Balancing Different Environmental Effects of Forest Residue Recovery in Sweden: A Stepwise Handling Procedure

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1. Introduction

The Swedish vision of zero net greenhouse gas emissions by 2050 requires a sustainable and resource-efficient energy supply. To this end, policy measures promote renewable energy sources, including forest fuels, which can reduce dependence on fossil fuels. In Sweden, 55% of the total land area is productive forest land. Climate objectives have increased interest in recovery of forest residues, not only tree tops and branches from logging but also stumps, resulting in additional forestry intensification and thus additional pressure on forest ecosystems. Climate objectives therefore risk being at cross-purposes with other environmental objectives. For forest fuels to contribute to a sustainable energy supply, the other environmental impacts of forestry must be kept within acceptable limits. Workable solutions for managing the environmental effects of forest residue recovery are therefore necessary.

1.1. Purpose and Scope

This study suggests how to use environmental quality objectives (EQOs) to evaluate forest residue recovery and how to balance the environmental effects, given the options for managing these effects and their potential impacts. We present an environmental evaluation model that helps highlight the effects that should receive preferential attention. Previous studies have linked environmental effects with EQOs without fully explaining what aspect of an objective applies to the type of forestry operation. This report clarifies these relationships, offering suggestions for how the EQOs can be used in the residue recovery context, in conjunction with the appropriate environmental systems analysis tools.

1.2. Outline of the Report

Chapter 2 summarizes the environmental effects of forest residue recovery based on the current scientific literature, describes the structure of the Swedish EQOs, and discusses how the components of these objectives can be used in an environmental evaluation of a specific forestry operation, linking the environmental effects with the relevant EQOs via general environmental impact categories. Chapter 3 discusses environmental systems analysis tools and their applicability in evaluating forest residue recovery. Properties of those tools found most suitable for the purpose are adopted and used as building blocks in a proposed model for evaluating the environmental effects of residue recovery. Chapter 4 applies this model to a case study and identifies useful indicators as well as some information gaps that make the model less functional. Finally, Chapter 5 discusses the report findings, focusing on the environmental evaluation model presented.

2. Linking Environmental Effects of Forest Residue Recovery to Environmental Quality Objectives North America

The terms *environmental effect* and *environmental impact* are not used as synonyms in the literature. In this report, an environmental effect is a change in a given state in the environment. For example, the removal of nutrients is an environmental *effect*. The reduced number of nutrients can in turn *impact* different functions and processes in the environment, contributing, for instance, to the environmental problem of acidification. Here, the effect is the actual change, whereas the impact is the environmental consequence the effect may have.

This report draws on two major sources, a synthesis by de Jong et al. (2012) of research on the environmental effects of forest residue recovery (logging residues and stumps) and a collection of assessments of the Swedish EQOs. To assess the potential magnitude of residue recovery under the constraint of meeting EQOs, de Jong et al. match a range of residue recovery scenarios to the relevant objectives, based on environmental effects. A modelling study by Belyazid et al. (2010) took a similar approach by evaluating the environmental effects of different scenarios of forest residue recovery in relation to the relevant EQOs. The assessments are mainly based on the 2012 in-depth evaluation (SEPA, 2012a) and regional follow-up assessments (Miljömålsportalen, 2013). These evaluations can be found at the "Environmental Objectives Portal" (miljomal.se), which gathers information on the environmental objectives. The objectives considered most relevant to forest residue recovery are matched with the relevant specific forestry operations and summarized (see section 2.3).

2.1. Environmental Effects of Forest Residue Recovery

The terms *environmental effect* and *environmental impact* are not used as synonyms in the literature. In this report, an environmental effect is a change in a given state in the environment. For example, the removal of nutrients is an environmental *effect*. The reduced number of nutrients can in turn *impact* different functions and processes in the environment, contributing, for instance, to the environmental problem of acidification. Here, the effect is the actual change, whereas the impact is the environmental consequence the effect may have.

Common environmental effects of forest residue recovery presented by de Jong et al. {2012 #8} are summarized, classified by geographical scale, matched to the relevant environmental impact categories, and linked with the relevant EQOs, in **Table 1**.

Table 1.Overview of potential environmental effects of recovery of logging residues and stumps (based on de Jong et al. 2012)

Logging Residue (tops and branches) and Stump Recovery							
Environmental Impact Category	Climate change		Acidification	Eutrophication	Biodiversity		Forest Productivity
Geographical Aspects	Global		Regional, Local	Regional, Local	Local	Regional, Local	Local
Environmental Effects	Alteration of the soil carbon pool	Methane and nitrous oxide emissions	Nutrient removal	Nutrient leaching	Loss of harvest residues with functions such as substrate and habitat	Hg methylation	Decreased forest growth
Description	Soil disturbances such as damage and compaction from vehicles and machinery (likely to increase when less logging residue material and stumps have been left to serve as a protective layer and to enhance the bearing capacity of soils).	Damage from vehicles and machinery in moisture-rich areas where the soil bearing capacity is low might have impacts on these types of emissions. Soil compaction can lead to poor oxygen supply and anaerobic conditions which favour the formation of these gases.	Recovery of nutrient-rich logging residues. Greatly increased by logging residues recovery compared with conventional stem wood recovery. Effect of stump recovery much less than that of logging residues.	Logging residues recovery and ash recycling should in theory not imply an increased risk of nitrogen leaching, which means that their contribution to eutrophication should in the worst case still be moderate.	The removal of logging residues and stumps that might function as substrate and provide habitats for different species. Stumps from felling activities make up a large proportion of the annual production of dead hardwood in the forests.	Soil disturbances due to damage from vehicles and machinery and stump recovery.	Decreased growth as an impact of logging residue recovery. Observed over a few decades. No permanent impact on the production ability of the forestland.
	Stump recovery with current technology means increased disturbances.	Increased intensification of recovery might lead to an increased need for nutrient compensation of nitrogen. Nitrogen fertilization can give	Areas suffering from acidification caused by air pollution are among those where the acidifying risks posed by forestry are the greatest.	Logging residue recovery can even give a relief of nitrogen in certain areas with high nitrogen loads (southern Sweden).	General conservation considerations – lack of/inadequate, etc.		Repetitive forest residue recovery at regeneration felling, clearance, and thinning, expected to restrain the forest production during parts of the rotation

				consequence of stump recovery and potential damages caused by driving of forestry machines affect leaching during the clearing phase is not clear.			and nutrient content of harvested biomass.
Relevant EQOs covered in the report[1]	Reduced Climate Impact		Natural Acidification Only Sustainable Forests A Rich Diversity of Plant and Animal Life	Zero Eutrophication Sustainable Forests A Rich Diversity of Plant and Animal Life	A Rich Diversity of Plant and Animal Life Sustainable Forests		Forest Production Objective

[1]The environmental effect of mercury methylation, which is likely to increase due to increased soil disturbance caused by vehicle traffic and stump recovery, is considered part of the *biodiversity* impact category, since a separate category of toxic compounds is not included in this report. The forest production objective is not an EQO but is central in Swedish forestry policy and shares features with some environmental objectives, e.g. *Sustainable Forests*, that also pertain to preserving the production ability of the forest land by sustainable use, etc.

De Jong et al. {2012 #8} find a clear potential for increased recovery of forest residues without a negative effect on the EQOs, provided a number of sustainability conditions are met (see Table 2). These conditions specify how and where forest residues are recovered as well as how current forestry functions. The minimum standard of the regulatory principle of *Environmental Consideration* ("miljöhänsyn") needs to be followed, as prescribed by law, both in current forestry practices and in recovery of logging residues and stumps. In certain cases *landscape values* call for stricter practices, providing guidelines that need to be followed. These conditions are central to the work in this report and are referred to in several contexts.

Table 2. The conditions identified by de Jong et al. {2012 #8} that need to be met to make a scenario of increased recovery of forest residues compatible with the EQOs considered in the study

Tree Types	Ash Recycling	Environmental Consideration	Other Restrictions
• **Primarily, logging residues and stumps from coniferous trees are harvested.** • **Residues from broad-leaved (incl. valuable broad-leaved) trees should be completely avoided in coniferous-dominated stands.** • **Only the dominating tree type should be recovered in broad-leaved-dominated stands (generally more restricted recovery of broad-leaved trees; regional assessments must be made, e.g. on species occurrence).**	• Ash recycling with ash of good quality is done to compensate for nutrient losses due to increased recovery. • Ash recycling is practiced where it is needed and adjusted to the stand type.	• The regulatory principle of Environmental consideration needs to function as intended, i.e. at least in accordance with law and in some cases up to the "advisory level" (a higher level than the legal stipulation).	• Without nitrogen compensation, logging residue recovery should be limited in connection to thinning, to avoid too many negative effects on production. • Increased logging residue and stump recovery involves more traffic in cutting areas with risk of increased soil damage. Restrict recovery to areas with good bearing capacity to reduce the risk of causing damage.

According to de Jong et al. {2012 #8}, satisfying these conditions is realistic even if Swedish forestry does not currently meet all of them. For instance, the legal principle of Environmental Consideration is not satisfied everywhere, and ash recycling is currently very limited. Table 1 gives an initial overview of the environmental effects of forest residue recovery, and the requirements in Table 2 highlight important conditions that need to be met to reduce the risk of negative environmental impacts. The environmental effects and their environmental impact categories are presented in more detail in section 2.3. This section also discusses the connections between the environmental effects and the relevant EQOs.

2.2. Environmental Quality Objectives

2.2.1. The Environmental Objectives System

The overall goal of Swedish environmental policy is to deliver, within one generation, i.e., by 2020, to the next generation a society in which the major environmental problems in Sweden are solved, without having exported environmental or health problems. Sixteen *environmental quality objectives* (EQOs), and eighteen *milestone targets* support this goal. This concerns all environmental actions at every level in society {Miljömålsportalen, 2012 #29}. The EQOs specify the conditions to be met by 2020 (2050, for Reduced Climate Impact). The earlier interim targets have now been replaced by 18 milestone targets, components of the strategies needed to solve the environmental problems. Government agencies assess the status of the objectives in annual reports and an in-depth evaluation report compiled once every parliamentary term{Miljömålsportalen, 2012 #29;SEPA, 2012b #30}.

2.2.2. Components of the Environmental Quality Objectives

The EQO-system is made up of a number of components and interactions among these. Table 3 provides an overview of the key components in the residue recovery context.

Table 3. An overview of the relevant EQO components and how they can be used as part of an environmental assessment of forest residue recovery

Specifications	Indicators	Policy instruments
Identify the affected parts of the meaning of the EQO.	Show how the environmental effects can be monitored and their relation to the EQOs.	Address the environmental effects and how these will affect the feasibility of potential measures.
Identify the environmental conditions that can be (negatively) impacted by the activity.	Measure how well the environmental effects can be covered by the EQOs.	Provide requirements and measures to mitigate the environmental effects.

Figure 1 shows our interpretation of the EQO-system, with the (general) environmental effects of forest residue recovery included and linked to the relevant components (i.e., to the specification, indicators, and policy instruments). The flowchart gives a structural overview of the components that make up the system and how these relate internally, as well as to the evaluation methodology. Note that the flowchart is an interpretation and freely developed by the authors. A more in-depth description of the components and the basis for evaluation follows.

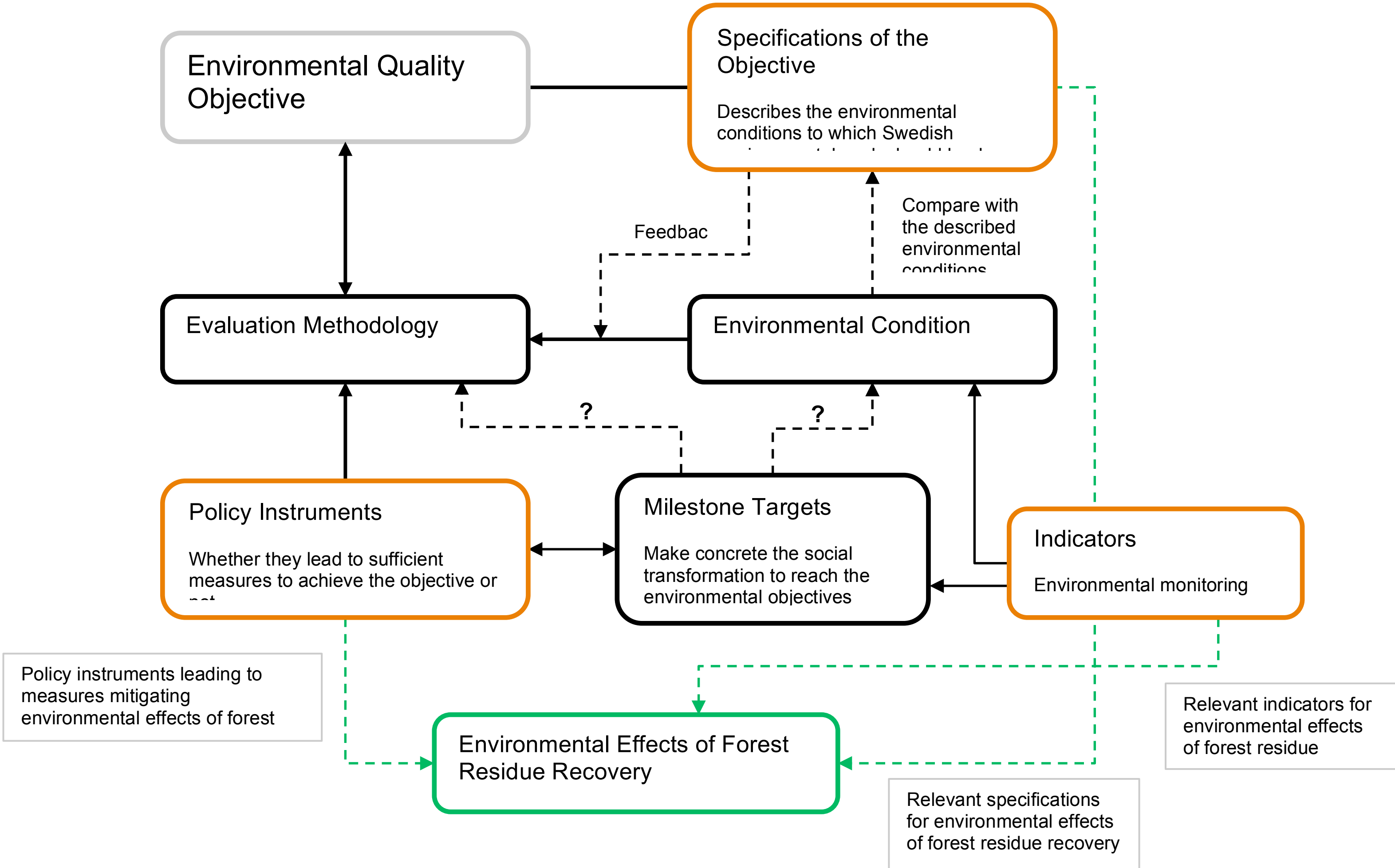

Figure 1. The flowchart shows the components of the EQOs and presents an interpretation of how they connect to the evaluation methodology. The activity of forest residue recovery is included to show how its environmental effects can be evaluated by the EQO components.

Specifications

The specifications serve to clarify and describe the meanings of the EQOs and the environmental conditions to which the environmental work should lead {SEPA, 2011a #9}, providing the basis for how to interpret the EQOs, criteria for evaluating the prospect of fulfilling them, and guiderails for environmental work {Gov., 2012 #11}.

Those specifications that can readily be seen as having a counterforce in forest residue recovery work as a general indicator of the compatibility between the EQO and such recovery. How and where the recovery of forest residues has the potential to affect the environmental conditions negatively can thus be correlated to the relevant specifications (see **Figure 1**). A counterforce arises if environmental effects of recovery have negative impacts on environmental conditions described by the specifications. There are also situations where the environmental conditions described by specifications can be expected to be affected positively (in addition to positive climate change effects from fossil fuel replacement).

Indicators

Every EQO also has a set of indicators for monitoring the conditions described by the specifications. Those indicators relevant to impacts caused by environmental effects of forest residue recovery serve to relate the activity to the EQO (see **Figure 1**). If the supply of relevant indicators is poor, this could result in environmental impacts being overlooked, leading to underestimates of the activity's environmental influence. This may also be a problem with indicators that are too unspecific. A supply of relevant indicators is important in providing incentives to follow up the environmental effects and their environmental impacts. By identifying relevant indicators and specifications of the EQOs, those parts of the objectives that are affected by the environmental effects of forest residue recovery are highlighted.

Policy Instruments

Policy instruments aim to provide measures that in turn improve environmental conditions so that the objectives are met. The policy instruments' ability to create the basis for meeting the objectives is an important part of the evaluation, see **Figure 1**. Policy instruments can be divided into those that target the actual environmental effects and those that prohibit forestry operations in certain areas altogether.

Milestone Targets

None of the few milestone targets introduced to date is directly applicable to forestry and forests, and the meanings of two biodiversity-related targets are broad and do not include forest residue recovery specifically, so we set milestone targets aside for now, marking their influence with question marks in **Figure 1**, as they are new components of the system and have not yet been used in evaluations.

A New Basis for Evaluation

The EQO-system has been restructured recently, and counties have adopted the new guidelines. The changes have led to a new basis for evaluation to assess the status of the EQOs. Current evaluations are based on two questions for each EQO: (i) can the conditions of the environment described by the EQO be achieved by 2020 (2050 for *Reduced Climate Impact*)? (ii) Is there a basis for achieving the EQO, in terms specified by national and/or international policy instruments, that will result in adequate measures being implemented before 2020/2050, to reach the described conditions at a later stage? The new version is stricter than its predecessor in one sense: what matters is the actual basis for achieving the objectives via the policy instruments decided, rather than the *potential* for creating that basis. But the timescale ("at a later stage") is more flexible. This allows for possible time lags before the effects of measures can be observed in the environment. What matters is the deadline for creating the basis via policy instruments, with adequate measures implemented before 2020{SEPA, 2012a #14}.

In the new EQO-system, the specifications play a prominent role, in part due to the expiration and phase-out of the interim targets. The current number of milestone targets is low compared to the number of interim targets, the last of which expired in 2010. The 2011 evaluation of the EQOs was the first based on the new (then, proposed) specifications. This evaluation differed from earlier evaluations of the EQOs and cannot be used for comparisons with previous years {SEPA, 2011a #9;Gov., 2010 #32}. In the in-depth and annual follow-up evaluations of 2012, the evaluation methodology was further developed, also leading to a slightly different evaluation than in 2011. The difference was the consideration of the current basis for achieving the objectives by already-decided policy instruments. In 2011, the potential for creating such a basis was included in the evaluation in terms of the probability to come to decisions on adequate policy instruments before 2020 {SEPA, 2012a #14}.

Background to the Changes and the Set-Up of the System

The Swedish Parliament (Riksdag) and Government (Regering) approved changes to the EQO-system in 2010. The Environmental Objectives Council (Miljömålsrådet) was disbanded. Now, Naturvårdsverket (the Swedish Environmental Protection Agency) is responsible for coordinating follow-up and environmental evaluation. The All Party Committee on Environmental Objectives (Miljömålsberedningen), an advisory group established in 2010, has been tasked with presenting environmental strategies to the Government in the form of milestone targets, policy instruments, and measures, etc. {SEPA, 2011a #9}.

In the Government bill, *Svenska miljömål – för ett effektivare miljöarbete (prop. 2009/10:155)*, the Government explained that the current specifications of the EQOs needed to be revised. In particular, the specifications of the objectives concerning types of environments and ecosystems were not functional. The Swedish Environmental Protection Agency (SEPA) was given the task to systematically review the specifications and present a set of revised specifications. SEPA presented its proposal for new specifications in the follow-up report *Miljömålen på ny grund* (2011). Several of the suggested specifications were fairly comprehensive, in order to provide satisfactory guidelines toward achieving the EQOs and to function as evaluation criteria {SEPA, 2011a #9}. When the specifications were subsequently processed and finally formulated by the Government, the basic intention was for them to describe an environmental condition, not be action-oriented, not be too comprehensive, and as far as possible all be formulated similarly{Gov., 2012 #11}. While the suggested specifications included points aiming at social transformation and various actions, the final and now adopted specifications are not very "specific" in their formulation. Directive properties were instead to come from the milestone targets, which serve to describe the social transformation required to achieve the EQOs, in order to highlight the need for change within society in order to achieve the EQOs {Miljömålsberedningen, 2011 #12}. The specifications were presented in their final version in the report *Svenska miljömål – preciseringar av miljökvalitetsmålen och en första uppsättning etappmål* (2012). The Government bill also suggested the fundamentals for the new basis for evaluation.

2.3. Environmental Impact Categories

The environmental impacts initiated by the environmental effects of forest residue recovery can be divided into five main categories: forest productivity, climate change, acidification, eutrophication, and biodiversity (see **Figure 2**). The relevant EQOs are matched with the impact categories with which they are most strongly connected. Note that the forest production objective is not an EQO and that the impact category of forest productivity is presented as part of the section on climate change (see section 2.3.1). The choice of relevant objectives is based on those presented by de Jong et al. {2012 #8}. Relevant specifications and indicators for forest residue recovery are presented for each of the EQOs (see Tables 4 to 8). These are also summarized at the end of this chapter. Unless otherwise cited, the text about environmental effects in this chapter is based on information from the synthesis by de Jong et al. {2012 #8}.

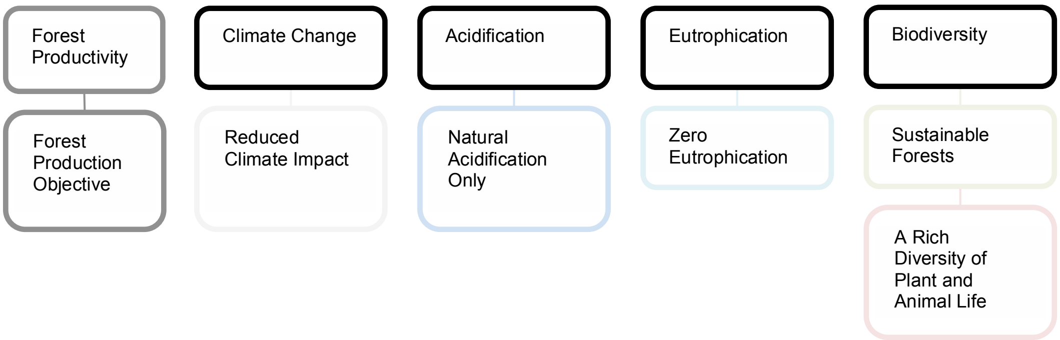

Figure 2. How the environmental impact categories match up with the EQOs presented in section 2.3.1.

