ja heikentymisen voimakkuus, tai sen vastapainona toipuminen missä tahansa paikassa. Tämän jälkeen kuvaamme menetelmän, jonka kehitimme mitataksemme systemaattisesti heikentymisen laajuutta, josta 15 prosenttia voidaan laskea sekä erilaisten ennallistamismenetelmien mahdollistamaa toipumisen laajuutta. Menetelmän kehittämisessä käytetty pääperiaate oli määrittää heikentyneiksi kaikki sellaiset ekosysteemit, jotka eivät ole luonnonvaraisessa tilassaan. On kuitenkin korostettava, että tarkoituksena ei ole saavuttaa ekosysteemien luonnonvaraista tilaa, vaan vähentää ekosysteemien heikentymisastetta ennallistamisen avulla. Näytämme lehtometsäesimerkin avulla, kuinka priorisoimme ennallistamistoimenpiteet ekosysteemissä. Priorisointi pohjautui niihin vaikutuksiin, joita ennallistamistoimenpiteillä on luonnon monimuotoisuudelle, sekä toimenpiteiden kustannuksiin. Otimme huomioon myös ennallistamistoimenpiteiden vaikutuksen joihinkin tärkeimpiin ekosysteemipalveluihin. Sen lisäksi, että priorisoimme ennallistamistoimenpiteitä kunkin ekosysteemin sisällä, teimme priorisoinnin myös ekosysteemien välillä. Ekosysteemien välinen priorisointi pohjautuu analyysiin, jonka avulla tunnistetaan ne ekosysteemit, joissa kohtuullisilla investoinneilla saadaan aikaan suurin ekosysteemin heikentymisasteen väheneminen. Menetelmä mahdollisti siis tasapainoisen ja kustannustehokkaan ennallistamismenetelmävalikoiman löytämisen kunkin ekosysteemityypin sisällä ja resurssien kohdistamisen tehokkaasti niihin ekosysteemityyppeihin, jotka tuottivat suurimmat hyödyt luonnon monimuotoisuuden ja ekosysteemin heikentymisasteen vähenemisen suhteen. Tietääksemme tämä raportti on ensimmäinen, jossa arvioidaan niitä kustannuksia, jotka syntyvät pyrittäessä tavoitteeseen ennallistaa 15 prosenttia yhden maan kaikista olennaisista maaekosysteemeistä. Työmme toimii esimerkkinä siitä, että samanaikainen priorisointi kaikissa suurimmissa maanekosysteemeissä vähentää 15 prosentin ennallistamistavoitteen saavuttamisen kustannuksia huomattavasti. Jos keskitymme ennallistamaan 15 prosenttia yhdestä ekosysteemityypistä kerrallaan, kuten monissa paikoissa tehdään, 15 prosentin ennallistamistavoitteen saavuttamisen kustannukset ovat yli kaksinkertaiset verrattuna tässä soveltamaamme priorisointimenetelmään. Sen sijaan että olisimme pitäytyneet vain 15 prosentin tavoitteessa, päätimme tuottaa myös lisävaihtoehtoja päättäjille. Raportissa siis annetaan vaihtoehtoisia vastauksia kysymyksiin siitä, mitä ekosysteemin ennallistamistoimenpiteitä tulisi tehdä, missä määrin ja missä ekosysteemeissä, jotta saavutettaisiin ekosysteemin ennallistamisen yleistavoite Suomessa.	
Asiasanat	Luonnon monimuotoisuus, Convention on biological Diversity (CBD), kustannustehokkuus, heikentyminen, ekosysteemi, priorisointi, ennallistaminen, tavoite, 15 prosenttia	
Rahoittaja/ toimeksiantaja	Ympäristöministeriö	

	ISBN 978-952-11-4603-9 (PDF)		ISSN 1796-170X (verkkoj.)	
	Sivuja 65	*Kieli* englanti	*Luottamuksellisuus* julkinen	
Julkaisun myynti/ jakaja	Julkaisu on saatavana vain internetistä: www.ym.fi/julkaisut			
Julkaisun kustantaja	Ympäristöministeriö			
Painopaikka ja -aika	Helsinki 2016			

PRESENTATIONSBLAD

Utgivare
Miljöministeriet
Naturmiljöavdelningen

Datum
April 2016

Författare
Janne S. Kotiaho, Saija Kuusela, Eini Nieminen, Jussi Päivinen och Atte Moilanen

Publikationens titel
Framework for assessing and reversing ecosystem degradation – Report of the Finnish restoration prioritization working group on the options and costs of meeting the Aichi biodiversity target of restoring at least 15 percent of degraded ecosystems in Finland
(Ram för bedömning och minskning av degradering av ekosystem – Rapport från den finländska arbetsgruppen för prioritering av restaurering angående alternativen och kostnaderna för att uppnå Aichimålen för biologisk mångfald att restaurera minst 15 procent av de degraderade ekosystemen i Finland)

Publikationsserie och nummer
Miljöministeriets rapporter 15en | 2016

Sammandrag

Denna rapport är en svensk översättning av ett engelskt sammandrag av det ursprungliga förslaget från den finländska arbetsgruppen för prioritering av restaurering angående alternativen och kostnaderna för att restaurera 15 procent av de degraderade ekosystemen i Finland.

