Including biodiversity aspects in life cycle assessments

– A case study of forest-based biofuel

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Inkludering av biodiversitetsaspekter i livscykelanalyser
En fallstudie av skogsbaserat biodrivmedel

Sammandrag

Analyser av miljöpåverkan kopplat till biodrivmedel har blivit mer och mer viktigt med tanke på de Europeiska Unionens energi- och klimatmål för 2020. Dessa mål innebär bland annat 20 procents minskade växthusgaser samt 20 procent energieffektivisering. En av de viktigaste lösningarna för att nå klimatmålet anses vara övergången till förnyelsebara drivmedel. För att kunna besluta om vilka biodrivmedel som ska satsas på är livscykelanalys (LCA) ett bra verktyg att analysera biodrivmedlens miljöpåverkan under hela dess livscykel. Biodiversitet och ekosystemtjänster är två begrepp som har blivit allt mer intressanta för att inkluderas i miljöpåverkansanalyser så som LCA. Biodiversitet innefattar mångfald av gener inom arter, mångfald av arter inom ekosystem samt mångfald av ekosystem inom ett område. Detta ligger till grund för alla ekologiska processer och är därför en förutsättning för att alla organismer skall kunna utnyttja ekosystemtjänster. Att inkludera detta i LCA är väldigt komplicerat och har fram tills nyligen innefattat väldigt få metodiker som möjliggör detta.

De största biodiversitetsförlusterna har visat sig bero på markanvändningsförändringar och på grund av detta har fokus för att inkludera biodiversitetsaspekter i LCA varit på markanvändning. Denna uppsats syfte är att undersöka om och hur biodiversitetsaspekter kan inkluderas i LCA, eller om det behövs kompletterande metoder för att analysera biodiversitet? För besvara dessa frågor har en fallstudie utförts där två metoder för att beräkna karakteriseringsfaktorer för biodiversitet kopplat till produktion av skogsbaserad DME testats.

Slutsatser från litteratur- och fallstudien är att de flesta biodiversitetsindikatorer är baserade på species richness (artrikedom) för en typ av mark jämfört med en referens. Detta är ett ganska förenklat mätvärde av hela biodiversitets-begreppet och kanske därför inte säger så mycket om hela ekosystemets påverkan av att några arter inte finns i en taxonomi-grupp och att detta skall användas som en approximering för hela statusen på biodiversiteten i den aktuella omgivningen. Utöver detta är det väldigt komplicerat att beräkna karakteriseringsfaktorerna. Med tanke på det bör man fråga sig hur mycket dessa karakteriseringsfaktorer egentligen säger om biodiversiteten som helhet och hur lämplig denna metod är. Vad som behövs är mer forskning inom detta område, mer data för fler taxonomi-grupper samt från fler geografiska områden. På detta sätt kan befintliga metoder förbättras.

Nyckelord

LCA, Biodiversitet, Biodrivmedel, Markanvändning, Metodik, Skog

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Abstract

Analysing the environmental impact connected to biofuels has lately become more important due to the European Commission's energy and climate target for 2020. These targets includes among others, 20 % reduction of greenhouse emissions and 20 % energy efficiency. One important solution for achieving this climate target is to increase the renewable fuel sector. In order to decide which biofuels that are of importance to focus on for further development is to use a life cycle assessment (LCA) to analyse the different environmental impacts caused by the biofuels life cycle. Biodiversity and ecosystem services are environmental categories that recently have become more of interest to include in environmental analysis assessments such as life cycle assessments.

Biodiversity involves the diversity of genes within species or ecosystem, diversity of species within ecosystems, and diversity among ecosystems with in an area. This underlies all ecological processes and therefore it is vital to be able to utilize ecosystem services. Including this concept in lifecycle assessments are very complicated and until recently few methodologies existed for enable this.

The largest biodiversity losses have been found to be caused by land use changes and for this reason has this been the main focus for including biodiversity in LCA. The aim of this thesis is therefore to investigate if and how it is possible to include biodiversity aspects in LCA, if not- what is needed to enable this or are alternative methods necessary? This were answered by conducting a case study for forest based DME where two different methodologies were tested.

From the literature and case study it was possible to draw some conclusions about the possibility for including biodiversity aspects in LCAs. First or all, most biodiversity indicators are based on species richness for a land use type compared to a reference. This is a very simplified measure of the whole biodiversity concept and may not say so much of the impact on the ecosystem by only analyse how many species that is lost in one taxonomic group as a proxy for the whole biodiversity. Moreover, it is very complicated to perform the calculations required for the characterizations factors. Against this background one can doubt how good this indicator is. What is needed is more research and data available to include more biodiversity indicators as well as more taxonomic groups and altered geographic locations in the characterization factors. In this way the current methodology be improved.

Keywords

LCA, Biodiversity, Biofuels, Land use, Methodology, Forest

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Foreword

This thesis have been conducted at Volvo Trucks Technology during the fall of 2014 and spring of 2015 as the last part of the engineering program Ekosystemteknik at Lund Technical University within the Master of Science program Environmental System. The work was performed for the Department of Technology and Society at Environmental and Energy Systems Studies. My examiner was Max Åhman and my supervisor at the institution was Pål Börjesson. Pål has supported, guided and helped me with the academic writing, structure as well as providing me with important biofuel information. Thank you for your support. The thesis were performed for the Chemistry & Environment division at Volvo Trucks Technology and my head-supervisor was Lisbeth Dahllöf with support from Carin Ström. They have both been supporting me in my work and helped in many decision making situations as well as my academic writing and with the structure of the thesis. Many thanks to you as well as to all the other people I have been in contact with through the work at Volvo Group Trucks Technology.
Moreover, I have received support from Maria Lindqvist at Chalmers. She has been very helpful when deciding which methodology I could test in the case study and also provided me with important guidance of how to find data for the calculations as well as other useful biodiversity information. Daniella de Souza at SLU have also supported me with guidance in the biodiversity and LCA field.

I would also like to thank my friend and M.Sc. Daniel Olsson who have helped me with developing the VBA programming code that was used to calculate the rarefaction equations, without your help the calculating of characterization for the Koellner case might not have been possible.

Lastly I would like to thank Jonas Dahlgren from Riksskogstaxeringen who provided all vascular plant data needed for the case study.

Göteborg, April 2015

Siri Willskytt

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1 Introduction

Biodiversity has been an important topic on the environmental agenda since the Rio convention in 1992, when the Convention of Biological Diversity was declared (UNEP, 1992). Since then many attempts have been made in order to find strategies to include biodiversity aspects in the environmental politics. Scientific papers over the past decades convey that biodiversity is directly affected by human interventions and unfortunately often in a negative context (Sala et al., 2005). Due to this fact the United Nations Conference on Sustainable Development (Rio+20 Summit) in 2012 decided to change the sustainability agenda of biodiversity, which is now the keystone of sustainable development (De Souza et al., 2014, UN, 2012). Meanwhile, the European Commission decided in 2012 on a new approach to maintain biodiversity in the EU Biodiversity Strategy 202020. The new aims focus on bringing down high species-extinction rates, restore natural ecosystems in the EU as far as possible and contribute more to illuminate the global problem (European Commission, 2014).

The European Parliament emphasised that the loss of biodiversity "has devastating economic costs for society which until now have not been integrated sufficiently in to economic and other policies" (European Commission, 2014). An examples of current European management control measures for increased biodiversity, is to provide grants to farmers who conserve and increase the variation in the cropland and farmland and similar regulations exist for forest management (Börjesson et al., 2013). Whereas, few regulations for increased and preserved biodiversity currently exist on the global level (Börjesson et al., 2013). Moreover, at company level, there are as well very few industry examples on how biodiversity aspects have been incorporated in the business strategies (de Schryver et al., 2010).

Responsibility is deeply rooted within the Volvo Group, and is based on the concept of economic, social and environmental responsibility for all operations throughout the entire value-chain (Volvo Group Global, 2014). One way of taking responsibility for the environment and for a sustainable future, is to enable a switch to alternative fuels and biofuels by producing trucks that can run on all different biofuels; biodiesel, biogas, ethanol/methanol, DME and synthetic diesel, to name a few. Former life cycle assessments (LCA) performed at Volvo Trucks Technology shows that over 90 % of the total environmental impact is coming from the use phase of a truck´s lifecycle. Moreover, almost 60 % of the environmental impact is coming from the fuel itself, and includes resource of the crude oil and production of the fuel (Dahllöf, 2013).

Taken this into account, the need for a less climate burdensome fuel in the transport sector, is put high on the political agenda. The European Energy 202020 target is one way of expressing this alarming need for more climate adapted fuels. It is a strategy for competitive, sustainable and secure energy. One of the main focuses is the transition to a green transport sector, where renewable energy will account for 10 % in the transport sector by 2020 (Energimyndigheten, 2014). Besides investigating the climate impacts of a transition to biofuels, it is also important to examine how the transition will affect the biodiversity. This investigation can be both tremendous and complex (Sala et al., 2009).

One way of examine a products environmental impact is to perform a life cycle assessments. This environmental evaluation tool enable environmental analyse through assembling and evaluating the inputs, outputs and the environmental impacts of a products system throughout its life cycle (ISO 14040, 2006). As implied earlier, biodiversity impacts are strongly linked to biofuels and are therefore important to consider in LCA (Immerzeel et al., 2014). Today there is a variety of methodologies that analyses different aspects of biodiversity (Koellner et al., 2013, Schmidt, 2008, de Souza et al., 2013). However, the recognition of including biodiversity aspects in LCA for biofuels have yet not resulted in a widespread inclusion (Davis et al., 2009), even though there have been some attempts lately (Immerzeel et al., 2014).

Impacts on biodiversity are mainly modelled as a result of land use and land use change interventions since these aspects are believed to be the main cause of biodiversity losses (Mace et al., 2005). However, these current methodologies do not fully convey the complexity of biodiversity by merely investigate the effects land use and land use change have on species richness as an indicator for biodiversity. Subsequently, current characterisation factors may not either represent all different land use types, generally they do not differentiate land use intensity or type of crop that is cultivated (Koellner, 2003, Goedkoop et al., 2013).The reason for this is predominantly the lack of species richness data for more land use types related to different types of biofuel production. Thus more knowledge is needed in this area to convey a more comprehensive environmental impact assessment from different products and biofuels.

1.1 Aim

The aim is to investigate the possibility to include biodiversity aspects in Life Cycle Assessments by examine a forest based biofuel. Addition to this, the aim is to evaluate if this is a sufficient approach for analysing biodiversity and take biodiversity aspects in to consideration in decision making regarding biofuels. In order to achieve this aim, following research questions will be answered:

- How can biodiversity aspect quantitatively be included in LCA?
- If not, what data, methods and tools are necessary to be explored to enable this quantitative study? Or is a complementary method to LCA needed to analyse biodiversity in a better way?
- How can Volvo efficiently take biodiversity in to consideration in business decisions?

The thesis will contribute with increased knowledge regarding the possibility to include biodiversity in the life cycle assessment tool. Moreover, the thesis will provide deeper knowledge regarding biodiversity issues linked to biofuels, which limitations there are today and how these barriers can be overcome.

2 Methods

In order to evaluate which methodologies that can be used to include biodiversity impact in LCA, a literature study were conducted. The literature study initially describes and defines what biodiversity is, how it can be measured and how these aspects can be incorporated in a life cycle assessment. The literature study also analyses the link between biofuels and biodiversity aspects and the main issues connected to these two subjects. Lastly, the literature study consists of a biodiversity methodology review where methodologies that can be incorporated into LCAs are investigated.

The literature study is followed by a case study where two different methodologies for including biodiversity aspects in LCA were tested. The characterizations methods were applied for a specific case that is connected to the Volvo Group operations.

The result were subsequently analysed to see if the output is a relevant and good measurement for analysing biodiversity, in order to answer research question number one. To answer question number two and three, information in the literature study were examined and evaluated.

Finally, recommendations of how the methods of including biodiversity aspects in LCA can be improved and what data and knowledge that is needed to better convey and include the complexity of biodiversity impacts from biofuels, will be presented.

Literature was found through searching in scientific databases, especially through LUB-Search which is Lund University's literature database. Mainly by searching on the following key words; biodiversity, biofuels, LCA, land use, land use change, ecosystem, methodology, rarefaction method, characterization factor, ecosystem, DME and forestry. The LUB-Search provides a scan trough: e.g. Wiley, Springer. Many of the journal articles have been found by investigating the reference lists of relevant articles. Another source for information have been through interviewing key persons in the biodiversity field; Maria Lindqvist (Chalmers) and Danielle Maia de Souza (SLU), and at Volvo for biofuel strategy information; Per Hanarp and Patrik Klintbom among others. Additional help regarding programming Excel equations in VBA have Daniel Olsson provided with.

2.1 Delimitations

Biofuels can be produced from a wide range of natural resources (e.g. energy crops, waste, and forest residue) and be delivered in an almost as wide diverse range of fuels (e.g. biodiesel, synthetic gas, biogas, oils and dimethyl ether) (Björkman and Börjesson, 2014). Thus, this thesis will not investigate this wide range of biofuels and their linkage and impact on biodiversity. This thesis will focus on the main links between biofuels and biodiversity and have a focus on the connection between biofuels based on forestry resources and biodiversity. The case study is based on a dimethyl ether (DME) project between Volvo Group and Chemrec that resulted in a pilot DME production plant in Piteå. More details about this are found in the case study section 4. For this reason, the literature study is further focused on forest-based Bio-DMEs impact on biodiversity.

3 Literature Study

The outline of the literature study starts with a broad description of what biodiversity is, followed by a background of biofuels and how they are linked to biodiversity impact. Thereafter are biodiversity linked to forest based biofuels described together legislation and other certification and management operations linked to this matter. Lastly indicators and methods for measuring biodiversity are described.

3.1 Biodiversity

Biodiversity is an essential and central part of the environment. Biodiversity was defined by the Rio Convention in 1992 as the genetic diversity within a specific species or a population, the diversity of species in an ecosystem or an area, and diversity of ecosystems in an area (UNEP, 1992).
Biodiversity underlies all ecosystem processes, and these ecological processes interact with the geosphere, atmosphere and biosphere, and determine the environment which all living organism, including which humans are dependent. This dependence of the nature is usually called ecosystem services. These services are for instance clean water, food crops, biomass, clean air, and these services are vital for all organisms and for these reasons we are all dependent on biodiversity (Mace et al., 2005, Rockström et al., 2009).

Millennium Ecosystem Assessment[1] (MEA) have defined four major headings of what ecosystem services provides (Mace et al., 2005):

- *Supporting roles* the underlying role of ecosystem through structural, compositional, and functional diversity.
- *Regulatory role* through the influence of biodiversity on the production, stability and resilience of ecosystems.
- *Cultural role* from the nonmaterial benefits for humans derive from the aesthetic, spiritual and recreational benefits from biodiversity.
- *Provisional role* from the direct and indirect supply of food, fresh water, and fibre among others.

As the definition of biodiversity is defined as the diversity of genes, species and ecosystem, measuring these can be represented as following (Mace et al., 2005):

- *Variety*, reflecting the number of types. E.g. how many bird species live in a particular place or have many varieties of a genetic crop strain are in production.
- *Quantity and quality,* represent how many there are of one type. Provision services (such as food) are the quality or the quantity more important for humans rather than the variation of genes, or presence of a particular species or ecosystem.
- *Distribution,* reflecting where the attribute of biodiversity is located. E.g. having all the world´s pollinators present put at one single location will not meet the needs for all the plants dependent on them. Therefore many ecosystem services are location-specific.

Biodiversity is a composite of number of species (species richness) and number of individuals (relative abundance). Most ecosystem services, clean water or food provision depends on the presence of sufficient number of individuals of each species. These services will decline locally with decreased species population before global extinction take place. Whereas other ecosystem services that are dependent on genetic diversity, the central concern is species diversity (Sala et al., 2005).

MEA summarizes the dependence on biodiversity and ecosystem services as many of the benefits from biodiversity is dependent on the functional and structural variety in species, whereas most providing

[1] The Millennium Ecosystem Assessment assessed between 2001 and 2005 the consequences of ecosystem change for human well-being. This involved work from 1360 experts around the world and their findings provided a state-of-the art scientific estimation of the trends and conditions for the world´s ecosystem .MEA. 2005. *Overview of the Millennium Ecosystem Assessment* [Online]. Available: http://www.millenniumassessment.org/en/About.html [Accessed 2015-02-24 2015]..

services are dependent on quality, quantity and distribution of populations and ecosystems. But in order to have a sustainable long-term service, a variation of genes is vital. Hence, variability plays a superior role and is therefore frequently stated as one of the more important roles of biodiversity (Mace et al., 2005).

Historical changes in the world´s biota have been driven by extrinsic processes to life on Earth such as tectonic movement or climate change. Whereas current biodiversity changes are primary due to intrinsic processes to life on Earth, and almost entirely caused by human activity: land use, rapid climate change, exploitation, pollution, pathogens, and introduction of alien species (Mace et al., 2005).

The main drivers of biodiversity loss in terrestrial system found in the MEA 2005 report, was dominantly caused by land use change, followed by changes in climate, nitrogen deposition, introduction of new species in an ecosystem, and atmospheric CO_2 levels (Sala et al., 2005). The most important direct effect on biodiversity has found to be habitat destruction (Mace et al., 2005). The primary cause for loss of habitat are through degradation or declining and subsequently cause a decline in species richness and population size (Mace et al., 2005). It have been noticed that the most dramatic form of habitat loss is when a diverse community of species, such a rainforest, is replaced with one single species crop, for example a monoculture plantation of eucalyptus (Sala et al., 2009).

A major issue with habitat and land use change is habitat fragmentation, which is caused either by natural disturbance (wind and fire) or by human intervention, such as clearing of natural vegetation for road construction or agriculture. Fragmentation affects all biomes but particularly forests. Globally, nearly a quarter of the tropical rainforest biome and almost half of the temperate broadleaf and mixed forest, have been fragmented or removed by humans, though only four percent of the boreal forest (Mace et al., 2005).

Human activities influence biodiversity in a wide range of ways. The interventions results in an increased possibility for some ecosystem or species to survive at the expense of others, which often lead to reduced biodiversity (Martikanien et al., 2000, Weidema, 2008). This could happen through:

- Physical changes to the fauna, flora, surface (including change in albedo) or soil
- Removal of soil, nutrient or biomass
- Release of nutrients, invasive species or toxic substances

3.1.1 Planetary Boundaries

The paper “Planetary boundaries: Exploring the safe operation space for humanity” propose a new approach for global sustainability in which the authors define nine different planet boundaries that humanity can operate safely within (Rockström et al., 2009). In Table 1 are the two planet boundaries that are connected to the objectivities in focus in this thesis; land-system change and rate of biodiversity loss conveyed.

Table 1. Proposed planetary boundaries (Rockström et al., 2009).

Earth process	Control variable	Threshold value	Planetary boundary	State of knowledge
Land-system Change	Percentage of global land cover converted to cropland	Trigger of irreversible and widespread conversion of biomes to undesired states. Primarily acts as a slow variable affecting carbon storage and resilience via changes in biodiversity and landscape heterogeneity	≤15% of global ice-free land surface converted to cropland (15%–20%)	1. Ample scientific evidence of impacts of land-cover change on ecosystems, largely local and regional. 2. Slow variable, global threshold unlikely but regional thresholds likely. 3. Boundary is a global aggregate with high uncertainty, regional distribution of land-system change is critical.
Rate of Biodiversity loss	Extinction rate, extinctions per million species per year (E/MSY)	Slow variable affecting ecosystem functioning at continental and ocean basin scales. Impact on many other boundaries: C storage, freshwater, N and P cycles, land systems. Massive loss of biodiversity unacceptable for ethical reasons.	<10 E/MSY (10–100 E/MSY)	1. Incomplete knowledge on the role of biodiversity for ecosystem functioning across scales. 2. Thresholds likely at local and regional scales. 3. Boundary position highly uncertain.

Land-system change is mainly driven by agricultural expansion and intensification and contributes to global environmental change, that jeopardize long-term sustainability (Rockström et al., 2009). The planet boundary that is proposed for maintaining a sustainable land-system is no more than 15% of the global ice-free land surface could be converted to cropland. This planet boundary is strongly linked to the boundaries for rate of biodiversity loss, global fresh water use, and phosphorous and nitrogen use. About 12% of the global land surface is currently occupied by crop cultivation. Subsequently, an expansion of 3 % could be allowed. This expansion could be possible on abandoned cropland in Europe, North America, former Soviet Union and some areas of Africa´s savannahs and South America´s cerrado (Rockström et al., 2009). Thus there are no consensus on how large areas with abandoned and un-used land are available for continued expansion (Lambin, 2014).

Rate of biodiversity loss is the planet boundary indicator for biodiversity. The loss of biodiversity can for example increase the vulnerability of terrestrial and aquatic ecosystems to climate and ocean acidity. Species play an important role to different ecosystems and thus resulting in different effects in different ecosystem. Hence, species loss affects both the functioning of ecosystem and their potential to respond and adapt to changes in the biotic and physical conditions (Rockström et al., 2009).

The current global extension per million species year (E/MSY) is about ≥100 E/MSY and has increased with 100-1000 times since the start of Anthropocene by human activities, and is estimated to increase another 10-fold during the current century. Of all the well-studied taxonomic groups, about 25% of the species are threatened to be extinct (from 12% for birds to 52% for caycads[2]). Rockström et al. suggest an uncertainty range of 10-100 E/MSY, and indicates a safe planet boundary of 10 E/MSY that is of magnitude of the background rate. This means that the current rate is exceeded by one to two orders of magnitude, hence indicates the urgent need for decreasing this biodiversity loss rate (Rockström et al., 2009).

A cause-effect chain for different land use impact on biodiversity is shown in Figure 1 (Milà i Canals et al., 2014). Milà i Canals et al. (2014) convey that there are three major direct effects from land use. Impacts on habitats: fragmentation, degradation, conversion, and reduction of habitat blocks. Impact on soil quality: water flow regulation, resilience and soil stability, filtration and purification of water, carbon sequestration, patterns of bacterial generic diversity. And lastly impact on fauna: altered species composition and population, and altered soil biodiversity. These impacts can thereafter be connected to different midpoint indicators, e.g. soil quality midpoint or biodiversity midpoints. The main indicators for biodiversity midpoints are species related indicators, number of endemic species or species richness, as can be seen in the flowchart.