2.3.1. Climate Change and Forest Productivity

Climate Change

The input-output energy of forest fuels is generally very beneficial, over and above the reductions of greenhouse gas (GHG) emissions when fossil fuels are replaced. Important parameters that greatly affect the climate benefits are how the carbon balance is altered, locally and over time, by different recovery practices and compensation of nutrients. Emissions of nitrous oxide and methane can also have some influence as two potent GHGs. Forest production has a great influence on the long-term carbon balance. Production can be somewhat negatively affected by the recovery of logging residues, while stump recovery does not seem to have an effect. Increased soil disturbance due to stump recovery, in tandem with increased damage due to the transport of heavy forestry machinery, can stimulate decomposition and increase carbon loss during the clearing phase. How the ground vegetation develops during this period also affects carbon balance. Increased decomposition during the clearing phase leads to greater liberation of nutrients, which in turn may stimulate growth, resulting in an increased litter formation and build-up of soil carbon. The GHG balance in a forestry operation needs to be evaluated during at least one rotation period so that all relevant stages can be included. LCAs (life cycle assessments) of the GHG balance for the whole forest fuel chain at the stand level show that the time perspective has a significant impact on the total climate performance. Decomposition of stumps is slower than for logging residues. Therefore it takes longer to compensate for the CO_2 emissions from the incineration of stumps compared to that of logging residues relative to their respective rate of natural decomposition. This is the reason why especially stumps do not give an immediate positive climate effect if the evaluation is based on a stand perspective (the trees that can take up the released CO_2 are removed in the stand by the harvest itself). The limited knowledge of indirect effects from increased soil disturbances as a consequence of stump recovery leads to uncertainties in LCA analyses. What LCA studies do show is that the energy output of logging residues and stumps is high compared with the input energy. Model simulations of carbon balances in which the stand level is scaled up to the landscape level (representing all stand ages) show that increased recovery of forest residues have a positive effect on the carbon balance already in the short-term. In the case of intensified forest production, such as the practice of fertilization adapted to stand-demand, more nutrients are added to the forest stands, especially nitrogen, which is the most growth-limiting nutrient in Swedish forests. This entails a risk of increased amounts of nitrous oxide emissions. If their magnitude turns out to be significant, this could counteract the positive climate effects that increased forest production offers.

The number of publications and data that describe the flows of GHGs after different forest operations on different types of forest land, at different development stages, are limited to date. Thus, more knowledge is needed of the GHG balance with increased harvest and production intensities. This concerns all three dominant GHGs, carbon dioxide, methane, and nitrous oxide. If this information could be improved it would facilitate increased LCA detail and a more thorough comparison of different energy sources from a climate perspective. The basic data are also important when evaluations are performed according to sustainability criteria in standardization systems developed or under development.

Forest Production

An additional way to increase the recovery of forest residues, apart from harvesting existing logging residues and stumps, is to increase the actual forest production. Either way entails escalation, and with intensified forestry comes the risk of affecting some of the Swedish EQOs negatively, such as *Sustainable Forests* {de Jong, 2012 #8}. In contrast, forest-based impact assessments show that increased future recovery is possible even when the volumes of forest residues that should be left in the forests, due to technical, economic and environmental restrictions, are subtracted from the total volumes used in the studies. The assessments also show that increased recovery may be feasible without counteracting or hindering the achievement of relevant EQOs {SFA, 2008 #27}. Increased forest production could even help to fulfil other environmental objectives such as *Reduced Climate Impact* {de Jong, 2012 #8}. Climate change is considered the topic that generally should be accounted for in all scenarios and problem descriptions of future forestry with increased forest residue recovery.

Some studies show growth reductions after the recovery of logging residues. However, results are not uniform and in some cases no changes have been observed. The growth reductions could perhaps be compensated for by increased plant survival, but on this point opinions vary. Some studies have shown possible compensations via vegetation control and/or fertilization as well as ash recycling. The recovery of stumps seems to reduce root rot attacks in the next forest generation. The practice might also reduce the need for soil scarification {SFA, 2009 #20}. Other beneficial outcomes are improved plant establishment and possibly increased forest production, but this requires smaller roots to be left in the ground and all stumps infected with root rot to be removed. There are also some risks connected with stump recovery, for instance, regeneration work may be delayed and soil compaction, damage due to traffic of forestry machines, and other ground disturbances may increase. Ash recycling has various impacts on forest production. This variability needs to be mapped {de Jong, 2012 #8}.

Individual studies need to be stepped up to comprise analyses of more extensive material in order to reach a uniform answer as to whether forest production is affected, and, if so, to what degree. Long-term field experiments should be continued, making it possible to study long-term effects of one or several recovery operations. This also applies to ash recycling and whether ash recycling can be combined with nitrogen fertilization. Long-term experiments are also important in order to avoid an ultimate dependence on modelling studies. The experiments also supply modelling studies with input data. Another aspect is the duration of growth effects in different soil types, which is important information for future production forecasts, carbon balances, and LCAs.

Reduced Climate Impact

"In accordance with the UN Framework Convention on Climate Change, concentrations of greenhouse gases in the atmosphere must be stabilized at a level that will prevent dangerous anthropogenic interference with the climate system. This goal must be achieved in such a way and at such a pace that biological diversity is preserved, food production is assured and other goals of sustainable development are not jeopardized. Sweden, together with other countries, must assume responsibility for achieving this global objective."

Biofuels can replace fossil fuels and thus reduce the emissions of fossil CO_2. Forest residue recovery can also affect GHG emissions from forest land, primarily via CO_2 emissions caused by soil carbon changes. Growing forests bind CO_2, functioning as a carbon sink. Operations that reduce this binding instead turn the forest into a carbon source. Activities such as forest residue recovery, nitrogen fertilization, and ash recycling are actions that can impact the carbon balance via the binding, turnover, and long-term storage of carbon. The use of fertilizers and ash can give rise to emissions of nitrous oxides {de Jong, 2012 #8}. The end-use of forest products also matters to the carbon balance {Belyazid, 2010 #10}.

Table 4. Relevant specifications and indicators of Reduced Climate Impact

Relevant Specifications
Temperature "The increase in global average temperature will be limited to no more than 2 °C above pre-industrial levels. Sweden will press internationally for global efforts to be directed towards achieving this target."
Concentration "Sweden's climate policy will be designed to contribute to ensuring that the concentration of greenhouse gases in the atmosphere is stabilised in the long term at no more than 400 parts per million of carbon dioxide equivalent (ppmv CO2 equivalent)."
Relevant Indicators
Emissions with impact on the greenhouse effect

Forestry Production Objective

Swedish forestry policy has two equally important objectives. One is a production objective and the other is an environmental objective. The latter means that the natural production capacity of forest land should be preserved. Biological diversity and genetic variation in forests are two aspects that should be secured. Much of the content in the environmental objectives is covered by the environmental objective *Sustainable Forests*. The production objective means that forestry and forest land should produce high and sustainable yields by efficient and responsible management {Gov., 2004 #26}.

Forest residue recovery matters to the forestry production objective via potential growth reductions as an impact of the removal of nutrient-rich logging residues and other effects due to this activity. Potential growth reductions could call for compensatory measures such as nitrogen fertilization. There are differences among the various types of felling operations, and the largest production losses are assessed to occur in residue recovery in connection with thinning.

2.3.2. Acidification

Growing trees give rise to a continuous acidification process by taking up base cations (nutrients). One hydrogen ion (H^+) is released to the soil for every base cation to maintain the charge balance {Belyazid, 2010 #10}. In conventional forestry of stem-wood recovery, logging residues and stumps are left on the clear-cut ground after felling. When the residues decompose, the base cations are liberated and returned to the soil to counteract the acidifying process that occurred during growth. However, the recovery of forest residues leads to an augmented loss of nutrients as base cations contained in the harvest residues are removed. This reduced soil base saturation equals a loss in buffering capacity and leads to increased soil acidification and eventually increased acidification of surface water. Compared to stem-wood, the concentration of nutrients is high in logging residues and needles. Stumps have a significantly lower nutrient content, but their recovery will nevertheless increase the effect of this acidifying impact.

Nutrient removal can be counteracted by ash recycling, although this method implies the possible addition of heavy metals, of organic, environmentally toxic compounds, and of radiocesium (Chernobyl). Uncontaminated recycled ash composed only of incinerated forest residues should not give a net addition of heavy metals and cesium. Soil damage such as track formation and water-logging caused by felling activities and other forestry operations are likely to increase the risk of transportation and methylation of mercury. In this organic form, mercury can more easily contaminate the food chain, especially in aquatic environments. Stump recovery risks increasing this process. Methylation of mercury and contaminated ash are environmental effects relevant to the EQO, *A Non-Toxic Environment*. However, this objective is treated separately in this report. Methylation of mercury is relevant for all forestry operations that give rise to soil disturbance and water-logging, which may favour anaerobic conditions.

Plenty is known about the effects of recovery of logging residues and ash recycling on soil and soil water. This knowledge comes from field experiments, modelling, and regional mass balances of chemical elements. However, the interplay between soil and surface water due to logging residue recovery and nutrient compensation is still insufficiently understood, with respect to practically all substances that are transported between soil and water. The comprehensiveness of the issue makes it relevant to several EQOs. The effects that ash recycling might have on soil and water quality are being studied. Studies are also being performed to map the "need" for nutrient compensation in quantitative terms at different locations in order to optimize the dosage. Stump recovery and fertilization adapted to stand-demand are new features in forestry and the production of fuels, and therefore an increased knowledge of their environmental effects is required. Knowledge of ash requirements in practical forestry, to optimize the dose based on a satisfactory balance between intended and unwanted effects, is also essential.

Natural Acidification Only

"The acidifying effects of deposition and land use must not exceed the limits that can be tolerated by soil and water. In addition, deposition of acidifying substances must not increase the rate of corrosion of technical materials located in the ground, water main systems, archaeological objects and rock carvings."

The increased removal of base cations as a consequence of an increased recovery of forest residues affects the achievement of this EQO negatively. The recovery of logging residues has a significant impact on this removal compared with conventional stem-wood recovery. For this reason, compensatory measures should be taken when materials beyond stem-wood are recovered. Primary targets are the areas sensitive to acidification found in southern Sweden. Predominantly, this concerns ash recycling, but biomass extraction should also be adapted to the status of the acidified areas. Ash recycling makes up for the loss of base cations. As long as the recovery does not exceed the potential for recycling sufficient amounts of ash to compensate for nutrient losses, the EQO is not necessarily affected negatively. Currently ash recycling is practiced to a very limited extent compared to the recovery of logging residues. In 2009, ash was spread on an area corresponding to 17 percent (11,600 hectares) of the area where logging residues were recovered {SFA, 2011 #13}. In 2010, this figure was 12 percent. The acidifying impact caused by forestry is expected to increase in the future. There are no policy instruments that regulate the practice of ash recycling today. Increased recovery of forest residues is a key player concerning measures intended to decrease emissions of GHGs. In practice it is difficult to completely compensate for the additional acidification caused by increased recovery. It is not clear either what the acidifying effects will be from future recovery of logging residues or the effects of ash recycling. There is a risk that the positive trend of decreased acidifying deposition might be counteracted by an increased logging residue recovery, intensive cultivation, and increased nitrogen fertilization {SEPA, 2012a #14}. As a result of the significant reduction in sulphur deposition during the past two decades, forest residue recovery and nutrient compensation have gained greater significance in the attempt to achieve the EQO of *Natural Acidification Only*, especially as the recovery of forest residues is increasing.

Table 5. Relevant specifications and indicators for Natural Acidification Only

Relevant Specifications
Acidifying effects of forestry *“The contribution of land use to the acidification of soil and water is counteracted by adjusting forestry to the acidification sensitivity of the site.”*
Acidified lakes and watercourses “Independently of liming, lakes and watercourses achieve at least good status regarding acidification in accordance with the Water Quality Management Ordinance (2004:660).”
Acidified soils ”Acidification of the soil does not accelerate corrosion of technical materials and archaeological objects in the ground and does not damage the biodiversity of land and water ecosystems.”
Relevant Indicators
Acidified forest land (also part of Sustainable Forests)
Acidified lakes

2.3.3. Eutrophication

Forestry does not make a significant contribution to eutrophication. Felling and nutrient supply alter the nitrogen balance {de Jong, 2012 #8}. Even though a large proportion of Sweden’s total land area is covered by forests, the contribution to the eutrophication of lakes and seas, compared to that from agricultural land and sewage water, is modest. However, in the southwest, soils show high nitrogen levels as a result of a long history of nitrogen deposition. Here, significant leaching of nitrogen occurs after felling, but nevertheless the relative contribution of nitrogen is low compared to other sources. If leaching increases after felling, and intensified leaching from growing forests occurs more frequently, nitrogen leaching from forest land could become a problem in Sweden, since the total area of forest land is high. Nitrogen fertilization in areas with high levels of nitrogen means increased risks of nitrogen leaching {Belyazid, 2010 #10}. It is not clear how ground disturbances due to stump recovery and potential damage caused by driving forestry machines affect leaching during the clear-cut phase. Ash recycling could under certain circumstances stimulate the formation of nitrate, which increases the risk of nitrogen leaching. The Swedish Forest Agency gives recommendations on logging residue recovery and ash recycling. Experimental studies show that the impact on nitrogen leaching is very limited if these recommendations are followed {de Jong, 2012 #8}.

A positive effect is that an increased biomass recovery can give relief in the long-term build-up of nitrogen storage in forest land caused by nitrogen deposition. The removal of excess nitrogen in high-load areas is beneficial from this point of view, assuming ash recycling. In contrast, the removal of nitrogen in areas with low levels of nitrogen increases the risk of nitrogen shortage {Belyazid, 2010 #10}. This process can be serious, since nitrogen is commonly a growth-limiting factor in Swedish forests and may therefore reduce forest productivity.

Zero Eutrophication

“Lakes and watercourses must be ecologically sustainable and their variety of habitats must be preserved. Natural productive capacity, biological diversity, cultural heritage assets and the ecological and water-conserving function of the landscape must be preserved, at the same time as recreational assets are safeguarded.”

Forests take up most of the free inorganic nitrogen and phosphorus, a process that essentially counteracts the effects of nutrient leaching and eutrophication. However, a significant amount of nitrogen leaches out, due to a natural leaching of organic nitrogen in which forestry is not implicated. The fraction that can be traced back to forestry arises principally after the final felling, during which uptake is significantly reduced. Alterations of soil conditions also have an effect on leaching since processes leading to increased amounts of mobile forms of nitrogen, such as nitrate, are favoured. Nitrogen accumulation in the soil due to deposition and fertilization also cause increased leaching. The risk of nitrogen leaching in growing forests is coupled to long-term accumulation of soil nitrogen. This is seen where the nitrogen load is high due to high deposition. In these regions, increased removal of forest residues is favoured from this perspective, which is positive for the development of the EQO even if it is assumed to be of a minor degree. Forestry can affect eutrophication in both directions, and current research focuses on how forest residue recovery, nutrient compensation, and fertilization affect nitrogen leaching to water ecosystems in the vicinity and to the Baltic Sea.

Table 6. Zero Eutrophication: Relevant specifications and indicators

Relevant Specifications
Pressure on the marine environment “Swedish and total inputs of nitrogen and phosphorus compounds into the seas surrounding Sweden are less than the maximum loads established within the framework of international agreements.”
Pressure on the terrestrial environment “Atmospheric deposition and land use do not result in ecosystems showing any substantial long-term harmful effects of eutrophying substances in any part of Sweden.”
Status of lakes, watercourses, coastal waters, and groundwater ”Lakes, watercourses, coastal waters and groundwater achieve at least good status for nutrients in accordance with the Water Quality Management Ordinance (2004:660).”
Status of the marine environment ”Sea areas achieve at least good environmental status as regards eutrophication in accordance with the Marine Environment Ordinance (2010:1341).”
Relevant Indicators
Addition of nitrogen to the coasts
Addition of phosphorus to the coasts

2.3.4. Biodiversity

Logging residues contribute to forest biodiversity by providing substrates and habitats for a wide range of forest species. The relative significance of logging residues compared with other substrates present in the forest is not totally clear. If it turns out that many species are heavily dependent on logging residues, the recovery of these can have clearly negative consequences for biodiversity. Even if this direct dependence concerns just a few species, recovery could impact populations because a lack of logging residues may reduce their chance of survival during the clearing phase (e.g. mosses and vertebrates). There are many indications that fairly large recoveries of logging residues and soft wood from Norway spruce are possible without jeopardizing the survival of species. In addition, recovery of logging residues from uncommon trees such as valuable broad-leaved species and aspen might have significant negative impacts. Another problem is that piles of logging residues from broad-leaved trees are attractive habitats for wood-living species such as many red-listed[1] species. The species might then be removed together with the residues, which thus function as traps for rare species. Another potential drawback of recovery is the risk of damage, or even causing the wood, trees, and habitats that have been left there for Environmental Consideration requirements to be removed in the recovery. The effects of logging residue recovery on functional organism groups seem to be very moderate. No direct changes to the ecosystem functions maintained by plants and soil organisms in a clear-cut area are therefore to be expected.

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[1] The Red list is a compilation of threatened and rare species in Sweden. The species are classified depending on their risk of extinction.

[2] Collection of organisms and species based on different criteria such as carrying out the same task (function), living in the same

The consequences of stump recovery are very similar to those identified for logging residues. Few rare or red-listed species are found in habitats consisting of low stumps. When it comes to red-listed fungi, mosses, and lichens, few species are found in intensely managed forests; therefore they are also absent on stumps. Concerning insects, the situation is somewhat different. Stumps represent the main part (approximately 80 %) of the thick dead wood found in today's managed forests. It is likely that most of the beetle species living in/on wood make use of the felled stumps left in clear-cut areas. Even if just a few red-listed species take advantage of the stumps, increased recovery could have some consequences, for example increased homogenization of the clear-cut environment, i.e. some habitats would disappear. This will in turn affect the prerequisites for life for several different species. Stumps provide protection, micro-habitat variation, and growth substrate for many species that are not strictly wood-dependent. Ground-living vertebrates (insects, spiders, etc.), and probably even mammals, use stumps as hiding places or nesting places. Birds feeding on insects search for food in stumps. Stumps probably function as refuges for drought-sensitive forest mosses during the clearing phase but can also constitute important growth substrates where mosses and lichens can avoid the competition of the vascular plants that dominate ground vegetation in clear-cut areas. Exposed Norway spruce stumps in clear-cut areas have been shown to house species requiring light. As with logging residue recovery, there is the augmented risk connected to stump recovery of causing damage to the soil and spoiling areas set aside for environmental reasons, as well as causing the loss of material left for Environmental Consideration reasons. Silviculture might be a way to combine forest residue recovery while maintaining or even improving biodiversity. Studies indicate that under certain circumstances thinning can increase diversity in groups of several species. The choice of management method will also potentially affect the development of different assemblages of organisms.

The effects of ash recycling on species diversity have not been studied sufficiently. Instead, current data are focused on the effects on functional organism groups[2] such as vegetation and soil organisms. The short-term effects on vegetation and soil organisms are to a large extent dependent on the ash properties. In general, it is clear that the higher the solubility of the ash, the faster and larger the direct effect tends to be. Easily dissolved ash can damage vegetation, especially the surface layer of moss, while no or only minor effects are seen with hardened ash. The ground fauna seems to be fairly insensitive to the small changes in soil chemistry that recycling of hardened ash causes. The same applies to the prevalence of mycorrhizal fungi.

Research concerning possible effects on species diversity in intensely managed forests (with limited consideration for biodiversity) at the stand level has been assessed. The findings suggest that only few species can live in such areas where consideration for biodiversity is limited. Many species are likely to disappear as a few less common species dominate. This type of forest management would thus lead to reduced species diversity at the stand level. None of the current red-listed species are considered able to live in such forests. Effects on species diversity of intensely managed forests with limited biodiversity consideration at the landscape level are more difficult to evaluate. Model simulations show that the risk of species extinction is reduced if intensely managed forests are clustered instead of being spread out randomly.

The total effect of all forest management in the landscape over a long period (including nature conservation) is the important aspect of increased production of forest fuel. Modelling tools are

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[2] Collection of organisms and species based on different criteria such as carrying out the same task (function), living in the same type of environment, and feeding on the same substrate, etc.

needed that analyse the long-term prospects of survival for wood-living species, both at the landscape and regional level, based on different scenarios of forest management and landscape dynamics. To evaluate the effects on biodiversity requires more data on the relative significance of different substrates and habitats, for example the importance of stumps in relation to other types of wood substrates and the significance of clear-cut habitats compared to other habitat types, for the purpose of mapping which species and groups of organisms are at the greatest risk of being impacted by increased recovery of forest residues in clear-cut areas. Better data are also needed on the effects of increased recovery of forest residues on nature conservation. Only a few studies concerning logging residues have been published, and studies on other activities are very scarce. Whether forest residue recovery can be combined with silviculture and restoration in order to achieve the objectives of biodiversity requires study, as does whether the ecological adaption in connection with felling and the restoration of the landscape has markedly positive effects on biodiversity.

Sustainable Forests

"The value of forests and forest land for biological production must be protected, at the same time as biological diversity and cultural heritage and recreational assets are safeguarded."

Sustainable Forests is one of seven objectives that comprise whole ecosystems, so this objective overlaps with *Natural Acidification Only*, *Zero Eutrophication*, and *Reduced Climate Impact*, which all describe environmental problems, as well as with *A Rich Diversity of Plant and Animal Life*, which is an intermediary between an environmental problem and an ecosystem-based objective. All potential impacts caused by the environmental effects of forest residue recovery can generally be correlated to this EQO. Hence, environmental problems that develop in the forest ecosystem will be expressed by the well-being of *Sustainable Forests*. In that sense, it acts as a general health indicator representing a wide palette of environmental problems. The discussion of *Sustainable Forests* and forest residue recovery will deal primarily with questions of biodiversity.

Table 7. Sustainable Forests: Relevant specifications and indicators

Relevant Specifications
Qualities and processes of forest land "The physical, chemical, hydrological and biological qualities and processes of forest land are maintained."
Ecosystem services "Ecosystem services of forests are preserved."
Green infrastructure "The biodiversity of forests is preserved in all natural geographical regions and species have the opportunity to spread within their natural range as a part of a green infrastructure."
Threatened species and restored habitats "Threatened species have recovered and habitats have been restored in valuable forests."
Preserved natural and cultural heritage values "The natural and cultural heritage values of forests are preserved and the conditions for continued preservation and development of these values are in place."
Outdoor recreation "The value of forests for outdoor recreation is safeguarded and maintained."
Relevant Indicators
Acidified forest land
Damages to ancient and cultural remains
Old forest
Old forest, rich in broad-leaved trees
Dead hardwood
Protection of forest land – Nature reserves
Protected area of forest land – Habitat protection area
Protected area of forest land – Nature conservation agreements

A Rich Diversity of Plant and Animal Life

"Biological diversity must be preserved and used sustainably for the benefit of present and future generations. Species habitats and ecosystems and their functions and processes must be safeguarded. Species must be able to survive in long-term viable populations with sufficient genetic variation. Finally, people must have access to a good natural and cultural environment rich in biological diversity, as a basis for health, quality of life and well-being."

Felling and other forestry operations make up the major impacts on the forest ecosystem and lead to homogenous conditions. Forestry thus results in insufficient amounts of dead hardwood and a lack of stands of long continuity. Substantial areas of old forest with long continuity are still felled in Norrland[3], which is a significant threat to many species (fungi, mosses, lichens, and insects living on wood). The amount of dead hardwood has increased over recent years but is still insufficient in total volume. Natural disturbances that are beneficial for certain species are also too few, such as fires and inundations, etc. There are many policy instruments in place that serve to protect forests in different ways, counteracting the loss of biodiversity. However, the effects of the various measures are difficult to assess. There is also a significant need for the restoration of valuable forest types. Measures are being taken, but their extent is unknown {SEPA, 2012a #14}.

Logging residues and stumps serve as substrates and habitats for forest-living species. Acidification and eutrophication are environmental problems that also impact forest biodiversity. Therefore, it is important to study how biodiversity is affected by different activities of forest residue recovery (logging residue recovery, stump recovery, intensive forest management, and nutrient compensation, etc.). The impact of stump recovery on different species such as insects, fungi, lichens, and mosses has been investigated in various studies. To evaluate the significance of stumps and logging residues as substrates, the species diversity present in and on the substrates has been compared to other wood substrates. Since dead hardwood is a crucial substrate for many species in forest ecosystems, much research is being focussed on the "correct" methods for the recovery of stumps, for example, identifying the type of stumps or forest stands that are the most valuable for biodiversity and how stump recovery should be planned (so that biodiversity disturbances can be kept within acceptable limits) {de Jong, 2012 #8}. Since the focus on biodiversity in this report is primarily related to its status in the forest, this implies a close link to the environmental conditions of the forest. Therefore, the indicators belonging to *Sustainable Forests* will also be a measure of the overall biodiversity status in the forest.