Vi inleder med arbetsgruppens viktigaste resultat och ursprungliga förslag. Utgående från erfarenheterna från Finland tillhandahåller vi även några nya förslag för internationella läsare för att bistå i planeringen och genomförandet av arbetet för att uppnå det globala målet att restaurera 15 procent av de degraderade ekosystemen.

I inledningen till rapporten beskriver vi arbetets konceptuella bakgrund, dvs. att det finns minst två komponenter i degradering eller förbättring av ekosystem: omfattningen på området som har degraderats eller restaurerats och omfattningen av degraderingen, eller förbättringen, på en viss plats. Därefter beskriver vi den metod vi utvecklade för att systematiskt mäta omfattningen av degradering som de 15 procenten kan beräknas ifrån och den omfattning av förbättring som olika restaureringsåtgärder kan erbjuda. Den riktlinje som antogs för att utveckla metoden var att behandla alla ekosystem som inte är i naturligt tillstånd som degraderade. Det är emellertid skäl att betona att syftet inte är att uppnå ekosystemens naturliga tillstånd, utan att minska graden av degradering av ekosystemen genom restaurering.

Med hjälp av ett exempel från växtrika skogar visar vi hur vi prioriterade restaureringsåtgärder inom ett ekosystem. Prioriteringen utgick ifrån de effekter restaureringsåtgärderna hade på biodiversiteten och på kostnaderna för åtgärderna. Vi beaktade även effekten restaureringsåtgärderna hade på vissa viktiga ekosystemtjänster. Förutom restaureringsåtgärderna inom varje ekosystem utförde vi även prioritering ekosystem emellan. Prioriteringen ekosystem emellan bygger på en analys som identifierar de ekosystem där skäliga investeringar ger den största reduceringen av graden av degradering av ekosystemet. Metoden gjorde det således möjligt för oss att hitta balanserade och kostnadseffektiva restaureringsåtgärder för varje typ av ekosystem och att fördela resurserna effektivt till de typer av ekosystem som ger störst fördelar vad gäller biodiversitet och minskning av graden av degradering av ekosystemen.

Så vitt vi vet är denna rapport den första som uppskattar kostnaderna för att uppnå målet på en restaurering på 15 procent i alla relevanta terrestra ekosystem i ett land. Vårt arbete är ett exempel på att simultan prioritering bland alla stora terrestra ekosystem kraftigt reducerar den totala kostnaden för att uppnå restaureringsmålet på 15 procent. Om vi fokuserar på att restaurera 15 procent av en typ av ekosystem i taget, vilket är det förfaringssätt som används i många delar av världen, blir den totala kostnaden för att uppnå restaureringsmålet på 15 procent dubbelt så hög som med det prioriteringssätt vi har antagit här.

Istället för att fokusera på målet på 15 procent, beslöt vi oss även för att förse beslutsfattare med ytterligare alternativ. Rapporten ger således alternativa svar på frågan om vilka åtgärder som bör vidtas för att restaurera ekosystem, på vilken skala och i vilka typer av ekosystem, för att uppnå det totala målet för restaurering av ekosystem i Finland.

Nyckelord
biodiversitet, Konventionen om biologisk mångfald (CBD), kostnadseffektivitet, degradering, ekosystem, prioritering, restaurering, mål, 15 procent

Finansiär/ uppdragsgivare
Miljöministeriet

ISBN	ISSN
978-952-11-4603-9 (PDF)	1796-170X (online)

Sidantal	*Språk*	*Offentlighet*	
65	engelska	Offentlig	

Beställningar/ distribution
Publikationen finns tillgänglig endast på internet:
www.ym.fi/julkaisut

Förläggare
Miljöministeriet

Tryckeri/tryckningsort och -år
Helsingfors 2016

Ecosystem and biosphere degradation ultimately caused by increasing human population size and per capita consumption, are among the greatest threats for biodiversity and ecosystem services and indeed for the future of humankind. This report comprises the summary of results of the original proposition of the Finnish restoration prioritization working group on the options of restoring 15 percent of degraded ecosystems in Finland. The basis of this work lies on the Aichi targets, EU biodiversity strategy 2011–2020, and the resolution made by the Finnish Government that Finland participates in the global efforts to restore at least 15 percent of degraded ecosystems by the year 2020.

Here we develop a procedure i) to systematically estimate the magnitude of degradation from which the 15 percent can be calculated, ii) to evaluate the magnitude of improvement different restoration measures can offer, and iii) to prioritize restoration measures within and between ecosystem types. The procedure is developed from the perspective of real-world operational feasibility while still retaining the ecologically most relevant components. Our results show that the overall loss of ecosystem condition of Finnish terrestrial ecosystems is close to 60 percent. We show that if we focus on restoring 15 percent of one ecosystem type at a time, which is the *modus operandi* in many parts of the world, the overall cost of meeting the 15 percent restoration target is more than twice compared to the prioritization approach we have developed here. If we were to choose one major conclusions from the report it is this: simultaneous prioritization of cost-effective restoration measures within and among ecosystem types is effective in delivering significant economic benefits. Thus, we must start preparing a shift from ecosystem-specific action plans and conservation schemes to plans focusing on multiple ecosystems simultaneously.

Ympäristöministeriö
Miljöministeriet
Ministry of the Environment

ISBN 978-952-11-4603-9 (PDF)
ISSN 1796-170X (online)