[2] Kotteplamer på Svenska

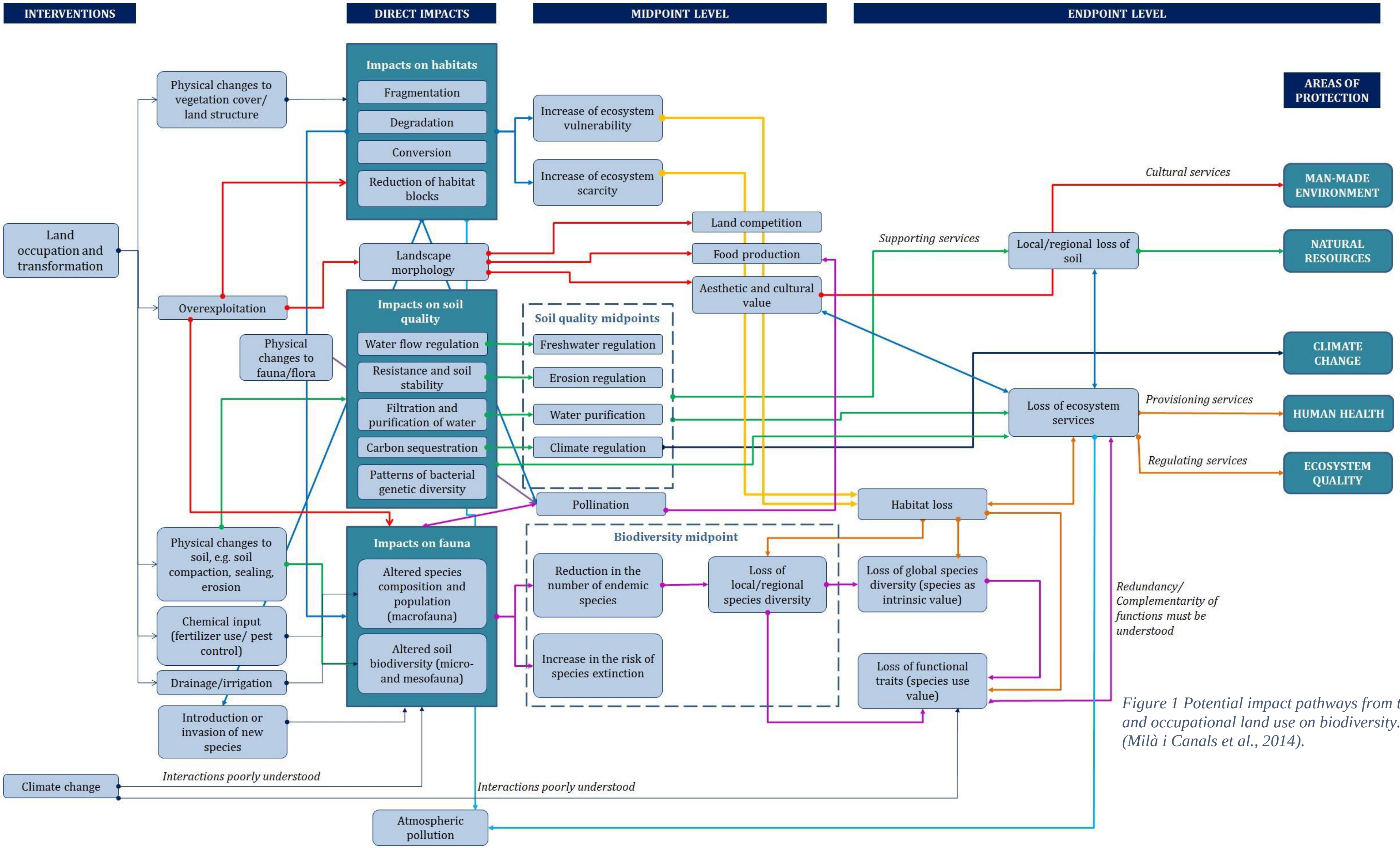

Figure 1 Potential impact pathways from transformation and occupational land use on biodiversity. Copied from (Milà i Canals et al., 2014).

3.2 Biofuels

Biofuels are fuels produced from renewable resources that can either be used directly in the engine or blended in conventional fuels. Globally the domestic use of bioenergy such as wood combustion have been used as energy resource for many thousands of years. However, using renewable resources to produce fuels for engines is a more recent development (Davis et al., 2009). Figure 2 convey a schematic over possible production pathways for biofuels today. Biofuels that are produced from energy crops, such as sugarcanes, rapeseed and cereals, are so-called "first generation" biofuels. These are crops cultivated on agricultural land and are thus competing with food on the available arable land. There are a large variety in biofuels that can be produced from first generation raw materials and the most common are: ethanol and different FAME (fatty acid methyl ester) (Börjesson et al., 2013).

Second generation biofuels are considered to be a solution for this land conflict. Therefore resources that do not require agricultural land are used. Biofuels that are produced from different kind of waste products or cellulosic materials are examples of these (Börjesson et al., 2013). The forest residues can be treated through gasification in to dimethyl ether (DME) or Fischer-Tropsch-diesel (FT-diesel), decay in to methanol or ethanol or into hydrogenated vegetable oils (HVO) through hydration when the forestry bi-product pine oil is used. Food waste products on the other hand, are generally fermented into biogas (methane) or if it is an animal bi-product the residue can be hydrated in to HVO (Börjesson et al., 2013).

The third generation biofuels on the other hand, are not produced from land resources; instead they are produced from resources harvested from water and the ocean such as different algae. Biofuels produced form algae are forecast to have a large potential in the future. The macro algae (sea weed) can be fermented into methane, whereas the micro algae are microscopic small, e.g. the blue algae, and those algae types with large oil, content could be hydrated into HVOs or transesterficated into FAME. (Börjesson et al., 2013)

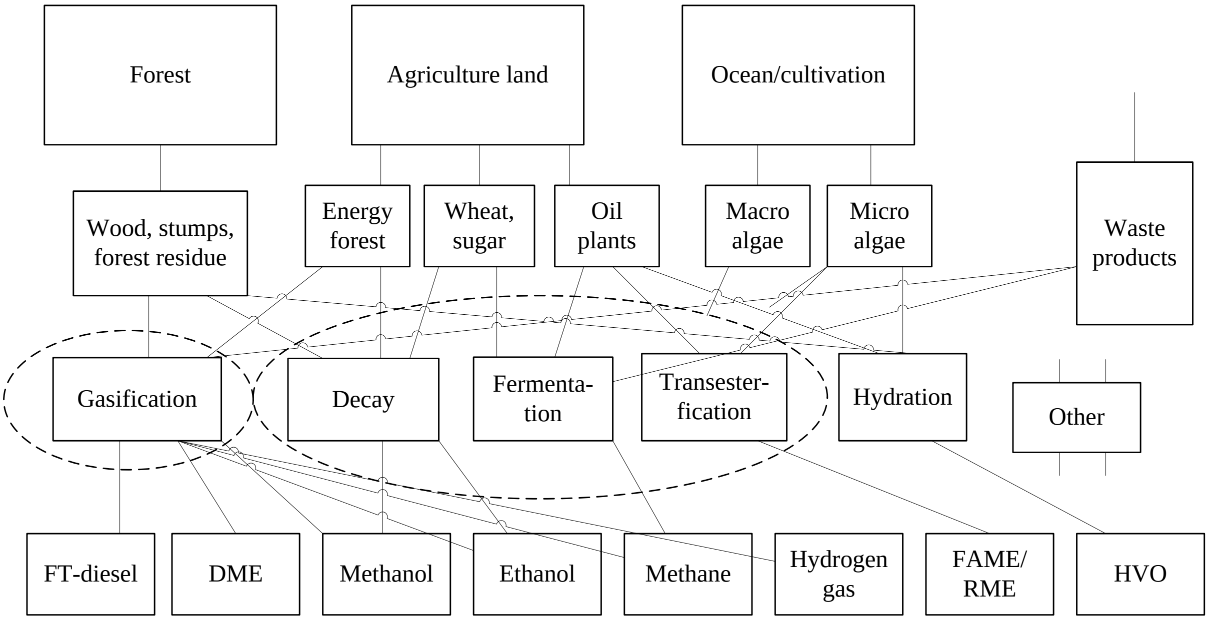

Figure 2. Schematic of present and available raw material and technologies for producing biofuels, inspired by (Börjesson et al., 2013).

It is not suitable to evaluate the environmental impact and the production cost for different biofuels exclusively based on whether it is an ethanol or methane biofuel. The entire value-chain of the specific biofuel must be analysed in order to make a conclusion of which biofuel is the most cost-efficient and suitable one (Börjesson et al., 2013). The same approach is needed for evaluating of biofuels for their biodiversity impacts; one must look into which type of energy crop is used, where it is grown and how it is processed, in order to be able to compare the different biofuels biodiversity impacts.

3.2.1 DME

As mentioned in the method section, a case study have been conducted to evaluate the possibility for including biodiversity aspects in a lifecycle assessment for a forest based biofuel, the biofuel that is chosen for this purpose is DME. Against this background, the production process for DME are described in this section.

Dimethyl ether (DME) is a fuel that is mostly produced from coal or natural gas based synthetic gas. The synthetic gas is generally converted to methanol over a copper catalyser. Thereafter the DME is produced throughout dehydrogenization over another catalyser (Börjesson et al., 2013).

Bio-DME on the other hand is produced from a renewable energy source, biomass or black liquor. The technique for producing the DME is similar to fossil-DME. DME produced from solid biomass can technologies such as pressurized and circulated fluidized bed combustion, and bubbling fluidized bed combustion technologies be used (Börjesson et al., 2013).

Producing Bio-DME from black liquor on the other hand, involves gasification through downstream gasification at a relative low temperature (1000-1100°C). Thereafter the synthetic gas is upgraded to vehicle fuel through a catalytic process (Börjesson et al., 2013). Black liquor is an energy-rich bi-product in paper mills and is generally used as energy source to the mill for heating and electricity. Subsequently, other sources for heating and electricity is needed to the mill and generally bark, forest residues and stumps used (Smurfit Kappa, 2014).

One way of analysing how effective a biofuel production is, is to analyse the “product-share”, in other words how much biofuel that can be produced from the inserted biomass. If one compares different gasified based biofuels, bio-DME is one of the best options. Around 56-65% of the inserted biomass result in biofuel, this is higher than for methanol production (50-60 %) and ethanol through fermentation of synthetic gas (around 30%). Bio-DME produced from synthetic natural gas is assumed to yield a number between 64-70% (Börjesson et al., 2013). However, a high total energy efficiency level can be obtained in integrated bio-DME production system, as the one in Piteå (Chemrec), when black liquor is gasified and an energy efficiency over 100% is possible, if the calculations are based on marginal input of biofuels (Börjesson et al., 2013).

DME is an attractive fuel for many reasons, it can be used in a diesel engine and it can be produced from biomass. The DME is gaseous in ambient conditions, thus the pressure have to be lowered in order for the fuel to become liquid or the engine have to be designed to be able to run with these conditions (Edwards et al., 2014).

3.3 Biofuels and Biodiversity

The biofuel production is expected to expand in the next coming decades, in line with the European Union target for 2020, that demand an increased biofuel production to meet this target, and will therefor put a high pressure on the nature and the biological diversity (Sala et al., 2009). There are many links between biofuel production and impact on biodiversity. Generally, negative impacts on biodiversity are associated with biofuels, but some positive aspect for the biodiversity exist as well (Sala et al., 2009, Immerzeel et al., 2014). The main negative impacts on biodiversity associated with increased biofuel production are a result of decreased habitat loss, increased invasive species, and pollution from the use of fertilizers and herbicides (Sala et al., 2009). Whilst, the positive effect from biofuel production may be the improved rate of change in atmospheric composition and global warming since some biofuels may reduce the global net carbon emissions by increase the carbon storage in the soil (Sala et al., 2009).

Biofuels based on energy crops are often associated with large land use demand as well as competition with food production (Immerzeel et al., 2014). In the Immerzeel et al. (2014) state-of-the-art review, 53 articles were selected and reviewed to give a broad insight on various aspects of how bio-crops affects biodiversity in both negative and beneficial ways. Several of different spatial scale, time horizons, production system and regions, methodology and biodiversity parameters were used in the review. The reported negative impacts on biodiversity were mainly due to change in land use and were most severe in tropical regions (Immerzeel et al., 2014). This is highly linked to the large extent of land transformation from tropical forest in to agricultural land that have been proven to have the largest negative impact on biodiversity (Sala et al., 2009).

Biofuels produced as a second generation biofuel tend to be less negative on land use change and are in some cases, mainly in field level in temperate regions, positive. For grasses and short rotation crops (SRC) in Europe the positive effects are especially noticeable, since perennial crops have the potential to provide shelter or habitat to for example migration birds. Moreover, these crops may improve connectivity or support restoration of degraded or marginal land and therefore improve the biodiversity (Immerzeel et al., 2014). Against this background, positive land use changes can be expected when an intensive land use is replaced with a less intensive one (Immerzeel et al., 2014).

Biofuels direct and indirect effects (see section 3.3.2) on land use are as well confirmed, although few reports exist on the impacts on large scale application (Immerzeel et al., 2014).

3.3.1 Method to Mitigate the Environmental Impact from Land Use

There are many strategies to avoid negative impacts on biodiversity when cultivating crops on arable land. Land sparing is a strategy were some land are set aside and are not used for agricultural purpose and are instead only conserved for maintenance of biodiversity, meanwhile other land is more intensively used to have a high agricultural output. On the contrary, in land sharing strategy, less land are set aside for conservation and less intensive production pressure are put on the other land in order to maintain some biodiversity on the cultivated land (Fischer et al., 2014). The idea of land sharing versus land sparing is to create a way of cultivating crops with an approach that is less harmful for the biodiversity. Thus, complications arise when one shall measure these trade-off benefits on biodiversity for these different strategies depending on the method for measuring biodiversity. Depending on the method, different biodiversity outputs are given as a result (Fischer et al., 2014).

3.3.2 dLUC and iLUC

Available land is finite and can historically be allocated to the following different land use. Total land area= Agricultural land + Forest land + Pasture land + Conservation land + Urban areas (Sala et al., 2009).

When introducing biofuels in the available land equation, land must be taken from either of the land types, and a new equation can describe the land composition. Total available land area = Agricultural land + Forest land + Pasture land + Conservation land + Urban areas + Biofuel production. The land that is allocated to biofuels production will either compete direct (dLUC) or indirectly (iLUC) with the other land types (Sala et al., 2009). The direct effect be that the biofuel crop land use will occur on land that previously have been used for food production or land conservation. Whereas, the indirect effect are the consequence of using the land for biofuel production instead of food production, which will result in that the food have to be produced in another place. That can either be on the lands that are set aside for land conservation or another countries food production (Börjesson et al., 2013).

Figure 3 convey the potential direct and indirect consequences of land use changes from an increased demand of a biofuel-crop (Börjesson et al., 2013). Four different outcomes are presented in this figure:

1. Increased demand of crop A could lead to increased price for the crop to such extension that the demand for crop A decreases
2. Intensified production of crop A to yield more crops from same arable land
3. Cultivation of crop A on former unfarmed land, or
4. Cultivation of crop A instead of crop B.

The last outcome will subsequently lead to the same alternative outcome once again depending on the situation. The problem with this is, that it is not possible to predict which situation will occur. This land competition can lead to crop cultivation displacement and result in a land transformation of high biodiversity land types, e.g. rainforest being transformed into agriculture land use instead, and thus decrease the biodiversity massively.

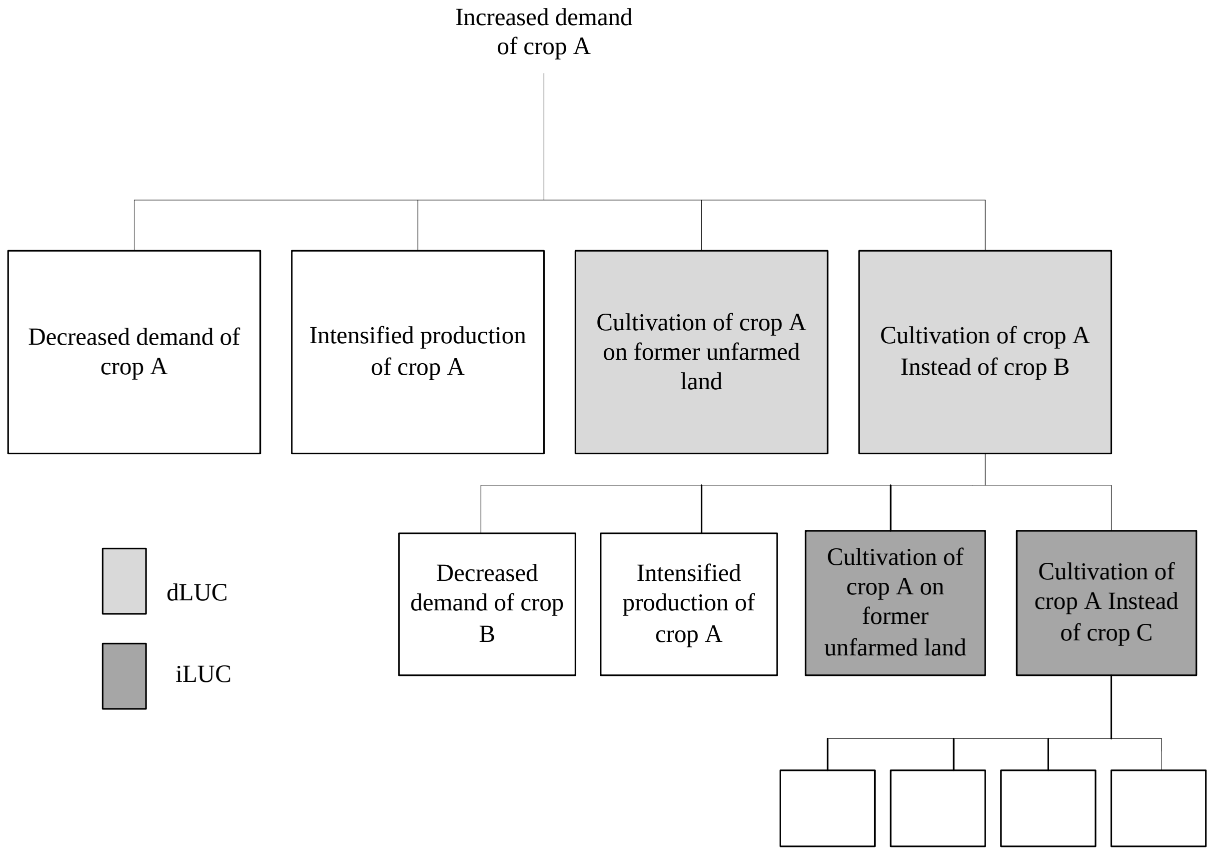

Figure 3. Schematic over dLUC and iLUC (Börjesson et al., 2013).

This land use change is often associated with negative effects, as mentioned above, whereas there are some cases when the indirect effect also can be positive. How great the indirect effects from biomass production are, is difficult to examine but some attempts have been made. One example is Hellman and Verburg (2010) that investigated what the direct and indirect effects on biodiversity would be on European level for different scenarios when implementing the EU Directive 2003/30/EC, which required that all member states should have 5.75% of their fuels in biofuels by 2010. It was found that the direct effects from converting semi-natural vegetation and forest with high natural value was small in all scenarios versions related to the biofuel directive. Whereas the indirect effects from the European land use on the biodiversity were much larger (Hellman and Verburg, 2010).

One solution to solve the available land equation is to use so called surplus land (Dauber et al., 2012). This can be defined as land that are currently not used for food production, animal feed, fibre or other renewable resources due to poor soil fertility or abiotic stress[3], land that is no longer needed for food or feed production due to intensification and rationalization which result in an increased yield and less land occupation (Immerzeel et al., 2014). Surplus land for this reason one of the main focuses for the bioenergy sector in order to reduce the competition between food production and crop production for

[3] Abiotic stress is the negative impact of non-living organisms on living organisms in a specific environment.

biofuels and therefore also reduce the iLUC. The amount of produced bioenergy without expanding the total agricultural land area is a matter of intensification of the agricultural sector as well as the suitability of the available land for bio-crops (Immerzeel et al., 2014). The availability of surplus lands that can be used for bioenergy production is thought very uncertain (Immerzeel et al., 2014).

Another solution to this land competition is an expansion of second generations biofuels, which do not initiate this land competition (Börjesson et al., 2013).

3.3.3 Biodiversity Change for Second Generations Forest-based Biofuels in Sweden

Biofuels based on forest residues are not meeting the same challenges as the ones based on crops. The challenges that those forest-based-biofuels meet are stronger linked to forest management rather than the indirect land use changes that are associated with crop based biofuels. This section describes the status of the Swedish forest and forestry and what the main biodiversity indicators are for the boreal forest, in order to exemplify the potential biodiversity impact the forest based and second generation biofuels may have.

Forest Description

The Swedish land area is today covered with approximately 28 million hectare forest land which corresponds to more than 60% of the total land area. The forest is dominated by pine and spruce, where each tree type corresponds to 40% each of the total production forest. The age distribution of the forest reveals that stand ages between 40 to 60 years are the most dominated age classes. There are approximately 3 million hectare forest older than 140 years in Sweden, which corresponds to 11% of the total forest area. This type of old forest is most common in Norrland and makes up to 17% in northern Norrland and 14% in southern Norrland (SLU, 2014b).

Areas with old forest and high natural values[4] have reached critical levels in Sweden. Despite this, these areas continue to decrease. This is mainly due to that not all of these are protected and means that key-biotopes are felled every year. Not only does this decrease the biodiversity, moreover it means that fragmentation of the forest landscape continues. Table 2 display areas for national parks, nature reserves and nature conservation areas in production forest land and unproductive land in 2011. The table covey that 7% of the total forest land is protected in some of these protection types, whereas only 3.9% of the productive forest land is protected (FSC, 2008).

3-years average on inventories on environment protection in connection with felling conducted before respectively one year after regeneration cutting during 2009/2010–2011/2012 from The Swedish Forestry Agency shows that (Eriksson, 2014):

- There was a strong negative impact on 7% of the sensitive habitats
- There was a strong negative impact on 10% of historical-cultural values
- There was a strong negative impact on 9% of buffer zones

Moreover, 1787 forest living animals, plants and fungi are red-listed in Sweden today. Of these, 861 are classified threatened (Hagberg and Terstad, 2012).

[4] Important areas for forest biodiversity

Table 2. Productive and unproductive forest area in Sweden 2011 (FSC, 2008).

		North Norrland	South Norrland	Sweden
	1000 hectares			
Productive forest land, total area		7126	5744	23223
	National park, nature reserve and nature conservation area	450	113	795
	Habitat protected area and nature conservation agreement	8	8	49
	Proportion of formally protected production forest land	6.4%	2.1%	3.6%
Forestland total area		9 843	6991	28 276
	National park, nature reserve and nature conservation area	1423	216	1924
	Habitat protected area and nature conservation agreement	9	10	54
	Proportion of formally protected forest land	14.5%	3.2%	7%
Unproductive forest land outside national park, nature reserve, habitat protection area and nature conservation agreement		3674	1587	7085
	Area with voluntary set aside for conservation purpose submontane	331	261	1112
	Land exempted from forestry	3674	1587	7085
	Proportion of the forest land exempted from forestry	37.3%	22.7%	25%

Riksskogstaxeringen

Riksskogstaxeringen have since 1993 performed inventories in the Swedish forests. They perform yearly cluster samplings in all the different types of forest land, thus the main sample activities are performed in the productive forest land. The reason for this is the purpose of detecting and describing the changes in the forest (Nilsson and Cory, 2014). Their work can be divided into five different pillars:

Stand inventories, describing the overall vegetation properties by inventory the different land´s fertility properties.

Area inventories, registration of variables that describe the growing stand together with different interventions.

Stock inventories, this together with area inventories is one of the main work for Riksskogstaxeringen. This work involves estimate amount of wood stock[5], tree distribution, age distribution, and growth. In this work area is amount of dead wood inventoried.