[3] The northernmost and largest of the three large regions into which all of Sweden was historically divided.

Table 8. A Rich Diversity of Plant and Animal Life: Relevant specifications and indicators

Relevant Specifications
Favourable conservation status and genetic variation ”Habitats and species that occur naturally in Sweden have a favourable conservation status and the status of threatened species has improved, and sufficient genetic variation is maintained within and between populations.” (Also for Sustainable Forests).
Impacts of climate change ”The increased risk of extinction indicated by climate scenarios is reduced regarding species and habitats facing the greatest risk of being affected adversely by climate change.”
Ecosystems services and resilience ”Ecosystems have the ability to cope with disturbances and adapt to change, such as a changed climate, so that they can continue to provide ecosystem services and contribute to combating climate change and its effects.”
Green infrastructure ”A functioning green infrastructure is in place and is maintained through a combination of protection, restoration and sustainable use within sectors, so that fragmentation of populations and habitats does not occur and the biodiversity of the landscape is preserved.”
Biological cultural heritage ”The biological cultural heritage is managed so that important natural and cultural values are preserved and the conditions for continued preservation and development of these values are in place.”
Nature on the urban fringe ”Natural environments near urban areas that are valuable for outdoor recreation, cultural heritage and biodiversity are safeguarded and maintained, and are accessible to the public.”
Relevant Indicators
Breeding birds in the forest

2.3.5. Compilation of Relevant Indicators and Specifications

To provide an overview of the connections between the environmental effects and the EQOs, the relevant indicators and specifications presented above are summarized in Table 9 and

Table 10. Connections between environmental effects and indicators and specifications are marked with an "x", which simply indicates some kind of connection. All environmental effects of forestry "connect" to the three indicators that monitor the progress of formally protected productive forest land in the sense that the effects are avoided by exemption from forestry, indicated by the columns shaded the same colour as the *Sustainable Forests* heading. The EQO *Flourishing Lakes and Streams* is not included in this report because it does not have any indicators clearly applicable to forestry operations. The EQOs presented in this report also depend on the research that has been carried out to date on the environmental effects of forest residue recovery. The environmental impact on lakes and streams of environmental effects connected with recovery has not yet been sufficiently studied.

Table 9. Relations between the relevant indicators and environmental effects

Environmental Quality Objectives		**Reduced Climate Impact**	**Natural Acidification Only**		**Zero Eutrophication**		**Sustainable Forests**								**A Rich Diversity of Plant and Animal Life**
Indicators		*Emissions with impact on the greenhouse effect*	*Acidified forest land (also part of SF)*	*Acidified lakes*	*Additions of nitrogen to the coasts*	*Addition of phosphorus to the coasts*	*Acidified forest land*	*Damage to ancient and cultural remains*	*Old forest*	*Dead hard-wood*	*Old forest, rich in broad-leaved trees*	*Protection of forest land – Nature reserves*	*Protected area of forest land – Habitat protection area*	*Protected area of forest land – Nature conservation agreements*	*Breeding birds in the forest*
Climate change	Alteration of the soil carbon pool	x													
	Methane and nitrous oxide emissions	x													
Acidification	Nutrient removal		x	x			x								
Eutrophication	Nutrient (nitrogen) leaching		x	x	x	(x)	x								
Biodiversity	Loss of substrates and habitats							x	x	x	x				x
	Soil disturbances /Damage fr. traffic														

Table 10. Relations between the relevant specifications and environmental effects

		Reduced Climate Impact		Natural Acidification Only			Zero Eutrophication			
		"The increase in global average temperature will be limited to no more than 2 °C above pre-industrial levels. Sweden will press internationally for global efforts to be directed towards achieving this target."	"Sweden's climate policy will be designed to contribute to ensuring that the concentration of greenhouse gases in the atmosphere is stabilised in the long term at no more than 400 parts per million of carbon dioxide equivalent (ppm CO2 equivalent)."	"The contribution of land use to the acidification of soil and water is counteracted by adjusting forestry to the acidification sensitivity of the site."	"Independently of liming, lakes and watercourses achieve at least good status regarding acidification in accordance with the Water Quality Management Ordinance (2004:660)."	"Acidification of the soil does not accelerate corrosion of technical materials and archaeological objects in the ground and does not damage the biodiversity of land and water ecosystems."	"Swedish and total inputs of nitrogen and phosphorus compounds into the seas surrounding Sweden are less than the maximum loads established within the framework of international agreements."	"Atmospheric deposition and land use do not result in ecosystems showing any substantial long-term harmful effects of eutrophying substances in any part of Sweden."	"Lakes, watercourses, coastal waters and groundwater achieve at least good status for nutrients in accordance with the Water Quality Management Ordinance (2004:660)."	"Sea areas achieve at least good environmental status as regards eutrophication in accordance with the Marine Environment Ordinance (2010:1341)."
		Temperature	*Concentration*	*Acidifying effects of forestry*	*Acidified lakes and watercourses*	*Acidified soils*	*Pressure on the marine environm*	*Pressure on the errestrial nvironment*	*tatus of lakes, atercourses, oastal waters and roundwater*	*Status of the marine environment*
Climate change	Alteration of the soil carbon pool	x	x							
	Methane and nitrous oxide emissions	x	x							
Acidification	Nutrient removal			x	x	x				
trophication	Nutrient (nitrogen) leaching						x	x (fertilization)	x	x (fertilization)
Biodiversity (species richness)	Loss of substrates and habitats									
	Soil disturbances/ Damage from traffic									

Table 10 continued

		Sustainable Forests						A Rich Diversity of Plant and Animal Life					
		The physical, hemical, ydrologi-cal nd biological ualities and rocesses of orest land re naintained.”	Eco-system ervices of orests are reserved.”	The biodiversity of orests is reserved in all natural geographical egions and species have he opportunity o spread within heir natural ange as a part of a green nfrastructure.	”Threate-ned species have recovered and habitats have been restored in valuable forests.”	The natural and cultural heritage values of orests are preserved and the conditions for continued preservation and development of these values are in place.”	The value of orests for utdoor ecreation is afeguar-ded nd naintained.”	”Habitats and species that occur naturally in Sweden have a favourable conserva-tion status and the status of threatened species has improved, and sufficient genetic variation is maintained within and between populations.” (Also for SF)	The icrea-sed sk of xtinction ndicated by imate cena-rios reduced egar-ding pecies and abitats acing the reatest sk of eing ffected dver-sely y climate hange.”	Ecosystems ave the bility to cope vith isturbances nd adapt to hange, such s a changed limate, so hat they can ontinue to rovide cosystem ervices and ontribute to ombating limate hange and its ffects.”	functioning een rastructure is place and is aintained rough a mbination of otection, storation and stainable use thin sectors, so at fragmenta-n of pulations and bitats does not cur and the odiversity of e landscape is eserved.”	The iological ultural eritage is nanaged so hat important atural and ultural alues are reserved nd the onditions for ontinued reservation nd develop-nent of these alues are in lace.”	latural nviron-ments ear urban eas that are luable for itdoor creation, iltural eritage and odiversity e ifeguarded id aintained, id are ccessible to e public.”
		Qualities and processes of the forest land	*Ecosystem services*	*Green infrastructure*	*Threatened species and restored habitats*	*Preserved natural and cultural heritage values*	*Outdoor recreation*	*Favourable conserva-tion status and genetic variation*	*Impacts of climate change*	*Ecosystem services and resilience*	*Green infrastructure*	*Biological cultural heritage*	*Nature on the urban fringe*
Climate change	Alteration of the soil carbon pool	x	x						x				
	Methane and nitrous oxide emissions								x				
Acidification	Nutrient removal	x	x							x			
Eutrophication	Nutrient (nitrogen) leaching	x											
Biodiversity (species richness)	Loss of substrates and habitats	(x)	x	x	x	x	x	x		x	x		x
	Soil disturbances/ Damage fr. traffic	x	x		x	x	x			x	x	x	x

2.3.6. Evaluation and Trends of Environmental Quality Objectives Based on the 2012 In-Depth Evaluation and the 2013 Follow-Up Evaluation

The current situation for the EQOs is complex. While the trends for some objectives show a slightly positive development, the general development is negative. Positive effects due to the reduction of certain emissions are difficult to observe due to the slow recovery rate of the environment, for instance regarding acidification and eutrophication. Global GHG emissions are increasing, and future climate change will have negative impacts on several of the EQOs. *A Rich Diversity of Plant and Animal Life* is one of the objectives showing the most negative trends. Evaluating the direction and development of the basis for achieving the EQOs (the second of the two EQO evaluation questions, see section 2.2.2) is considered more difficult than evaluating the development of the environmental condition (the first of the two EQO evaluation questions). The basis needs to be assessed by analysing complex connections of a wide range of different factors, such as the world economy, political developments, and policy instruments, etc. An overall assessment of the bases for the objectives, the current situations, and developments is difficult, but we have complied some of the most important bases to summarize EQO achievability at a general level. Among these, we find the need for policy instruments at the national level, EU's common political agenda of, among other things, agriculture and fishing, the need for efforts within political areas other than the environmental, law enforcement, and cooperation and the provision of resources by the authorities for environmental work.

Fourteen of the 16 EQOs are found to be unachievable by year 2020. The objectives face different challenges and their distances-to-targets vary. The in-depth evaluation of 2012 was the first time-gap analysis of the objectives to be carried out since the introduction of the environmental policy system. The gap analyses are estimations of the remaining distance to go from the current state to the achievement of the aim, a kind of distance-to-target approach. The analyses of the various objectives' distances-to-target situations are not based on common criteria and are qualitative. This means that they are difficult to sum up collectively. However, from the evaluations the most apparent reasons for failing to reach the aims can be grouped as follows, as translated by the authors of this report.

- Long recovery rate of the environment gives uncertainties in the evaluation as to whether the bases for fulfilling the EQOs are sufficient.
- The majority of the EQOs cannot be solved within Sweden.
- Negative impact or competition from other areas and sectors.
- Lack of policy instruments (national and/or international).
- Insufficient implementation of policy instruments (this includes insufficient measures as a result of the policy instrument as well as insufficient resources for implementation).

The number of reasons (see **Table 11**) and the development trend (see **Table 12**) for each of the EQOs found to be unachievable by 2020 (assigned the status "No") are combined in the in-depth evaluation to assess the respective distances-to-target on a scale of four (see Figure 3). Note that an objective that is nearer "Close" is not necessarily easier to achieve than an objective further down the scale, since the reasons that make up the distances of each objective may vary in complexity, but the scale does not take this into account. The gap analysis is a first attempt to perform this kind of evaluation in this context and is in need of further development, for example, the equal weighting of the five common reasons.

Table 11. The five common reasons for failure to achieve the objectives, i.e. for the label "No" in Table 12

	Long recovery rate in the environment	Major international dependence	Negative impact or competition	Lack of policy instruments	Insufficient implementation of policy instruments
Reduced Climate Impact	x	x	x	x	
Natural Acidification Only	x	x	x	x	
Zero Eutrophication	x	x	x	x	
Sustainable Forests	x		x		x
A Rich Diversity of Plant and Animal Life	x		x		x

The evaluation grades development trends as ↗ Positive, → Neutral, or ↘ Negative.

Table 12 The statuses and trends of the most relevant EQOs from the 2013 follow-up evaluation

	Reduced Climate Impact	Natural Acidification Only	Zero Eutrophication	Sustainable Forests	A Rich Plant and Animal Life
Status and trend	No ↘	No ↗	No ↗	No ⟶	No ↘

The results for Reduced Climate Impact, Natural Acidification Only and Zero Eutrophication in Table 12 are all due to the first four reasons in Table 11. For Sustainable Forests and A Rich Diversity of Plant and Animal Life, the first, third, and fifth reasons apply. This analysis is expanded in Chapter 4, where the case study integrates regional assessments of the EQOs based on the follow-up evaluations by the counties.

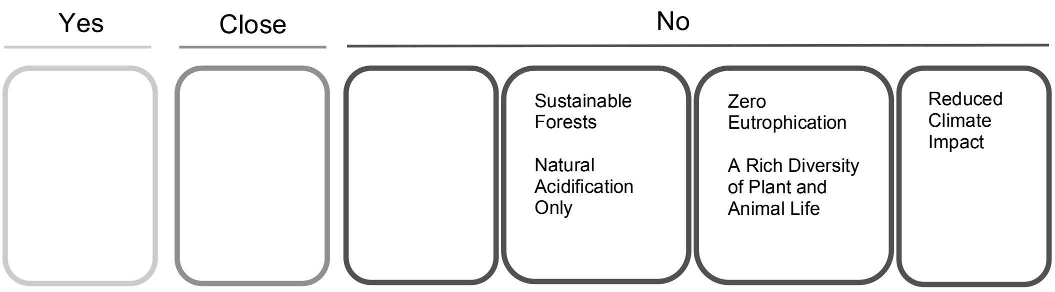

Figure 3. The figure is adapted from the 2012 in-depth evaluation {SEPA, 2012a #14} of the EQOs. It shows the assessed distance-to-target (the distance to the achievement of the EQOs based on the trend and the five common reasons for failure, see Table 11 and Table 12) of the EQOs most relevant for the recovery of forest residues.

A general overall assessment of the distance-to-target, as well as the current condition and trend, is given below for each EQO.

Reduced Climate Impact

Distance-to-target

Global greenhouse gases emissions are rising. To likely keep warming below the two-degree limit requires substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived GHGs by the end of the century. Since 2000, the rate of increase in emissions has itself increased. There is a trend towards increased emissions in countries with high economic growth. China has doubled its emissions since 1990. Climate change impacts biodiversity and ecosystems and these impacts are projected to increase this century with increased warming, with further changes in the ranges of species and increased acidification of the oceans.

Current Situation and Development of the Environmental Condition

To stay below the two-degree limit, global emissions have to decrease drastically in the near future. In order to meet this challenge and achieve *Reduced Climate Impact*, additional policy instruments are required that reduce emissions on the national level and direct implementation towards the most cost-effective measures from a global perspective. Measures and policy instruments to achieve this EQO have synergies and conflicts with other EQOs. GHG emissions and air pollutants often originate from the same kind of sources, offering opportunities for synergies in developing new policy instruments for *Reduced Climate Impacts* and *Fresh Air*. Conflicts primarily arise among objectives *A Varied Agricultural Landscape*, *Sustainable Forests*, and *A Rich Diversity of Plant and Animal Life*. The potential intensification of forestry and agriculture due to increased demand for biomass for bioenergy is a clear example. Intensification can result in landscape fragmentation and the use of species that are not consistent with current biodiversity. Wind power parks, both on land and offshore, and an expansion of hydropower are other measures that can break up the landscape.

Swedish climate change mitigation takes place at several levels. Sweden contributes to work at the international level through the implementation of the EU's climate and energy package. The package includes development of renewable energy, energy efficiency, and trade in emission permits. The Swedish government has adopted a vision of a sustainable and resource efficient energy supply with zero net emissions of GHGs to the atmosphere by 2050, with "soft" interim objectives. By 2020, fossil fuels for heat are to have been phased out in populated areas. Transportation energy efficiency is to increase gradually and the dependence on fossil fuels eventually broken, with the vehicle fleet preferably independent by 2030 by transitioning to sustainably renewable biofuels and a further substantially developed electric drive technology. The vision thus relies on three action plans that frame the transition: a vehicle fleet independent of fossil fuels; increased energy efficiency; and promotion of renewable energy.

Natural Acidification Only

Distance-to-Target

Achieving this EQO depends heavily on international agreements and EU directives. Preliminary calculations indicate that during the period 2005-2020 there will be a reduction of SO_2 emissions of about 60 percent and NO_x of about 40 percent within EU-27. The corresponding value for NH_3 is estimated to reach 6 percent. Emissions of NO_x from the shipping sector are expected to increase during the same period, with nitrogen deposition in Sweden from this sector estimated to increase by percent. Currently, NO_x emissions from shipping constitute about 20 percent of Europe's total. Whether additional instruments are to be expected to tackle this negative trend, and what they will be, is not clear. The influence of climate change impacts on the possibility of reaching satisfactory statuses is another question mark.

Acid deposition is mainly caused by non-domestic pollution sources, so the development in other European countries is of key interest. Preliminary reports show that for 2010, the *EU National Emission Ceilings Directive*:

- The target for sulphur dioxide emissions was reached in all countries.
- Finland and Spain were the only two countries not to reach the target for ammonia.
- For nitrogen oxide emissions, the situation is worse. Eleven countries did not reach the target, and some of these are far off the mark (Luxemburg, Austria, France, and Germany). Sweden will not make the target.

Current Situation and Development of the Environmental Condition

Emissions of acidifying compounds from land-based sources in Europe have dropped substantially in recent decades. In the period 1990-2009, emissions of SO_2 decreased by 77 percent and NO_x by 42 percent. By contrast, from international shipping, emissions of SO_2 have increased by 6 percent and emissions of NO_x by 20 percent since 2000. The situation in Sweden follows the trend of reductions seen in Europe. During the period 1990-2010, the emissions of SO_2 decreased by 67 percent and of NO_x by 40 percent. NH_3 emissions were reduced by 20 percent between 1995 and 2010. The acidification status of lakes and watercourses has slowly improved, while the conditions of forestland and groundwater have remained unchanged. Some improvement of soil water has been observed. The recovery will take time. The major share of acid deposition in Sweden originates from sources in other countries and international shipping, about 90 percent of the SO_2 and NO_x and approximately 70 percent of the NH_3 emissions. Deposition is highest in the southwest, and that is also where the greatest problems can be found, demonstrating the international impact. However, Swedish emissions also affect other countries and surrounding seas. Hence, the EQO must rely on international measures. Additional EU directives and treaties within the *UN Convention on Long-Range Transboundary Air Pollution* are required to further limit the emissions of acidifying compounds. International agreements are also needed to constrain emissions from international shipping. On the national level, instruments that restrict the emissions of NO_x are the most significant in Sweden.

The acidification caused by anthropogenic activities affects primarily forest land, lakes, watercourses, and groundwater. Corrosion damage to ancient remains and other objects in the ground can also be problematic. The deposition of acidifying compounds must be reduced to levels that do not cause biological damage in ecosystems, otherwise the EQO will not be reached. Particularly sensitive areas are those with thin soil layers or soils subjected to low levels of natural weathering. Emissions of SO_2 have their primary origin in the combustion of fossil fuels. NO_x arise during combustion, with the major emissions coming from the transport sector. Other sources are industries with large-scale combustion activities. Forestry also contributes; the acidifying impacts depend on forest growth and the fraction of trees that are felled. Its impact is predicted to increase with increased recovery of logging residues. To attain reductions of the acidifying impacts of forestry and an increased extraction of biomass, both strategies and more powerful instruments need to be developed. Even though the critical limit concerning acidification has been exceeded less in the forest land area and the lakes run-off area since 2000, analyses show that the while the situation will be further mitigated, overruns will still take place in 2020. The data on which this contention is based indicate that the limit will be exceeded by 9 percent in forest land and 19 percent in the lakes run-off area, compared with 19 and 22 percent, respectively, in 2010.

Zero Eutrophication

Distance-to-Target

Currently, the environmental condition is either unchanged or modestly improved. The fulfilment of the EQO is heavily dependent on international measures and on the fact that the recovery of the environment takes a long time. Additional decisions on measures within the EU, the UN, and international shipping are needed. This applies applied to *Natural Acidification Only*, too. The time for recovery, as a response to different measures, can be long, making it hard to observe positive effects in the short term. Furthermore, the implementation of all the required measures for achieving the objective will presumably also take a long time.

Current Situation and Development of the Environmental Condition

The eutrophying substances containing phosphorus and nitrogen originate as air emissions from shipping, automobile traffic, and energy use, and as emissions to water via agriculture, sewers (municipal and individual), industries and forest land. Some slight improvements have been observed over recent years, primarily in coastal areas. Measures taken within the agricultural sector to reduce the leaching of phosphorus and nitrogen have had some effect, and a decrease has been seen over the past twenty years. While there is a general reduction of emissions to air, there is a trend of increasing emissions from shipping. The achievement of the EQO relies on an ambitious international effort. Five critical tools for achieving the objective are mentioned in the evaluation: the EU Water Framework Directive, the EU Marine Strategy Framework Directive (the Marine Directive), HELCOM (The Helsinki Commission) Baltic Sea Action Plan, the EU National Emission Ceilings Directive, and the Gothenburg Protocol within the UN Convention on Long-Range Transboundary Air Pollution. The future EU agricultural policy is also expected to play an important role. These tools and directives summarize the need for different measures on both national and international levels to reduce the pressure on the seas and the airborne deposition of the eutrophying substances.

Sustainable Forests

Distance-to-Target

According to the in-depth evaluation, achieving *Sustainable Forests* is a great challenge. The potential for improvements of the environmental condition within the structure of current policy instruments is, however, significant. In the current environmental work, it is important to learn from already implemented measures in order to increase our knowledge of how ecosystems respond to different actions. That it generally takes a long time before the effects of the measures taken can be observed and that several of these are seen to be urgent makes the work difficult. Large and comprehensive research campaigns are essential in reaching the targets set by the objective. Some aspects require additional political considerations, primarily concerning the objective's level of ambition in terms of protection and conservation of forest land, and possibly additional requirements for the ecological adaption of forestry. The specifics of the forestry sector's responsibility[4] and the extent of state commitment are ambiguous. These questions need to be clarified so that actors can reach a unified perspective. Other points in need of clarification concern the precise meaning of the 'ecosystem approach'[5], and, furthermore, the concept of forest ecosystem services is not sufficiently firm. This concerns authorities at the national and regional level. This ambiguity has resulted in the various opinions and interpretations underlying policy instruments and measures called for across the country. At present it is difficult to assess the distance to achieving the EQO. For some aspects, the targets are very distant and will take a long time to reach. None of the counties assess the EQO to be achievable by 2020.

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4 "Sector responsibility" – a principle that says that forestry has a fundamental responsibility concerning how forestry policy is developed and implemented. This responsibility includes developing and interpreting concepts and principles such as *Environmental Consideration* and instructions for sustainable use of natural resources and responsible management.

5 A work method originating with the UN Convention on Biological Diversity with the purpose of achieving the goals set by the convention. The approach is described by twelve guiding principles (SEPA, 2008).

Current Situation and Development of the Environmental Condition

Swedish forests are affected in many ways, and conditions vary. Some environments are improving, while others are deteriorating. Some areas face problems of eutrophication and acidification, and climate change is an overall threat. Nitrogen deposition is the greatest in the central and southern parts of Sweden and has been fairly constant over the past ten years. In spite of the great reduction in acid deposition in recent decades, no clear recovery of forest land can be seen. Mercury in the soil and impacts on natural hydrology are also important complications. Forest processes are generally slow, making a potential recovery difficult to assess. For this reason, long series of measurements are required. Increased understanding of the relations among impact factors and the real conditions is needed. Structural problems and deficits include ecological discontinuities, fragmentation, overgrowth, and insufficient amounts of dead hardwood. The problems differ in different parts of the country and across landscapes. The reasons for the problems also vary. Forest management programmes contribute, as do changes in customs and natural disturbances, and exploitation of forest areas due to construction and infrastructure activities. The conflict between the need for more renewable energy and the risks posed by increased forest residue recovery must be addressed. Current use of ash is limited, and a national council on ash recycling is being established to increase ash recycling, although bio-ashes may come to be classified as hazardous waste according to the EU Hazardous Waste Directive.