Flora and fauna inventories, inventories of plants and specific objectives, such as woodpecker tracks, anthills, that are of importance for biodiversity.

Stump inventories, describes the annual deforestation and diameter measures of the stumps. (SLU, 2014a)

Every year 11 000 sample areas with a diameter of 10m and area of 100m^2, are inventoried. This amounts to around 260 hectare and half of that area is in productive forest land area. Thus this only represents 0.006‰ of the total production land (Nilsson and Cory, 2014).

[5] Virkesförråd på Svenska

Indicators for biodiversity that have been inventoried since the beginning of the inventory activities by Riksskogstaxeringen in the Swedish forest, are amount of dead hardwood and area of old forest. Later, other indicators for biodiversity such as coarse trees, distribution of tree species, and cover of field and bottom stratum have been added to the inventory procedure. Other indicators for analysing the biodiversity in the Swedish forest are through inventory different forest types with high biodiversity such as: old leafed marsh forest, pine heath land, and herb-spruce-forest. These forest types compose qualifications for high biodiversity (Nilsson and Cory, 2014). Moreover, since 2003, inventory objectives direct linked to biodiversity such as wood fungi also have been added (Nilsson and Cory, 2014).

Biodiversity Indicators

Fire: Under natural conditions one of the main factors for conserving forest biodiversity is the interaction between forest and fire. The pines tolerate fires well and the density in pine forest are generally low which leads to ground fires and results in great variation in size and age distribution in the forest (Larsson, 2001).

Dead wood: The amount of dead wood is an established indicator for the level of biodiversity within a forest (Larsson, 2001, Nilsson and Cory, 2014, De Jong and Almstedt, 2005). Many species are dependent on dead wood in different stages of digestion and the absence of dead wood is considered to be the greatest threat to forest existing species are red-listed (SLU, 2014b). Approximately 39% of the forest living species are dependent on this forest structure. Moreover, the volumes of dead wood have increased massively the last years and due to coincide of the severe storms such as Gudrun and Per (Nilsson and Cory, 2014). The amount of dead wood is estimated to be about 212 million m^3 or 7.8 m^3/ hectare (SLU, 2014b).

Diversity of trees: A diversity of tree species is also an indicator for good conditions for biodiversity. In productive forest land the majority of the land (84%) are areas with 2 to 4 tree species, 11% are areas with 5 to 8 tree species and 5% is estimated to be of so called monoculture with only one tree species (Nilsson and Cory, 2014).

Coarse trees: the amount of coarse and old trees is an indicator for high biodiversity. The amount of these have increase together with the increase areas with old forest. This increase is most significant for hardwood trees and oaks. (Nilsson and Cory, 2014)

Stokland et al.(2003) recommend different properties for species diversity that no indicators exist on at the moment (Stokland et al., 2003):

- Number of endemic forest species, subdivided on organism groups
- Number of introduced forest species, subdivided by organism groups
- Population trends of indicator species, subdivided by environmental pressure factors and organisms groups.

Forest Residue

The interest and demand of energy produced from biomass have increased during the last couple of years in Sweden. The increased renewable goals from 40 to 49% by 2020 will increase the demand even further (Stendahl, 2010). One of the potentials for increasing the output from the biomass production areas, is to increase the output from forest residues (Stendahl, 2010).

In the report "Balancing Different Environmental Effects of Forest Residue Recovery in Sweden" (Björkman and Börjesson, 2014), different environmental effects that can arise as a consequence of logging residue and stump recovery are investigated, and is mainly based on (De Jong et al., 2012).

Logging residues provides substrate and habitats for a wide range of forest species and are therefore important for the forest biodiversity. How important it is compared to other substrates present in the forest is not entirely clear. Even if it is only concerning a few species, the recovery from this might have negative consequences on the whole population due to the dependence of logging residues after a clearing phase. Moreover, piles of logging residues from broad-leaved trees are attractive habitats for wood-living species such as many red-listed species. The species might be removed together with the logging material, thus rare species might disappear. Another negative aspect of removing logging residues is the risk of damage and removal of trees, wood and habitat that are left for environmental consideration. The recovery on functional organism groups are thus seemed to be rather temperate. Therefore no significant changes in ecosystem functions provided by plants and soil organism in a clear-cut area are to be expected (Björkman and Börjesson, 2014).

The impacts of stump recovery are similar to those mentioned for logging residues. Nevertheless, few red-listed species are found in habitats consisting of low stumps. Hence few rare species of fungi, mosses and lichens are found in heavily managed forest. Stumps represent approximately 80 % of the dead wood found in a managed forest and forms therefore habitat for insects. Even if the stumps form habitat for only few red-species, removal of them could have very negative effects on the biodiversity due to increased homogenization. The stumps provide micro habitat variation, growth substrate and protection for a large variation of species. It can assist as a nesting or hiding place for example mammals. Birds find food in form of insects inside the stumps. These are only a few examples of what important services the stumps and logging residue provide to the whole forest (Björkman and Börjesson, 2014).

The effects of ash recycling on species richness have not been studied in such large extent. It is however known that in short-term perspective, the effects on vegetation and soil organisms are to a large extent dependent on properties of the ash. The higher solubility of the ash, the faster and larger the direct effects appear to be. Easily dissolved ash can thus damage vegetation, whereas no direct effects have been seen on hardened ash (Björkman and Börjesson, 2014). The Swedish Forest Agency consider it is important to return ash from the biofuels to the forest so that the important lime-substances and phosphorus are return to the forestland. Assumed that the ash is treated and do not contain tracks of heavy metals. Moreover, it is important that this is done with caution and after consolation with the Forest Agency. Not only does this action have positive effects for the nutrient balance in the soil, it also decreases the possibility for acidification of the forest and surrounding watercourse (Hjerpe, 2014).

In Table 3 an overview of the environmental effects on biodiversity and forest productivity are conveyed that can arise of logging residues and stump recovery. For biodiversity there are two different environmental effects that can be caused by logging residue and stump; loss of substrate that might provide as habitat for different species and mercury methylation that cause soil disturbance (Björkman and Börjesson, 2014) .

Table 3. Overview of environmental effects that can arise as a consequence of logging residue and stump recovery (Björkman and Börjesson, 2014).

Environmental Impact Category	**Biodiversity**		**Forest productivity**
Geographical Aspect	Local	Regional, local	Local
Environmental Effects	Loss of harvest residues with functions such as substrate and habitat	Hg methylation	Decreased forest growth
Description	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 production of the annual production of dead hardwood in the forest.	Soil disturbance due to driving damages and stump recovery	Decreased growth as an impact of logging residues recovery. Observed over a few decades. No permanent impact on the production ability of the forest land.
	General conservation considerations- lack of inadequate etc.		Repetitive forest residue recoveries at regeneration felling, clearance and thinning, expected to restrain the forest production during parts of the rotation period in a stand.
			Dependent on recovery intensity and nutrient content of harvested biomass.
Connection to environmental quality objectives	A rich diversity of Plant and Animal Life Sustainable Forest		Forest Objectives

In order to perform a sustainable logging and stump recovery, different requirements are needed to take into consideration. (Björkman and Börjesson, 2014):

Tree types

- Primarily logging residues and stumps from coniferous trees
- Both residues from broad-leaved and valuable road-leaved trees should be completely avoided in coniferous-dominated stands
- Only the domination tree type should be recovered in broad-leaved-dominated stands (should generally be more restrictive with recovery of broad-leaved trees and it is important that regional assessments are made, for instance on species occurrence).

Ash recycling

- Ash recycling with ash of good quality is done to compensate for nutrient losses due to the increased recovery.
- Ash recycling is practiced where it is needed and adjusted to stand type.

Environmental Consideration

- The environmental consideration needs to function as intended, according to law and in some cases up to advisory level.

Other Restrictions

- Without nitrogen compensation logging residues recovery should be limited in connection to thinning, in that way reducing too many negative effects on the production.
- Increased logging residues and stump recovery will subsequently increase traffic in the forest and might increase soil damage. Restrict the recovery to areas with good bearing capacity to reduce the risk of damage the soil (Björkman and Börjesson, 2014).

3.4 Sustainability Criteria's and Legislations

There are many global and national legislations, certifications and sustainability criteria's for biofuels and forest management. In the following section some of those are presented to convey which areas that today are affected by law and which are voluntary actions. It is important to understand the link and difference between what is of importance for maintained biodiversity and what obligations biofuel producers and forestry owner have to achieve this.

3.4.1 Certification for Sustainable Forestry

In Table 4 different environmental aspects in the Swedish Forestry Act and the guidelines for Forest Stewardship Council Sweden are summarized together with the effects for biodiversity (Enetjärn Natur AB, 2013).

Table 4. The Swedish Forestry Act versus FSC standard for Sweden (Enetjärn Natur AB, 2013).

Environmental aspect	The Swedish Forest Act	FSC Sweden	Effect in forest	Effect for biodiversity
Forest set aside and key biotope:	Prevent and limit damage in and close to key biotopes and cultural heritage in the nature	5% of the production forest shall be set aside for conservation. Selection is based on high natural values and representativeness. All key biotopes are saved.	Support age variation within the forest and intact forest areas	Longer rotation period, positive for disturbance-sensitive species that are favourable in the late part of succession
"Allowance tree"	Save individual trees or groups of trees. Priority of trees with high natural values.	Save all trees with natural values, at least 10 "allowance trees" per hectare for future generations	Work as a minimum-criteria	Increased amount of deadwood, sun bleached wood is a good habitat for beetles
" High-stumps"	-	Either 3 high-stumps or 3 unbarked trees per hectare	Increased dead wood	Substrate for some species, especially for some beetles
"Fire"	-	5% of the rejuvenate deforested areas shall burn down	Contribute with forest-burnt areas	Increased and improved conditions for burn-supportive species and pyrophilia species
Landscape picture	Consideration should be taken to the landscape picture	Plan the forestry according to an ecological-landscape perspective	Balancing the age-distribution at landscape level	Species that are present in old forest, forest edge and cultural land are supported
Broad-leaved forest	Hardwood trees shall not be replaced with other trees	>10% of the volume is broad-leaved forest at the end of the rotation	Broad-leaved forest are supported	Birds, bats, and vascular plants are supported

		time, 10% shall be of healthy/ damp forest (5% in northern SWE)		
Red listed species	Avoid and limit damage on red-listed animals and plant species from forestry	Inventions that are proved to work (documentation) should be taken	-	Red listed species chance for survival is enhanced
Damage on land and in water	Forest cleaning is not acceptable, bottom of watercourses shall be intact	Guidelines to minimize erosion, forest damage, road construction, and protect watercourse	-	Support to water organisms
Forest roads	Should not be constructed close to beaches, watercourses, key biotopes, commonly used walking trails, digging in wetlands should be avoided	Routines for avoiding disturbing and damage watercourses and	-	Support to water organisms
Saving-zones	Saving-zones are set aside when it is needed to protect animal- and plant-life, and watercourses	In connection to biotopes with high natural values, wetlands, and around water areas	-	The biodiversity in the areas that are protected are less disturbed by the forestry. The saving-zones can become new habitats.

There are some differences between the demands that the Swedish Forestry Act (SFA) and the Swedish FSC put on the forestry. The most important difference in between them may be the difference between voluntary actions for conserving trees, stumps, and other structures important for biodiversity, and actual demands on minimum actions that FSC have set.

The global FSC Forest Stewardship does not have the same principals as the Swedish section presented above. The global FSC Forest Stewardship have 10 overall principals:

1. Compliance with laws and FSC principles
2. Tenure and use rights and responsibilities
3. Indigenous people´s rights
4. Community relations and worker´s rights
5. Multiple benefits from the forest
6. Assessment of environmental impact
7. Management planning
8. Monitoring and assessment of management impacts
9. Maintenance of high conservation values
10. Responsible management of plantations

The level of demands and obligations one have to achieve to receive a FSC certification seems to differ between the global and Swedish certification system. If “High Conservation Value Forest” are found in the production forest, special precautions have to be performed to avoid damage of the values that exist in that area. Thus it may still be possible to harvest in the area. No requirements such as 5% area set aside are neither necessary to obtain the certification (FSC, 2008).

The Programme for the Endorsement of Forest Certification (*PEFC)* is another certification system that is a developed through the FSC principals but focus on private forest owners. PEFC works as a third party certifier for sustainable forestry and have an “Act local, think globally” approach when it comes to biodiversity. This approach contributes positively to maintenance and enhancement of global forestry biodiversity. A forest certified by PEFC must be managed in a way that biodiversity is maintained, conserved and enhanced. Examples of actions to achieve this are by support natural regeneration and favour native species in reforestation and afforestation. The forest manager must also ensure that important key biotopes are protected, harvest levels are forest productivity, and degraded forest ecosystems are rehabilitated. Due to the non-consensus regarding GMO in the science, PEFC have decided that GMO- plants cannot be certified. Another criterion for PEFC-certified forest is that chemical pesticides and herbicides must be substituted with natural alternatives or minimized (PEFC, 2015a).

Since the introduction of forest certification in the 1990s, about 300 million hectares of forest have certified, mainly in temperate and boreal areas. Less than 20 million hectares are certified in the tropics (2009), mainly by FSC. (van Kuijk et al., 2009) In November 2014 was 264 million hectare forest area certified by PEFC (PEFC, 2015a). In Sweden 11 million hectare of forest are certified with PEFC (PEFC, 2015b) and 12 million hectare are certified with FSC which is almost half of the total production forest area (FSC, 2015).

In a study by van Kuijk et al. (2009), the forest certification system was evaluated whether certifications had a positive effect on biodiversity or not. 67 studies were reviewed to see if the hypothesis that certified and well managed forest had higher biodiversity than similar conventional forests. However, the study had difficulties to reveal a clear answer to the hypothesis due to many reasons. Firstly, systematic collection of information needed to study the effects of management on biodiversity did not take place. The same problem was for the non-certified forests. The same goes to the scientific community that have had a focus on different species based methodologies to measure biodiversity and have not addressed the temporal and spatial scale that is appropriated for forestry and forest ecosystems. Despite the lacking on data, the conclusion of the study was that “*the forest management practices associated with forest certification appears to benefit biodiversity in managed forests”* (van Kuijk et al., 2009).

3.4.2 Nagoya Protocol

Nagoya protocol is a global strategic plan on how to protect the biodiversity and ecosystems of the world that was developed in 2010. The protocol is connected to the United Nation convention on biological diversity and is divided into 20 goals that shall be met until 2020, some of them before that (Hagberg and Terstad, 2012).

1. By 2020 will all humans will be aware about the benefits from biodiversity and what is needed to maintain it. In order to achieve this, an action plan is need to be developed to include the biodiversity awareness in all levels of the education system.
2. By 2020 biodiversity values will be integrated in national and local strategies and planning processes for development and anti-poverty-program, as well as include biodiversity in national account systems in a suitable way. Consequently, national inventories and investigations must be conducted of how large the ecosystem services are in monetary measures and before that develop consensus methods for calculating this as well.
3. By 2020 all incentives and subsidies that are harmful for the biological diversity discontinue shall be phased out, or changed so that their negative impact are minimized or can be avoided. Positive incentives shall be implemented that supports sustainable development and maintenance of biological diversity.
4. By 2020 governments, industries and other operators on other levels shall take necessary actions for obtain a sustainable consumption, and delimit the effects of use of natural resources within

the economic boundaries. This can e.g. be done by implement environmental taxes, so called green tax-switching policies.

5. By 2020 the losses form natural environments, including natural forests shall have decreased to at least half and where it is possible the losses shall be ended. Fragmentation and degradation of natural land types shall be decreased significantly.
6. By 2020 manage and assess all populations of fish, invertebrates animals and water living plants in a legal, sustainable and ecosystem services based approach, so that over-fishing is delimited.
7. By 2020 manage areas that are used for agriculture, water and forestry in a sustainable way so that maintained biodiversity is guaranteed.
8. By 2020 emissions of pollutants as wells as surplus of nutrients shall be limited to levels that do not harm the ecosystem function or the biodiversity.
9. By 2020 the invasive species and their spread shall be identified and priorities carried out. Actions on how to control the continued spread shall be taken so further establishment for these species are delimit as well. Those species that are prioritized shall be exterminated or under control.
10. By 2015 the total pressure from human operations against coral reefs and other vulnerable ecosystems affected by climate change and acidification of the oceans shall be minimized.
11. By 2020 at least 17 % of all land and sweet water areas, and 10 % of coast and ocean areas, that are of importance to biodiversity and ecosystem services shall be preserved. This shall be obtained by efficient and fair management, ecological representative and natural reserve arrangements, that are well integrated in the surrounding landscape.
12. By 2020 extinction of known threatened species shall be stopped and their conservation status improved, especially species that decreases most rapidly.
13. By 2020 the genetic diversity in agricultural crops and livestock and domestic animals and their wild relatives, as well as socioeconomic and cultural valuable species shall be secured. Strategies for minimize the genetic diversity shall be developed and implemented.
14. By 2020 ecosystems that delivery important service for water supply, health, provision and well-being shall be preserved by taking woman, indigenous people, and local community’s needs in to consideration, as well as the poor and vulnerable.
15. By 2020 the ecosystem stability and the importance of biodiversity for the world’s coal-supply will be improved trough protection and preservation. So that at least 15 % of the degraded ecosystem are restored and thus lead to decreased and less adjusted to global warming as well as to cancel the desert spread.
16. By 2015 the Nagoyo protocol “Access to genetic resources and the fair and equitable sharing of benefits arising from their utilization” shall be implemented in line with national legislation.
17. By 2015 every contracting part developed, shall start to implement an efficient and up-to-date national strategy and action plan for biodiversity built on participation.
18. By 2020 indigenous and local society´s traditional knowledge, traditions and customs that is of relevance to sustainable usage of biodiversity and their usage of natural resources, shall be respected in relevant international obligations.
19. By 2020 the knowledge, the scientifically base and technologies connected to biodiversity and its values, state and trends as well as the consequences of decreased biodiversity shall be improved, spread and applied.
20. By 2020 the mobilization of the financial resources from other sources for implementation of the strategic plan for biodiversity will be increased majorly relative today. As in line with the “Strategy for Resource Mobilization”.

(Hagberg and Terstad, 2012)

TEEB

TEEB "The Economics of Ecosystem and Biodiversity", is a series of reports from United Nations on how ecosystems services, especially connected to biodiversity, can be evaluated in monetary terms and how these evaluations can be used in decision making for counties, communities and companies (TEEB, 2012). TEEB point out that ecosystem services must be included in economic analyses even though it is not possible to put a monetary value of the service. If it is not included, ecosystem service will not be considered as services with a value for the human consciousness. For companies it would mean including environmental damage cost in annual reports together with all the other external expenses (Hagberg and Terstad, 2012).

3.4.3 Sustainability Criteria for Biofuels

There are some European directives and political instruments linked to biofuels and sustainability. Fuel Quality Directive and Energy directive are examples of these and a briefing of them are presented below.

Fuel Quality Directive

In order for a biofuel to be approved for financial support, there are a couple of sustainability criteria's that the biofuel have to obtain (SFS, 2010:598). This directive is a part of the European Fuel Quality Directive (98/70/EC).

1§ The biofuel most at least decrease the greenhouse gas emissions with 35% compared with fossil fuels, and includes the lifecycle of the biofuel from that the bio crop is grown until it has combusted in the engine. In 2017 this emission limit will be increased to a 50% greenhouse gas descend.

2§ Land where the biofuel crop is grown, may not be of any of the following types:

- Natural forest or other tree covered area with domestic species, that shows no signs of human intervention or ecological processes have noticeable been disturbed
- Grassland with high biodiversity values that without human intervention will maintain as grassland
- Grassland with high biodiversity values that with human intervention will maintain as grassland, with exception if it is necessary to gather natural resources to maintain the status of the grassland
- Areas that are assigned as nature conservation area
- Except if it is necessary to harvest the resource to maintain the lands status as grassland

3§ Biofuel may not be produced from areas that is conservation areas in order to protect rare, threatened or endangered species.

4§ Land where the resource of the biofuel is grown may not be of any of the following types:

- Wetland, land that is during the whole year or a dominating part of the year is covered with water.
- Continuous tree-covered areas, that is areas that include more than 1 hectare with trees higher than 5 meters and a tree-crown coverage more than 30% or existing trees that can meet this values.

5§ Biofuels may not be produced from areas that have been classified as peatland, provided that the growing, harvest or felling of the resource, result in drainage of former un-ditched land.

6§ Biofuels produced on agricultural resources in the European Union shall follow the ordinance 6.1 (EG) 73/2009 that involves direct support for farmers.

Policy Instruments for Biofuels

In order to increase the biofuel production of alternative biofuels to ethanol, different management instrument must be implemented. The quota system that exist in Europe today premium blend-in-biofuels, thus biofuels such as biogas and DME that are driven independently are disfavoured. One way of supporting that kind of biofuels is to implement productions target support for second generation biofuels. This was up on the agenda but was not permitted.

Moreover the European Commission has proposed a change in the Renewable Energy Directive and Fuel Quality Directive in order to, among other, reduce the effects from indirect land use change (European Commission, 2012). This will be achieved by ensuring:

- Biofuels from new installations shall emit at least 60% less greenhouse gases than conventional fossil fuels.
- Emissions that might be caused by indirect land use change must be reported in the reporting of fuel providers and EU countries. This emission-estimations will be done by estimating emissions that would take place globally when land is used for growing crops for biofuels in EU instead of crops to food and feeding (estimating iLUC emission values)
- Only half of every EU country´s 10% renewable target in the transport sector shall be meet by first generations biofuels, the second half shall be meet by the 2nd and 3rd generation biofuels that do not compete with food and feed crops production.

3.5 Methods for Analysing Biodiversity in LCA

The Rio convention´s definition of biodiversity is described as "*the genetic diversity within a specific species or a population, the diversity of species in an ecosystem or an area and diversity of ecosystems in an area"* (UNEP, 1992). In Table 5 different biodiversity indicators for different biodiversity components are conveyed together with examples of assessment tools and methods (Curran et al., 2010).