Measures implemented through formal protection of forests and ecological adaption of forestry as land voluntarily set aside for nature conservation and Environmental Considerations are important methods for achieving the objective of *Sustainable Forests*. Environmental Considerations are an obvious part of today's forestry, but nevertheless there are shortfalls, and improvements are underway. Responsibility taken by the industry itself is paramount. Forest certifications, such as the *Forest Steward Council (FSC)* and the *Programme for the Endorsement of Forest Certification (PEFC)*, can be considered an integral part of this responsibility. More than 60 percent of Swedish forest land is certified. Over the past decade there has been an increase in areas of old forests (in northern Sweden > 140 years, southern > 120 years), old forests rich in broad-leaved trees, and the amount of dead hardwood. The increase varies across the country, however. These are indicators that point to enhanced conditions for some aspects of biodiversity. Positive developments can likely be linked to measures in forestry such as ecological adaption when felling and land voluntarily set aside for nature conservation.

Just over 7 % of forested land in Sweden is formally protected. The protection is unevenly distributed, with 77 % of the protected area located in the highlands. This region also has the largest fraction of formally protected forest land. The percentage in the remaining part of the country is significantly lower, with approximately 2 % of productive forest land formally protected. Conserving biodiversity in forest ecosystems to attain satisfactory conservation statuses for prioritized forest types and species is a great environmental challenge. Functional formal protection of nature reserves and habitat protection areas is vital, as are nature conservation agreements. That areas of high nature values (areas particularly valuable for the environment), e.g. key biotopes, are felled or damaged is problematic from a long-term conservation perspective. Good and easily accessible information is needed about the location of such valuable forest areas, to aid operative, strategic, and political decisions. The positive trend of voluntary conservation areas now constitutes an important part of the work to conserve biodiversity.

Since 1999, the Swedish Forest Agency has undertaken annual follow-ups of Environmental Consideration in connection with regeneration felling, within the framework of Polytax. The follow-up inventories show Environmental Consideration deficits. A government commission report compiled by the Swedish Forest Agency {SFA, 2011 #13} shows that forestry is capable of adapting the Environmental Consideration at the time of regeneration felling based on the existing required information about the stands' environmental values. In many cases sufficient consideration is shown but not in all. Loss of habitats of high value for diversity is prevalent. Forestry machines also cause damage and insufficient consideration is shown for water. Forestry causes damage to about 50 percent of the historical-cultural remains located in an area subjected to felling. Approximately two out of five culture environments are exposed to negative impacts by regeneration felling and regeneration measures. The degree of consideration shown for these environments is closely linked to whether they are already known and are listed in some kind of register accessible to the actors concerned. Among the different operations performed from the actual point of felling to the end of regeneration activities, soil scarification seems to be the practice that affects Environmental Consideration most. The Polytax inventory shows damage on one third of the regeneration felling sites, from heavy machinery. This rate of this damage has been constant over the past decade, and data are insufficient to distinguish between severe and less severe damage. A joint policy on damage caused by driving forestry machines on forest land has been developed by the forestry sector, which also assists with teaching and instruction. To further decrease damage from forestry machines, guidelines concerning terrain transport and ground preparation have been issued. Nitrogen fertilization of forest land increases the risk of nitrogen leaching. Leaching from the soil with a normal fertilizer dose is estimated at 5-10 % within 1-2 years after fertilization. Fertilization of forest land is primarily practiced in northern Sweden, which is also the part of the country where nitrogen deposition is the lowest. In recent years fertilization has increased from small areas to 80,000 hectares in 2010, the most since 1988. The Swedish Forest Agency gives recommendations and advice regarding nitrogen fertilization to minimize its negative effects on forests, soil, and water.

A Rich Diversity of Plant and Animal Life

Distance-to-Target

In summary, the measures based on existing policy instruments are insufficient. Work on preserving ecosystems and stopping loss of biodiversity is too slow to achieve the EQO. The gap is too wide, although it is not known by how much. There is insufficient knowledge about ecosystem services and their economic values. Furthermore, not enough is known about genetic diversity, foreign species, and the magnitude of the impact of climate change. It will also take time to implement all policy instruments developed for the long-term sustainable use of resources in different sectors. Regional assessments of the EQO are performed by the Swedish County Administrative Boards and direct measures are taken to preserve species and sensitive habitats. However, no county assesses that the EQO can be achieved. Important habitats are still being destroyed, including via felling of key biotopes and overgrowth of natural grazing areas. The deficiencies and the negative trend need to be tackled with increased financial support, and current measures have to be implemented to their full extent by all actors concerned on a national, as well as on a regional and local, level.

Current Situation and Development of the Environmental Condition

The use of natural resources has a great influence on an ecosystem's stability and its ability to deliver services. The production of commodities with a market demand may initiate a one-sided use of certain ecosystem services leading to excessive use and multiple negative impacts on materials, functions, and processes. Examples include monoculture practices in forestry and agriculture, foreign tree species, and types that are not adapted to growth in the area in question, as well as ocean overfishing and construction of hydropower plants in waterways. The socio-economic costs of the loss of ecosystem services can be high. These services are also complex in that they often do not function in isolation, instead co-varying. Since forests, agricultural lands, wetlands, lakes, and other bodies of water often coexist, they also affect each other. Thus, the whole landscape must be included at the planning stage, in order to create and preserve a green infrastructure containing a variety of ecosystems and thereby securing essential ecosystem services. There is also a national strategy that serves to protect those forests most in need of protection. The Swedish Forest Agency has produced a definition of *sustainable use of forests*, but the general conservation practiced the forestry industry is not currently sufficient. Important international prerequisites for the protection and conservation of biodiversity are the UN Convention on Biological Diversity, the strategic plan formulated at the meeting held in Nagoya in 2010, and the EU Habitat Directive and Birds Directive, which both constitute parts of the EU Nature Conservation Act.

3.Tools for Environmental Systems Analysis

3.1. General Description

The environmental impacts of various activities can be described with a variety of tools and methods. The suitability of a tool depends on what is to be analysed. Based on earlier work, Finnveden et al. (2005) present four questions that can be used to distinguish these tools (see Table 13) to determine applicability to a specific operation, activity, product, or other objected to be analysed.

Table 13. Four questions for distinguishing tools for environmental systems analysis

1. Is it a procedural or analytical tool? **Procedural tools (e.g. Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA)) focus on the procedures and the connections to the decision-making context. Analytical tools (e.g. Life Cycle Assessment (LCA), Material Flow Accounting (MFA)) are directed at technical aspects of the analysis and can be used within the framework of a procedural tool.**
2. What types of impacts are considered? **Tools can focus on the resources used or the environmental impacts, or both, and on economic aspects or not.**
3. What object is being study? **A distinction is made between five kinds of objects:** • **Policies, plans, programmes, and projects** • **Regions or nations** • **Organizations or companies** • **Products or services** • **Substances** **Normally, one object can be identified as the main object under analysis..**
4. Is the tool used in descriptive or change-oriented studies? **A change-oriented study analyses the consequences of a choice and helps present the outcome of the changes made. Descriptive studies describe systems as they are at a given time. This means that the appropriate data and system boundaries should be valid for what was actually happening in a system. In a change-oriented study the data and system boundaries should instead reflect the changes taking place.**

Below, several analytical tools for environmental systems are described, and their applicability to environmental evaluations of forest residue recovery is briefly discussed. We then proceed with the tools considered most suitable for the purpose of the work in this report. The tools presented are: Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Cost-Benefit Analysis (CBA), Input-Output Analysis (IOA), Position Analysis (PA), Life Cycle Assessment (LCA), Substance Flow Analysis (SFA), and Ecological Risk Assessment (ERA). For an overview of the activity of forest residue recovery and its environmental effects, see Table 1 (section 2.1) and

Table 15 (section 3.3.2).

3.2. Existing Tools and Methods for Quantification of Environmental Effects

3.2.1. Environmental Impact Assessment (EIA)

Environmental Impact Assessment is a systematic process that examines the environmental consequences of plans and projects, such as exploitation of natural resources, construction of infrastructure, etc., in advance. It is used for preventative measures. The assessment should be performed in a systematic, holistic, and multidisciplinary way. The procedure involves a number of steps that should eventually result in a compiled document called an Environmental Impact Statement (EIS), serving as an aid to decision-making {Glasson, 2012 #15}. EIA is a change-oriented procedural tool mainly used for assessing the environmental impacts of projects {Finnveden, 2005 #1}.

On a slightly more detailed level, an EIA serves to identify and describe the direct and indirect effects that a planned activity or measure might have on humans, animals, plants, soil, water, air, climate, landscape, etc. This concerns the management of soil, water, and the general physical environment and other management issues such as those pertaining to materials, commodities, and energy. The overall aim is to make possible a combined assessment of these effects on human health and on the environment {Moberg, 1999 #2}. The process is regulated by Swedish law and should be performed if the planned activity will (or is expected to) have impacts on the environment in any way. It is part of the Swedish Environmental Code (Miljöbalken), which also states the minimum requirements for what should be included in an EIA-document. There are no clear guidelines on how environmental impacts should be analysed and assessed in an EIA, and there are no strict instructions regarding the environmental aspects that should be included. This is decided on a case-by-case basis.

EIA has the potential to cover a broad spectrum of environmental effects and thereby also identify potential conflicts among environmental objectives. It is a tool (or more of a process) that makes suggestions on how measures and restoring practices can be undertaken to compensate for and counteract environmental impact. Since the tool is site-specific (at least on a forest area level) this makes it suitable to account for environmental effects with impacts on biodiversity, acidification, and eutrophication. However, the environmental impact category of climate change is not assessed in EIA since this tool lack the design to handle GHG balances, thus EIA needs to be complemented with other tools handling the GHG performance.

3.2.2. Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment can be seen as a development of EIA and offers a way to include a "sustainable way of thinking" in the early stages of general decision-making. The method allows for environmental aspects to be introduced at an earlier phase of the project, compared with EIA {Moberg, 1999 #2}. SEA is used to compare several different solutions before too many parameters are fixed {Johansson, 2004 #3}. Like EIA, SEA is a change-oriented procedural tool {Finnveden, 2005 #1} for assessing the impacts of projects. Compared to EIA, SEA is less applicable in an environmental assessment of forest residue recovery. Since it is a tool to be used in the initial stages of the planning of a project or the like, its range is broader than necessary for the recovery of forest residues.

3.2.3. Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis is an analytical, changed oriented-tool that measures the total monetary costs and benefits of a planned project {Finnveden, 2005 #1}. It is used to valuate activities from a socio-economic perspective and also attempts to include and put a monetary value on non-monetary commodities. The method is based on the market price for valuation but may require adjustment. When there is no relevant market price to be found (especially for non-monetary commodities), a common way is to derive costs and benefits from individual preferences where the willingness-to-pay principle plays a salient role. Other socio-economic values found suitable can also be derived for this purpose. To put a market price on something that has no monetary value may prove difficult {Moberg, 1999 #2}. The purpose of the valuation in monetary terms is to create a general sum of all costs and benefits in the analysis. In this way, the CBA aggregates all positive and negative effects included to give a final sum and a unified answer {Söderbaum, 1986 #4}.

CBA contributes to the discussion with a cost perspective, an aspect that may be difficult to leave aside. The willingness-to-pay principle can be used to estimate society's interest in fulfilling the environmental objectives in economic terms. Such an estimation may then convey the importance of the objectives as viewed by society, giving an additional dimension to the field. As discussed by Wenzel et al. {Wenzel, 1997 #28}, this type of estimation can be combined with political targets as a way to differentiate the importance among different objectives. Doubtlessly, there are questions of complexity due to the fact that many of the environmental objectives are linked and overlap. For example, *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life* are both broad objectives affected by a great number of factors. *Natural Acidification Only*, *Zero Eutrophication*, and *Reduced Climate Impact* all have an impact on the two above-mentioned objectives. Since economic aspects of forest residue recovery are not within the scope of the work in this report, CBA is not of direct use here.

3.2.4. Input-Output Analysis (IOA)

Input-Output Analysis is another analytical socio-economic tool that builds on a kind of a bookkeeping methodology and used in descriptive studies. Deliveries of commodities and services between different actors in the economy are recorded in a simplified manner. The analysis can be performed at the national or regional level. Different activities, but with sufficient similarities within the industry, are summed, and the average input and output values used. Linear production connections are included. A basic assumption is that the proportion of input commodities from different industries is constant. The method can be used for long-term planning purposes in order to reach consistent forecasts for different sectors and to illuminate connections between them, for example, how changes in one industry will affect others etc. Economic and physical IOA are kept apart. An economic IOA handles flows in financial terms. In order to use this tool for environmental studies, information about environmental aspects such as emissions must be coupled to the economic calculations. In a physical IOA, financial flows are replaced by material- or energy flows. A possible application of IOA from an environmental point-of-view is to see how policy instruments implemented for a certain industry affects other industries and thereby avoid a transfer of problems {Moberg, 1999 #2}.

This method may be difficult to apply on an evaluation of the actual recovery of forest residues, which is a specific activity in which the raw material is itself the product of logging residues and stumps. However, it may possibly be applicable if the extraction of forest biomass shifted towards the use of forest residues compared to the current situation where the extraction is mainly driven by the market for wood as building material and use in the pulp and paper industry. In that respect, the tool could help to map potential effects from different incentives and "drivers" of forestry.

3.2.5. Position Analysis (PA)

If CBA is a method by which the effects included are aggregated to give a general sum, Position Analysis embraces the act of disaggregation for the purpose of emphasizing conflicts and opposing interests in the decision-making process. Different opinions have to be explained based on the actors' own individual stands. *Versatility* is a key term and concerns the ways of regarding a problem, alternative solutions, influence, vested interests, and basis for appraisal. Institutional economy and systems theory form the basis of the method. The method is carried out in an iterative manner, and readers seeking further details are referred to the several publications that describe the approach. Monetary and non-monetary terms are treated separately and viewed as positions (conditions) and flows. A certain analysis of effects that are irreversible and/or difficult to repair should be carried out as part of the methodology. These are just a few of all steps involved, on which the information is eventually put together and presented in a document for decision support {Moberg, 1999 #2}.

PA may have some procedural points that are suitable for the assessment of an increased forest residue recovery. The method includes an analytical part of irreversible effects, and effects that are difficult to repair and restore. This could constitute a basis and offer ideas for how to address biodiversity complexity, which is a major issue for the forest ecosystem and forestry that makes use of its services. However, the method as a whole is not considered applicable to the recovery of forest residues.

3.2.6. Life Cycle Assessment (LCA)

Life Cycle Assessment is a method that analyses the environmental impact of products and services. The tool is based on the whole life cycle, which means that it accounts for the overall industrial system involved in the production, as well as the use and waste management phase of the product or service. Natural resource use and pollutant emissions are described in quantitative terms. LCA is also a method that describes how studies are carried out and interpreted. The requirements for LCA are rather strict (ISO, 2006). This is different from, for instance, EIA, which has no fixed directives for what is to be included in a study. LCA can be used for many different applications, which put different requirements on the methodology. Some fields of applications are decision-making, product development, and market communication. International standards for life cycle assessments belong to the series ISO 14040. The LCA procedure normally consists of four stages: goal and scope definition; inventory analysis; impact assessment; and interpretation and presentation of results {Baumann, 2004 #5}.

LCA is used to compile the potential environmental effects expressed in quantitative terms, and when possible, aggregated and expressed as equivalents. One example is the recalculation of greenhouse gases into carbon dioxide equivalents. Therefore, an LCA approach would be suitable to account for GHG balances, serving as an analytical tool within the framework of a procedural tool such as EIA or SEA. An EIA can supply the LCA with information on possible causes of alterations in GHG balances (soil damages/disturbances, nitrogen fertilization, litter production etc.) and thereby extend its use in this field. Some parts of the methods can potentially be used or adapted to assess the feasibility of increased recovery of forest residues. LCA could also be suitable for modelling different scenarios (short-term, long-term, types of fuels that are substituted by forest fuels, etc.).

3.2.7. Substance Flow Analysis (SFA)

Substance Flow Analysis focuses on the natural and anthropogenic flows of one substance at a time. Normally substances related to some kind of environmental impact are monitored, for example detection of sources, sinks, and storages. A common approach is to study the total flow of a substance in a certain region. In the current context, the regional use and consumption of a substance might be an interesting aspect, e.g. the flows of nitrogen, as fertilization will probably play a larger role in many parts of Sweden with an increased forest residue recovery. Mercury flows may also be of interest.

3.2.8. Ecological Risk Assessment (ERA)

Ecological Risk Assessment is a tool to assess the risks of a contaminant's impact on populations of plants and animals and ecological functions such as the mineralization of organic carbon and the turnover of nutrients. The method is for instance used to assess contaminated land {Jones, 2006 #7}. Forest residue recovery does not lend itself well to assessment with this tool, since it does not involve pollution, as such, and is not a source of contamination. It could perhaps be used as part of a larger quantification and evaluation process to include the identified risks of increased mercury methylation and possible ash contamination.

3.2.9. Other Methods

Environmental Accounting (EA) is a method by which environmental statistics are systemized and combined with economic statistics. This is a way to include natural resources and the environment in the national accounts of resource use. Both physical and economic environmental accounting require large amounts of data. Perhaps certain indicators and recognized economic values from the environmental accounting system can be used within the field of forest residue recovery, while the method as such is probably too general for the task.

Ecological Footprint (EF) is a method by which the impact of humanity on the global environment is calculated to comprise acreage use (area required to meet the demand of a given number of people with their specific living standards). This type of figure can then be compared with the total amount of accessible productive area. A global average of accessible productive area per person is one of many ways to present the data. The value can be used for a comparison with the actual average of inhabitants in different countries. The method does not suit the approach in this report.

Physical flows can be presented using Material Flow Accounting (MFA) tools. These tools provide information about society's resource use and give an indirect valuation of the environmental impact. There are several ways to perform these kinds of analyses, but the applicability for this type of biomass extraction, namely, forest residue recovery, is inadequate. Substance Flow Analysis (SFA) is an exception that may prove useful in connection with the recovery of forest residues and is therefore described separately above. Material flows related to the forestry operation are limited because forest residues are a raw material and constitute the product in itself, which is incinerated for the generation of energy. Material Intensity per Service Unit (MIPS) and Total Material Requirement (TMR) are two other methods that belong to MFA and are therefore not discussed here.

3.2.10. Suitable Tools for Forest Residue Recovery

Forest residue recovery includes both procedural and technical elements. The operation leads to an intensification of forestry, which calls for guidelines and directions. Increased recovery may be seen as a plan that needs to be evaluated for environmental impacts. The overall tool should thus preferably be a procedural tool within the framework of which analytical tools can be used to cover relevant technical aspects. Environmental impact is central in the evaluation and makes up the basis of what is to be analysed. The assessment should highlight important factors that can be guidelines when the suitability of forest residue recovery is evaluated for a certain stand. Both technical and economic aspects are important parts of the recovery but outside the scope of the work of this report. Forest residues are a renewable resource and a by-product of conventional forestry of timber and pulpwood. Therefore, apart from the recovery, the operation comprises a second object of evaluation, namely the products with the function of generating heat. Since the forest residues are the actual products, there is no direct use of natural resources but instead a utilization of ecosystem services. Because the evaluation asks what happens when more of the forest residues are removed than the current amounts, it is a change-oriented study.

When the four questions that categorize the tools for environmental systems analysis are applied to the parts of forest residue recovery as above, several of the tools presented can be neglected. The tools remaining are EIA, SEA, and LCA, where SEA is considered less suitable than EIA for this purpose. The choice of EIA methodology can also be motivated by its site-specificity, which rhymes well with a stand's suitability for forest residue recovery, as it accounts for environmental effects with impacts on biodiversity, acidification, and eutrophication. Since there are no strict guidelines for how an EIA should be carried out and what should be included, the process can be formed to fit the specific activity. LCA is used as part of the EIA approach to account for GHG balances by which the climate performance of forest fuels can be evaluated.

3.3. Suggested Environmental Evaluation Model: Stepwise Handling Procedure

We offer an environmental evaluation model of forest residue recovery to determine which environmental effects are most important in the Swedish context. The characteristic differences of the environmental effects determine the approach for covering each effect's important aspects. The model needs to be broad enough that the effects all fit within its framework but not so general that important aspects are missed. The model aims to balance the environmental effects according to the possibilities for managing them and how compatible they are with the relevant EQOs. The following sections introduce our environmental evaluation model, *Stepwise Handling Procedure*.

3.3.1. Components of the Environmental Evaluation Model

The Stepwise Handling Procedure (SHP) is inspired the Schmitz matrix {Finnveden, 1999 #6}. Adapting the Schmitz matrix by inserting the environmental impact categories connected to the environmental effects of forest residue recovery yields the form seen in Table 14

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Table 14. Schmitz matrix with the environmental impacts caused by the environmental effects of forest residue recovery

Environmental impacts	Environmental parameters				
	Ecological threat potential	Reversibility – Irreversibility	Geographical aspects	Environmental preferences of the general public	Relationship of actual and/or previous pollution to relevant environmental objectives
Climate change					
Acidification					
Eutrophication					
Biodiversity					

Based on three main tools, as per section 3.2.10, the environmental effects can be evaluated step by step, with the framework divided into two parallel tracks: an Environmental Impact Assessment Approach (EIAA), comprising the parameters *Ecological threat potential* and *Reversibility/Irreversibility,* and an EQO Approach (EQOA), to which *Relationship to environmental quality objectives* belongs. The parameter *Geographical aspects* is a key component for both approaches and is treated as part of both. *Ecological threat potential* is also important for the EQOA but will be principally handled in the EIAA. The parameter *Environmental preferences of the population* is not included in the evaluation model. Figure 4 shows an overview of the model with its two approaches running in parallel. The dotted line between the EIA Hierarchy and the Distance-to-Target indicates that information and feedback flow between the two boxes. The principle is that integration of the two approaches should generate a combined result on ecological significance based on critical aspects and distance-to-target evaluations.

Negative environmental effects that can be avoided are categorized as *low* or *not critical*. Environmental effects that cannot be avoided but can be minimized or reduced are more critical aspects, followed by negative environmental effects that cannot be minimized or reduced but can be compensated for. The most critical aspects will be those negative environmental effects for which we cannot even compensate.

The Reversibility/Irreversibility part highlights the importance of considering environmental effects that could lead to irreversible environmental impacts. Since an irreversible environmental impact, e.g. the extinction of a species or the destruction of an ecosystem, is in principle impossible to return to its original state, this question should be given considerable attention and serve as a constraint – an early warning sign -- on the evaluation. The EIA hierarchy approach is used to categorize the environmental effects according to the possibilities of handling their occurrences and potential impacts. The EIA hierarchy and the previous step of Reversibility/Irreversibility make up the principal part of the handling procedure for a specific environmental effect. These two steps should to a large extent determine the actions taken in a specific situation concerning forest residue recovery. "Distance-to-Target" refers to the approach in which the environmental effects and their environmental impacts are evaluated by the statuses and development trends of the in-depth and follow-up evaluations of the relevant EQOs. This links the current situation to the general well-being on both national and regional levels, and serves as an indicator of compatibility (the significance of the specific environmental impact from forest residue recovery in relation to the overall EQO) and an indirect prioritization of the objectives. The distance-to-target approach highlights that the status and development of the EQOs' achievability differ in different regions and counties in Sweden. It also brings up the question of synergies and conflicts among the EQOs. Subsequent chapters further address the components of each approach. The geographical aspects parameter clearly influences both approaches and their components and will be discussed before the other parts of the model are considered more closely.