Table 5. Biodiversity indicators across hierarchical components (genes, species, communities' ecosystems) and suggestions of assessment tools and methods (Curran et al., 2010).

hierarchical components	biological attributes			assessment tools and methods
	composition	structure	function	
genes (biotic)	heterozygosity, allelic diversity, % polymorphic loci, genetic variance, phylogenetic diversity	chromosomal or phenotypic polymorphisms, physical genetic distance, effective population size, generation overlap, heritability	mutational diversity, mutation rate, duplication rate, selection intensity, rate of genetic drift, gene flow	visible polymorphisms, molecular markers (protein electrophoresis), DNA markers (microsatellites, DNA sequencing), parent-offspring regression, sibling analysis
species (biotic)	(meta)population size and number, absolute or relative abundance, frequency, biomass, cover, intactness, density	size, morphological variability, physiognomy, population structure, home range size and distribution in space, dispersal patterns, habitat requirements	metapopulation dynamics (drift, bottle necks, inbreeding, outbreeding trends) demographic processes (growth, reproductive, feeding, nesting, dispersal rate)	population censuses, time series analysis, remote sensing and GIS, habitat suitability index, species-habitat modeling, population viability analysis, species distribution modeling
communities (biotic, abiotic)	species richness, relative abundance, higher taxon diversity, phylogenetic diversity, number of endemics, invasive, threatened or focal species, similarity and turnover of species assemblages	habitat structural complexity, foliage physiognomy and layering, habitat density, gap density, volume, surface area, slope, aspect, rugosity index, nearest neighbor distance	nutrient turnover and cascades, functional group or guild diversity, number and strength of interspecific interactions (predator–prey, parasite-host), biomass production, extinction, colonization rates	remote sensing and GIS, aerial photographs, time series analysis, physical habitat measures, observation habitat descriptions, multispecies, local sampling techniques, multivariate integrative indices (Shannon–Wiener index, dispersion, layering, biotic integrity)
ecosystems and landscapes (abiotic)	patch diversity, richness, composition, number of ecosystems, relative or absolute area, area of seminatural vegetation in agriculture, emergent patterns in species distribution (richness, endemism)	patch shape and configuration (fragmentation, isolation, connectivity, spatial linkage), patch size frequency distribution, topography, river and shoreline profile	disturbance patterns and regimes (frequency, extent, intensity, seasonality), pattern metrics (patch turnover), erosion potential, geomorphic and hydrologic processes, land use patterns and trends	remote sensing and GIS, aerial photographs, time series analysis, spatial statistics, mathematical indices (pattern, connectivity, heterogeneity, layering, edge extent, diversity, fractal measures and autocorrelation)

In order to include biodiversity impacts in a LCA, data must be collected and calculated into a characteristic factor. The characterization factor makes it possible to convert an impact derived from the life cycle impact inventory into an impact category that is the mutual for that impact environmental category. This means that the impact can be weighted along with the other impacts contributors and subsequently be compared with the other contributors as well as the other environmental impact categories (ISO 14040, 2006).

Methods for measuring biodiversity impacts can either be inductive or deductive (Lindqvist, 2014). The inductive methods have a bottom-up-approach and could involve investigating the species number in an area in order to draw a conclusion of the biodiversity state. Methods that are of inductive nature can measure for example species richness, functional diversity, species abundance or evenness (Lindqvist, 2014). Methods that are deductive nature on the other hand, have a top-down-approach. These methods are dependent on expert statements and the indicator for biodiversity impact can be ecosystem scarcity or ecosystem vulnerability (Lindqvist, 2014).

There are thus many challenges for assessing impacts on biodiversity in LCA (Geyer et al., 2010b). The first obstacle is the difficulty to assess the whole complexity of biodiversity. Biodiversity is as mentioned before not only constituted of species diversity, it includes diversity within species and also between ecosystems, therefore it includes diversity of all type of aspects of life and nature. The second complexity is how to approach the spatial aspects of biodiversity. The impact on biodiversity requires that the location of where the land use occurs is considered. Greenhouse gases, which are an important impact category in life cycle assessments, are not dependent on where it has been emitted, the impact on the environment will be globally and are therefore not locally dependent to the same extent. Different ecosystem and land use types will also respond differently to changes in the biodiversity, for this reason some biodiversity indictors can be suitable for one land use type but not for another. The third complication is the nonlinear relationship between species viability and land use. Depending on the productivity of the land, a change in intensity of the crop production might either have major or minor effects on the biodiversity; and it is not possible to forecast the effect (Geyer et al., 2010a, Geyer et al., 2010b).

3.5.1 Land Use

As stated in MEA rapport, the major damaged to biodiversity is caused by land use change (Mace et al., 2005). UNEP/SETAC Life Cycle Initiative developed a framework on how to consider land use impacts for life cycle assessments and this approach is considered to be the foundation within a majority of all characterization factors methodologies (Milà i Canals et al., 2007). Land use can be divided in to three different categories: occupational, transformational and permanent impact (Schmidt, 2008). Land use can be caused by agriculture, forestry, mining, house-building or industry, and lead to both impacts on soil quality as well as on biodiversity and indirect to ecosystem services (Milà i Canals et al., 2007).

The permanent effects on the land are irreversible impacts that can either be caused by transformation or occupational activities. In Figure 4 are the three different impacts conveyed as a function of time and the difference in biodiversity quality A-D represents the permanent impacts. Transformation impacts from land transformation, which is represented by the triangular area, represent the biodiversity degradation caused by transformation. Occupation impact from land occupation, which is presented by the parallelogram in the figure, is representing the biodiversity degradation caused by occupation. Different literature denotes the permanent impact as transformation impact as well, hence the major impacts that are defined in literature is the transformational and occupational impacts (Schmidt, 2008).

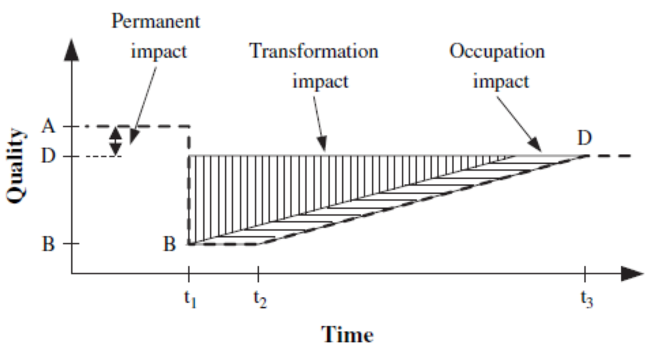

Figure 4. Different land use impacts as a function of time and quality (Schmidt, 2008).

Land uses are in reality a mix between the occupational and transformational impacts and whether the impacts are permanent or not, are difficult to predict. A transformational process generally results in a large change in quality and is normally followed by a smaller change in quality caused by occupational process (Milà i Canals et al., 2007). Possible effects from human activities on land use are explained and conveyed in Figure 5.

Q_{his} represent the quality of the land before human intervention which is the state before t_0 in the time line; the land could be a natural forest. At t_0, different transformation processes occur such as e.g. weeding, ditching or regeneration felling. The decrease of land quality after this transformation is represented of the difference between Q_{his}-Q_0. Thus, depending on initial land quality the transformation process can either have a negative or positive impact. From t_0 to t_{fin} an occupational process occur, which could be using a forest for forest production. This could either have a negative, neutral or positive affect on the land quality, but negative in most cases of occupation. From the time point t_{fin} to t_{rel} there are no human intervention, instead natural spontaneous land changes occur which generally increases the land quality. This could be increased soil quality and biodiversity if natural succession take place. After t_{rel} the land reaches a new steady-state in land quality if no new land use follows (Milà i Canals et al., 2007).

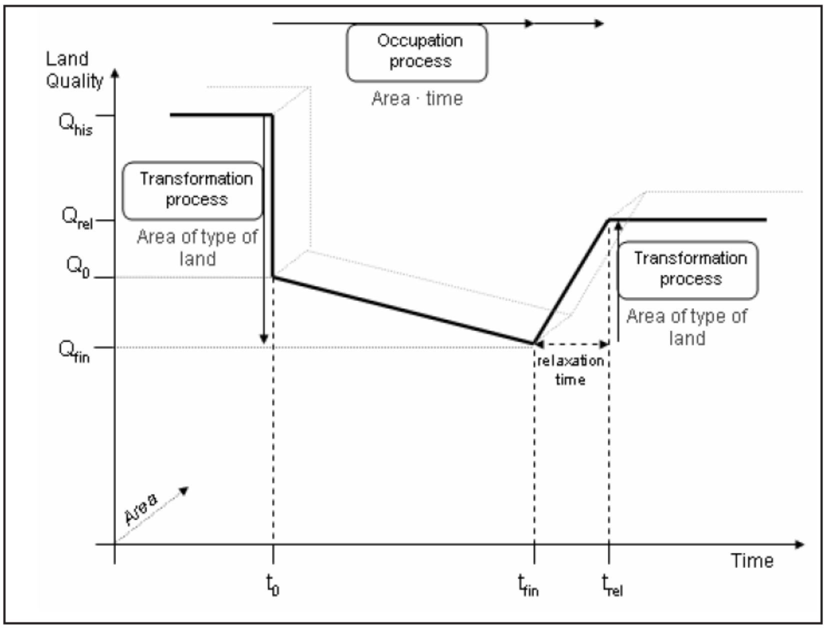

Figure 5. Evolution of land quality with land use interventions (Milà i Canals et al., 2007).

3.5.2 Reference state

In order to analyse and calculate the impact from the occupation and transformation of land use, a reference state is needed in the temporal-spatial model. The most used reference state is Potential Natural Vegetation (PNV) and was introduced by Tüxen (1956). PNV is assumed to represent the vegetation that would have been developed if no human intervention would occur (Milà i Canals et al., 2014).

Historic natural land state and potential state after relaxation are mentioned in literature as a common used reference state (Milà i Canals et al., 2007). Thus, that reference do not take into consideration the dynamic of nature of land evolution and the problems concerning how to deal with allocation between successive land uses. The method that UNEP recommend to use is the term dynamic reference situation, which is set as baseline in Kyoto protocol terms, this reference refers to the non-use of the area (Milà i Canals et al., 2007).

Two other common reference states are considered to be: *Best Potential Area,* and *Regional Average Species Richness.* Best Potential Area is a reference where the studied land is compared with a land type in the region with highest biodiversity and thus highest ecosystem quality. Whereas Regional Average Species Richness is the average species richness in the studied region (Koellner, 2003). A modified version on this reference is the (quasi-) natural land cover, that is a mix of forest, grassland, shrubland, rivers etc. in the studied region (Koellner et al., 2013).

3.5.3 Analysing Biodiversity on Different Scales

Biodiversity can be examined on different spatial scales. Figure 6 convey spatial hierarchy of viewing biodiversity.

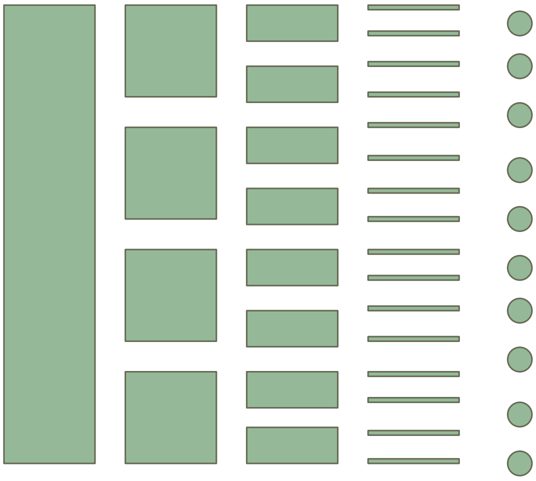

Figure 6. Biome, eco-region, region, habitat and ecosystem

Biome: A vegetation area on continental or global scale which is defined by its species interaction, geology and climate. Tropic rainforest, grassland or tundra is examples of biomes.

Eco-region: "Large unit of land or water containing a geographically distinct assemblage of species, natural communities and environmental conditions" (WWF, 2014). Eco-regions can be explained as a complex pattern all over earth determined by climate, geology and the evolutionary history of the planet (WWF, 2014).

Sweden consist of several types of ecoregions, the main types are Baltic mix forest (Figure 7; costal and plain level of topography with low pH soils that supports a mixed forest of beech and oak. In inland the flora consist of European hornbeam, scots pine and linden), Sarmatic mixed forest (Figure 8; mixed conifer-broadleaf plant that dominates by Norway spruce and scots pine), Scandinavian and Russian taiga (Figure 9; boreal/taiga zone). Scandinavian montaine birch forests and grasslands (Figure 10; extensive vegetated areas and dwarf birch forest) (Hogan, 2011).

Figure 7. Baltic mix forest (Hogan, 2011)

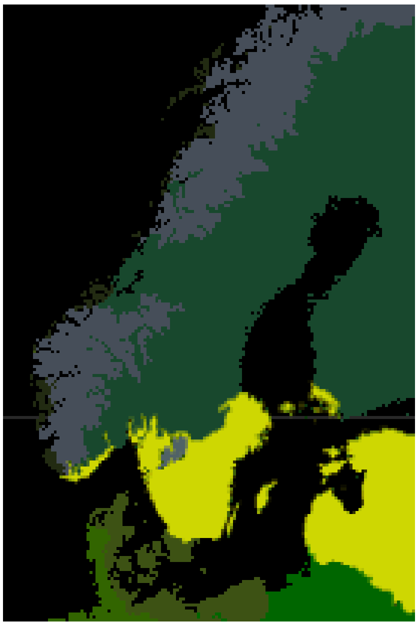

Figure 8. Sarmatic mix forest (Hogan, 2011)

Figure 9 Scandinavian and Russian taiga (Hogan, 2011)

Figure 10 Scandinavian montaine birch forests and grasslands (Hogan, 2011)

Habitat: an ecological or environmental area that is inhibited by certain species of plants and animals or organisms. The physical factors such as soil type, moisture, range of temperature, availability of light as well as biotic factors for instance availability of food, and predators is also important factors that compose the habitat.

Ecosystem: A dynamic complex of plant, animal and microorganism communities and the non-living environment interacting as a functional unit (Reid et al., 2005)(Reid et al., 2005). Ecosystem services are the benefits organisms and humans obtained from ecosystem as mentioned in section 3.1.

Analysing biodiversity on these different scales requires different types of data and altered methods. Figure 11 conveys the distribution of negative, neutral/both or positive impact on biodiversity with different spatial scales for different reviewed publications (Immerzeel et al., 2014). It was only possible to detect a positive impact on the biodiversity when the spatial scale was defined as field level. It can therefore be difficult to notice a positive effect at a larger geographical scale. More research must be done within this area to confirm this conclusion (Immerzeel et al., 2014).

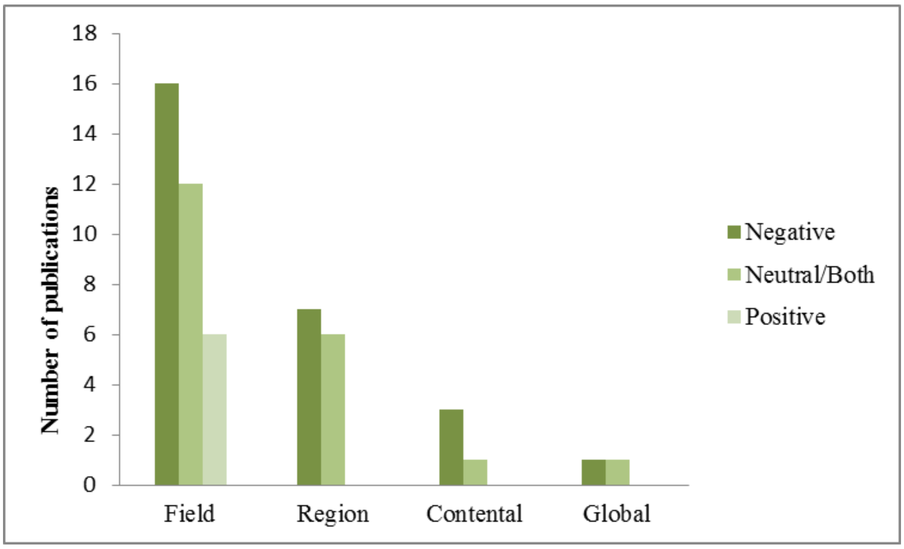

Figure 11. Number of publications that had a negative, neutral/both or positive impact on biodiversity with in different spatial scales. Based on (Immerzeel et al., 2014)

Biodiversity impact can subsequently be monitored and examined on local, regional or global scale. Moreover a land use change can have an impact on all above mentioned scales simultaneously, since a biodiversity loss in one small local area might indirectly have an impact on a global scale (De Baan, 2013).

3.5.4 Biodiversity Indicators

As aforementioned there are several approaches to measure and evaluate biodiversity, in Table 6 different impacts pathways together with altered indicators are conveyed (Milà i Canals et al., 2007).

Table 6. Possible indicators at midpoint and damage levels for different impacts from land use and their requirements of LCI information (Milà i Canals et al., 2007).

Impact pathway	Indicator	Level	LCI modelling aspects
Biodiversity (intrinsic value) – Natural environment	PDF [a] or PAF [b]	Damage	It may be fruitful to work with these indicators as they are currently used by eco-toxicity categories (Jolliet et al. 2004). However these indicators do not reflect other important aspects like the relative scarcity of species
	% of threatened vascular plant species in region	Midpoint	Description of the land use interventions to render possible a link to empirical data on number of vascular plant species per km^2 (Müller-Wenk 1998)
	Red-listed species; key features	Midpoint	Species correlation with habitat, the ecological habitats found and affected area (Kylakörpi et al. 2005)
	Global species diversity; nature protection	Midpoint	Effects of agricultural activities (e.g. nitrogen flows; number of grass cuts; etc) on eleven groups of indicator species (Jeanneret et al. 2006)
Biotic production potential – Natural resources	Surplus energy (+ possibly other interventions) [c]	Damage	Requirements to restore soil quality through e.g. addition of organic amendments and other soil fractions (clay; sand); other interventions may include e.g. gaseous emissions from organic amendments (Milà i Canals et al. 2006)
	Deficit of Soil Organic Matter (SOM) [Mg SOM year]	Midpoint	Changes in SOM due to the studied system, which may be obtained by different means (Milà i Canals et al. 2006); additions of organic matter (e.g. manure; crop residues); effects of agricultural practices on degradation rates
	Eroded soil [kg soil lost]	Midpoint	Measured or calculated with empirical or contextual models of the soil-erosion process (e.g. USLE[d] or SLEMSA[e]), requiring slope gradient; rainfall intensity; vegetation cover; soil type
Ecological soil quality – Natural environment	To be explored, according to the affected impact pathways	Damage	To be explored, according to the affected impact pathways (e.g. global warming, toxicity…)
	Combinations of 9 indicators: pore volume; SOM (see above); microbial activity; etc.	Midpoint	Effects of agricultural activities (e.g. heavy metals flows; preceding and following crop; etc) on nine soil quality indicators (Oberholzer et al. 2006)

[a] Potentially Disappeared Fraction of species
[b] Potentially Affected Fraction of species
[c] the impacts from land use-based activities are not properly represented by energy indicators (Walk et al. 2005, Huijbregts et al. 2006) and therefore the 'surplus energy' indicator should be combined with other emissions related to the restoration activities, leading to other damages
[d] Universal Soil Loss Equation (Wischmeier and Smith 1978)
[e] Soil Loss Estimation Model for Southern Africa (Elwell and Stocking 1982, Elwell 1984)

These indicators are not the only ones for measuring biodiversity, thus the most common approach to measure biodiversity is to use species richness as indicator.

Species Richness

It is in the species level that the term biodiversity is most applied by scientist, even though higher classification of diversifications occurs as well. Among species based indicators species richness is the most established one and is defined as number of species in a community, landscape or a region for a specific taxonomic group (birds, plants) (Colwell, 2009).

Species diversity and species richness is often considered to be the same thing, thus species diversity is a matter of fact number of species found in a particular total area (Colwell, 2009).This difference can be explained by e.g. 30 species on a 100 m^2 area versus species richness of 300 species for a certain ecosystem.

Species richness/species diversity can be measured in many different ways; Alpha diversity is the species richness that can be measured in absolute species numbers. Suppose one investigate one square meter land and measure all the species within that area (Whittaker, 1972). Alpha diversity is a way to express the species diversity for one land use type on a local scale. Beta diversity on the other hand, defines diversity from local to regional scale and can be expressed as the difference in species richness between two different habitats (Whittaker, 1972, Koellner and Scholz, 2008). The diversity is high when the studied areas differ with respect to their species community and low when the difference between the species composition with in the habitats are similar (Koellner and Scholz, 2008).

The third species diversity concept is gamma diversity. It is defined as the total species richness in a region or ecoregion and can be expressed as the product of difference in alpha diversity between different communities/habitats and the difference in beta diversity (Geyer et al., 2010a).

Direct measurement of species richness is thus not considered to convey the whole multidimensional picture of biodiversity according to MEA (Mace et al., 2005). The reason for this is the most common used indicator for biodiversity is for four reasons mentioned in (Michelsen, 2008): species richness is often used as a synonym for biodiversity by many authors and is also considered by many to be the essence of biodiversity. Moreover, species richness is widely understood and not as complex as the concept of biodiversity. Species richness is also measurable as on the contrary to the broad concept of biodiversity and lastly, much data is available for species richness around the globe (Michelsen, 2008).

Against this background, studies have shown that only 10-11 % of the variation in species richness of one taxonomic group can be predicted by the change in richness of another group (Michelsen, 2008). Koellner (2003) argues that plant species correlate very well with other species such as insects, whereas a field study on 16 different Swedish farms showed no significant correlation between vascular plants and other taxonomic groups studied in the case (Schmidt, 2008).

New studies show that species richness as a sheer number of species may not be the best indicator for biodiversity, it has been shown that specific species and species functions are far more important in revealing new global biodiversity hotspots (Stuart-Smith et al., 2013).

SAR

Species-area relationship (SAR) is one important part of ecology and biogeographic and explains how species number and area size relates to each other. The relationship has been found through striking regularity in the pattern of increase in species number as larger and larger areas are investigated (Koellner, 2003). The function for this relationship was established by (Arrhenius, 1921).

$$S = cA^z \qquad \textit{Equation 3-1}$$

The c parameter represent species local density and are dependent on the taxonomic group and the region studied. The z parameter is the slope of the relationship and is dependent on the type of SAR (ocean islands, nested areas in a region, or biological providence). The z value is also influenced by other factors such as the scale of sampling (Sala et al., 2005).

This pattern can be seen when plotting number of species or the logarithmic number of species is plotted against area or logarithmic area. The pattern of the log-log power curve or semi-log exponential curve shows an increased species number with increased area (Colwell, 2009).

There are several factors that contribute to increased number of species with increased area. The first reason is that the larger the area is, the more habitats can be found and therefore more specialized species can be found. Moreover, when comparing isolated areas, such an island or habitat fragments, with larger areas, larger units will have lower extinction rates and a somewhat higher immigration rate. Another problem is that larger areas have a larger number of individuals and a higher probability to include rare species, which may be problematic when sampling (Sala et al., 2005).

The Species-Area relationship has been called one of the few universal patterns in ecology (Colwell, 2009) and is well documented in more than 150 articles for many taxonomic groups and many systems, and was inter alia used in the MEA 2005 report to estimate the future effects on biodiversity trough land use change and climate change (Sala et al., 2005).

Rarefaction Method

One widely used method for estimating species richness is to use the rarefaction method developed by (Heck et al., 1975, Hurlbert, 1971). The equation calculates the probability to find a new species based on drawing an individual or a sample with different species from a larger set of samples. This larger set of samples can consist of many small samples with equivalent area sizes, taken from same type of area, thus differing species inventoried. Figure 12 convey the two different approaches to estimate the total number of species within the whole sample. In the beginning of the drawing of individuals or samples, the probability of finding a new species is large, whereas that probability decreases after time and eventually the plot reaches an asymptote and no new species can be found (Gotelli and Colwell, 2001).