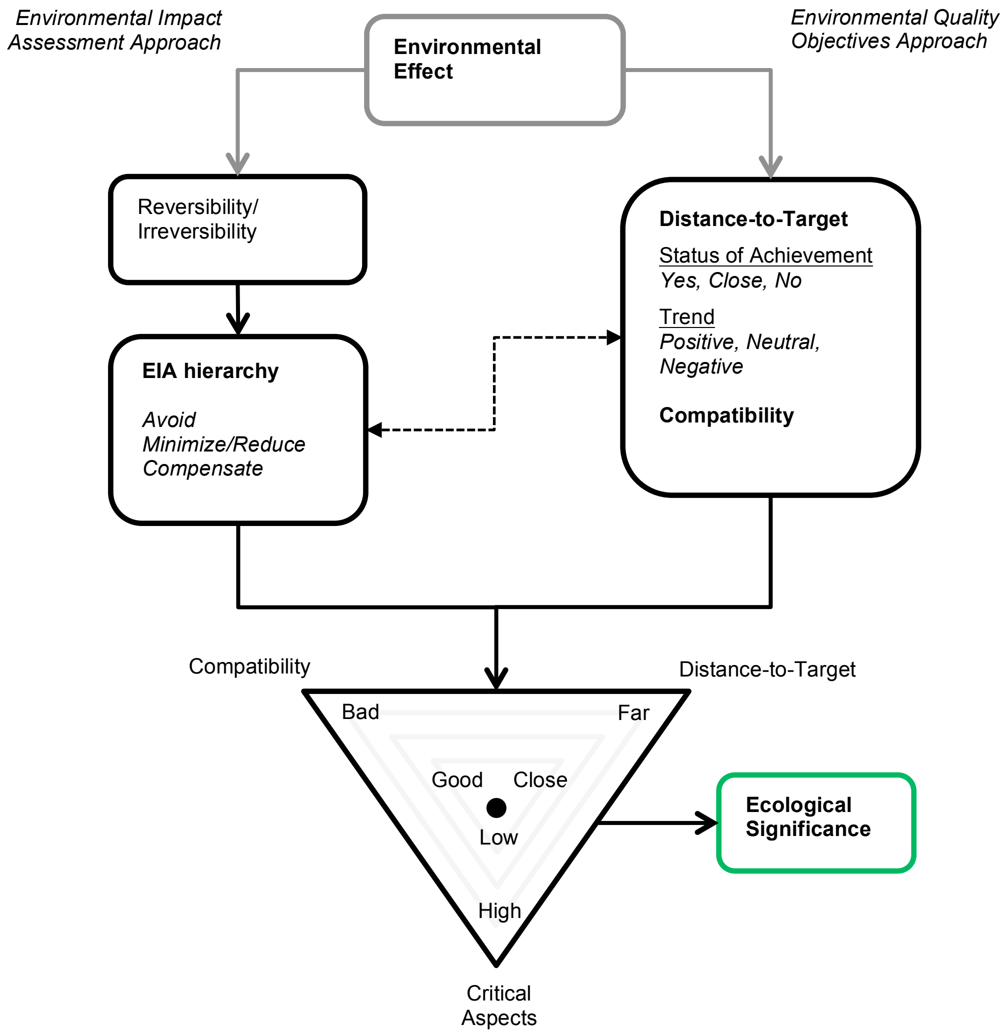

Figure 4. An overview of the environmental evaluation model, which is constructed as a stepwise handling procedure with two principal approaches running in parallel: an Environmental Impact Assessment Approach (EIAA) and an Environmental Quality Objectives Approach (EQOA).

Figure 5 shows the geographic magnitude of the environmental impact categories that may be affected by the environmental effects of forest residue recovery. The impact categories are also marked LCA or EIA, whichever is considered more suitable for the evaluation of their potential impacts. Climate change is the only category marked LCA. Recoveries that give rise to GHG emissions will have a negative impact on climate performance, whereas the replacement of fossil fuels will have a positive impact, so LCA is a suitable method. Climate change is also the only category with a global impact.

The connections between the environmental impact categories on the EQOs side and the EIAA box indicate flows of information. Based on the evaluations of the EQOs, this information can be used to assess the environmental conditions with regard to the environmental impact categories in a specific county.

The figure also shows the impacts over which Sweden has control. Achieving *Reduced Climate*

Impact depends substantially on international efforts, and the net GHG emissions of forest residue recovery will have a global impact. Achieving *Natural Acidification Only* and *Zero Eutrophication* is also characterized by significant international interdependence, with nitrogen deposition in Sweden mainly originating from sources beyond its borders. However the environmental effects of recovery that contribute to acidification and eutrophication or with impacts on biodiversity happen within the country, so national control is strong. The EQOs that relate to these environmental problem categories require county-based distance-to-target evaluations due to the extension of the regional environmental effects and the degree to which the individual counties are affected by international impacts. For instance, there is less acid deposition in northern than southern Sweden. Therefore, the bases for fulfilling the EQOs vary across counties, and this must be taken into consideration.

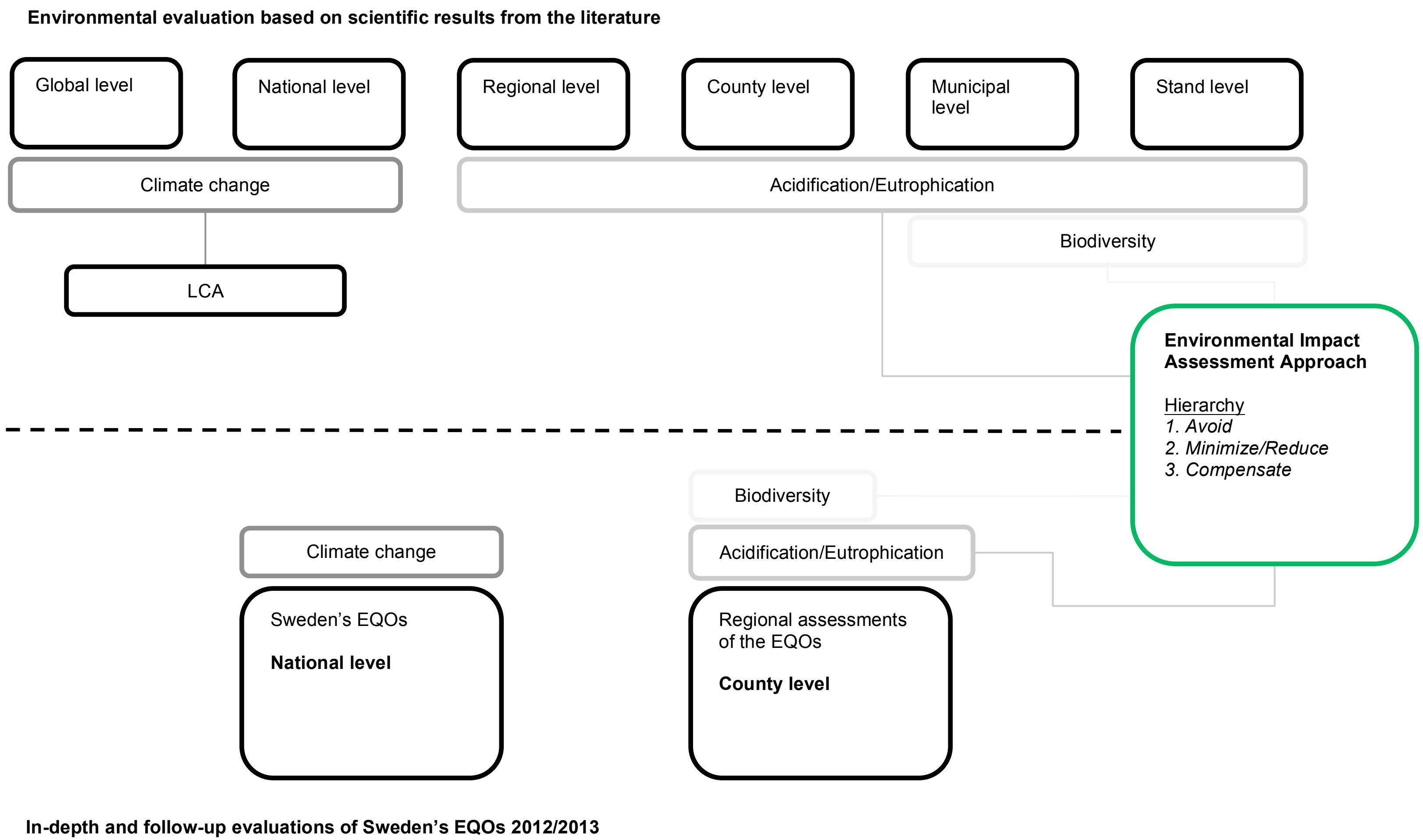

Figure 5. Overview of the geographic scale of the environmental impact categories. The impact categories are marked LCA or EIA depending on which can better account for the specific environmental impacts.

3.3.2. Environmental Impact Assessment Approach

The requirements specified in the synthesis by de Jong et al. { 2012 #8} that need to be fulfilled in order for increased recovery of forest residues not to negatively affect the achievability of the EQOs can be interpreted as the results of a prediction of what can be done to prevent and mitigate the potential impacts. The results of a modelling study by Belyazid et al. { 2010 #10} can also serve as a guide and provide information for impact prediction. The purpose of the Environmental Impact Assessment Approach is to discuss and categorize the different effects based on their likelihood of occurring and the options for handling them. The Swedish Forest Agency's recommendations on logging residue recovery, stump recovery, and ash recycling also provide information about impact prediction and mitigation measures {SFA, 2008 #19;SFA, 2009 #20}.

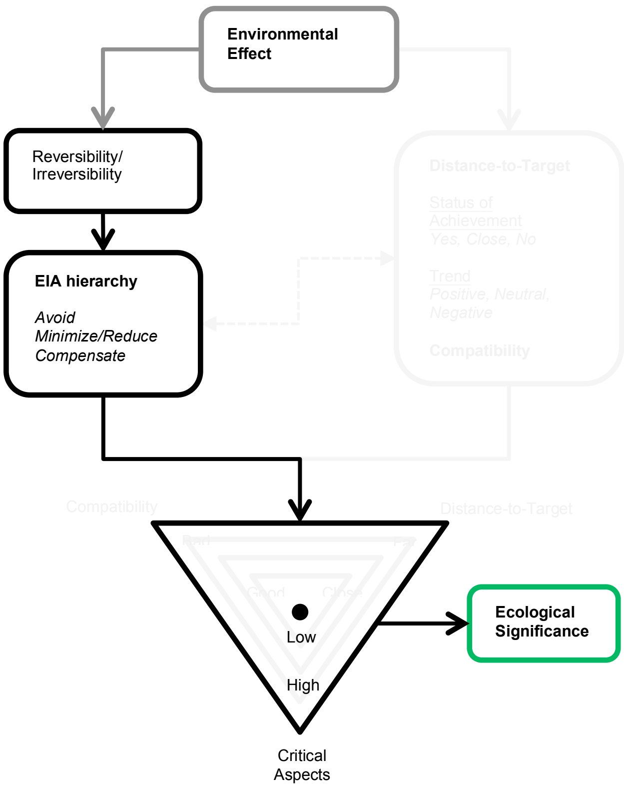

Figure 6. The Environmental Impact Assessment Approach (EIAA) of the Stepwise Handling Procedure (SHP).

Handling Based on Irreversibility – The Precautionary Principle

Environmental effects with the potential to lead to irreversible environmental impacts need special attention. For this reason the environmental evaluation model treats this question separately. The recovery of forest residues is directly linked to the forest ecosystem and biodiversity, a complex subject since impacts on biodiversity can stem from indirect effects from other environmental impacts (acidification, eutrophication, climate change, etc.) in turn caused by a wide range of environmental effects. According to de Jong et al. {, 2012 #8}, there are several areas with unique species that require wood for their habitat, such that should the species disappear from those areas, they would disappear entirely from Sweden. These areas need to be identified and completely exempted from the removal of critical substrates, in accordance with the Ecosystem Approach that stresses the importance of the precautionary principle {SEPA, 2008 #21}. However, an exaggerated use of the precautionary principle should be avoided, for instance in situations where social interests are important and the risks of biodiversity losses are minimal {Sandström, 2007 #18}. There are several forest-based indicators that can be used to assess the need for the precautionary principle in a specific situation. A relevant indicator is the presence of broad-leaved forest harvest residues, a highly valuable substrate for a broad range of species. Other indicators are the type of environment in the felling area (properties of the ecosystem such as the types of trees that have been felled and the biodiversity in the area, etc.) and how the forest in the felling area has been managed historically (whether or not forestry has previously been practiced in the area), etc.

Handling Based on EIA Mitigating Hierarchy

The EIA mitigation hierarchy characterizes the extent of environmental effects and their environmental impacts. The magnitude of environmental effects depends on what caused them as well as the prospects for measures that minimize and compensate for these effects. Potential mitigation measures are elucidated in the assessment work and are of great importance. The hierarchy should result in a summary of the general properties of all the relevant environmental effects. Table 15which briefly describes and categorizes the environmental effects according to the EIA hierarchy, is based on the research and the corresponding results compiled by de Jong et al. {, 2012 #8}. The measures are built on the requirements identified in that synthesis for not negatively affecting the achievability of the EQOs, the *EQO requirements*. The reference scenario is the current management of the existing forest.

Table 15. Summary of the most salient environmental effects of forest residue recovery, impact categories, and the mitigation measures along with their EIA categories

Environmental impact categories	Environmental effects	Description	Measures	Overall EIA mitigation category
Climate change	Alteration of the soil carbon pool	Soil disturbances such as damage and compaction caused by forestry machines (likely to increase when less logging residue and stump material is present to serve as a protective layer and increase the bearing capacity of the soils). Stump recovery using current technology increases disturbance.	Recovery on soils with good bearing capacity (avoid, minimize/reduce).	Avoid, Minimize/Reduce
	Methane and nitrous oxide emissions (effect of fertilization and soil compaction/water logging)	Damage caused by forestry machines in moisture-rich areas could have impacts on these types of emissions. Increased intensification of recovery leads to an increased need for nutrient compensation of nitrogen. Nitrogen fertilization can give rise to emissions of nitrous oxides.	Follow the Swedish Forest Agency's recommendations on nitrogen fertilization. Avoid fertilization where recommended (areas with high nitrogen loads) (avoid, minimize/reduce).	Avoid, Minimize/Reduce
Acidification	Nutrient removal	Recovery of nutrient-rich logging residues. Greatly increased by logging residue recovery compared with conventional stem wood recovery. Effect from stump recovery much less than that of logging residues. Areas suffering from acidification caused by acid deposition belong to those areas where the risks of acidification originating from forestry are the greatest.	Ash recycling (compensate). Adaption of the forestry based on the acidification sensitivity (minimize/reduce).	Minimize/Reduce, Compensate

Eutrophication	Nutrient leaching	Logging residue recovery and ash recycling should in theory not imply an increased risk of nitrogen leaching, which means that their contribution to eutrophication should in the worst case still be moderate. Nitrogen leaching in connection with final felling of fertilized stands needs to be quantified. Fertilization adjusted to stand demand can lead to increased nitrogen leaching. Logging residue recovery can mitigate nitrogen in certain areas with high nitrogen loads (southern Sweden). Insufficient knowledge of how ground disturbances and potential damage caused by forestry machines as a consequence of stump recovery affect leaching during the clearing phase.	Follow the Swedish Forest Agency's recommendations on recovery, ash recycling, and nitrogen fertilization. Avoid fertilization where recommended (areas with high nitrogen loads) (avoid, minimize/reduce). Recovery of logging residues might work as a measure in itself in areas with high nitrogen loads (minimize/reduce). Recovery on soils with good bearing capacity (avoid, minimize/reduce).	Minimize/Reduce
Biodiversity	Loss of forest residues, which function as substrate and habitat	The removal of logging residues and stumps that might function as substrate and provide habitats for living organisms. Stumps from felling activities make up a large part of the annual production of dead hardwood in forests. Fragmentation. Environmental Consideration – lack of/inadequate, etc.	Functional Environmental Consideration, as legally required (minimize/reduce, compensate). Avoid damage to and removal of material left as part of earlier Environmental Considerations (avoid). Avoid recovery in close proximity to key biotopes and nature reserves (avoid). Regional assessments with regard to species occurrence (avoid, minimize/reduce). Avoid recovery of valuable broad-leaved and other broad-leaved trees completely in coniferous-dominated stands (avoid). Wildlife corridors (minimize/reduce, compensate).	Minimize/Reduce
	Damage caused by driving of forestry machines and damage to natural and cultural values.	Increased forestry machine traffic due to intensified forestry.	Recovery on soils with good bearing capacity (avoid, minimize/reduce).	Avoid, Minimize/Reduce
Forest productivity	Decreased forest growth	Decreased growth as impact of logging residue recovery. Observed over several decades after final felling. No permanent impact on the production capacity of forest land. Thinning seems	Nutrient compensation: ash recycling and nitrogen fertilization (compensate). Consider in connection with the type of forestry operation (weeding, thinning,	Minimize/Reduce, Compensate

		to be more serious. Repetitive forest residue recoveries at regeneration felling, clearance, and thinning, expected to limit forest production during parts of the rotation period in a stand. Dependent on recovery intensity and nutrient content of harvested biomass.	felling) the recovery is done (avoid, minimize/reduce). Easier with earlier ground preparation and planting when harvest residues are recovered. This can compensate for growth reductions (compensate).	

Site Specificity

The EIA hierarchy evaluation depends on the properties of a given location. One location might be more sensitive than another, which affects the magnitude and impacts of a certain environmental effect. For example, nutrient removal can cause different degrees of environmental impact depending on the location and the prevailing environmental conditions, as shown by Belyazid et al. {, 2010 #10}, which highlights the marked difference in conditions between northern and southern Sweden. The environmental effects of forest residue recovery identified will thus yield different bases for EQO achievability depending on the prevailing environmental conditions. This in turn affects the need for measures as well as their potential effect. Even though an evaluation should be based on the conditions of a certain stand, clear environmental trends can be an incentive to carry out the evaluation at a less detailed geographic level. The current status and potential risk of acidification is probably an environmental impact category for which evaluation in many cases can be performed at a higher level than the stand level. This would make the total evaluation less time- and labour-intensive. In contrast, biodiversity is a complex subject that needs to be assessed for each location due to its explicit dependence on the prevailing environmental conditions. The greater the need for geographical detail, the greater the need for specific attention to the environmental effect in question. In summary, an evaluation must specify the given location but the level of detail required should be considered.

A Measure's Potential

If negative effects cannot be avoided, the measures available will help determine whether the effects can be minimized or compensated for. This will not always be obvious. Categorization will also depend on whether the EIA hierarchy is applied on environmental effects or environmental impacts caused by environmental effects. For example, ash recycling does not reduce the actual nutrient removal caused by forest residue recovery but reduces the decrease of nutrients in the forest stand. Ash recycling is thus a compensatory measure by which the negative environmental effect of nutrient removal is levelled out. In contrast, ash recycling minimizes the risk of acidification caused by nutrient removal and is therefore a minimizing measure if the environmental impact is considered. A measure to reduce nutrient removal would be to limit the recovery of forest residues by leaving a certain amount in the stand. Since the environmental impacts caused by the environmental effects are fairly well known, these will follow indirectly as part of the evaluation. Compensatory measures can also be divided into two groups, *levelling measures* and *replacing measures*. Levelling measures constitute practices carried out at the place of the activity (e.g. forest stand) and aim to recreate a lost environmental function. Replacing measures widen the concept and aim at recreating a lost environmental function at another place (e.g. forest area) or at the same place but with other functions than those that have been lost {Wallentinus, 2007 #24}. Focusing on environmental effects rather than impacts has the advantage of providing higher detail and connection to certain indicators.

A Measure's Practicability

Environmental effects that can be counteracted by general compensatory measures will give these effects a "manageable status". Once again the compensatory measure of ash recycling for minimizing the risk of acidification due to nutrient removal is used as an example. Although nutrient removal is categorized as an environmental effect that can be compensated for, the lowest grade in the EIA hierarchy, the measure of ash recycling could perhaps be seen as trivial compared with some other measures. Since ash recycling seems to be working satisfactorily when practiced, it may be appropriate to say that the operation has certain characteristics that increase its applicability as a measure. In contrast, a negative environmental effect that can be minimized according to a best-case scenario might still require measures requiring great effort in order to reach the level of "minimization". Therefore, categorizing environmental effects according to the

EIA hierarchy should be done with care and should be reviewed in an assessment. For example, in the gap analysis in the 2012 in-depth evaluation, an objective placed at "No", but near the status of "Close", is not necessarily easier to achieve than an objective further down the "No"-scale (see section 2.3.6). Impacts caused by environmental effects can of course also be of different magnitudes. An environmental effect that in principle or in general is possible to avoid may result in a significant environmental impact if it does occur. Categorizing this as "avoid" is of little value.

3.3.3. Environmental Quality Objectives Approach

To link the identified environmental effects and their potential impacts to the relevant EQOs is quite straightforward. However, to extend the assessment and relate the environmental effects to the EQOs with the intention of attaining a "compatibility indicator" by comparing the effects and their corresponding impacts with the development of the relevant EQOs is harder. The sections below discuss this.

Part of an Environmental Evaluation Model

To determine the relation between the EQOs and forest residue recovery, the relevant components of the EQO that relate to the effects and impacts of the recovery have to be identified, see Figure 7. This process also indicates the general applicability of EQOs in environmental evaluations of residue recovery. The idea is to use the current "official" evaluation methodology and the components that form the structure of the EQOs for two closely linked purposes:

1. Clearly and consistently *relate* the environmental effects and their impacts to the EQOs.
2. Estimate the *compatibility* of the effects and their impacts with the EQOs. How do the effects affect the estimates of distances-to-target in the 2012 in-depth evaluation?

The basis for the first point is discussed in section 2.2. By focusing on the specifications, indicators, and policy instruments, which are directly linked to the evaluation of the EQOs, a framework can be outlined to give the necessary "tools" for evaluating a specific activity, based on the methodology that is used to evaluate the status of the EQOs. The availability of policy instruments and their role in creating the basis for achieving the EQOs is crucial to handling the impacts caused by the environmental effects. Well-functioning policy instruments can mitigate the extent of environmental effects and reduce their "impact significance", which leads to less severe conflicts (increased compatibility) with the EQOs. This part can be seen as an extension of the EIA mitigation hierarchy to include the influence of policy measures.

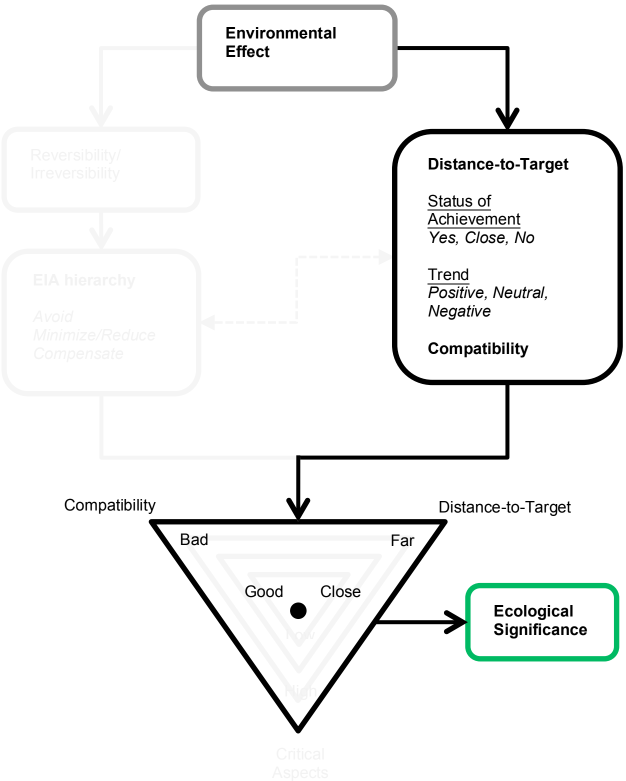

Figure 7. The Environmental Quality Objectives Approach of the Stepwise Handling Procedure.