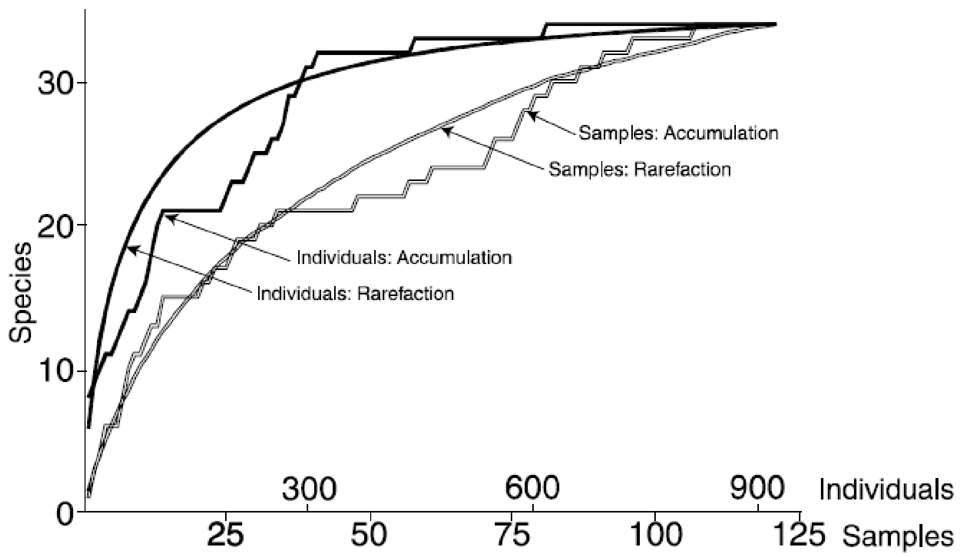

Figure 12. Species- sample/individual based rarefaction curve as well as accumulation plot (Gotelli and Colwell, 2001).

The method can be used for either calculating expected species on a type of land based on species number and types of species or sample numbers and species. Calculating rarefaction curves based on individuals are generally resulting in a slightly higher expected species number, see Figure 12 (Gotelli and Colwell, 2010). Whereas, the sample-based rarefaction is more realistic treatment of the data and is more often used in biodiversity studies. One other important reason to use the sample-based calculations is that it can for some species be difficult to distinguish individuals and therefore not be suitable to have an individual based calculation (Gotelli and Colwell, 2001). For example how do one calculate the number of individuals for heathers *Calluna vulgaris*[6].

The equation for estimating number of species is the following:

$$E(S_n) = S - \frac{\sum_{i=1}^{S} \binom{N-N_i}{n}}{\binom{N}{n}} \qquad \textit{Equation 3-2}$$

$E(S_n)$ is the expected number of species when randomly choosing a sub-sample n from all the N in the sample. N is the total number of plots in the sample, N_i the number of plots where *i* is found, *n* the number of randomly chosen plots, and S the total number of species on all the plots. Given a fixed number of species S and a fixed number of species is dependent on the species abundance. The more abundant a species is, the more plots N_i, are inhabited by it. The expected number for *n* plots increases

[6] Ljung på Svenska

with the increase in abundant species, since it is more likely that a common species is found than a rare species (Koellner, 2003).

This method for estimating number of species is commonly used for estimating number of species found in a certain area, and thus is used for estimating species-area relationship.

Relative Abundance

Species that belongs and constitute to a community or an ecosystem, differ in relative abundance. Abundance means in ecology the concept of relative representation of species in a specific ecosystem. Usually most individuals belong to a few common species in a community. The more individuals found of one species in a community- the more abundant it is. At the same time there are few individuals of rare species within the community or ecosystem (Colwell, 2009). This concept is described in Figure 13.

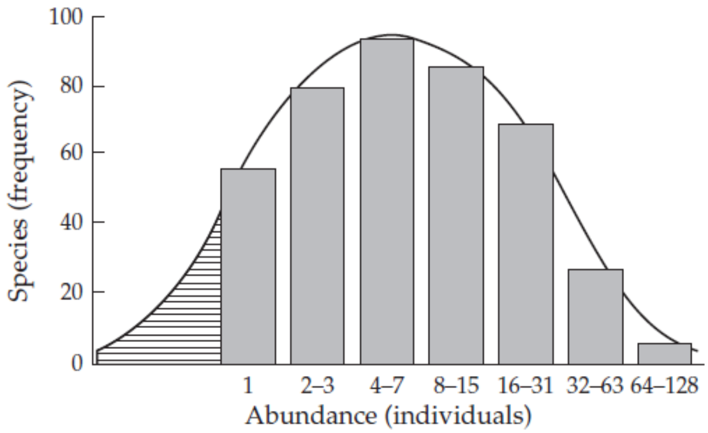

Figure 13 Abundance of individuals of species (Gotelli and Colwell, 2010).

Functional Diversity

Functional diversity is defined as the variety and number of species that fulfil different functional roles in a community or ecosystem (Colwell, 2009). Functional diversity (FD) is a measurement for biodiversity by investigating species phenotypes[7] and the numbers of individuals of each species are critical for determining the nature and strength of the relationships between species diversity and a range of ecological functions (Stuart-Smith et al., 2013).

There are two different ways of calculating functional diversity: discourteous measures, which mean group/society-based and classification of species traits according to functional group richness, and continuous measures, which do not involve division among functional groups. Instead the continuous measure starts with calculations of the multivariate distance between each pair of species in an assemblage (de Souza et al., 2013). The group-based measures may not be suitable to use for all ecosystem processes thus a large amount of decisions and assumptions are required such as where to place the boundaries of each group and number of groups to include (de Souza et al., 2013).

The FD index is expected to increase the environmental relevance to the land-use biodiversity impact indicator, by enhanced account for each species role in an ecosystem and its stability. Generally if one species is not found in a certain land use type in relation to the reference land use this represents species loss, the same applies for the FD indicator. Thus this may not affect changes in functional diversity since one or more species may play the same functional role in the ecosystem (de Souza et al., 2013).

[7] The noticeable traits of an organism that is decided by genetic disposition in collaboration with the environment, this can be color and size of the eyes for example.

3.6 Potential Ecosystem Damage (Koellner)

This method is chosen to be tested in the case study. The motivation for this is described in section 4. For this reason this method is more thoroughly described.

3.6.1 Characterization Concept

Thomas Köllner or Koellner that he calls himself in later publications, is a German scientist who developed a method for investigating how the land use and land use change has an impact on biodiversity. The method is of inductive nature and is based on species diversity (Koellner, 2003). In his PhD thesis "Land use in product life cycle and ecosystem quality" the methodology to calculate Ecosystem Damage Potential ($EDP^{sp\text{-}div}$) is described (Koellner, 2003).

Basic principles of the EDP characterization factor (Koellner, 2003):

- Land occupation and land transformation are regarded as basic types of interventions. *Land occupation* is considered to be a continuous intervention, which means that no spontaneous land transformation can occur. *Land transformation* means a change from one land use type to another one, it can either be due to human intervention or not. Restoration of land after an occupation is considered to be a special kind of transformation.
- The assessment of land use is *not site-specific*. The characterization factor takes information about land use type, management style and bio-geographical region in to account, but not the exact geographic location.
- The method can be used across *all land use types*.
- The specific endpoint for effect analysis is the *diversity of the regional species-pool*. That is, the endpoint considered is on the ecological level and not entirely on the abiotic impact level.
- The *number of species missing* on the plot in comparison to a reference is the indicator for impacts on the local diversity of the species-pool.
- *Vascular plant species richness* is considered as a proxy for the total species richness and all species are equally weighted.

Potential Ecosystem Damage for occupation

Land occupation damage integrated over time taking species diversity into account (D_{occ}^{sp-div}) can be calculated as:

$$D_{occ}^{sp-div} = EPD_{occ}^{sp-div} * Area * Time_{occ} \qquad \textit{Equation 3-3}$$

And *Potential Ecosystem Damage for transformation*

$$D_{trans}^{sp-div} = \left(\frac{EPD_{trans}^{sp-div} * Area * Time_{occ}}{2}\right) * Area * Time \qquad \textit{Equation 3-4}$$

Local and Regional effect

The concept of the EDP characterization factor can be divided into a local and a regional effect. The purpose of local factor is to capture the value of biodiversity for ecosystem functions, whereas the intention of the regional factor is to reflect the conservation value of biodiversity (Koellner, 2003). Conservation status of species can only be assessed in the context of a region, thus ecosystem functioning is better to assess on a local scale (Koellner, 2003).

This difference in local and regional effect can be explained by the following example from (Koellner, 2003). Imagine two regions, each completely composed of two land use types: region X that have a large proportion of land use type M and a small proportion of land use type B. Region Y on the other hand, have a rather small proportion of M but a larger proportion of land use type B. Suppose that the ecosystem quality of land use type M is lower than B. This would mean that the average ecosystem quality of region Y would be less than in region X.

$EQ_{region\_Y} < EQ_{region\_X}$

If one look at local scale one unit of land of land use type B were transformed into land use type M, the damage on local scale would be equal in both regions.

The amount of damage would be the difference between levels of quality in M and B multiplied by the area transformed. Whereas looking at the whole region, the local transformation would be more damaging in region Y than region X, since land type B is more exceptional in region Y. Therefor the regional effect of land occupation or transformation changes are considered to be a averaged quality of a regions ecosystem changes (Koellner, 2003).

EDP is first calculated on local and regional scale and then added in to one EDP.

$$EPD_{total} = k_l \frac{EDP_{local}}{n_l} + k_r \frac{EDP_{regional}}{n_r} \qquad \textit{Equation 3-5}$$

The procedure for developing the characterization factor for land use and biodiversity have the following flowchart appearance for local effect:

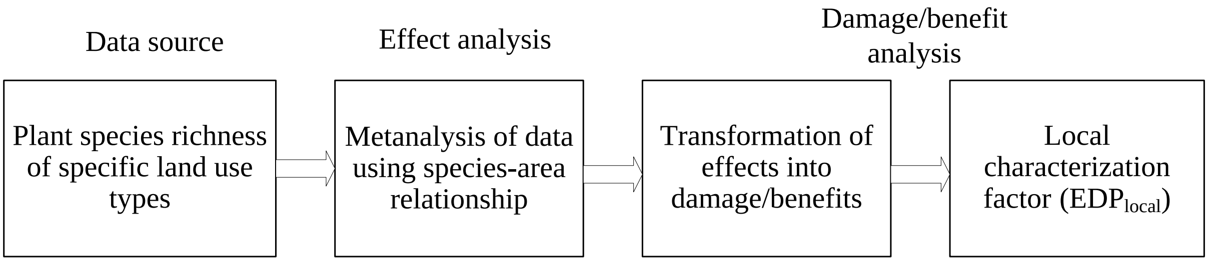

Figure 14 Structure of model to derive characterization factors, thus local effects is only considered in this model whereas in the original structure is regional effects included (Koellner, 2003).

3.6.2 EDP_{local}

The characterization factors that Koellner developed are as aforementioned based on number of species absent in a specific land use type compared to a reference. The EDP calculations are based on the species area relationship (SAR) concept that is described in section 0

The data can be collected from two different types of sources:

Type 1: species richness for different areas is available. If this type of data is found, one can draw a regression line directly from the plots. S_{100} are calculated as an average of all the plots relocated parallel to A=100m^2 along the regression line in the log-log species-area diagram.

Type 2: species richness that is based on numbers of species in several equally sized plots. In this case it is not possible do establish a direct species-area relationship; instead the “rarefaction method” is used. The method estimates species richness in all plots from n=1 to N, where N are all the total number of plots in the sample. Due to that the area is known, the estimated species richness can be plotted for different areas (Schmidt, 2008) .The rarefaction method is further described in section 3.5.4.

3.6.3 Transformation of Local Effects into Damage/Benefit

In order to calculate the ecosystem damage potential on the local scale (EDP_{local}) the observed effects from the land use must be known. The observed effects from land use are the difference or change in species number per area. Species number per area could either be expressed in absolute species (alpha) or relative species (beta), the relative species number is the number species compared with a reference. Koellner chooses to use *Regional Average Species Richness* as reference for assessing species richness on local plots. Koellner chooses to use two different land types with different land use intensity. One with low intensity and one with high intensity (Koellner, 2003). The reference state is needed for two reasons, to divide absolute figures (species number per area) to get a relative measure, in order to make a comparison between different land use types and the second reason is to be able to trace back changes in time resulting from land transformation (Koellner, 2003).

The effect damage function can either be calculated through a linear or a logarithmic function. They both describes the functional relationship between species richness and ecosystem processes and are based on ecosystem science (Koellner, 2003).

Linear effect-damage function:

$$EDP_{local} = 1 - \frac{S_{occ}}{S_{ref}} \qquad \textit{Equation 3-6}$$

Where S_{occ} is the species richness of the occupied area for $100m^2$ and S_{ref} is the species richness for the regional reference.

Nonlinear effect-damage function:

$$EDP_{local} = 1 - \left\{a ln\left(\frac{S_{occ}}{S_{ref}}\right) + b\right\} \qquad \textit{Equation 3-7}$$

Where a and b are parameters that have been estimated by Schläpfer et al. (1999) that is based on the relationship of how many percent species that are sustained in an ecosystem and how much of the ecosystem processes that is sustained. The parameters of the function were estimated from the following equation from Schläpfer et al. (1999) (Koellner, 2003):

$$Ecosystem\ process = 0{,}27 * ln\left(\frac{S_{occ}}{S_{ref}}\right) + 1 \qquad \textit{Equation 3-8}$$

That results in the new non-linear equation:

$$EDP_{local} = 1 - \left(0.27 ln\left(\frac{S_{occ}}{S_{ref}}\right) + 1\right) = -0{,}27 * ln\left(\frac{S_{occ}}{S_{ref}}\right) \quad \textit{Equation 3-9}$$

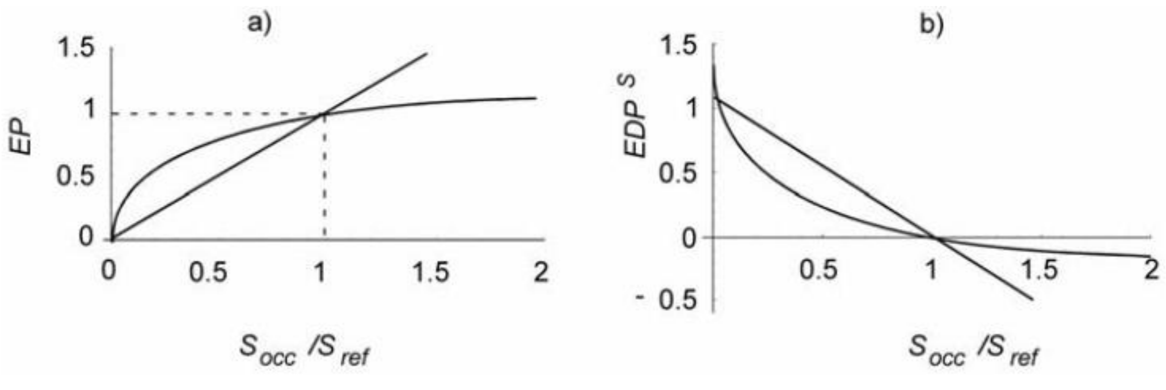

Figure 15. The linear and non-linear relationship reflecting relative species richness (S_{occ}/S_{ref}) and ecosystem processes EP in a) and in b) relative species richness and EPD (Koellner and Scholz, 2008).

The non-linear function supports the redundant species hypothesis which is that the addition of one species results in a decrease in the marginal growth of utility in terms of ecosystem processes (Koellner and Scholz, 2008).

3.6.4 $EDP_{regional}$

The regional characterization factor for ecosystem damage potential ($EDP_{regional}$) is based on the regional intensity land use and the number of species potentially lost by using a regression analysis (Koellner, 2003). Koellner performs two types of regional assessments, one that only take threatened species in to consideration and one that includes all species, threatened and not. By focusing on threatened species, the importance of conserving species diversity is stressed. Whereas taking all species in to account, the value of species diversity for ecosystem functioning is included (Koellner, 2003). The latter approach is congruent with the local scale effect and can therefore be added into a total damage effect. Thus if the focus is on the threatened species, an addition of the regional and local scale would require weighting the two characterization factors (Koellner, 2003).

Further information regarding this part of the methodology will not be described in this report. The reason for this is due to the time limitation, the complexity of this part of the method and the low contribution to the total impact characterization factor.

In (Koellner, 2003) a number of cases were conducted in order to exemplify the method. From these cases it was noticeable that the local damage on ecosystem was much greater than the regional (12% of the damage was assigned to the regional damage in one case, in another it was about 17%). The variation in contribution also depends on how the total damage is calculated and if weighting factors are taken in to consideration or not. The lower percentage was received when no weighting was taken in to consideration (Koellner, 2003). Not including the regional aspect in this thesis may for this reason be an acceptable delimitation.

3.6.5 Transformation Times

In order to calculate the damage of land use from transformation, information about the time which is necessary for transforming one land type to another is needed, see Table 7. High-intensity land use cover types are rather quickly to be reproduced. Whereas low-intensity land use types need longer time for restoration. Restoration is considered here as transformation towards a more favourable land type with or without human intervention. In addition to this, are the estimated time in year for transforming different land use types to their initial land intensity presented in Table 8 (Koellner, 2003).

Table 7. Restoration tome of ecosystem types (Koellner, 2003)

Restoration time (years)	Ecosystem (biotope types)
<5	Vegetation on arable land, pioneer vegetation
5-25	Species poor meadows and tall-herb communities, mature pioneer vegetation
25-50	Species poor immature hedgerows and shrubs, oligotroph vegetation of areas silting up, relatively species rich marshland, with sedges, meadows, dry meadow and heathland
50-200	Forest quit rich in species, shurbs and hedgerows
200-1000	Low and medium (immature) peatbugs, old dry meadows, and heathland
1000-10000	High (mature) peatbugs, old growth forest
>10000	

Table 8 Estimated times in years for transforming an initial land intensity into a final land intensity (Koellner, 2003)

	Final						
Initial	Agri_hi	Agri_li	Artifical_hi	Artifical_li	Forest_hi	Forest_li	Non_use
Agri_hi	-	10	<1	2	25	50	500
Agri_li	<1	-	<1	2	25	50	500
Artifical_hi	5	10	-	2	25	50	500
Artifical_li	2	5	<1	-	25	50	500
Forest_hi	2	2	<1	2	-	25	?
Forest_li	2	2	<1	2	10	-	?
Non_use	<1	<1	<1	2	10	25	-

Agri_hi: conventional arable, integrated arable, organic arable, fiber/energy crops, intensive meadow
Agri_li: less intensive meadow organic meadow, organic orchard, natural grassland
Artifical_hi: built up land, continuous urban, discontinuous urban, sport facilities, industrial area- part with vegetation
Artifical_li:greeb urban, rural settlement, rail embankments,
Forest_hi: forest plantations
Forest_li: semi-natural broad leafed forest, 10-90% conifer forest can be included (either moist or dry)
Non_use: heatland, hedgerows, peat bog

3.7 Indirectly Biodiversity Measure (Michelsen)

The second methodology that is tested in the Case study is the methodology proposed in the paper by Michelsen (2008). It is a new deductive methodology for including biodiversity aspects in life cycle assessment tested, which is instead focusing on at three indirect biodiversity indicators:

- The Ecosystem Scarcity (ES)
- The Ecosystem Vulnerability (EV)
- The Conditions for Maintained Biodiversity (CMB)

This method focuses on the key factors for maintained biodiversity for a specific land use type (CMB) combined with intrinsic values of the specific area (ES and EV)(Michelsen, 2008).

3.7.1 Methodology concept

These three indicators are assesses in order to quantify the land use impact of biodiversity, the concept based on which is described in section 3.5.1 (Milà i Canals et al., 2007). First, a quality measure of biodiversity must be established and assessed. Thereafter, the area affected must be recognized and lastly duration of the impact, see Figure 16. The quality of biodiversity (Q) is calculated according to the following equation:

$$Q = ES * EV * CMB \qquad \textit{Equation 3-10}$$

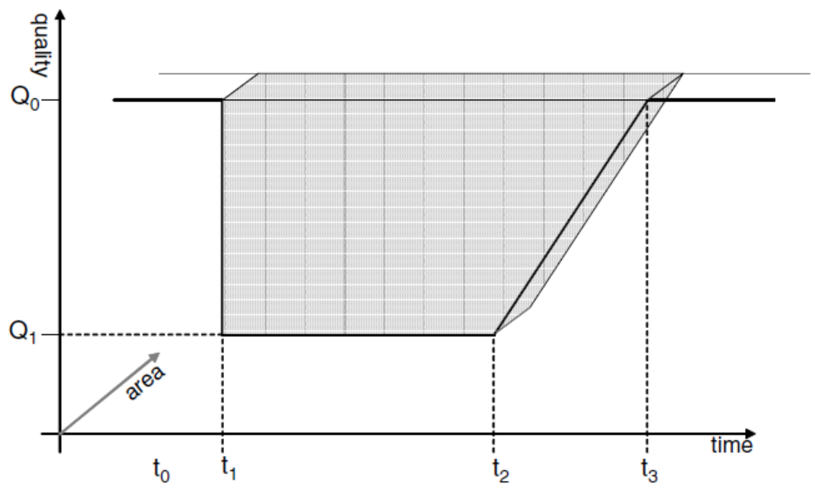

Figure 16. Changes in land quality and total impact due to land use changes (Michelsen, 2008)

Ecosystem Scarcity

Ecosystem Scarcity (ES) is an indicator that is based on the concept that biodiversity linked to scarce ecosystem normally would be more vulnerable than biodiversity linked to more widespread ecosystem. Hence, the population in the scarce ecosystem will generally be smaller and the risk for extinction due to stochastic processes is higher. The ES can be calculated as the invers value of area of the structure A_{pot} (e.g. biome, ecosystem, vegetation type) (Michelsen, 2008):

$$ES = \frac{1}{A_{pot}} \qquad \textit{Equation 3-11}$$

The indicator can be used for different spatial levels, and due to this, it is necessary to normalize the equation:

$$ES = 1 - \frac{A_{pot}}{A_{max}} \qquad \textit{Equation 3-12}$$

Where A_{max} is the most widespread structure at the relevant level. The structures are given different scores, and the structure with highest scarcity is given a score close to 1 and the other structures are given scores relative to this. This normalization will result in a linear relationship between potential area and ecosystem quality (Michelsen, 2008).

Ecosystem Vulnerability

Ecosystem Vulnerability (EV) is an indicator that gives information about the present total area pressure to an ecosystem type by relating the existing area of an ecosystem to the potential area. This means that the more of an ecosystem that is lost, the more vulnerable it is and the more valuable the remaining area is. This is based on the consequence of the species-area relationship. This can as well be applied on different structural levels (e.g. biome, ecosystem, vegetation type) (Michelsen, 2008).

$$EV = \frac{1}{1 - fraction\ lost} \qquad \textit{Equation 3-13}$$

Or

$$EV = \left(\frac{A_{exi}}{A_{pot}}\right)^{z-1} \qquad \textit{Equation 3-14}$$

A_{exi} is the existing area of the structure and A_{pot} is the potential area. The z parameter varies with different ecosystems but is often given 0.25 (Michelsen, 2008). This is the same z parameter that is used in the species area relationship.

The two options result in a score between [1,∞]. It is possible to normalize the value in the same manners as for ES by giving the most vulnerable structure the score 1, and other structures relative this this. However, it is difficult to find data on appropriate level and most likely it is needed to use an estimated value. World Wildlife Fund provides a three degree grade scale on conservation status for the different ecoregions of the world. This grading system does Michelsen use in absence of better data. A 1.0 score represent a critical conservation status, 0.5 for vulnerable and 0.1 represent intact ecoregion (Michelsen, 2008).