Estimating compatibility should preferably be done at the county level for more specificity than at the national level. The in-depth evaluation is the overall result of the evaluations of the EQOs in each county. This aggregated form disguises the fact that environmental conditions may differ significantly in different parts of the country. The general approach is to relate the environmental effects of forest residue recovery to the EQOs and put them in a reasonable context based on the objectives' content and the information found in the in-depth and follow-up evaluations. In this framework, compatibility is a measure that describes how the activity could affect the development of an EQO.

Distance-to-Target – Meaning in This Context

The distance-to-target section is meant to highlight the fact that the distance, for a given EQO, varies from county to county. Compatibility of the EQOs and forest residue recovery differs throughout the country. To use a gap analysis methodology, some modifications are necessary. The number of common reasons for failing achievements and the development trend of the environmental condition are parameters to which the environmental effects of forest residue recovery need to be related (see section 2.3.6). This makes it possible to integrate the environmental effects in the distance-to-target approach. Hence, an effect's influence on the development of an environmental condition has to be elucidated and related to the "overall" status of the objective.

The common reason "negative impact or competition from other objectives and sectors" (see Table 11) is an important issue for the forestry sector with its production objectives, land use, and use of ecosystem services, etc., but isn't considered part of the environmental effects. The remaining four common reasons/questions can be adapted and applied to the environmental effects to be used in a distance-to-target context (see Table 16). These four questions are:

- Does the environmental effect have an impact on an environmental problem with a slow recovery rate? If so, positive effects of implemented measures are unlikely to be observable in the short term.
- What policy instruments are directed at the environmental effect and its impacts? Are there enough instruments?
- If relevant policy instruments exist, what are their prospects and functionality? Do they provide a basis that leads to sufficient measures to handle the environmental effect, and what about their potential implementation?
- Can the major part of the environmental objective to which the environmental effect belongs be solved within the county?

Table 16. Parameters adapted from the gap analysis of the 2012 in-depth evaluation to be applied to the environmental effects and used in a distance-to-target context

	Does the environmental effect have an impact on an environmental problem with a slow rate of recovery? (National/Regional)	Are there enough policy instruments directed at the environmental effect and its impacts? (National)	Are the functionality and outlooks of the policy instruments satisfactory? (Regional)	Can the major part of the relevant EQO be solved within the county? (Regional)
Yes				
Neutral (in between)				
No				

Each parameter is labelled with the relevant geographic level. The development trend of the EQO should also be considered when considering compatibility. The distance-to-target approach is made up of two main parts. The first considers how the environmental effects "behave" in relation to the four common reasons. The connections between the environmental effects and the common reasons should be highlighted. The second part compares the outcome of the first part with the official gap analysis of the EQOs, to assess the approximate influence of the environmental effects on the overall development of the relevant EQOs.

The generality that limits the gap analysis, which is based on the national evaluation of the objectives, needs to be reduced by performing county-based gap analyses, to account for regional differences. However, no regional gap analyses have been performed to date, and the case study in Chapter 4 attempts to compensate for this. A regional gap analysis should preferably be based on the same common reasons as the national analysis in order to keep the methodology uniform (see Table 11). Information on the development trends of the environmental conditions in each county can be found in the follow-up evaluations of the objectives compiled by the county administrative boards (see section 4.3).

Since the same policy instruments are used throughout Sweden, an identified lack of policy instruments concerns the whole country. However, implementation may vary differ among counties, which, along with the development trends, can inform regional gap analyses. The consequences of EQOs not being achievable within Sweden also differ among the counties and affect a regional gap analysis. One example is the significant nitrogen deposition in the southwest, which mainly originates from sources beyond the Swedish border. The distance-to-target of

Natural Acidification Only depends much less on impacts from abroad in the northern than the southern parts of Sweden. Therefore, international interdependence will have a major influence on a regional gap analysis. Once the environmental effects of forest residue recovery are evaluated and placed in a distance-to-target context, they should be compared with the gap analyses of the EQOs on a county level, to estimate compatibility between the environmental effects and the EQOs.

4. Case Study of Forest Residue Recovery in Four Swedish Counties

4.1. Introduction

The EIAA in the SHP depends on the options for handling the environmental effects of forest residue recovery. The prospects for these options vary across the country due to regional environmental conditions. The purpose of the case study is to elucidate these factors, by studying four counties, Västerbotten, Dalarna, Stockholm, and Skåne, see Table 17 and Figure 8 for basic facts. As part of the EQOA, the follow-up evaluations of relevant objectives are summarized to show the environmental status of each county and the prospects for achieving the objectives. The gap analysis methodology is based on this kind of information. The aim of the case study is to generate general findings regarding pros and cons of the SHP.

Table 17. General facts about the four counties in the case study {SCB, 2013 #43}

County	Västerbotten	Dalarna	Stockholm	Skåne
Vegetation zone	Boreal	North-South/South Boreal	Boreo-Nemoral	Nemoral
Land area [hectares]	5,540,100	2,819,300	649,000	1,102,700
Population	259,290	277,050	2,054,340	1,243,330

Västerbotten and Dalarna are located in northern Sweden. Both are sparsely populated and consist largely of forest land. They are also substantially larger than the other two counties in the study. Therefore, their forest fuel potential is significant. Stockholm and Skåne are two densely populated counties with a relatively small proportion of forest land and forest fuel potential, but their high population generates a greater demand for forest fuels. Västerbotten and Dalarna export forest fuels, while Stockholm and Skåne import.

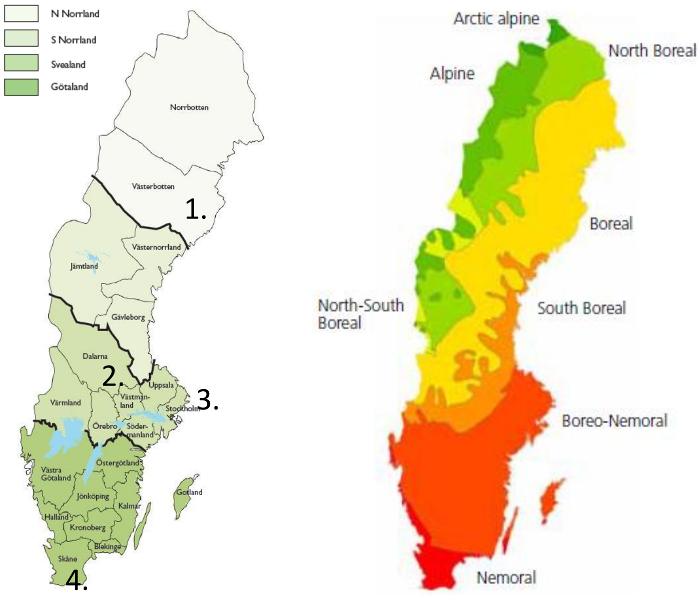

Figure 8. (A) Location of the four counties {SFA, 2012 #33}. (B) Vegetation zones {KSLA, 2009 #42}.

4.2. County and Regional Indicators from Forestry Statistics

The choice of type of data for this study is guided primarily by the requirements in de Jong et al. {, 2012 #8}. Table 18 can be used as a checklist and shows how the different forestry data relate to the EQO specifications. Each section below begins with a set of indicators based on the information presented. These indicators can be related to the relevant specifications and imply either negative of positive impacts on them.

Table 18. An overview of how the requirements by de Jong et al. {, 2012 #8} and relevant specifications of relevant EQOs relate to the different categories of forestry statistics presented in the case-study

Categories of forestry statistics	**Forest and Forest Land**	**Protected Productive Forest Land**	**Environmental Consideration**	**Felling and Wood Measurement**	**Recovery of Logging Residues**	**Ash Recycling**	**Large-Scale Forestry Fertilization**	**Urban Forests**	**Wood Fuel**
Requirements									
Tree Types	X	x	x	x	x				
Ash Recycling	X				x	x			
Environmental Consideration	X		x						
Other Restrictions (nitrogen deficiency, damage fr. machinery)	X		x						
Specifications									
Reduced Climate Impact									
Temperature					x				x
Concentration					x				x

Natural Acidification Only									
Acidifying effects of forestry	X					x			
Acidified soils	X					x			
Zero Eutrophication									
Pressure on the marine environment							x		
Pressure on the terrestrial environment	X						x		
Sustainable Forests									
Qualities and processes of the forest land	X	x	x	x	x	x	x		
Ecosystem services	X	x	x	x	x	x	x		
Green infrastructure	X	x	x		x				
Threatened species and restored habitats	X	x							
Preserved natural and cultural heritage values	X	x	x	x	x				
Outdoor recreation	X	x	x					x	
A Rich Diversity of Plant and Animal Life									
Green infrastructure	X	x	x		x				
Biological cultural heritage	X	x	x						
Nature on the urban fringe	X		x					x	

4.2.1. Forest and Forest Land

Indicators: (i) Area of productive forest land (measure of the potential extent of forestry land use), (ii) area distribution by age class of productive forest land (measure of the proportion of old forest with comparatively long continuities of the total forest), (iii) distribution of productive forest land by site productivity (guidance for recommended ash dosage, indication of regional production differences).

Area of Productive Forest Land

Productive forest land is forest land suitable for timber production that is able to produce an average volume of timber of at least one cubic metre per hectare and year. Data on the area of productive forest land are key to assessing forestry prospects, see Table 20. The definition of old forest depends on the region. In northern Sweden (Västerbotten and Dalarna), an "old forest is over 140 years of age"; in Stockholm and Skåne, the minimum age is 120 years, see Figure 9 and Table 20Table 20 for county data. The data for 2011 are used for the total area of productive forest land, if not otherwise defined.

Table 19. Share of productive forest land of total county land area {SCB, 2011 #46} in 2011

County	Productive forest land	County land area	Share of productive forest land

	[1,000 hectares]	[1,000 hectares]	
Västerbotten	3,125	5,519	57 %
Dalarna	1,984	2,820	70 %
Stockholm	276	652	42 %
Skåne	350	1,104	32 %

The area distribution by age class gives the area where final felling and forest residue recovery is, or is not to be advocated, based on the age of the forests.

Figure 9. Area of productive forest land in each county over the period 2006-2010 (excl. protected productive forest land), by age class.

Table 20. Area of productive forest land in each county over the period 2006-2010 (excl. protected productive forest land), by age class

County	0-2	3-10	11-20	21-30	31-40	41-60	61-80	81-100	101-120	121-140	141-	Total
	[1,000 hectares]											
Västerbotten	119	246	280	336	243	512	332	278	261	242	267	**3,114**
	4 %	8 %	9%	11 %	8 %	16 %	11 %	9 %	8 %	8 %	9 %	
Dalarna	78	147	198	257	196	236	130	128	147	170	186	**1,872**
	4 %	8 %	11 %	14 %	10 %	13 %	7 %	7 %	8 %	9 %	10 %	
Stockholm	17	18	19	34	32	46	47	29	25	12	13	**293**
	6 %	6 %	6 %	12 %	11 %	16 %	16 %	10 %	9 %	4 %	4 %	
Skåne	23	26	45	37	36	89	51	40	27	9	2	**387**
	6 %	7 %	12 %	10 %	9 %	23 %	13 %	10 %	7 %	2 %	1 %	

Site Productivity

Site productivity is a measure of the timber production capacity of a forest site under ideal conditions. It is calculated as the average timber production per hectare and year of a stand. Site productivity clearly demonstrates regional differences, see Table 21. Site productivity is also relevant for wood ash recirculation. The Swedish Forest Agency uses the specific soil fertility, which is equivalent to site productivity, as a basis for the recommended dosage of ash. As can be seen in Table 21, Skåne has the highest soil fertility with 71 percent of its productive forest land area in the two top classes (11-12 m^3 standing volume over bark/ ha, year).

Table 21. Productive forest land area and site productivity during the period 2006-2010 (excl. protected productive forest land)

County	Forest land area [1,000 hectares]	Site quality class (by best species) [m^3 standing volume over bark/ha, year]											
		1-	2-	3-	4-	5-	6-	7-	8-	9-	10-	11-	12-
		percent of forest land area											
Västerbotten	3,114	6	33	42	16	4	0	0	0	0	0	0	0
Dalarna	1,872	3	15	19	15	23	12	9	3	1	0	0	0
Stockholm	293	0	1	4	10	19	8	17	23	6	9	3	0
Skåne	387	0	2	1	1	2	6	6	3	2	7	35	36

4.2.2. Protected Productive Forest Land

Indicators: (i) Formally protected area of productive forest land, Distribution of general forest types in national parks and nature reserves, (ii) area of productive forest land left to be protected until the end of the expired interim target on long-term protection, (iii) area of key woodland habitats on privately owned productive forest land (estimation of unprotected area of forests with high conservation values on productive forest land).

The category "protected productive forest land" generates indicators that describe conditions in line with many of the relevant specifications (see Table 18) and therefore have positive impacts on the EQOs to which they belong.

Formal Protection

Sweden has four formal natural environment protection categories. A *national park* is a large area of continuous land conserved to "preserve a certain type of landscape in its natural state or in essentially unspoiled condition". The Parliament and Government decide on the establishment of national parks. The land must be owned by the state. *Nature reserves* are the most common type of formal protection. County Administrative Boards and municipalities have the power to decide on their establishment. According to Chapter 7, Section 4, of the Swedish Environmental Code, the purpose of nature reserves is to preserve biodiversity, conserve and maintain valuable natural habitats, satisfy needs for outdoor recreation, and/or protect, restore or create natural environments and valuable habitats for specific species. The term *habitat protection area* is used for smaller land and water areas that provide habitats for plants and animals threatened with extinction, or are worthy of protection for some other reason. Commercial activities that might damage the natural environment are not permitted on these sites. On agricultural land, the County Administrative Board decides on the establishment of habitat protection areas. Concerning forest land, the Swedish Forest Agency usually decides, but the County Administrative Board also has the authority. In general, this type of protection is used to protect key biotopes. Finally, there is *nature conservation agreement*, which is an agreement between a landowner and the state or a municipality. This may imply that timber production is restricted to a small section of the forest for the benefit of biodiversity. The agreement is based on the landowner's voluntary co-operation and is valid for at most 50 years {SFA, 2012 #33}. About 60 % of the Natura 2000 sites in Sweden are covered by protection other than national parks, nature reserves, and habitat protection areas {SFA, 2013 #25}. To avoid double counting, the Natura 2000 sites are not included in the total number of protected areas (see Table 22). The information on voluntary conservation areas is given by region, not county, and is therefore not included in the table. Voluntary conservation means no economic compensation to landowners whereas nature conservation agreements include economic compensation to the landowners. The protected area of productive forest land summarised in Table 22 is thus somewhat underestimated.

Table 22. Protected area of productive forest land in 2011

	Västerbotten	Dalarna	Stockholm	Skåne
	[hectares of productive forest land]			
National parks and Nature reserves (incl. montane forest) (2011)	100,610	74,207	14,758	9,693
Habitat protection areas (incl. montane forest) (2011)	1,670	1,927	894	818
Nature conservation agreements (2011)	1,892	2,954	1,056	723
Total	**104,172**	**79,088**	**16,708**	**11,234**
Share of total area of productive forest land	3.3 % 3.7%	4.0 %	6.1 %	3.2 %
Total area of productive forest land	3,125,000	1,984,000	276,000	350,000

The importance of substrates from valuable broad-leaved trees for many wood-living species makes it reasonable to consider the distribution of forest types in the national parks and nature reserves. The figures in Table 23 can be compared with the standing volume on productive forest land based on tree species in Table 30.

Table 23. Protected productive forest land based on "forest type" in national parks and nature reserves in 2011

	Västerbotten	Dalarna	Stockholm	Skåne
	[hectares of productive forest land]			
Coniferous forest	91,470	62,251	9,675	1,237
	82.7 %	83.9 %	65.6 %	12.8 %
Mixed forest	11,889	7,180	1,862	747
	10.7 %	9.7 %	12.6 %	7.7 %
Broad-leaved forest	5,013	2,569	2,088	6,559
	4.5 %	3.5 %	14.1 %	67.7 %
Felled area and young forest	2,238	2,207	1,133	1,149
	2.0 %	3.0 %	7.7 %	11.9 %
Total	**110,610**	**74,207**	**14,758**	**9,693**
Proportion of total area of productive forest land	3.5 %	3.7 %	5.3 %	2.8 %
Total area of productive forest land	3,125,000	1,984,000	276,000	350,000

Formal Protection by an Expired Interim Target

The previous interim target for *Sustainable Forests* with respect to long-term protection of forest land aimed to exempt a total of 900,000 hectares of productive forest land nationally, between 1999-2010. This area was distributed and regionalized by the counties, which formed their strategies for the exemption of forest land by formal protection and voluntary conservation. The areas of voluntary conservation are not presented by county in the forestry statistics and therefore are not considered in this section of the case study. However, areas of voluntary conservation made up a substantial part of the area covered by the strategies established. At the national level, 500,000 hectares of the total 900,000 hectares were assumed to be protected by voluntary conservation. Table 24 shows that none of the counties fulfilled the interim target when areas of voluntary conservation are excluded (although the target was achieved on a national level).

Table 24. The formal protection of productive forest land compared with the former interim target on the long-term protection of forest land for the period 1999-2010 (N/S – not specified)

	Västerbotten	Dalarna	Stockholm	Skåne
	[hectares of productive forest land]			
Nature reserves 1999-2010	26,300	N/S	6,880	3,556
Nature reserves according to objective	34,000	32,160	12,300	5,180
Habitat protection areas and Nature conservation agreements 1999-2010	6,000	N/S	1,650	1,317
Habitat protection areas and Nature conservation agreements according to objective	3,056	8,040	4,100	2,220
Total 1999-2010	**29,356**	**21,400**	**8,530**	**4,873**
Total according to objective	40,000	40,200	16,400	7,400
Proportion of objective area	**73 %**	**53 %**	**52 %**	**66 %**

Key Habitats

A key habitat is an area that has great significance for the flora and fauna of the forest, and it contains, or can be expected to contain, species found on the red list. Thus, key habitats are important for the conservation of biodiversity and several of the specifications that belong to *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life*. In 1993, the Swedish Forest Agency started to inventory key habitats on small-scale forestry holdings, an area corresponding to almost 12 million hectares. The inventory has been divided in two phases prior to the current period. The first phase continued until 1998, and the second lasted from 2001 to 2006. Today's inventory is carried out on a small scale. Owners and operators of medium-size and large-scale forestry conduct their own inventories, which are not presented as part of the forestry statistics. A control inventory in 2000 brought to light a large number of previously unrecorded key habitats. The investigation estimated the number and area of key habitats to be five times as many and five times as large as identified in previous inventories {SFA, 2001 #34}. The control inventory showed a significant need for on-going inventories. Many key habitats remain unrecorded, but many are being identified {SFA, 2007 #35;SFA, 2007b #36}. According to the 2012 in-depth evaluation of *Sustainable Forests*, nearly 500 hectares forests with key habitats are felled annually. About one third of these had already been identified, while the rest were unidentified at the time of felling. Due to high values for biodiversity in key habitats, felling and forest residue recovery should be restricted or preferably avoided.

Skåne and Stockholm show higher frequencies of key habitats than Dalarna and Västerbotten (see Table 25 and Figure 10). Relative to the other counties, the share of key habitat area of the total area of productive, privately owned forest land is high in Stockholm. Recovery of forest residues in these areas is likely to have extensive negative impacts on biodiversity.

Table 25. Area of key forest habitats on privately owned land (individual forest owners), in 2011

	Västerbotten	Dalarna	Stockholm	Skåne
Privately owned productive forest land [1,000 hectares]	1,296	797	162	273
Number of key habitats	1,970	3,280	2,505	2,513
Total area of key habitats [hectares]	13,122	16,259	11,032	3,883
of which is productive forest land [hectares]	11,798	14,080	9,434	3,463
Share of key habitat area of privately owned productive forest land	0.9 %	1.8 %	5.8 %	1.3 %
Total area of productive forest land [1,000 hectares]	3,125	1,984	276	350
Proportion of privately owned productive forest land of total area of productive forest land	41 %	40 %	59 %	78 %

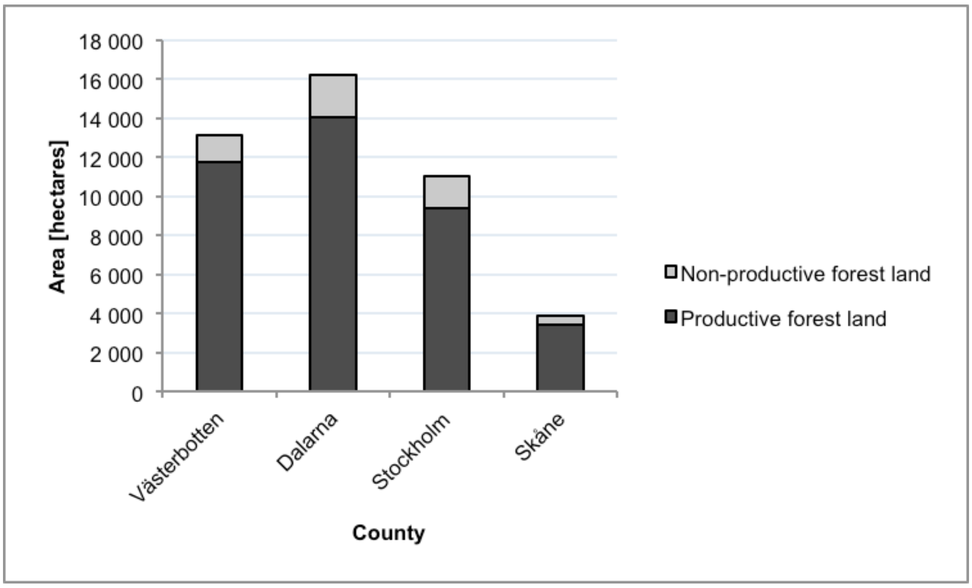

Figure 10. Area of key habitats on privately owned forest land, year 2011.

The Swedish Forest Agency recommends that forests with high biodiversity values, such as key habitats, should be exempted from forest residue recovery. Wetland forests have a high frequency of such high values and are also found on the list of key habitats. This type of forest usually has soil of poor bearing capacity, and therefore forestry machines easily cause soil damage {SFA, 2008 #19}. The requirements by de Jong et al. {, 2012 #8} also stipulate that recovery of logging residues and stumps should be avoided adjacent to key biotopes and nature reserves.

Data from Forest Companies in Sweden

The large forest companies conduct their own inventories of key habitats, and general figures can easily be found on their websites (see Table 26). The data presented primarily pertain to forest land voluntarily set aside for nature conservation; the extent to which these areas qualify as key biotopes cannot be read from the data. However, the information can be used for comparisons between companies and as indications of their work on biodiversity conservation and protection of forest land.

Table 26. Data on the area of forest land owned by large forest companies and the portion set aside for nature conservation

Svea Skog
About 4.1 million hectares of forest land of which 3.1 million hectares are productive forest land. 300,000 hectares are nature conservation forests of which about 75,000 hectares are key biotopes (www.sveaskog.se).
SCA Skog
2.6 million hectares of forest land of which 2 million are used for forestry and about 1 percent is key habitats, which is equivalent to approximately 20,000 hectares (www.sca.com). No data on area set aside for nature conservation.
Bergvik Skog
Has 1.9 million hectares of productive forest land. Just over 100,000 hectares of productive forest land are voluntarily set aside for nature conservation located below the boundary of sub-montane forests (www.bergvikskog.se).
Holmen
1,032,800 hectares of productive forest land. 60,000 hectares of productive forest land voluntarily set aside for nature conservation (www.holmen.com).
Statens fastighetsverk
Northern Sweden: 870,000 hectares of productive forest land. 450,000 hectares are nature reserves. Another 110,000 hectares are to become nature reserves. 35,000 hectares are voluntarily set aside. 250,000 hectares are used for forestry. Southern Sweden: 11,700 hectares of productive forest land. 2,000 hectares are nature reserves. 2,000 hectares are voluntarily set aside. 8,600 hectares used for forestry (www.sfv.se).
Svenska kyrkan
396,000 hectares of productive forest land. Of these, 8.6 % are voluntarily set aside for nature conservation (www.svenskakyrkan.se).