Conditions for Maintained Biodiversity

The core indicator of this method is the Conditions for Maintained Biodiversity (CMB), which contributes with information about present conditions for biodiversity in the area, if it is sustained, decreased or even improved. CMB is in fact an index based on different indicators known to be of importance to biodiversity in the studied area. The index is for this reason very ecosystem specific since the key factors of the index, differ for different ecosystems (Michelsen, 2008).

$$CMB = 1 - \frac{\sum_{i=1}^{n} KF_i}{\sum_{i=1}^{n} KF_{i,max}} \qquad \textit{Equation 3-15}$$

Key factors for biodiversity for the specific land use type are identified and KF_i are the status of different key factors within land use type:

- No impact
- Slight impact
- Moderate impact
- Major impact

Moreover, one must multiply the key factors with a relative importance factor:

- Slightly importance
- Moderate importance
- Major importance

$KF_{i,max}$ is the maximum score of KF_i , thus CMB can vary [0,1] independent of the number of included key factors. 1 indicates that the biodiversity in the area is not affected and 0 indicate that the land use have a negative impact on the biodiversity (Michelsen, 2008).

The Quality of Biodiversity

The quality of an area before a land use intervention is thus (t_0):

$$Q_{t_0} = ES * EV * CMB_{t_0}$$

And after an intervention (t_1):

$$Q_{t_1} = ES * EV * CMB_{t_1}$$

The difference between Q_0 and Q_i represents the biodiversity impact due to the land use activity and works as the characterization factor.

3.8 ReCiPe

The recommended method for characterization method from midpoint to endpoint of land use according to Life Cycle Assessment Handbook (Curran, 2012), is models for species diversity loss as developed in ReCiPe (Goedkoop et al., 2013). ReCiPe is used as method to classify, characterize, weight and normalize the data from the LCI. The method is a combination and development of the midpoint method which is used in Handbook in LCA (Guinée et al., 2002) and the endpoint method Eco-indicator 99 (Goedkoop et al. 1999).

The inventory data can be classified into 18 midpoints and three endpoints, see Table 9 below. There is one midpoint indicator for each midpoint and one endpoint indicator for each endpoint.

The endpoints are: Human health, Ecosystem and Resources with the endpoint indicators:

1- damage to human health (HH)
2- damage to ecosystem diversity (ED)
3- damage to resource availability (RA)

Figure 17 below convey an example of midpoint to endpoint for climate change linked to the human health and ecosystem damages.

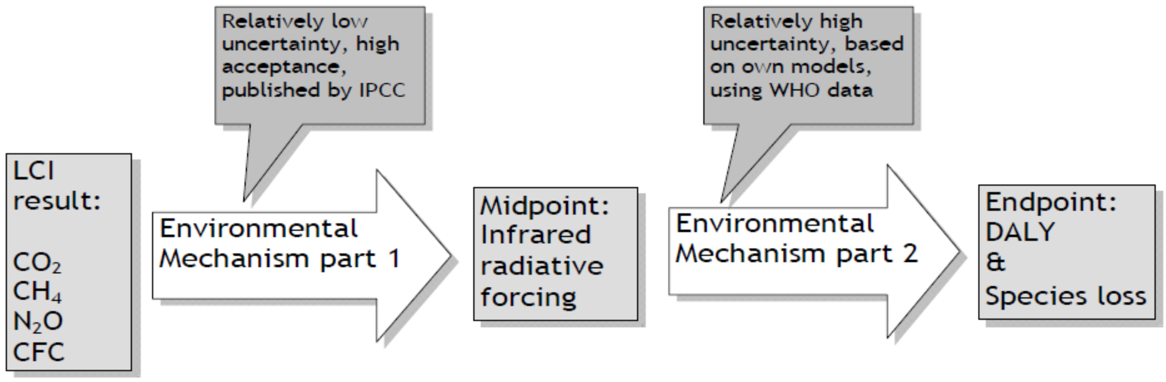

Figure 17 Example of harmonised midpoint-endpoint model for climate change, linked to human health and ecosystem damages (Goedkoop et al., 2013).

The quality of an ecosystem is complex to monitor since it is a heterogeneous system. In order to simplify this complex system, ReCiPe is designed to convey the quality of an ecosystem as the diversity of species. It is also impossible to monitor all anthropogenic factors that can affect all species groups. Therefore they have chosen species groups that can represent the total ecosystem quality. For ecosystem damage, the effects on the ecosystem will be given in a PDF-factor (Potential Disappear Fraction). This factor calculate how fast a species disappear in an area due to human activity and is expressed as loss of species during a year for terrestrial ecosystem (PDF* m^2 *yr). For aquatic ecosystem, the unit of this indicator is PDF*m^3*yr which involves integration over volume instead of area (Goedkoop et al., 2013).

The endpoint characteristic factor for ecosystem damages can therefore be calculated as the sum of the different PDF types, terrestrial (terr), freshwater (fw) and marine water (mw):

$$CF_{ED} = PDF_{terr} * SD_{terr} + PDF_{fw} * SD_{fw} + PDF_{mw} * SD_{mw} \qquad \textit{Equation 3-16}$$

$CF_{ED} = endpoint\ characteristc\ factor\ for\ ecosystem\ damage$

$PDF_{terr} = the\ characterisation\ factor\ in\ PDF * m^2 * yr,\ SD_{terr} =$
$the\ species\ density\ factor\ for\ terrestrial\ system,\ \ (species/m^2)$

$PDF_{fw/mw} = the\ characterisation\ factor\ in\ PDF * m^3 * yr, SD_{\frac{fw}{mw}} =$
$the\ species\ density\ factor\ for\ aquatic\ and\ marine\ system,\ \ (species/m^3\ )$

As can be seen in Table 9, there are many midpoint categories that are effecting damage to ecosystem diversity.

Table 9 Connection between midpoint and endpoints categories (Goedkoop et al., 2013)

Midpoint impact category		**Endpoint impact category***		
Name	**abbr.**	**HH**	**ED**	**RA**
climate change	CC	+	+	
ozone depletion	OD	+	–	
terrestrial acidification	TA		+	
freshwater eutrophication	FE		+	
marine eutrophication	ME		–	
human toxicity	HT	+		
photochemical oxidant formation	POF	+	–	
particulate matter formation	PMF	+		
terrestrial ecotoxicity	TET		+	
freshwater ecotoxicity	FET		+	
marine ecotoxicity	MET		+	
ionising radiation	IR	+		
agricultural land occupation	ALO		+	–
urban land occupation	ULO		+	–
natural land transformation	NLT		+	–
water depletion	WD			–
mineral resource depletion	MRD			+
fossil fuel depletion	FD			+

** Legend: + means that a quantitative connection has been established for this link in ReCiPe 2008; – means that although this is an important link, no quantitative connection could be established.*

3.8.1 Midpoint Characterization for Land Use

Three different midpoint characterization factors exist for land use, see Table 10 (Goedkoop et al., 2013):

Table 10. Midpoint characterization factors for land use(Goedkoop et al., 2013)

Midpoint impact category	CF	LCI	Description
Agricultural land occupation (ALO)	CFagr= 1	Ao(agr) · t	Ao(agr) the amount of agricultural area occupied (in m2) and t the time of occupation in years.
Urban land occupation (ULO)	CFurban= 1	Ao(urban)·t	With Ao(urban) the amount of urban area occupied (in m2) and t the time of occupation in years.
Natural land transformation (NLT)	CFtrans= 1	Ao(trans)·t	With Ao(trans) the amount of transformed area (in m2) and t the time of occupation in years.

No differentiation of land use types on midpoint levels are made due to uncertainties (Goedkoop et al., 2013).

3.8.2 Endpoint Characterization for Land Use

The endpoint indicator for land occupation is the Potential Disappeared Fraction (PDF) of species. In order to calculate the characteristic factor for damage on the ecosystem, the PDF factor is multiplied with the LCI parameter expressed in m^2 x yr and the species density (SD).

$$CF(occ) = PDF * m^2 * yr * SD \qquad \textit{Equation 3-17}$$

The endpoint indicator factor for land transformation is the PDF multiplied by the restoration time and species density. For the damage, the characteristic factor is calculated by multiplying this factor with the LCI parameter which is expressed in m^2.

$$CF(trans) = PDF * m^2 * yr * SD \qquad \textit{Equation 3-18}$$

Both of the damage characterization factors are expressed as PDF x yr.

The species densities (SD) are calculated from the global estimation of species number and land and ocean cover/volume:
-terrestrial species density: 1.48 E-8 [$1/m^2$]
-freshwater species density: 7.89 E-10 [$1/m^3$]
-marine species density: 3.46 E-12 [$1/m^3$]

3.8.3 Potential Disappeared Fraction

The potential disappeared fraction is based on the species area relationship concept described in section 0 and the characterization factors are calculated according to the following equation for environmental damage for occupation (Goedkoop et al., 2013):

$$ED_{occ} = (z_r - z_i + \frac{c_r - c_i A_0^{z_i - z_r}}{c_r}) \times A_0 \times t \qquad \textit{Equation 3-19}$$

The parameters z and c are conveying the status before ($_r$) and after the occupation ($_i$), z is species accumulation factor, c is the species richness factor and A_0 is the size of the occupied area (Goedkoop et al., 2013).

The equation for transformation is the following:

$$ED_{trans} = (z_o - z_i + \frac{c_o - c_i A_0^{z_i - z_r}}{c_o}) \times A_{trans} \times t_{rest} \qquad \textit{Equation 3-20}$$

Where ($_o$) stands for original, A_{trans} is the transformed area, and t_{rest} is restoration time (Goedkoop et al., 2013).

3.9 Functional Diversity

The focus in land use modelling in life cycle assessment has been on species richness by taxonomic measurements. However, increased available data on trait for different species have led to a development of functional diversity concept (FD), which is the metric that reflects on the distinctiveness of species. This progress have subsequently lead to a development of new characterization factors (CF) that analyses the functional diversity for land use impact as an indicator for biodiversity (de Souza et al. 2013).

The literature reviewed for calculating functional diversity characterization factors are based on data established by previous American-regional meta-studies for species richness (SD) and FD. The taxonomic groups that were included were mammals, birds, and plants. For each study, a FD value was calculated for each land use type, and are thereafter compared with a natural or as close to natural state as possible. The calculated FD values among different land use types were standardized and CFs was thereafter calculated (de Souza et al. 2013).

3.9.1 Calculating FD

In this paper the Petchey and Gaston´s index of FD was used and involve four steps for calculating the FD index (de Souza et al., 2013):

1. Construction of a matrix containing species, traits value, e.g. Table 11
2. Calculating the multi-derivate distance between species, using their trait data
3. Hierarchical clustering of the distance matrix into a dendrogram (tree diagram) to show the arrangements of clusters
4. Calculations of FD values based on the total branch length of the dendrogram, for the species present in a particular community.

Table 11. Taxonomic groups, traits and categories. (de Souza et al., 2013)

Taxonomic group	Traits	Categories
Birds	Mass	-
	Feeding guild	Carnivore, herbivore, insectivore, and omnivore
	Food type	Invertebrates, small fruits, seeds, nectar, fish, and generalist
	Foraging location	Ground, upper canopy, shrub layer, mid-canopy, forage throughout, and aquatic
	Foraging habitat	Ground, leaves, perch and attack, steams, aerial, water, soar and attack, and other
Mammals	Mass	-
	Feeding guild	Carnivore, herbivore, and omnivore
	Food type	Invertebrates, fruit, seeds, vertebrates, and vegetation
	Activity	Diurnal, nocturnal, and either
	Nesting	Aquatic, arboreal, burrows, multiple, and terrestrial
Plants	Leaf area	-
	Height	-
	Fruit type	Fleshy and not fleshy
	Fruit length	-
	Foliage	Deciduous and evergreen
	Growth form	Tree, shrub, tall herb, low herb, and grass
	Legumious	Legume and not legume

FD factors can be used in the same way as SR factors. Thus, SR factors are generally based on plants species and for this reason gives the FD factors a broader application of the indicator in LCA and possibly a better representation for biodiversity (de Souza et al. 2013).

3.10 EPS

EPS stands for "Environment priority strategies in product development", which was developed by Bengt Steen (Steen, 2000). The system is mainly aimed to be a tool for product development with in companies, but can also be used for external use in environmental declarations (Steen, 2000). The EPS method is described as a top-down manner, where the goal is to describe the willingness to pay (WTP) for different environmental damages. The tool includes five different safeguards defined by the Rio Convention with human perspective (Steen, 2000).

Biodiversity is included in the tool as the index Normalised EXtincion of species (NEX) which is defined as quota of red listed species per different land use types. The normalisation is made with respect to species extinct during one year on a global basis. The red listed species is collected from IUCN and are set as a global mean value (Steen, 2015). The WTP for preserving all NEX on the globe is estimated to amount to 110 billion euro dollar (Steen, 2000). There are 24 different land use types and there are three that are linked to biofuels: Renewable energy, Logging and wood harvesting, and Wood and pulp plantations (Steen, 2000). The different land use types have been also been collected from IUCN (IUCN, 2014).

3.11 Coupling GIS and LCA for Biodiversity Assessments of Land Use

It is important to have geospatial details in order to investigate land use potential impact on biodiversity. Geographic information system (GIS) is a tool which can facilitate the geospatial information that is needed to create a characterization factor for biodiversity losses. The GIS tool have the ability to store observed data for specific locations, with details on soil type or climate factors, and can combine this information to model new information such as potential crop yield through statistical analysis, mechanistic process models or rule based logic methods (Geyer et al., 2010a).

GIS-based inventory model can be regarded as a spatial explicit component within the traditional life cycle inventory model. The GIS coupling can for example be used to calculate elementary flows of habitat-types areas as a function to fuel crop type and production level (Geyer et al., 2010a).

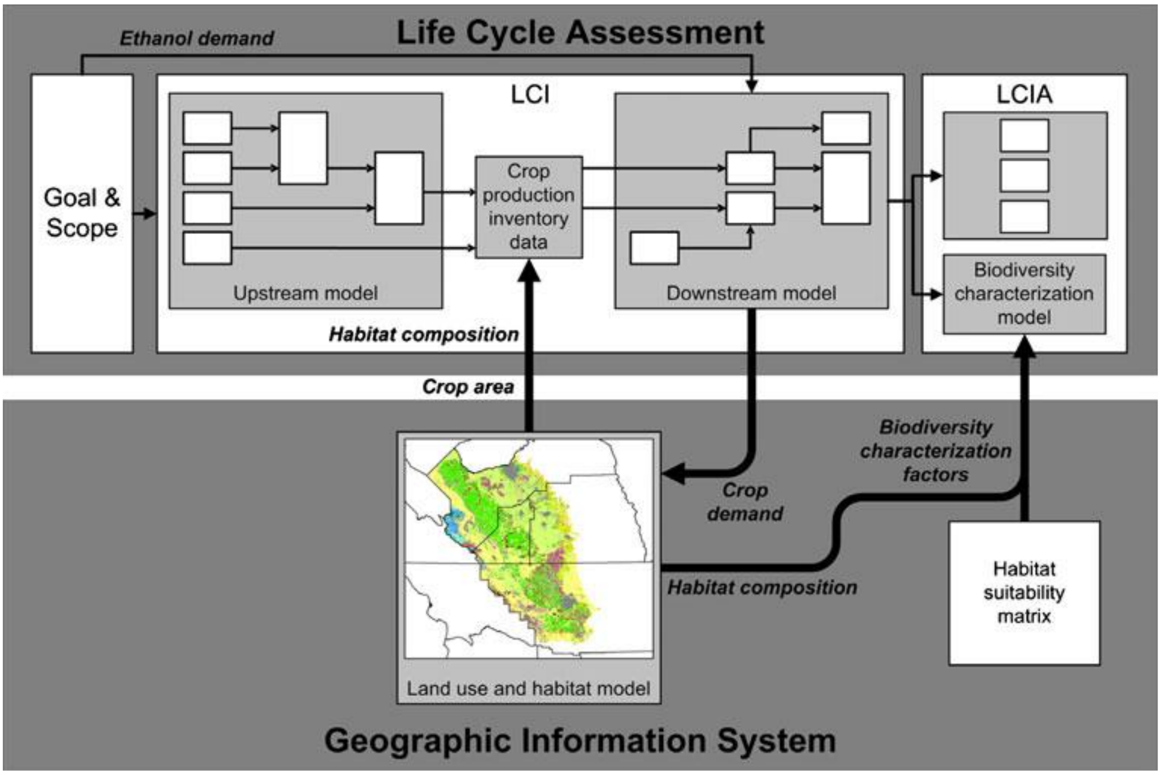

Figure 18. Example of flowchart for coupling LCA and GIS (Geyer et al., 2010b).

3.12 Description of Different Characterization Methods

There is a broad spectrum of methodologies for analysing the effects on land use change on biodiversity that can be included in life cycle assessment. In Table 12 five methodologies are conveyed and in order to distinguish the differences between the methods, the different evaluation categories presented in (Milà i Canals et al., 2014) are used. These aims to answer the following questions:

General completeness of scope: What is the geographic and temporal scope of the assessment offered by the method? What is the reference state and biodiversity indicator? What taxonomic[8] group/groups are investigated? Are permanent impacts considered?

Compatibility and availability: Is the method compatible with the established outline of the LCA framework? Are the underlying data and impact factors available for LCA practitioners?

Environmental relevance: Does the method link the major impact pathways of land use and land use change with biodiversity loss? Are the different biodiversity components reflected in the methods (genes, species, and ecosystem)? Is there a specific link between rare or threatened species and ecosystems?

Scientific robustness and certainty: Are uncertainties quantified and presented in the method documentation? What is the usability of the indicator for the LCA practitioners (Volvo in this case)?

[8] Taxonomic group are for example mammals, birds, plants.

Table 12. Selected method for including biodiversity aspects in lifecycle assessments.

		Methods				
Evaluation categories		**(Koellner, 2003)**	**Recipe (Goedkoop et al., 2013)**	**(Michelsen, 2008) (Forestry specific)**	**FD (de Souza et al., 2013)**	**EPS**
Indicators and model	**Type of indicator**	Ecosystem damage potential (EDP)	Potential Disappear Fraction of species (PDF)	-Ecosystem scarcity (ES) -Ecosystem vulnerability (EV) -Conditions for Maintained Biodiversity (CMB)	OI (Occupation impact) = CF_{FD}*A*t	Monitory/ WFP (Willingness to pay)
	Indicator	Species richness	Species richness, potential species disappeared during one year	Q=ES*EV*CMB	Functional (traits) diversity (FD)	NEX=Normalised EXtinction of species
	Reference state	Regional average species richness	Potential vegetation/ "Nature"	No reference situation is needed. Forest is already altered due to centuries of forestry	Natural/ close- to natural (NPV)	No reference
	Underlying biodiversity model	Inductive method: Species-area based	Inductive method: Species-area based	Deductive method: based on "experts statements"	Species-area based + functional traits	Monitory/ WFP (Willingness to pay)
	Number and description of land use	33 different land use types from forest to urban	18 different land use types from forest to urban	Forestry specific. Land use is a postponement of the natural processes (ESxEV)	Six land use types, based on 18 different land use types	24 different land use types
	Intensive/ extensive LU class distinction	General intensity is included, thus not detailed so different type of agricultural processes are differentiated	Do not differentiate between different "nature"- types, or different type of agriculture land type	Forestry intensity is taken in to consideration	Differentiate between intensive and extensive, as well agriculture mosaic	How intensive the land use is not included
Spatial and temporally characterization (Brudvig et al., 2009)	**Spatial and temporally explicit characterization**	Based on Central European data, thus must be taken in to consideration (CWHR, 2015)	Based on Central European data, thus must be taken in to consideration	Not explicit for any region, thus	Data on SR from North, Central and Northern part of Latin America	Based on Swedish data
	Permanent impacts, if how?	No	No	No	No recovery information and thus no permanent effects	Yes, since based on what the cost is for losing the threatened red-listed species
	Geographic scope and spatial resolution	Local & Regional	Local & Regional	Global, regional and local (mainly ecoregion)	Regional	Global, but possible to use for regional figures if those are found
	Taxonomic coverage	Based on vascular plants	Based on vascular but also "all "species	Not species based	Mammal, birds, plants	All threatened red-listed species

General properties	**Land transformation framework**	Area*impact*recovery time	Area*impact*recovery time	Not included, due to past centuries of forestry	No transformation impact	-
	Land occupation framework	Area*impact*occupation time	Area*impact*recovery time	Area*impact*occupation time	Area*impact*occupation time	
Hierarchical components considered by method	**Multi- species community level[9]**	Richness loss	Richness loss	No indicators for this	Functionality loss to ecosystem	Threatened species loss
Biological attributes considered by method	**Composition diversity[10]**	No	No	No	No	No
	Functional diversity	No	No	No	Yes	No
	Structural diversity[11]	No	No	No, but possible to choose an indicator that analyses this	No	No
Conservation relevance of indicator	**Quantitative change in species extinction risk**	No	Yes	No	No	-
	Vulnerable/ red-list or rare/endemic species treated separately	No, Possible to include red-listed species according to (Koellner and Scholz, 2008)	No	No	No	Red listed species is only taken in to consideration
	Vulnerable/ red-list or rare/endemic ecosystem treated separately	Do not analyse on ecosystem level	Do not analyse on ecosystem level	Yes	Do not analyse ecosystem level	Do not analyse ecosystem level
Reproducibility	**Type of documentation**	Ph.D thesis- hence detailed described method	Report/instruction book	Journal article	Journal article	Report/instruction
	Documentation, Transparency & Reproducibility	Much documentation, thus not very transparency in all calculations and assumptions.	Much documentation, thus, difficult to reproduce since lacking in transparent calculations / not suitable to reproduce	Good documentation and transparency – reproducible	Good information, but difficult to reproduce due to not complete description on method	Much documentation, thus might difficult to reproduce
	Available data for reproduction	Depending on geographic limitation and which land use type- generally no	Not reproducible	Depending on geographic limitation and which land use type- generally no	Depending on geographic limitation and which land use type- generally no	Depending on which geographic region that is of interest

9 Community level: richness loss, or compositional loss.
10 Relative abundance, presence and relative proportion of biodiversity features
11 Topography, number of vegetation layers, configuration of elements in space

	Type of data needed	Data on vascular species-area relationship for specific land use types as well as regional average as reference.	Not reproducible	Knowledge about key factors for maintaining biodiversity of the specific land use type of interest	Data on different taxonomic groups (mammal, plants and birds) for the geographic area of interest	Red-listed species threatened for a specific land use type
	Time consuming	Very	Very	Moderate	Very	Moderate
Overall	**Biodiversity coverage**	Cover only species richness for vascular plants- may not cover the whole complexity	Potential disappeared fraction of species may not say so much about the quality of the biodiversity	Identify key factors for biodiversity- good biodiversity coverage	More complex approach than just species richness-relative good coverage	Only threatened red-listed on global level for land use types- not so good coverage
	Scientific robustness & Certainty:	Not so certain but robust	Not so certain but robust	Based on experts/ science statements of what is of importance to maintaining biodiversity as indicator-good- thus the index itself may not say so much	Includes both SD and FD and therefore maybe more certain than the other methods, but robust	Not certain, rather order of magnitude analyse

4 Case Study

The methods described in section 3.12 require different input data and more important, different knowledge and are more or less time consuming. This paper is a master thesis and for this reason the time is limited to only 20 weeks. Therefore the chosen methods to analyse biodiversity aspects must be reasonable when it comes to time consumption.

Two methods chosen for investigating the possibility to calculating a characterisation factor for land use and biodiversity aspects were (Koellner, 2003) and (Michelsen, 2008). (Michelsen, 2008) was chosen for the reason that the method is explicit developed for forestry operations, it is a deductive method, and is assumed to not be very data, time and knowledge demanding. (Koellner, 2003) was on the other hand chosen due to it is an inductive method that requires more data, more knowledge and is subsequently a more advanced method, and more importantly the data needed for the calculations are available.

4.1 Description of the Case Study

Between year 2008 and 2012, a unique cooperative venture between the European Union and the Swedish Energy Agency, fuels companies and transport industries, regarding producing Bio-DME was initiated (Volvo, 2012). Volvo Group led the project and built 14 trucks that could be run on Bio-DME that Chemrec produces in the Chemrec DP-1 plant in Piteå. In that plant black liquor is used as raw-material, which is an energy rich bi-product from pulp plants, and generates a clean and energy-efficient fuel through gasification. The black liquor is generally used as energy source to the mill for heating and electricity (Chemrec, 2008). Thus, for the heat and electricity demand, bark, forest residues and stumps is used as energy sources (Smurfit Kappa, 2014). The gasification plant is connected with the pulp mill Smurfit Kappa Kraftliner (Chemrec, 2008). Figure 19 below convey the supply chain of the Bio-DME.

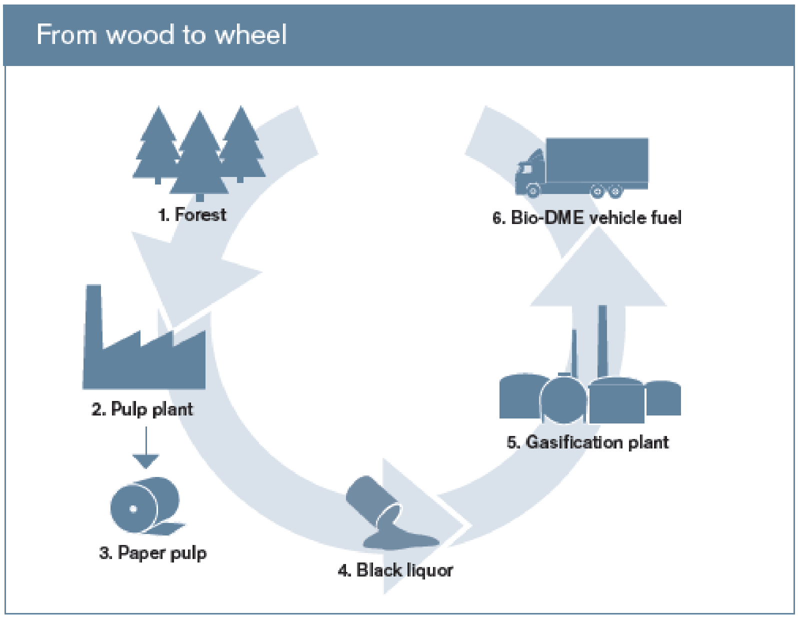

Figure 19. Description of DME production process (Volvo, 2012)

According to Smurfit Kappa Kraftliner 75% of the wood fibre for the pulp is from renewable sources, and 25% from FSC certified virgin fibre (Smurfit Kappa, 2013). The virgin fibres are primly from:

- *Forest clearing*: immature trees that are removed from the cultivated forest.
- *Forest residues; Treetops and branches* (round wood goes to sawmill)
- *Sawmill-residues from wood industry*

The information about the Chemrec Bio-DME is used as base for the case studies. The biomass sources used in the pulp and Bio-DME production, are assumed to be harvested from the production forest surrounding Piteå, Norrbotten.

The forest type in Piteå and its surrounding is the *middle and south boreal and hemiboreal pine forest D11* type (Larsson, 2001). This type of forest is found on dry and nutrient poor sites and can be on shallow soil layers on crystalline bed rocks as well as on deep sandy and gravely soils. *Pinus sylvestris* (pine) is the dominating tree species and at more fertile sites other three species are found as well (Larsson, 2001).

4.2 Koellner Method

The method that Koellner uses in “Land use in product life cycle and ecosystem quality” is based on data from Switzerland (Koellner, 2003). Koellner chooses to use Switzerland due to the good data availability. The country has a long history of collecting data regarding species richness, land use types and all other necessary information and data needed to perform these calculations.

Unfortunately Sweden does not have the same data availability as Switzerland, which makes it difficult to perform a case study by using the same methodology. For this reason was the method Koellner has developed modified and the *regional effects* was not be taken in to consideration due to lack of available data as well as lack of time.

4.2.1 Calculating EDP

The data was sorted in to five different cases:

- Regional average
- 100% pine production forest, monoculture
- Production forest with variation of trees (pine, spruce & birch)
- “Natural forest”, forest in protected areas with old stand age
- Forest with high amounts of dead wood

Koellner states that two different types of data can be used in order to calculate the species-area relationship (SAR); data on species numbers with variation in areas size (from small to large areas), or many plot-samples with same area and differing inventoried species numbers, see section 3.6.2. The latter data type was used for the calculations, since the first data type was not available. Koellner (2003) does explain how to conduct the calculations for both data types, but not into detail for data type number two. Therefore additional information about the method approach was used (Koellner et al., 2004, Schmidt, 2008)

Data Source

The required species-area data have been provided by Riksskogstaxeringen that is the part of SLU that collects forest data in Sweden. The DME-biofuel that is used as base for this case study is produced in Piteå, and it is assumed that the biomass used in production is harvested from the production forest surrounding the production plant in Norrbotten. The data used was subsequently collected from that area and included the regions: Norrbotten coastland, Norrbotten highland, Västerbotten coastland and Västerbotten highland, through the time span 2004 to 2013 to get as many samples that meets the requirements as possible. The data samples with an area size of 99 m^2 were selected, since it is important to have as many samples as possible and have the same sample size in order to get correct calculations. 268 different species are inventoried by Riksskogstaxeringen, these species are manly vascular plant species, but do also include a few mosses and lichens species. Further information of the inventory data for the Koellner method is found in Appendix A1

Rarefaction Calculations

In order to calculate the relationship between number of species and area, rarefaction calculations are needed. The rarefaction calculation makes it possible to estimate the species number based on a number of samples, find more information under the heading Rarefaction Method in section 3.5.4. Since the area of the samples is known – a species area relationship can be estimated.

The data for all the cases were sorted in to the following parameters from:

$$E(S_n) = S - \frac{\sum_{i=1}^{S}\binom{N-N_i}{n}}{\binom{N}{n}} \qquad \text{Equation 3-2}$$

S= number of species found in the specific case
N= number of samples in the case (inventory-samples with a known area of 99m^2)
Ni= number of samples where species *i* were found
n= sample number (1,2,3…N)

In order to perform the calculations a programming code for the rarefaction function had to be computed in Visual Basic for Application (VBA) which is a part of Excel. The programme code can be found in Appendix A2. The rarefaction function calculates the estimated number of species that can be found in n samples (from 1 to N) and are thereafter plotted against sample numbers and the area of the samples, see figures in section 4.3.

The continuous species area relationships were fitted into the discontinuous rarefaction function and the subsequent parameters were used for calculating the EDPs (Koellner et al., 2004). The species rarefaction is a monotonically increasing function and can be expected to be straight in a semi logarithmic plot or a log-log plot with high R values (Koellner et al., 2004). The R^2 value is the correlation coefficient and indicates how well the data plots correlate with each other. Two different models used for fitting the relationship:

Exponential semi log fitting model(Koellner et al., 2004):

$$E(S)=c+z\ln(A) \qquad \textit{Equation 4-1}$$

The power model with log-log plot (Schmidt, 2008):

$$E(S)=cA^z \qquad \textit{Equation 4-2}$$

4.3 Result

In the following section are the result from the five different land use types cases presented.

4.3.1 Reference State

Koellner uses region average species richness as reference state to calculate the Ecosystem Damage Potential of a certain land use type. How to decide the borders of the region is not defined in (Koellner, 2003). He states that species richness on biogeographical scale can vary tremendously. From 200-500 in northern Scandinavia to 2000- 3000 in southern parts of the Mediterranean per 10 000 km^2. For this reason is it important to use a reference within the region the occupation occur. (Koellner, 2003) The reference used in this case study was chosen to be an average in the Norrbotten and Västerbotten region. The data used for this calculation were sample areas for all type of forest sampled. This resulted in 606 sample plots in Norrbotten coast and highland and Västerbotten coast and highland with sample size of 99 m^2, stand age between 0-110, tree cover of 1-96 percent. There was no inclusion of sample areas situated in national parks. The estimated species number calculated with the rarefaction function based on these 606 samples is conveyed in Figure 20 and are plotted against the accumulated sample area and in Figure 21, plotted against sample area in log-log axis. Thereafter was a power function trend-line fitted to the log-log plot to estimate the parameter for the $E(S)=cA^z$ Equation 4-2.

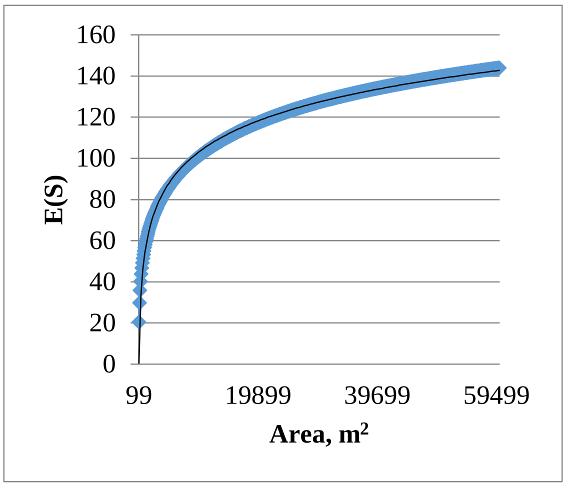

Figure 20. Rarefaction curve for "regional average" plotted against accumulated area and fitted trend line: E(S)= 22,214ln(A/99) + 0,4096, R^2 = 0,9939, N=606

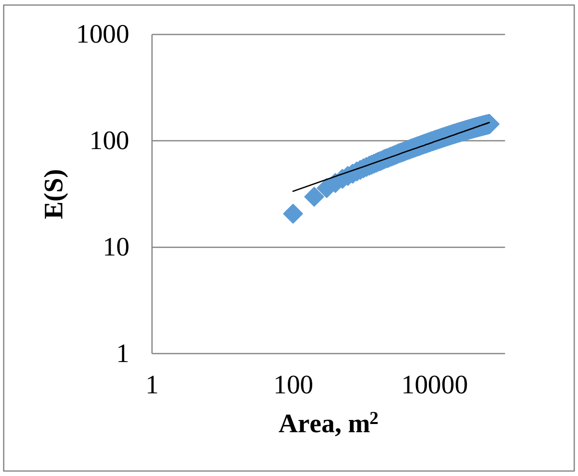

Figure 21. Estimated species number for "regional average" against accumulated areas and ,fitted power equation: E(S)= $11,521A^{0,2325}$, R^2 = 0,9803, N=606

The fitted trend-line for Figure 20 seems to correspond well to the plotted estimated species numbers – area-curve. Whereas the log-log plot and fitted trend-line do not follow each other in to the same extent, seen in Figure 21. The fitted trend-line seems to overestimate the species number for small areas and fit better for larger areas.

4.3.2 100% Pine Production Forest

This case represent a production forest with 100% pine trees, a so called monoculture production forest. This land use type is representing a land use type that could be used for assuming the effects on biodiversity by using forest products for DME production. The data used for this case had a stand age from 0 to 80 and a tree cover from 3 to 93% in Norrbotten coastland, which resulted in 52 sample areas. The estimated species number calculated with the rarefaction function based on these 52 samples is conveyed in Figure 21 and are plotted against the accumulated sample area and in Figure 22, plotted against sample area in log-log axis. Thereafter was a power function trend-line fitted to the log-log plot to estimate the parameter for the $E(S)=cA^z$ Equation 4-2

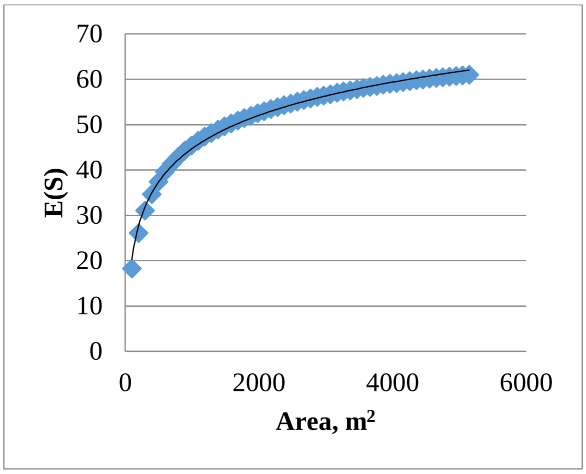

Figure 22. Rarefaction curve for 100% pine in forestry plotted against accumulated area and fitted trend line:, $E(S)= 10,568\ln(A/99) + 20,284$, $R^2 = 0,9953$, N=52

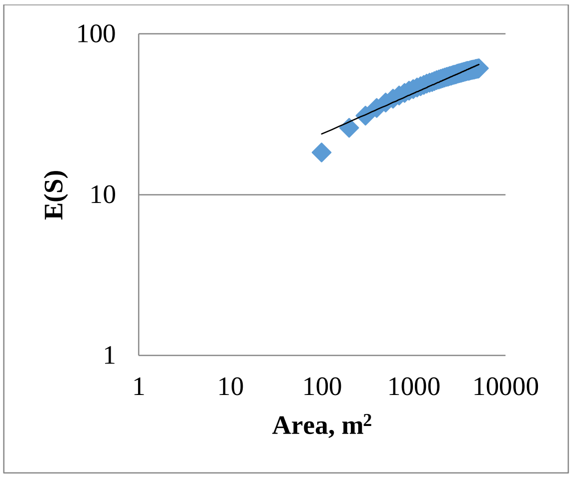

Figure 23. Estimated species number for 100% pine forestry plotted against accumulated area, and fitted power equation, $E(S) = 7,4751A^{0,2524}$, $R^2 = 0,9447$, N=52

The fitted trend-line to the plotted estimated species number in Figure 22 seems to correspond well to the plotted estimated species numbers –area-curve. Whereas the log-log plot and fitted trend-line do not follow each other in to the same extent, Figure 23. The fitted trend-line seems to overestimate the species number for small areas and fit better for larger areas.

4.3.3 Traditional Production Forest

This land use type represent a traditional production forest containing different types of trees, not only pine as in the previous section. This land use type represents a land use type that could be used for assuming the effects on biodiversity by using forest products for DME production. The data was collected from Norrbotten coastline, stand age from 0 to 80 and a tree cover from 3 to 93% and resulted in 171 sample areas. See Figure 24 and Figure 25.

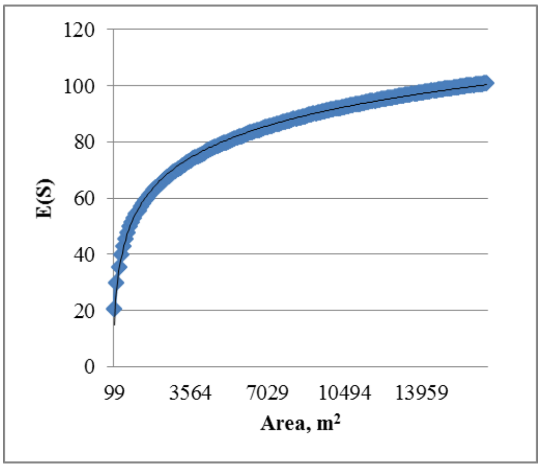

Figure 24.Rarefaction curve for traditional production forest plotted against accumulated area, fitted trend line: $E(S)=16,587\ln(A/99) + 15,056$, $R^2 = 0,9975$, N=171

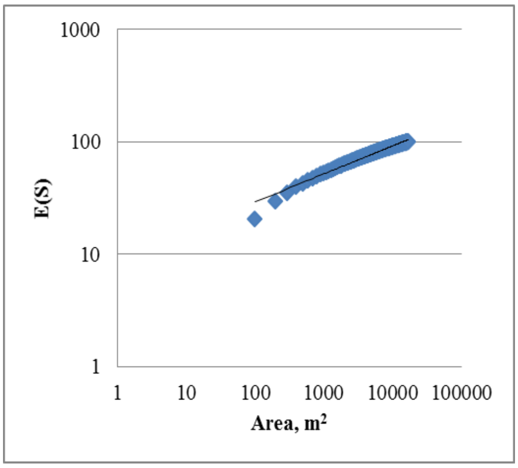

Figure 25. Estimated species number for all type of trees in forestry plotted against sample area, fitted power equation $E(S)=9,3756A^{0,247}$, $R^2 = 0,975$, N=171

The fitted trend-line in Figure 24 seems to correspond well to the plotted estimated species numbers – area-curve. Whereas the log-log plot and fitted trend-line do not follow each other in to the same extent,

Figure 25. The fitted trend-line seems to overestimate the species number for small areas and fit better for larger areas.

4.3.4 Natural Forest

Other literature, (Milà i Canals et al., 2014) states that *natural potential vegetation* is a preferable reference for calculations if land use impact. This land use type do not represent a land use type that is used for estimating the biodiversity effects from DME production by harvesting biomass from the forest, since this land use type is representing forest that is protected. The data from Riksskogstaxeringen did also state if the sample area was situated in a national park or a protection area where no felling or forestry activity is allowed to occur. In the region of Norrbotten coast and highland and Västerbotten coast and highland there were 54 sample areas that met the requirements and standards set for the calculations. Both Norrbotten and Västerbotten were included in this case in order to receive as many samples as possible.

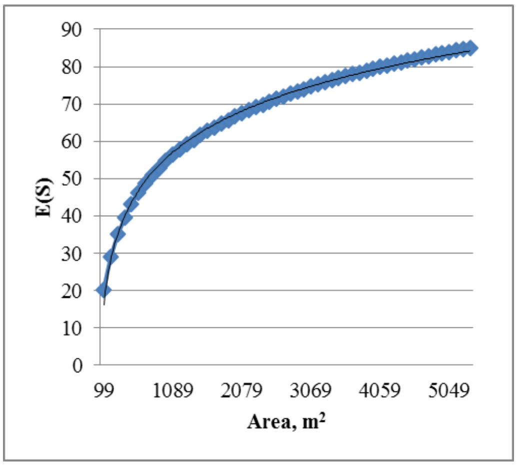

Figure 26. Rarefaction curve for natural forest plotted against accumulated area, fitted trend line:
$E(S) = 17{,}018\ln(A/99) + 16{,}294$, $R^2 = 0{,}9972$, N=54

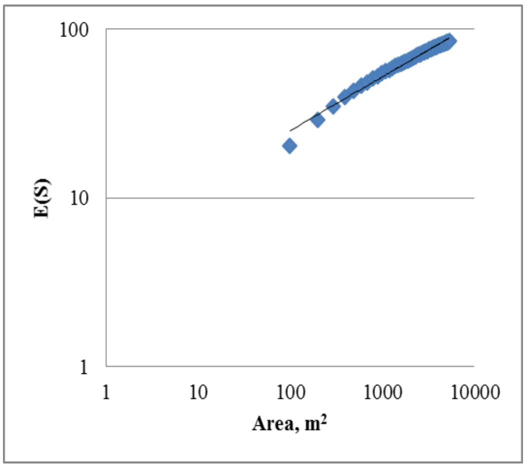

Figure 27. Estimated species number for natural forest plotted against accumulated area,, fitted power equation: $E(S) = 5{,}8521A^{0{,}3169}$, $R^2 = 0{,}9781$, N=54

The fitted trend-line in Figure 26 seems to correspond well to the plotted estimated species numbers – area-curve. The log-log plot and the fitted trend-line do not follow each other to the same extent, Figure 27. The fitted trend-line in Figure 27 seems to overestimate the species number for small areas and fit better for larger areas, thus if one compared Figure 27 with the other log-log plots this trend line seems to fit much better.

4.3.5 Dead Wood

As aforementioned, the amount of dead wood is a good indicator for biodiversity in boreal forest and in the calculated "dead-wood"-case are sample areas with different kind of dead wood used to see if there are a correlation between dead wood and species richness.

Data for amount of dead wood can also be received from Riksskogstaxeringen and give information about:

- Declination of the dead wood (standing or laying)
- If it is part of a root or not
- Tree species
- Diameter, volume, grade of decomposing, dry weight, %of bark
- Year and sample area identification name

Sample areas with identified dead wood were linked to the data about plant species information and rarefaction calculations were computed on the samples found in Norrbotten during 2004-2013. It resulted in the following graphs, Figure 28 and Figure 29. The fitted trend-line for the semi-logged plot in Figure 28 seems to correspond well to the plotted estimated species numbers –area-curve. Whereas the log-log plot and fitted trend-line do not follow each other into the same extent in Figure 29.

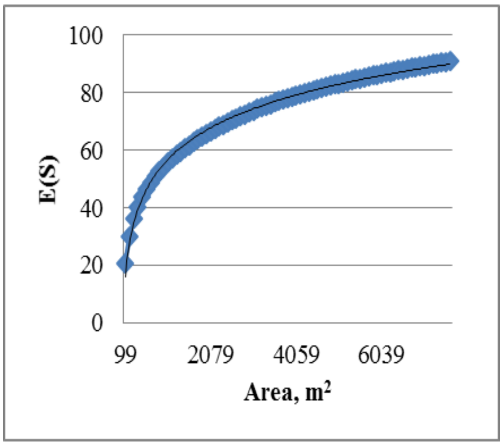

Figure 28. Rarefaction curve plotted against accumulated area, fitted trend line: :
$E(S) = 17.05\ln(A/99) + 15.904$, $R^2 = 0.9959$, N=77

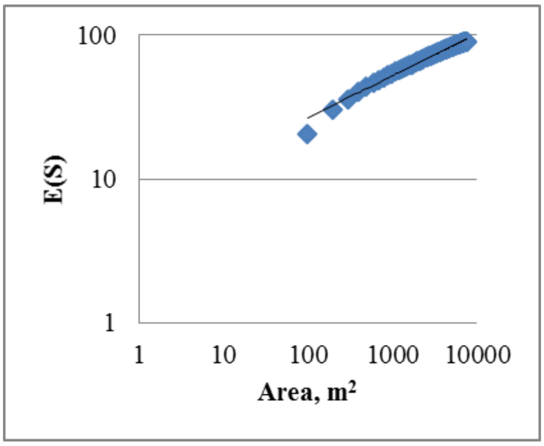

Figure 29. Estimated species richness as function of area in log-log plot. power equation trend line:
$E(S) = 6.9338A^{0.2923}$, $R^2 = 0.9789$, N=77

4.3.6 Calculating Standardized Species Richness and EDP

The parameters from the fitted power equation to the rarefaction curve plotted in a log-log axed plot are shown in Table 13. The land use type that had the highest species richness for the standardized area of 100 m² were regional average with the 606 samples and a species number of 34. The land use type with the lowest species richness was the production forest with 100% pine trees with 25 species. When, however the standardized area increased to one hectare the land use type with highest species richness was instead the area that represented forest national parks and resulted in 225 species. The monoculture pine forest remained as the area with the lowest species richness.