4.2.3. Urban Forests

Indicators: (i) *Urban forests of recreational importance, (ii) share of protected urban forests*

The category "Urban forests" includes two applicable specifications for EQOs, a specification about outdoor recreation ("the value of forests for outdoor recreation is safeguarded and maintained"), for *Sustainable Forests*, and a specification about forests close to urban areas, *A Rich Diversity of Plant and Animal Life* ("natural environments near urban areas that are valuable for outdoor recreation, cultural heritage and biodiversity are safeguarded and maintained, and are accessible to the public"). Currently, the recovery of logging residues is high in densely populated areas due to the high demand for forest fuel in district heating plants. Logging residue recovery is the lowest in the inner parts of Norrland, where the demand is lower and the costs of transportation are higher {SEPA, 2011b #37}. In recreational and urban forests, recovery of logging residues provides easier access for visitors {SFA, 2008 #19}. However, stump recovery may have short-term negative effects on the landscape and temporarily restrict access{SFA, 2009 #20}.

Urban forests are defined as forests within a radius of 1 km from the border of an urban area. The data used are from Lantmäteriet (the Land Survey), and the area of forest land is based on their definition and not entirely compatible with the definition of forest land in the Swedish Forestry Act (see Table 27). Areas of national recreational interest are defined by the Government, according to Chapter 3, Section 6, of the Swedish Environmental Code, a policy instrument for the management of land and water areas. Areas of national recreational interest are shown for each county in Table 27. The population and urban forest land per resident indicate the "recreational intensity" and the demand for forest fuels. The protected area in Stockholm County is almost twice as large as the area of national recreational interest.

Table 27. Urban forests of recreational importance in 2011

	Västerbotten	Dalarna	Stockholm	Skåne
Population	259,667	276,565	2,091,473	1,252,933
Area of national recreational interest [hectares]	51,846	360,574	68,879	69,775
Urban forests				
Forest land [hectares]	36,757	88,956	83,687	56,220
Forest land per inhabitant [m^2/resident]	1,416	3,216	400	449
Protected area [hectares]	407	1,310	11,107	2,760
Area of national recreational interest [hectares]	1,307	23,562	6,094	7,590
Key habitats (incl. company-owned) [hectares]	130	1,115	3,336	721

4.2.4. Environmental Consideration

Indicators: (i) Environmental consideration in connection with regeneration felling (measure of a sustainable forestry including forest residue recovery).

"Environmental Consideration" is a broad category that comprises many components and therefore generates many indicators that can be used to "measure" the sustainability of forestry and logging residue recovery (see Table 17 and Table 18). The practice of Environmental Consideration is explained in the Forestry Act (30 §); it serves to reduce the impact by forestry on forest ecosystems throughout the country. Therefore, the various indicators of this category relate to almost all specifications in Table 18. Environmental Consideration is a way to increase the compatibility of recovery with the relevant specifications and their EQOs.

Table 28. Percentage of logged area in which Environmental Consideration is observed in accordance with the Swedish Forestry Act in 2007/2008-2009/2010

Factor requiring Consideration	Proportion of logged area requiring Consideration [%]	Degree of Consideration taken [%]		
		Complete	Partial	Negligible
Sensitive habitats	61	47	25	29
Unusual trees and shrubs	89	54	31	16
Buffer zones	53	61	24	15
Red-listed unusual species	24	33	35	31
Non-productive forest land	23	85	12	3
Historical-cultural values	31	58	29	13

Land and water	98	66	26	8
Social values	15	71	16	14
Size of felling area and demarcation	46	77	16	7

Table 29. Impact on some impact categories during regeneration felling in 2008/2009-2010/2011

	N. Norrland	S. Norrland	Svealand	Götaland	Private individual land	Other owners	Entire country
Proportion (%) of regeneration fellings requiring Consideration							
Proportion of the number of […] divided into degree of impact (%)							
Sensitive habitats							
Proportion	30	76	55	41	44	58	48
None negative impact	63	65	65	63	58	72	64
Moderate negative impact	17	14	23	21	22	17	20
Strong negative impact	20	21	12	16	20	11	16
Buffer zones							
Proportion	59	50	41	29	36	51	40
None negative impact	68	79	63	60	65	69	67
Moderate negative impact	26	11	25	29	24	22	23
Strong negative impact	6	10	12	11	11	9	10
Historical-cultural values							
Proportion	7	19	40	31	28	28	28
None negative impact	60	74	52	56	57	55	56
Moderate negative impact	18	13	41	34	33	40	35
Strong negative impact	22	13	7	10	10	5	9
Stream crossings							
Proportion	13	28	20	17	17	24	19
None negative impact	74	58	50	68	56	72	61
Moderate negative impact	23	18	38	24	29	22	27
Strong negative impact	2	25	12	9	15	6	12

4.2.5. Felling and tree species

Indicators: (i) Potential supply of substrate from valuable broad-leaved trees based on the standing volume, (ii) annual gross fellings as a rough indicator of which tree species are likely to be felled.

Standing volume

According to de Jong et al. {, 2012 #8}, the recovery of forest residues should be limited in stands with broad-leaved tree species. This requires regional assessments based on species occurrence. Oak and beech are the two most valuable trees for red listed species in Sweden {SEPA, 2004 #38}. In Skåne in particular, oak and beech constitute a significant percentage (15.5 %) of the total standing volume on productive forest land (see Table 30 and Figure 11). These data provide information about potential substrates important for biodiversity that could be treated as forest residues and thus be removed. The supply of this type of substrate is crucial for the species richness and the biodiversity of the forest as a whole and therefore pertains to several specifications of *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life*. Data regarding felling of specific tree species are limited, but national data on the applications for permits for final fellings of valuable broad-leaved forests under § 27 of the Swedish Forestry Act are available. This can give a rough indication of the final felling of broad-leaved tree species.

Table 30. Standing volume on productive forest land by species in 2006-2010 (excl. protected productive forest land)

	Västerbotten	Dalarna	Stockholm	Skåne
Tree species				
million cubic metres standing volume (stem volume)				
Scots pine	131	122	19.4	10.4
Norway spruce	114	76.6	20.9	35.1
Other coniferous	4.1	0.9	0.2	0.1
Birch	48.4	21.9	6.0	8.1
Other broad-leaved	4.6	4.4	5.7	5.8
Oak	0.0	0.0	1.8	5.4
Beech	0.0	0.0	0.0	10.1
Other selected valuable broad-leaved	0.0	0.0	0.7	2.1
Total	**302**	**226**	**54.6**	**77.1**

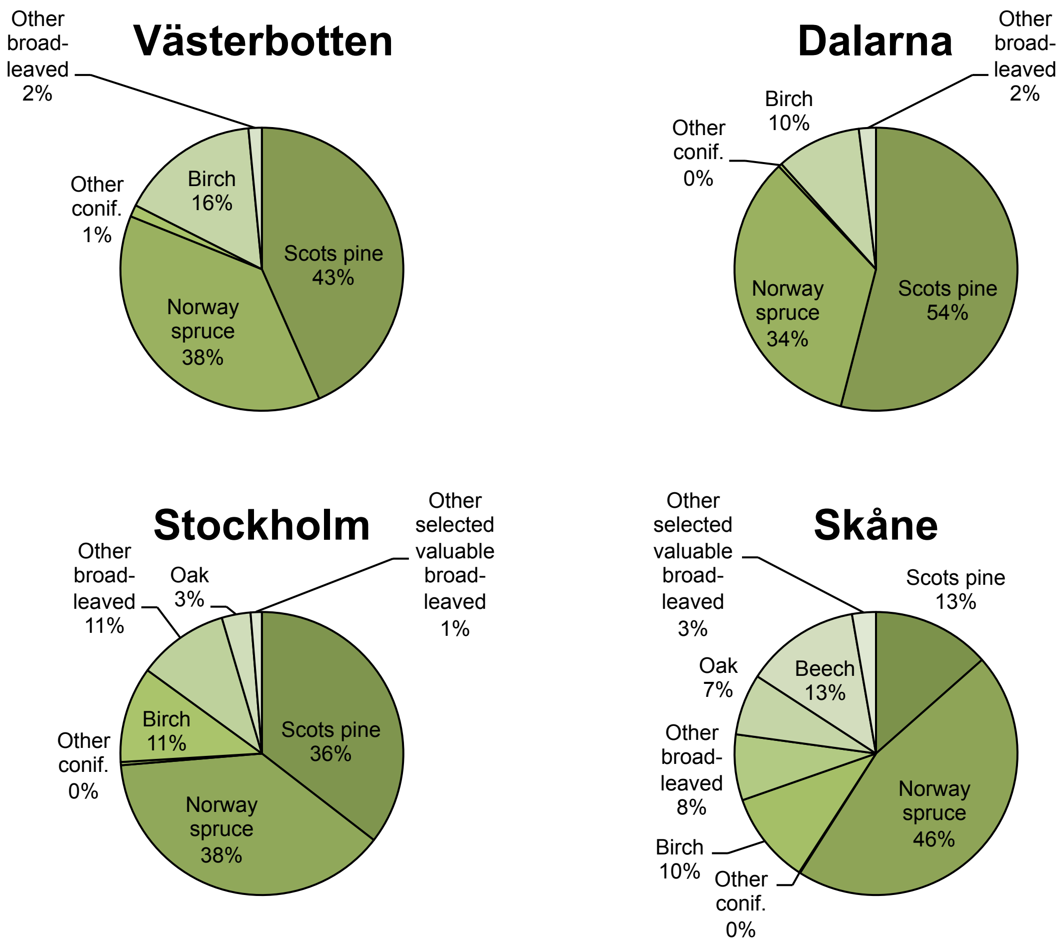

Figure 11. Proportion of tree species of the standing volume on productive forest land in 2006-2010 (excl. protected productive forest land). Values of other coniferous trees equivalent to 0 % are rounded figures.

From a biodiversity point-of-view, recovery of residues should mainly be from coniferous trees. The percentage of coniferous trees of the total standing volume in each county is therefore shown in Table 31.

Table 31. Proportion of coniferous trees of the total standing volume on productive forest land, in 2006-2010

County	Percentage of coniferous trees [%]
Västerbotten	82
Dalarna	88
Stockholm	74
Skåne	59

Annual gross fellings per county and ownership category is another relevant indicator, shown in Table 32.

Table 32. Annual gross fellings per county and ownership category in 2008-2010

	Västerbotten	Dalarna	Stockholm	Skåne
[1,000 m^3 standing volume/year]				
State and other public owners	1,138	748	106	280

Private companies and other private owners	2,998	3,942	405	728
Individual owners	1,602	1,581	673	1,791
Total	**5,738**	**6,270**	**1,183**	**2,798**

4.2.6. Recovery of Logging Residues and Ash Recycling

Indicators: Intensity of forest residue recovery, Area of ash recycling per unit area of logging residue recovery, Ash dosage (tonne DW per hectare – compared to recommendations by the Swedish Forest Agency).

Recovery of Logging Residues

Surveys of large- and small-scale forestry present data on thinning and final felling logging residue recovery in cubic metres of loose volume (wood chips) per year {SFA, 2012 #33}. The proportion of forest residue recovery in conjunction with thinning is an indicator of the intensity of forest residue recovery in a county. Recovery in connection with thinning can result in growth reductions, the removal of nitrogen probably being the main reason in northern Sweden {de Jong, 2012 #8}. Therefore, de Jong et al. (2012) recommend that logging residue recovery without nitrogen fertilization as a compensatory measure should be limited in connection with thinning. The damage on roots and trees, and soil compaction due to driving of forestry machines, may also be more serious in thinning than in final felling. The recovery of forest residues in conjunction with thinning, relative to total recovery, is particularly high in Stockholm, see Table 33. This fraction is fairly high in Skåne, too, as is total recovery, which is almost as much as in Västerbotten, where the volume of annual gross felling is more than twice that of Skåne. With their intensive logging residue recovery and high biofuel demand, Stockholm and Skåne both risk deficits of local forest fuels relative to biomass energy demand, see Figure 12.

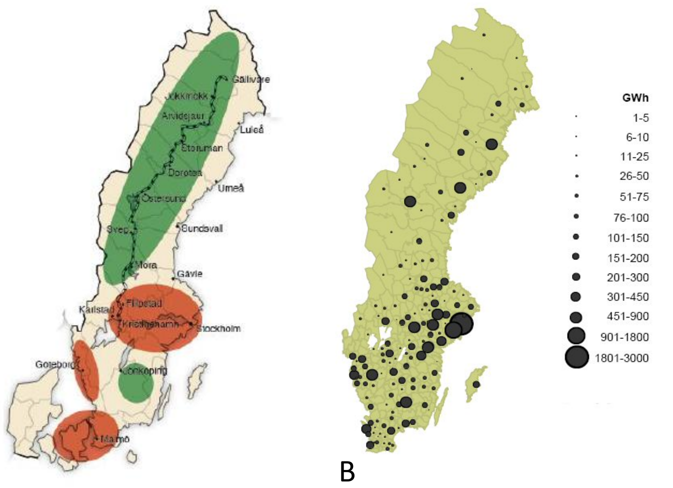

Figure 12. (A) Red indicates regions with deficits of, or risks of deficits of, local forest fuels relative to the demand, while green indicates areas of surplus where the current infrastructure allows cost-efficient transports of forest fuels to red areas (de Jong et al. (2012), p. 171). (**B**) Inflows of biofuels to district heating plants given in GWh (Source: Skogsforsk.se. Picture downloaded on 2013-02-15).

Table 33. Recovery of logging residues (LR – "tops and branches"), 3-year average, in 2008-2010 {SFA, 2012 #33}

	Västerbotten	Dalarna	Stockholm	Skåne
[1,000 m^3 loose volume/year]				

LR - final felling	378	186	61	321
LR - thinning	15	18	20	59
Total	**393**	**203**	**81**	**380**
Thinning as share of total recovery	4 %	9 %	24 %	15 %

The Swedish Forestry Agency report additional data in *Skogs-och miljöpolitiska mål – brister, orsaker och förslag på åtgärder* {SFA, 2011 #13}, with recovery shown in hectares (see Table 34).

Table 34. Recovery of logging residues (LR – "tops and branches"), 3-year average in 2007-2009 {SFA, 2011 #13}

	Västerbotten	Dalarna	Stockholm	Skåne
Area [hectares/year]				
LR - final felling	4,175	3,141	793	3,716
LR - thinning	135	635	243	3,619
Total	**4,310**	**3,776**	**1,036**	**7,335**

In the forest impact assessment SKA-VB 08 {SFA, 2008 #27} the potential recovery of forest residues from different forestry operations was calculated for the period 2010-2019. The calculations are based on a base-line "Reference" scenario, corresponding to the current Swedish forestry situation. The harvest includes final fellings and thinnings and also small/young trees in early thinnings. The potential was calculated based on three different restriction levels affecting the final amounts (see Table 35).

Table 35. Forest residue recovery scenarios (2010-2019) in SKA-VB 08 based on three restriction levels {SFA, 2008 #27}

Level	Restrictions	Additional information
Level 1	No restrictions at all. Includes all forest residues generated by the different felling actions.	
Level 2	Follows ecological restrictions based on the Swedish Forest Agency's recommendations on the recovery of forest residues and ash recycling regarding the choice of stands and actions within stands	.
	Primary restrictions for recovery in a stand.	Areas within reserves and special consideration areas.
		Areas located within 25 metres of land use categories other than productive forest.
		Areas on peat bogs, wet or damp soils with low bearing capacity.
	20 % of the logging residues and stumps are left in the stand. All stumps of broad-leaved trees are left as they are.	
Level 3	Ecological and technical/economical restrictions are taken into account.	
	Additional restrictions beyond those in Level 2.	Another 20 % of the logging residues and stumps are left in the stand where recovery is performed. This means that a total of 40 % of the logging residues and stumps available are left in the stand.
		Areas with surface structures of class 4 and 5 and elevation of class 4 and 5

		according to a classification of terrain types of Swedish forests. are excluded.
		All stands smaller than 1 hectare have been deducted due to economic considerations.

Based on the heat values *1 tonne DW = 4.9 MWh* {SFA, 2008 #27} and *1 m³ (loose volume) = 0.83 MWh* {Skogforsk, 2013 #39}, the data on volumes can be converted to dry weight. The Statistical Yearbook of Forestry {SFA, 2012 #33} data are average values for the period 2008-2010. The calculated amounts in SKA-VB 08 show a significant potential of increased logging residue recovery in all four counties, even at the highest restriction level (see Table 36 and Figure 13).

These results indicate lower logging residue harvest intensity than discussed above (see Figure 12 and Table 33). For example, the yearly average recovery of logging residues (including both thinning and final felling) in Stockholm County for the period 2008-2010 is equivalent to about 25 % of the estimated potential in final felling at the highest restriction level. Since Stockholm is a densely populated county with a high demand for forest fuels (see Figure 12), and where a substantial part of the recovery is carried out in connection with thinning (see Table 33), the share was expected to be higher. Data for the period 2007-2009 are also shown in Table 36, and in

Table 37, expressed per area. The percentage of actual logging residue recovery, compared with the estimated potential, is higher by area than by weight. For example, the actual harvest in Skåne is calculated to be equivalent to approximately 60% of the estimated potential based on weight, but approximately 95% based on area.

Table 36. The annual potential of logging residue recovery and the actual (real) recovery given in weight. The data on the restriction levels show only the recovery of logging residues in connection with final felling. The actual recovery is shown for both final felling and final felling + thinning {SFA, 2008 #27}{SFA, 2011 #13}{SFA, 2012 #33}

	Potential recovery in connection with final felling based on three restriction levels for the period 2010-2019			Real, 3-year average 2008-2010		Percentage of real recovery of Level 3	Real, 3-year average 2007-2009		Percentage of Level 3
	Level 1 - Gross	Level 2 - Ecological	Level 3 – Ecological and economical/technical	Final felling	Final felling + thinning	Final felling + thinning	Final felling	Final felling + thinning	Final felling + thinning
	[1,000 tonnes DW/year]								
Västerbotten	748	498	335	64.0	66.6	19.9 %	49.5	50.0	14.9 %
Dalarna	525	391	219	31.4	34.4	15.7 %	36.2	39.5	18.0 %
Stockholm	121	77	55	10.3	13.6	24.8 %	10.0	13.2	24.0 %
Skåne	257	181	117	54.3	64.3	55.0 %	52.5	69.8	59.6 %
Sweden	7,420	5,105	3,168	911	1,006	31.7 %	844	944	29.8 %

Table 37. The annual potential of logging residue recovery and the actual (real) recovery measured by area. The data show the recovery of logging residues in connection with final felling {SFA, 2008 #27}{SFA, 2011 #13}

	Potential recovery in connection with final felling based on three restriction levels for the period 2010-2019			Real, 3-year average 2007-2009	Percentage of level 3
	Level 1 - Gross	Level 2 - Ecological	Level 3 – Ecological and economical/technical	Final felling	Final felling
	[hectares/year]				
Västerbotten	31,254	27,053	23,666	4,175	17.6 %
Dalarna	18,382	17,151	12,748	3,141	24.6 %
Stockholm	2,931	2,234	2,103	793	37.7 %
Skåne	5,110	4,485	3,905	3,716	95.2 %
Sweden	231,994	204,017	169,204	57,178	33.8 %

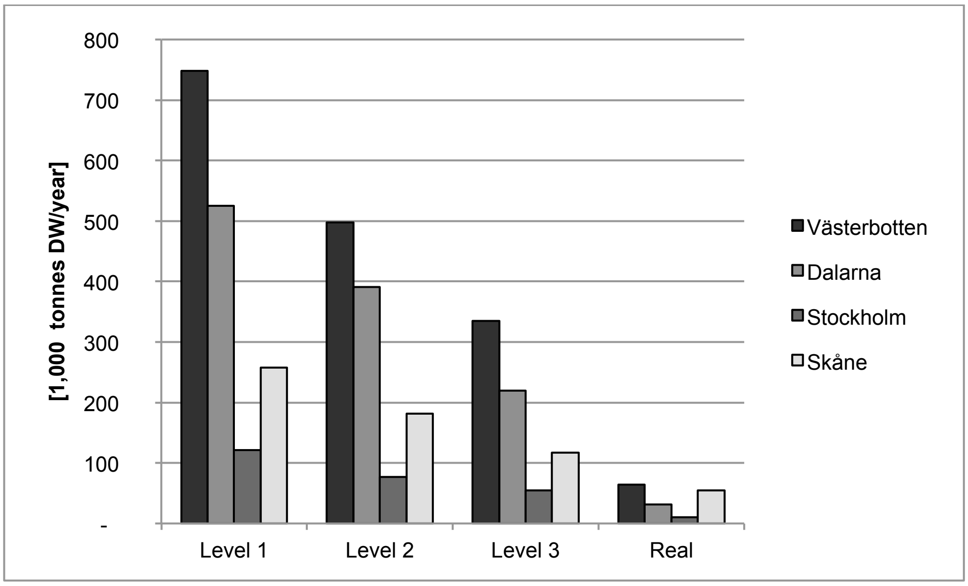

Figure 13. The potential of logging residue recovery per year (2010-2019) and the actual (real) recovery per year (2008-2010) {{SFA, 2008 #27}{SFA, 2012 #33}

Ash Recycling

The data on ash recycling are based on an annual questionnaire sent out to the companies most active in ash recycling {SFA, 2011 #13}. About five companies make up more than 95 % of the total ash recycling practiced throughout the country. Skåne is exposed to the highest levels of acid deposition and had the largest area on which ash was spread in 2010. No ash recycling was performed in Stockholm or Västerbotten (see Table 15).

Table 38. Area of ash recycling in 2010. According to the 2012 follow-up evaluation of Sustainable Forests in Stockholm County, no ash recycling was performed in Stockholm County {SFA, 2011 #13}.

	Area	tonne DW	Average ash dosage
	[hectares]		[tonne DW/hectare over a rotation period]
Västerbotten	0	0	-
Dalarna	125	250	2.0

Stockholm	0	0	-
Skåne	1,004	4,749	4.7

The high productivity per site in Skåne (equivalent to, on average, 11.3 m^3 standing volume over bark per ha and year) {SFA, 2013 #40} motivates the higher recommended ash dosage of 3 tonnes DW ash per hectare and ten-year period, after logging residue recovery. However, the actual dosage in Skåne is, on average, 4.7 tonnes DW per hectare over a rotation period (see Table 38). The recommended maximum ash dosage is 6 tonne DW per hectare during a rotation period {SFA, 2008 #19}.

The area of ash recycling, shown in Table 38, compared with the area of logging residue recovery, shown in Table 34, shows that only a minor fraction of the harvested area is fertilized by wood ash (less than 10%). The sector target regarding ash recycling is far from achieved (see below).

Sector Target on Ash Recycling

In 2005, the Swedish Forest Agency stipulated that, by 2010, the area of ash recycling should be equivalent to the area of logging residue recovery in final felling. This target has not been met. According to the Swedish Forest Agency, many ash producers find less expensive handling alternatives, such as using the wood ash as fill in road construction, etc. Some ash is contaminated due to co-combustion with waste and fossil fuels and is therefore not used. Recyclable ash is also generated from by-products in the forest industry (bark, sawdust, etc.), which are not covered by requirements for recycling wood ash from logging residues (leading to increased acidification). Furthermore, ash producers and forest owners are insufficiently informed about their responsibility to recirculate wood ash, and methods for this, from the Swedish Forest Agency and other authorities. The debate among researchers about, on the one hand, the acidifying impact of logging residue recovery and the need for ash recycling in the long-term, and on the other, the associated risk of short-term growth reduction, might have led to some reluctance. The possibility of spreading ash and nitrogen fertilizers in combination to avoid short-term growth reduction is poorly studied {SFA, 2011 #13}.

Large-Scale Fertilization on Mineral Soils

Indicators: Fertilized area.

In 2011, nitrogen fertilization was carried out in Dalarna and Västerbotten on 5,600 and 9,900 forest hectares, respectively. No fertilization was undertaken in Stockholm and Skåne. For Skåne this is in line with the Swedish Forest Agency's recommendations. Nitrogen fertilization (in combination with ash recycling) to compensate for the removal of nitrogen in conjunction with logging residue recovery is relevant in the northern parts of Sweden where nitrogen deposition is low and the risk of increased eutrophication from nitrogen fertilization is low.

4.3. Evaluations of EQOs by County

The following section is based on the 2012 regional follow-up evaluation, found on the Environmental Objectives Webpage {Miljömålsportalen, 2013 #44}.

Table 39. The status and development of the EQOs in each of the four counties

	Natural Acidification Only	Zero Eutrophication	Sustainable Forests	A Rich Diversity of Plant and Animal Life
Västerbotten	No →	Close →	No ↘	No ↘
Dalarna	Close ↗	No →	No ↘	No ↘
Stockholm	Yes ↗	No ↘	No →	No ↘

Skåne	No →	No ↘	No ↘	No ↘

The conditions and developments of Sustainable Forests and A Rich Diversity of Plant and Animal Life are similar in all four counties. For Natural Acidification Only and Zero Eutrophication they instead differ.

4.3.1. Reduced Climate Impact

The County Administrative Boards did not evaluate *Reduced Climate Impact,*, as this is a global objective and county evaluations do not differ from national evaluations{SEPA, 2013 #41}, given the official interpretation and specification of this EQO.

4.3.2. Natural Acidification Only

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
No →	*Close ↗*	*Yes ↗*	*No →*

Even though sulphur and nitrogen depositions have been reduced significantly since the mid-20th century, the long history of acidification still affects the present environmental condition and the development of the objective. As for many other environmental problems, the time needed for the environment to recover is long. The current nitrogen deposition in Skåne exceeds the critical load in the forest areas, leading to nitrogen leaching from forest land. In the northern part of Skåne, lakes do not seem to recover even though liming is practiced.

The other three counties are all exposed to lower levels of acid deposition, both historically and currently. Several of the lakes and streams in these counties have recovered from historical acidification. In Stockholm, liming was terminated some years ago when measurements showed that no more than two percent (by area) of the county's lakes were acidified. Also the quality of the forest land is sufficient to meet the EQO in Stockholm, and the trend is positive. However, the basis for this is that acid deposition continues to be reduced.

The trend in Dalarna is also positive but slower, and acid deposition must decrease further in order to achieve the EQO. In Västerbotten, acidification caused by soils rich in sulphur is a problem specific to the region. This is the case mainly along the coast of the Gulf of Bothnia due to the fact that these soils were historically below sea level, and on these soils liming has limited effect. Despite a significant recovery from acidification, about six percent (by area) of the lakes in the county are still acidified.

In Stockholm and Dalarna, the contribution of forestry to acidification has been calculated at 50-70 percent. Intensification of logging residue recovery is estimated to increase this percentage if compensatory measures, such as ash recirculation, are not developed. In Skåne, the two prioritized measures to reduce acidification are to minimize the negative effects of logging residue recovery and to reduce the nitrogen emissions from all types of traffic activity, as well as the sulphur emissions from coastal shipping.

4.3.3. Zero Eutrophication

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
Close →	*No →*	*No ↘*	*No ↘*

Stockholm County has a fast-growing population, which increases the burden on the environment. The wastewater treatment plants have continuously improved their performance of phosphorus and nitrogen removal, but since the population is increasing these reductions are not adequate. Also, increased traffic causes increased emissions of eutrophying emissions. Stockholm County has the greatest problems with eutrophication of coasts, lakes, and streams.

Skåne has the highest proportion of farm land in Sweden, and the agricultural sector is the largest contributor to the nitrogen and phosphorus load in water bodies in the county. Measures and efforts undertaken to adapt fertilization, cultivation of catch crops, construction of wetlands, and other water management practices have been implemented to reduce eutrophication, but have proved insufficient to meet the environmental targets. Additional policy instruments and measures are needed.

Dalarna and Västerbotten are much less populated, and are rich in forest land. However, the eutrophication target is not met in Dalarna. Only three percent of the county area is used for agriculture, but since the soil is sensitive to erosion, agriculture makes a significant contribution to eutrophication. The trend is neutral in Dalarna.

With Västerbotten consisting mainly of forest and mountainous land, the eutrophication problems are limited. Three out of four specifications in the eutrophication target are achieved, and the trend is positive. Nitrogen deposition on forest land is below the critical load. However, deposition of nitrogen has started to increase over recent years, so additional measures are needed to meet the environmental target.

4.3.4. Sustainable Forests

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
No ↘	*No ↘*	*No →*	*No ↘*

All counties show negative status and developments for *Sustainable Forests*, except for Stockholm, where the development is neutral. Forestry operates at similar intensities throughout the country, so conditions in the counties reflect national development. The problems and different aspects that mainly determine *Sustainable Forests* development are also common to all four counties. The two most important aspects are insufficient protection of forest areas with high nature values and the generally inadequate Environmental Consideration in forestry operations. The indicators, old forests, old forests rich in broad-leaved trees, and dead hardwood are developing positively in all counties, but the actual volumes are still too low.

Many forest types and forest-living species show unfavourable preservation statuses, and the number of species on the red list is increasing. More than 850 species are connected to forests in Skåne, and over 80 of these have their main existence in this county. Due to the high proportion of forest land in Dalarna and Västerbotten, a significant fraction of the threatened species there are associated with forests. Most of these are developing negatively, while information on other species is too poor to allow their trends to be assessed.

Stockholm has the largest area of key biotopes in relation to the area of productive forest land. The number of key biotopes is estimated to be even larger, but they have not been identified due to limited resources at the Swedish Forest Agency. Current resources for protection of high-value forest areas are also insufficient in all counties, and these areas are subjected to fragmentation on an on-going basis, and forests of long biological continuity are decreasing. In conventional forestry, the impact on sensitive habitats, soil and water, and historical-cultural heritages needs to be reduced. There seems to be a trend of increased damage caused by driving of forestry machines, as a consequence of the increased recovery of logging residues. The high proportion of valuable broad-leaved trees is a prominent feature in Skåne. So as not to aggravate the situation of red-listed species even further, there is a need for incentives, policy instruments, and follow-up procedures for larger-scale recovery of broad-leaved logging residues and stumps.

4.3.5. A Rich Diversity of Plant and Animal Life

Västerbotten	*Dalarna*	*Stockholm*	*Skåne*
No ↘	*No ↘*	*No ↘*	*No ↘*

The overall biodiversity situation is the same for all counties: Habitats are being lost and fragmented by unsustainable forestry. The EQO is developing negatively and clearly dependent on the development of other objectives.

Skåne is the county with most red-listed and extinct species. In Dalarna, the number of species on the red list increased from 690 to 810 from 2005 to 2010. In 2010, the red list had 280 nationally threatened species in Västerbotten. The status is not possible to determine under current conditions for several species. The work of protecting valuable biotopes and restoring and conserving already protected areas is not moving forward fast enough to create the basis for meeting the objective. Increased knowledge, improved Environmental Consideration, appropriate planning, and restoration of natural environments are all important factors if the species are to survive in the ecosystems.

Landscape level strategies are needed, to reduce the current trend of fragmentation of valuable forests. The pressure on ecosystems is especially high in Stockholm due to sprawl. Therefore, it is important to preserve and "build in" biodiversity as part of the community development.

4.4. Synthesis

The case study shows regional differences among the four counties. Basic information, such as population, county land area, and forest land area, indicates the demand for forest fuels and thereby the potential intensity in forest residue recovery. The proportion of forest land of the total land area indicates competition from other sectors and the relative importance of forestry for the development of the EQOs. The proportion of productive forest land that is formally protected gives an indication of how preserving biodiversity is developing. Stockholm has the highest proportion of formally protected productive forest land, with 6.1 percent, while Skåne has the lowest at 3.2 percent. The area and number of key habitats not protected, show the potential risk of biodiversity losses due to final felling and forest residue recovery. The current forest statistics only present data on key biotopes linked to private land, not company- or state-owned forest land. Therefore, no complete figures are presented in the case study for all ownership categories in the forestry sector. The data from forest company webpages give information about the area of productive forest land that the companies voluntarily set aside. The key biotopes areas that are not protected and that could be damaged by forestry operations including forest residue recovery are more important, however.

Eutrophication is a manifest problem in Stockholm and Skåne. In Stockholm this is primarily due to the dense population, while the high proportion of agricultural land is the main reason in Skåne. The high demand for forest fuels is reflected by the intensity of forest residue recovery in Stockholm, where 24 percent of the annual amount of logging residues is removed in conjunction with thinning. For Skåne, it is 15 percent. Nevertheless, the annual removal of logging residues is significantly lower than the potential calculated in SKA-VB 08, even with at the most restricted recovery level. Logging residue recovery in thinnings in Västerbotten and Dalarna is less frequent (representing 4 and 9%, respectively). In these two counties there is an excess of forest fuels, in accordance with the low population and large area of forest land.

Wood ash recycling is limited in forestry practice today. The most extensive use of ash is in Skåne, but the practice is still far from the sector target, namely an area equivalent to the total area of logging residue recovery after final felling. The average ash dosage in Skåne is higher than recommended, which indicates that an adjustment is needed in a future expansion of ash recycling.

Skåne is also the county with the highest need for ash recycling due to the current status of acidification. Its geographical location is unfavourable since the atmospheric nitrogen deposition exceeds the critical load for forests.

The negative status and development of *Sustainable Forests* in the four counties reflects the overall situation in Sweden. This is also the case for *A Rich Diversity of Plant and Animal Life* for which all counties have a "No"-status and show a negative trend. The distance-to-target for these two objectives is vast, and forestry practices, and forest residue recovery, are critical factors that need improved adaption.

5.Discussion

The Environmental Evaluation Model

This report presents an approach to the balancing of environmental effects of forest residue recovery. The categorization step in the model attempts to highlight the environmental effects that deserve special attention. The evaluation model clearly shows the importance of regional and local assessments due to the significant regional/local differences for several environmental effects and impacts. However, the model needs further development before being put to practical use, together with the development of more locally-focused databases and statistics. This report seeks to contribute to a new way of thinking that can inspire further work on forest residue recovery and balancing environmental effects.

Balancing environmental effects is a complex task that often includes subjective judgments based on individual interests and experiences. Our intention has been to minimize the opportunities for subjective judgments, by using existing and generally accepted environmental tools and the most up-to-date scientific knowledge about forest residue recovery and environmental effects compiled in scientific syntheses. The model is based on key aspects and tools covered by two approaches running in parallel. The Environmental Impact Assessment Approach (EIAA) (with Life Cycle Assessment for greenhouse gas balances) includes: (i) the issue of irreversibility, which calls for the precautionary principle, and (ii) the mitigation hierarchy, which categorizes the environmental effects based on the options for handling their occurrences and potential impacts. The environmental impacts considered are climate change, acidification, eutrophication, and biodiversity.

The parallel EQOs Approach (EQOA) links the environmental effects of forest residue recovery to the relevant EQOs. This approach aims to estimate the degree of compatibility between forest residue recovery and critical environmental issues in Sweden. Jointly, the two approaches should give the degree of *ecological significance* to be used when balancing the environmental effects.

The benefits of replacing fossil fuels with forest-based fuels should be put in relation to the environmental effects assessed in this report, facilitating discussion of when a positive effect of using forest fuel can be considered greater than a negative effect, and vice versa. This type of comparison is affected by local/regional differences and the type of aspects that are taken into consideration. For instance, when is a loss in biodiversity the acceptable price to pay for a climate benefit? What biodiversity loss corresponds to what degree of climate benefit? Since climate change also affects biodiversity, there is an indirect relationship making the assessment even more complex.

Irreversibility

The environmental evaluation model presented in this report stresses the importance of thinking in terms of precaution and of carefully considering aspects that may be connected to irreversibility. Examples include harvests in areas with unique wood-living species, for which extinction is imminent, as well as the importance of being restrictive regarding the removal of broad-leaved harvest residues, including valuable broad-leaved residues. Irreversibility shows the complexity of, primarily, biodiversity, a category that needs more attention and knowledge based on specific local conditions, etc.

EIA Mitigating Hierarchy

The categorization according to the EIA mitigation hierarchy is one approach to structuring and balancing environmental effects (see Table 15). However, this approach can be made increasingly wide-ranging by increasing the number of aspects included in the categorization of the environmental effects (cf. the 2012 in-depth evaluation of the EQOs). Where to set the limits on the aspects to include and use as a guide in a certain categorization is a critical question; the answer will also depend on the data available and the specific conditions. Thus, good access to relevant information and data is a fundamental requirement.

Distance-to-Target

The distance-to-target approach is a measure of the compatibility of the environmental effects and the EQOs. The approach focuses on questions such as which environmental effects affect the EQOs the most and how to consider this based on the current status and development. This, in turn, will raise questions such as what "room" there is for negative impacts, based on the overall status in the counties, etc. This report identifies relevant indicators and specifications for the EQOs connected to the environmental effects of forest residue recovery, to increase the practical applicability of the objectives in an environmental evaluation. The relevant indicators and specifications provide an estimate of how well the activity can be linked to and covered by the objectives.

The use of a distance-to-target approach has previously faced criticism for assuming that all targets are equally important and may therefore be controversial, as may the gap analyses in the 2012 in-depth evaluation, where the authors discuss potential drawbacks regarding non-proportional relations. However, the EQAA in this report is not ultimately dependent on the distance-to-target method as such, but builds on the components of the five common reasons for failure and the development trends, which are used to estimate the gaps to achieving the objectives (see Table 11 and Table 12). This makes the approach fairly flexible, which is in line with an EIA methodology.

Applicability of Using the EQOs in Environmental Evaluations

The supply of relevant indicators for the EQOs decides how well the environmental effects of forest residue recovery can be covered by the environmental monitoring in the evaluation process. Since the specifications are deliberately formulated to avoid action-oriented contents, the indicators point out the potential measures. In this way, the indicators serve to clarify the specifications, which in turn serve to clarify the EQOs. The EQOs' utility in environmental evaluations largely depends on the "relevance" of the selected indicators and specifications. If the relevance is too poor and/or the numbers of relevant indicators and specifications are too limited, it is difficult to relate an activity and its environmental effects to an EQO. The specifications are generally broad, while the indicators' specificity restricts their use for certain environmental effects. Among the relevant indicators in Table 9, the degree of applicability varies. Since the five EQOs differ in their structures, the utility of the indicators for evaluation purposes will differ, just as the applicability of the objectives in general will differ. Three of them aim at specific environmental problems (climate change, acidification, and eutrophication), whereas the objective *Sustainable Forests* describes a certain type of ecosystem. The objective *A Rich Diversity of Plant and Animal Life* is a mix of an environmental problem and a description of ecosystems. The indicators that belong to the objectives that describe environmental problems are normally expressed in quantitative terms (e.g. greenhouse gas balances, pH, etc.), whereas objectives that describe a type of ecosystem are much broader and include indicators expressed in qualitative terms. Such broad indicators are more difficult to apply to specific forestry operations, such as forest residue recovery. Belyazid et al. (2010) presented their own set of indicators to better "tailor" the evaluation of different scenarios of forest residue recovery (including ash recycling and nitrogen compensation fertilization), its environmental effects, and connections to relevant EQOs. A specific set of indicators for a certain activity, instead of the more broadly defined "official" indicators, makes it more practical to integrate the EQOs in an environmental evaluation. Even if the study by Belyazid et al. (2010) did not use the official components of the objectives, their structures were adopted.

The overall relation – significance, compatibility -- between a specific environmental impact of forest residue recovery and an EQO cannot necessarily be estimated without practical and functional measures. More focused information about the connection between environmental effects and related EQOs is crucial to describing this relation in a clear and consistent way. The sector targets for forestry convey this type of information, but more directed information for certain activities, such as forest residue recovery, is needed. Figure 14 interprets the applicability of using the EQOs for two different purposes, namely, as public information and for use in environmental evaluation models. The applicability is based on which parts are integrated. The accessibility is defined as the potential for reaching the target group, namely the general public in Sweden, when distributed as public information. The formulation, specifications, and indicators, make up three levels of "scientific detail". It is assumed that an environmental assessment of a certain activity, in which the EQOs are integrated, requires the highest level of scientific detail. The formulation of an EQO is the most general information and describes its overall meaning. This level is normally sufficient for public information.

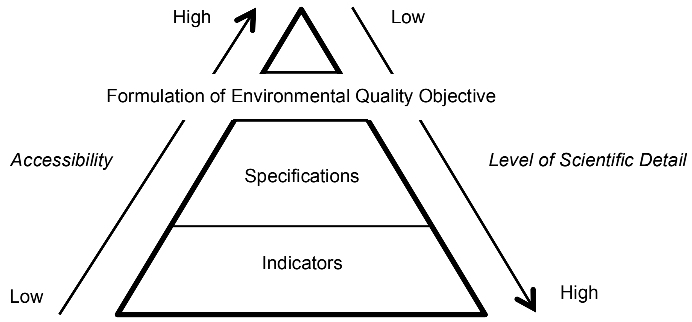

Figure 14. An interpretation of the general applicability of the EQOs as public information (requiring high accessibility) and for use in environmental evaluation models (requiring high level of detail).

Question of Allocation

When evaluating the environmental effects of forest residue recovery and their corresponding environmental impacts, it is important to differentiate impacts that should be attributed to stem-wood recovery. This can be difficult for some impact categories. Inventories that evaluate the Environmental Consideration taken during the regeneration felling include the whole operation, i.e. stem-wood and forest residue are aggregated. Therefore, these inventories would need greater detail. From a practical point-of-view, such a change is unlikely. Since forest residues are by-products of stem-wood harvest, conventional forestry determines which forest stands are to be felled. Thus, the indicators of "old forest" and "old forest rich in broad-leaved trees" are directly applicable to stem-wood harvest but only indirectly to forest residue recovery. The responsibility of the recovery of forest residues begins where the activity of stem-wood harvest stops. The most salient negative environmental effects that recovery of forest residues adds to the existing stem-wood harvest are: the acidifying impact, the reduction of dead wood due to stump removal, the increased risk of damage by increased use of forestry machines, and the removal of logging residues and , which decreases the bearing capacity of soils.

Reflections from the Case Study

The case study in Chapter 4 aims to implement the environmental evaluation model and find relevant information to serve as indicators and supply the model with the necessary data. Here, specific indicators were developed and connected to relevant EQOs (analogously to Belyazid et al., 2010). Since the forestry statistics present easily accessible information, data collection from this source is straightforward. However, information in the regional follow-up evaluations of the EQOs is scarce for forestry, since the objectives comprise several sectors and various effects that also depend on the current conditions in each county. The forestry statistics can, to some extent, be used to add information to this gap and improve evaluation. However, there are also some important indicators of forest residue recovery that cannot be established based on forestry statistics due to a lack of data, e.g. on the removal of valuable broad-leaved forest residues. Furthermore, data that demonstrate a connection between the recovery of logging residues and ash recycling would have been useful, since ash is considered an important measure to increase the compatibility between the forestry operation and relevant EQOs.

EQOs over which Sweden has National Control – Prioritizing Aspect?

The 2012 in-depth evaluation includes information on the geographic level relevant to each EQO and an estimate of when the EQO will be achieved. These parameters are indicators of the potential to handle the actual environmental effects on the national and regional/local scale. Except for the objective *Reduced Climate Impact*, with its exclusive international relevance, the other effects of forest residue recovery relate to EQOs with geographical relevance ranging from European to the regional/local level. The objective *Natural Acidification Only* and *Zero Eutrophication* depend on reductions of nitrogen oxides and ammonia emissions abroad. Therefore, the national control of these objectives is somewhat limited. This may result in less ambitious mitigation efforts at the national level regarding objectives significantly affected by air emissions from other countries', compared with when the objectives are mainly controlled within the country. One strategy could be to focus on the environmental effects that both occur and have their impact in Sweden, for example the acidifying effects of logging residue recovery if ash recirculation is not applied. By focusing on the national relevance and the regional/local/national scale of the measures, ambitious mitigation efforts could be more clearly motivated. Biodiversity is an impact category for which national relevance dominates and regional/local conditions are crucial. The connections between cause and effect are clearer for EQOs with regional/local relevance and a narrower time span. For both *Sustainable Forests* and *A Rich Diversity of Plant and Animal Life*, the main geographical relevance is the regional/local level but the time span ranges from short-term to long-term. Potential measures towards achieving the two objectives can be expected to be noticeable where practiced, which may lead to increased incentives and mitigation efforts.

6. Conclusions

The Stepwise Handling Procedure, SHP, presented in this study is the first version of an environmental evaluation model for balancing the environmental effects of forest residue recovery. Additional work is required to improve the model and increase its applicability. The SHP is made up of two cornerstones, (i) an Environmental Impact Assessment Approach (EIAA) and (ii) an Environmental Quality Objectives Approach (EQOA), integrated in an innovative way. Life Cycle Assessment is also used as part of the EIAA, to calculate greenhouse gas balances.

The EIA mitigation hierarchy categorizes the environmental effects of forest residue recovery. This approach gives a good overview and compiles information on the environmental effects and different measures to counteract their impact. This categorization can be improved further to increase reliability.

Since the compatibility of the environmental effects and the EQOs depends on local and regional conditions (and global, in the case of climate change), which differ throughout Sweden, dedicated distance-to-target analyses similar to national analyses are required on the regional/local level. Distance-to-target analysis developments are expected in the forthcoming in-depth evaluation of the EQOs in 2016. The distance-to-target approach in the model presented here can then be adapted accordingly.

The feasibility of integrating the relevant EQOs in this environmental evaluation model will depend on the environmental effects. The specific indicators for each objective are decisive regarding how well the environmental effects can be monitored and related to the objectives. The broader the EQO, the more difficult it is to find indicators that specifically target the relevant environmental effects. Precise indicators are critical components in the integration of the two approaches, EIAA and EQOA.

Developing additional precise indicators will improve the model. Such indicators should use science-based statistics and information found in easily accessible sources. Biodiversity is a particularly important impact category due to its involving irreversibility. Normally, biodiversity requires site-specific indicators at the stand level, as well as the landscape level, and is often difficult to quantify. Establishing critical limits could be one way to quantify acceptable impact levels, in accordance with the precautionary principle. The environmental evaluation model must provide safety margins for the forestry operations involved in recovering forest residues, thereby securing an overall positive development of the environmental condition in Swedish forest ecosystems.

To make the model operational, and make possible the reliable and adequate balancing of the environmental effects of forest residue recovery, judgements about the type and amount of information required are made on an on-going basis. Therefore, relevant information and high-quality data have to be easily accessible in the future. Also, the required level of detail (e.g. geographic) is expected to differ depending on the situation and the environmental effects considered. The model should therefore be further developed to include more precise prioritisations regarding the information and input data needed and suggestions for how this information can be obtained, to make the model as efficient and useful as possible.

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