Table 13. Log-Log power model trend-line, calculation of $E(S)=cA^z$ for A=100 m² and 1 ha.

	Total nr of species	**Total Area [m²]**	**Nr of Samples**	**Species/samples**	**c**	**z**	**R^2**	**$E(S)=c100^z$**	**$E(S)=c10000^z$**
Regional average	144	60000	606	0.24	11.52	0.2325	0.99	34	167
Norrbotten coast-100% pine	61	5000	52	1.17	7.48	0.2524	0.94	24	137
Norrbotten coast-“Total forestry”	171	10000	101	1.69	9.38	0.2478	0.98	29	163
Forest in “National parks”	85	5000	54	1.57	5.85	0.3169	0.98	25	225
Forest with high volume of dead wood	91	8000	77	1.18	6.93	0.2923	0.98	27	201

The EDPs for the different land use types presented calculated from:

$$EDP_{local} = 1 - \frac{S_{occ}}{S_{ref}} \quad \text{Equation 3-6}$$

and

$$EDP_{local} = 1 - \left(0.27ln\left(\frac{S_{occ}}{S_{ref}}\right) + 1\right) = -0,27 * ln\left(\frac{S_{occ}}{S_{ref}}\right) \quad \text{Equation 3-9}$$

In Table 14 the EDP calculations with the reference regional average species richness with 606 samples are conveyed. The calculations are based on the standardized species richness number from Table 13. The EDP calculated with the linear equation gives a higher value than the non-linear one. The higher number or closer to 1 the EDP have, the larger risk for damaging the biodiversity. The EDP calculated with the standardized area of 100m^2 result in the largest damages. The case that represented a monoculture, 100 % pine trees was the land use type that had the highest damage potential in all of the different EDP calculations.

The closer to zero the EDP value is, or if the EDP value is negative, the lower the damage is for the land use activity for the biodiversity and the ecosystem. The land use activity with the lowest damage value based on the standardized area of 100 m^2 were the "total forestry" – case; whereas when the standardized area increased to 1 hectare the National park area did instead have the lowest damage. It generated a negative value, which is due to that the species number is higher than the reference, and thus may indicate the land use type is positive for the biodiversity.

Table 14. EDP calculated through S_{occ}/S_{ref} with the reference with 606 and power-model species area relationship.

	$EDP_{local\_linear,E(100)}$	$EDP_{local\_non-linear,E(100)}$	$EDP_{local\_linear,E(10000)}$	$EDP_{local\ non-linear,E(10000)}$
Norrbotten coast- 100% pine	0.288	0.0918	0.183	0.0547
Norrbotten coast- "Total forestry"	0.126	0.0364	0.0287	0.00787
Forest in "National parks"	0.250	0.0777	-0.343	-0.0797
Forest with high volume of dead wood	0.207	0.0625	-0.199	-0.049

In Table 15 the EDPs are calculated with the estimated Natural Potential Vegetation as a reference. Due to the small difference in estimated species richness for the NVP and the other land use types the EDP values are even smaller in this case. Thus in this case the EDPs calculated with the standardized areas of 1 ha are the ones EDPs with the highest values.

Table 15. EDP for different type of forestry in Norrbotten with "NPV" as reference situation.

	$EDP_{local\_linear.E(100)}$	$EDP_{local\_non-linear.E(100)}$	$EDP_{local\_linear.E(10000)}$	$EDP_{local\ non-linear.E(10000)}$
Norrbotten coast- 100% pine	0.0509	0.0141	0.392	0.134
Norrbotten coast- "Total forestry	-0.165	-0.0413	0.277	0.0875
Forest with high volume of dead wood	-0.0579	-0.0152	0.107	0.0306

4.4 Analysis of the Koellner Method

The methods developed by Koellner has many questionable aspects. First and foremost, it was not possible to investigate the regional aspects that the method includes due to lack of time and available data. Data required to perform the regional calculations are historical data from 1850th century and present data from more regional areas than Norrbotten and Västerbotten. The historical data was not available and processing the data for more regions would be very time consuming. The regional effects do not influence the final damage to such large extent and contribute in the range of 12-17 % as is described in section 3.6.4. For this reason and the limited time for the case study calculations, this aspect was not included in the thesis.

4.4.1 Data

There are many sources of errors within the calculations of species richness and EDPs. Riksskogstaxeringen inventory 268 different vascular plant species including some mosses and lichens. Whereas it is estimated to be found up to 445 forest vascular plant species in Sweden and additional 84 red-listed forest vascular species (Stokland et al., 2003). Mosses found in Swedish forests are estimated to amount to 300 species whereas lichens up to 800 species. Red-listed mosses and lichens are assumed to be 102 and 209 forest species and regular (Stokland et al., 2003). With this in mind, one may question the limited data from Riksskogstaxeringen to analyse the total species richness since some species might not be taken in to account in the inventory part. Subsequently, the species richness might be under estimated in the different rarefaction calculations.

Another aspect that might influence the data quality is the lack of knowledge about the exact position for the sample areas. The single information known about the location is the county position, e.g. Norrbotten coastland or Norrbotten highland. In order to make a distinction and aggregate the data into the different cases, the data were sorted according to the knowledge of stand age, type of tree cover and tree species. Based on those indicators the different land use type were designed, although, Norrbotten coastland is a very large area and may differ a lot if one analyse the land in closer loupe, geology, pH and other factors that may influence the species richness, factors that are not taken in consideration when designing the different land use types.

4.4.2 Fitting Species-Area Relationship to Rarefaction Curve

The rarefaction method was developed to be able to estimate the species number of a large sample by using different subsamples. This relationship can thereafter be used to estimate the relationship between species number and area relationship by plotting the samples area size and estimated species number. The fitted trend-line for the estimated species number and area size seemed to be well fitted for the semi-logged equation $S=c+z\ln A$. The parameters derived from that equation, varied very much, see *Table* in appendix. The c parameter varied between 0.4 to 20 and z between 10 and 22. Numbers in this magnitude is not so likely to represent the parameters in the $S=cA^z$ equation. In literature z vary in the 0.1 magnitude. For habitat islands and heterogeneous regions the parameter varies in the range of 0.2 to 0.4, whereas for true island the number should vary between 0.12-0.19 (Koellner et al., 2004). This means that not many conclusions can be drawn from that semi-logged equation. Moreover, this may indicate that the parameters from the semi logarithmic fitted equations are not suitable to be used for further calculations. The parameters from the fitted semi logarithmic plot do not either seem to be used for EDP calculations in the literature (Koellner et al., 2004).

The log-log plotted relationship between estimated species number and area size and the fitted power equation $S=cA^z$ on the other hand, corresponded to literature numbers to a much larger extent. The z values varied between 0.23 and 0.34 and do therefor match the z values for heterogeneous regions and land types. The correlation coefficient R^2 indicated good correlation between the fitted curve and the plotted one since it varied from 0.94 to 0.99. The correlation was not so well for the small areas whereas was improved for larger areas. For this reason the standardized area size of 1 hectare is more appropriate than 100 m^2 to be used for the EDP calculations. Though caution must be taken if one use the estimated parameters to calculate species richness for much larger areas, it may be rather overestimated in those cases, since the species richness will at some point reach an asymptote and no more species can be found in that specific land use type (Gotelli and Colwell, 2010).

4.4.3 EDP Calculations

In this section the EDP calculations for the different cases are analysed. First, the difference between the linear and the non-linear EDP calculations are analysed, thereafter the reference state is investigated and lastly the different cases are analysed.

Difference between Linear and Non-linear Calculation

The effect-damage function that the EDP calculation is based on describes the functional relationship between species richness and ecosystem processes (Koellner, 2003). The difference between the linear and the non-linear EDP calculations is that the logarithmic and non-linear relationship is supported by the redundant species hypothesis and means that the addition of one species results in a decrease in the marginal growth of utility in terms of ecosystem processes. According to literature, the logarithmic relationship is supposed to be the model that conveys the relationship between species richness and ecosystem process in the most accurate way (Koellner, 2003). When comparing the calculated EDP values in the case study, it was shown that the logarithmic calculation did estimate the damage potential lower than the linear EDP calculations.

Reference State

Koellner uses regional average species richness as reference state. He does not give instruction of how to decide where the region starts and ends. He only points out the importance to use a reference that is relevant to the different land use types and the geographic area. The region chosen for this case study where the Norrbotten and Västerbotten area and is dominated by boreal pine forest. The data included in this case consisted of a variation in stand age between 0 to 110 year old, tree cover of 0-93 % and the data included all different tree species. The standardized species richness for the reference was 33 for 100 m^2 and 167 for 1 hectare for the case. These numbers are quite high for the standardized area of 100 m^2 and low for 1 hectare compared to the other cases.

One of the possible explanations for this outcome is the design of the rarefaction method. The calculations consisted of many sample plots, 606. Since the equation calculates the estimated number of species found and since it is depending on number of samples, the more samples the higher total species found. This does also mean that the possibility to find species is distributed over a high number of samples but not so high number of species, see column number of species/ number of samples in Table 13. These relationships influence the shape of the semi plot curve in Figure 22 and results in a steep slope in the beginning, but there after the slope declines, whereas the other cases with higher species/sample rate the slope is not as steep in the beginning but higher for the larger areas. If one compares the different z and c values for the different cases one can also distinguish a trend in magnitude. The c value is higher for the reference case, 12 compared to 6 to 9 for the others, but the z value is lower (0.23 versus 0.3).

100% Pine Production Forest

The first case for calculating EDP was the estimated case for production forestry with 100 % pine trees which would represent a monoculture plantation. These calculations were based on 52 samples that met the requirements. The estimated species richness based on the rarefaction calculation and adapted trend-line was the lowest one of all the different cases. For 100 m^2 the species richness was 24 species and 137 for 1 hectare. This confirmed the expectation that the production forest would have low species richness and a lower biodiversity than the reference case. Production forests with only one tree species are quite rare in Sweden; only 5 % of the total production forest consists of monoculture plantation.

Traditional Production Forest

Another case for production forest in Norrbotten was computed, that included not only pine trees but also spruce, birch and aspen. This resulted in 101 samples with a total species number of 171 species. The estimated species richness was higher for this case and were 29 for $100m^2$ and 163 for 1 hectare, however still lower than the reference situation for 1 hectare. In the productive forest land the majority of the land (84 percent) are areas with 2 to 4 tree species. For this reason this EDP land use type, is the one that is most representative for the production forestry in northern Sweden.

Natural Forest

The third case is both calculated as an estimation for natural forest in Norrbotten and Västerbotten, but also as an alternative reference state, *Natural Potential Vegetation*, which is a commonly used reference state in literature. This reference is assumed to represent a land use type that conveys the situation when no human intervention occurs in the forest. The data collected for this case was taken in areas that either are nature reserve or protected forest which generally means natural forest. Inventories in these types of areas started in 2003, and from then to present time (2015), 54 samples were found that had a vegetation area of $99m^2$ and were situated in Norrbotten and Västerbotten. The samples had a total of 85 species and resulted in a standardized species number with 25 species for $100m^2$ and 224 species for 1 hectare. This confirms the expectations that the highest species richness would be found in this land use type. The EDP calculations based on 1 hectare resulted in a negative EDP value, which indicates positive effects for the biodiversity.

Dead Wood

Amount of dead wood is considered to be a good indicator for biodiversity, for this reason it was interesting to investigate the link between sample areas with inventoried dead wood and number of species.

Two different calculations were performed for this purpose. The first case included 77 different samples with 91 species and included samples found in Norrbotten coastland with area size of $99m^2$ and a stand age distribution between 0 and 80 years. The second case included all stand ages and resulted in 187 samples and 115 species, see appendix A4.3. This means that not that many more species where found in the older stands. Due to the nature of the rarefaction equation and the fitted power equation $S=cA^z$, the estimated standardized species richness differ between the two cases. The first case resulted in a standardized species richness of 27 species for $100m^2$ and 201 for 1 hectare, whereas the second case estimated a standardized species richness of 30 species for $100m^2$ and 184 species for 1 hectare.

Both of the EDP for land use with high volume of dead wood were therefor negative for the 1 hectare case, and indicate an increased biodiversity and no ecosystem damage potential which seems to be in line with the assumptions of high biodiversity with higher volume of dead wood.

Despite the large difference of estimated species richness for 1 hectare and $100m^2$, one can come to the conclusion that there might be a linkage between presence of dead wood and increased species richness. This hypothesis might be further confirmed if more species were to be inventoried and not grouped in to the section “other lichens” or “other mosses” since, these types of species may be supported by these types of structure and habitats. However, the taxonomic group that are thriving in these structures are insect and they are not inventoried by Riksskogstaxeringen and could therefore not be included in the calculations nevertheless.

Improvements of Calculations

In order to make a correct analyse of the different land use types and decide if the calculations are accurate or not, the calculations should have been performed with the same number of sample of plots, due to the statistical basis differs. Thus the more plots used the more accurate estimations about the species number for each land use type. It would have been interesting to analyse which of the parameters influence the estimated species number the most, number of plots or species number. As was stated previous, the more sample plots the higher c value and lower z value, which gives a low species number for small areas, compared with the other cases with fewer sample plots.

Figures from Koellner

One aspect that obstructs the result from the case study to be compared with the EDP values that Koellner proposes is that his calculations are not entirely based on the rarefaction calculations. Most of the data was gathered from meta-studies and was presented in data type 1 (variation in area size and species number, and a linear regression line could be interpreted with the area species pot). All the different land use types were plotted in the same figure and the log function: lnS=4.1 +0.2lnA could be extracted and had the correlations coefficient R^2=0.64 (low correlation). This low correlation might be caused by that the average plot size differed (Koellner, 2003). This relationship was used for calculating the different standardized species richness for the different land use types and thereafter used in order to calculate the EDP. Knowing the low correlation between found species and the calculated relationship, makes one question the suitability to use this equation to calculate indicators for biodiversity and characterization factors.

Koellner discussed the influence from the species area relationship and concluded that the number of investigated plots have an impact on the number of species, this differ from land use type to land use type. A mean value for 136 plots (agricultural fallow) is of course more accurate than for 6 plots (heathland) (Koellner, 2003).

A majority of the data for the different land use types were gathered through meta-studies with differing area size and plot numbers, and few or none of the data sources for the land use types were gathered from data type 2, with small and equal area size and inventoried species numbers. Koellner argues that his data can be considered to be reliable due to the data was sampled according to the standardized method from Braun-Blanquet, which is applied in vegetation science. With Braun-Blanquet many small plots with equal size are sampled (data type 2) (Koellner, 2003). However it is not clear to which extent data was defined as data type 1 and which as data type 2 in his thesis. This resulted in difficulties to conclude to which extent the rarefaction method was used. Koellner only explained the complexity and inconvenience in using that method due to the need for extrapolating in order to calculate the data from local (100 m^2 to 1 km^2) to regional scale (100 km^2 to 100 000 km^2), and performing this extrapolating would increase the uncertainty. For this reason Koellner applied the approach where he standardized the species-area relationship by using one single species-area relationship for all land use types and adjust the relationship according to equation lnS=lnc+zlnA, that yields a straight regression line on a ln-ln scale that fit all the empirical data together (Koellner, 2003). Against this background, it is not so likely that Koellner used the Braun-Blanquet methodology for data sampling to such large extent as he stated. Thus he points out that the difference in number of plots has also an impact on the external validity since the statistical basis differs. External viability means the ability to generalize the result. This was in line with the findings in this thesis.

One of the disadvantages with the method Koellner describes is the lack of transparency as mentioned above. It is not crystal clear how he master different obstacles and perform different calculations. This makes it problematic to reproduce his calculations. The regional effects on biodiversity were not tested in the case study in this thesis. The reasons for this were the time limit and availability of data to compute these EDP calculations.

The methodology Koellner presents in (Koellner, 2003) is further analysed and evaluated in (Koellner and Scholz, 2008). Koellner and Scholz (2008) provide uncertainty estimations for CFs caused by empirical variation in species richness data and limited sample size. The authors also compare results of linear and non-linear calculation model (model uncertainties) and analyse the different species groups: plant, mosses and molluscs. They used a fixed z value 0.21 and 0.23 for calculating CFs for different land use. The z factor which is species accumulation factors is discussed and depends of habitat, the taxa and size of the area. The above mentioned conclusions from Koellner and Scholz (2008) harmonizes with my conclusions from the case study.

Inclusion of more mobile species groups (birds, mammals, amphibians) would convey a better link to ecosystem functions. Hence these species groups provide functional links between habitats and the landscape. An introduction with these taxonomic groups would change the CFs due to their habitat preference (Koellner and Scholz, 2008).

A relative indicator for alpha diversity is suggested by Koellner and Scholz (2008), because local species richness diversity generally increases from South to North, even for same land use types.(Koellner and Scholz, 2008) My suggestion is to have more specific and geographical differential land use types, instead of having one generalized type so different kind of forests and different kind of crop that is cultivated, is taken in to account.

4.5 Michelsen Method

The second method that is tested in the case study for analysing how biodiversity can be included in life cycle assessments is the method developed and proposed by Michelsen (2008).

The methodology is described in section 3.7 and the method is applicable on different spatial scales (different structures); and was in his paper performed at ecoregion level. In this case study the method will be tested on a more local level, at the same level and for the same case as for the Koellner method in order to make a comparison.

The method was developed as an alternative to the other species richness focused biodiversity methods and was tested on the Norwegian forestry as a case study (Michelsen, 2008).

The method analyses the quality of biodiversity (Q) of a certain land use type by assessing three different factors; ecosystem scarcity (ES), ecosystem vulnerability (EV) and conditions for maintained biodiversity (CMB).

$$Q = ES * EV * CMB$$

4.5.1 Ecosystem Scarcity

The calculation of ecosystem scarcity can be calculated on many different spatial levels, where A_{pot} is the potential area of the structure and A_{max} is the potential area of the most widespread structure at the chosen level. This means that if one choses to look at ecoregion, the ecoregion that are most widespread of all the different ecoregions will be $A_{max.}$ Since it is difficult to find information on a more local scale than ecoregion, this structure will be analysed in the case study.

The ecoregion relevant to this case study is the Scandinavian and Russian taiga (PA0608) and has the A_{pot} of 134000 km ^{2} and A_{max} is the Saharan desert (2880000 km ^{2}) (World Wildlife Found, 2015) (Michelsen, 2008).

$$ES = 1 - \frac{A_{pot}}{A_{max}} = 1 - \frac{1340000}{2880000} = 0.535$$

4.5.2 Ecosystem Vulnerability

The ecosystem vulnerability status have been collected from World Wildlife Found for ecoregions and is considered to be critical for the Scandinavian and Russian taiga and is thus given the value 1.0 (Michelsen, 2008, World Wildlife Found, 2015).

4.5.3 Conditions for Maintained of Biodiversity

The third parameter to assess the quality of biodiversity is the conditions for maintained biodiversity and is calculated by adding up key indicators for biodiversity in boreal forest:

$$CMB = 1 - \frac{\sum_{i=1}^{n} KF_i}{\sum_{i=1}^{n} KF_{i,max}}$$

Key Indicators

Michelsen performs a case study for the Norwegian production forest in his paper and identifies three key indicators for the boreal forest and the same indicators are used to calculate the CMB for this case:

- Amount of decaying wood
- Areas set aside
- Introduction of alien tree species (Michelsen, 2008)

Amount of Decaying Wood.

The amount of dead wood correlates strongly with stand age of the forest, the older forest, the more dead wood can be found, from 2.1 m^3 dead wood per hectare for 0-40 year old forest, to 19.7 m^3 dead wood per hectare for forest up to 141 year old (De Jong and Almstedt, 2005). In mean values this is 6.5 m^3/ha for the Swedish forest. There is a large difference between natural forest and production forestry when it comes to amount of dead wood. In natural forest the amount dead wood can vary between 19 to 141 m^3/ha. This difference in amount of dead wood indicates also a large different in biodiversity (De Jong and Almstedt, 2005).

In northern Sweden where the study case is, the amount of dead wood in the forestland 7.3 m^3/ha in Norrbotten and 7 m^3/ha in Västerbotten, which can be seen in Table 16. Whereas if only production forest is investigated, 6.1 m^3/ha dead wood is found in Norrbotten and 6.7 m^3/ha in Västerbotten, see Table 17.

Table 16. Volume dead wood by tree species. forestland excluding alpine birch forest (2009-2013) (Nilsson and Cory, 2014)

County/region	Pine (m^3/ha)	Spruce (m^3/ha)	Sum conifer (m^3/ha)	Broadl. (m^3/ha)	Sum (m^3/ha)
Norrbotten	3.6	2.3	5.9	1.4	7.3
Västerbotten	2.2	3.1	5.3	1.7	7.0

Table 17. Volume dead wood in productive forest land (2009-2013) (Nilsson and Cory, 2014)

County/region	Hard dead wood (m^3/ha)	Decomposed dead wood (m^3/ha)	Sum (m^3/ha)
Norrbotten	2.3	3.9	6.1
Västerbotten	3.0	3.7	6.7

Table 18. Proposed scale for the key factor "Amount of decayed wood" (Michelsen, 2008)

Amount of decay wood	Impact	
>20m^3/ha	0	No impact
10-20m^3/ha	1	Slight impact
5-10m^3/ha	2	Moderate impact
<5m^3/ha	3	Major impact

The value used for this calculation is 6.1 m^3 /ha from Table 17, and will therefore result in an impact value of 2, Table 18.

Area Set Aside.

Area set aside is important since it is unlikely that the normal forest dynamics can be maintained within managed forests. This can be dynamics such as forest fires, storm felling and browsing. It is not the total size that is important; it is both representative areas and large areas. Exact how much that is necessary to set aside in order to maintain the biodiversity, is not consensus (Michelsen, 2008).

There are no regulations in the Swedish forestry act on how much area that should be set aside, however FSC Sweden have regulations that 5 % should be set aside for conservation (Enetjärn Natur AB, 2013). There is no clear information on how much area that is set aside, for this reason the percentage from FSC is used in this calculation, since the wood Smurfit Kappa purchase are FSC certified and results in a moderate impact of 2, see Table 19.

Table 19. Proposed scale for the key factor "Area set aside"(Michelsen, 2008).

Area set aside	Impact	
10%	0	No impact
6-10%	1	Slight impact
1-6%	2	Moderate impact
<1%	3	Major impact

Introduction of Alien Tree Species

Introduction of new species in a region is usually considered as a potential threat to the native species (Stokland et al., 2003). In Sweden *Pintus Contorta* was introduced in the 1930´s and currently around 550 000-600 000 ha exist of the tree (Skogsstyrelsen, 2011). The species originates from North America and have similar qualities as pine trees. Studies have shown that the bird-fauna can be affected by the amount of Contorta, if an area consist of more than 30 % of an area larger than 25 000 hectare, the species richness is expected to be effected very negatively. The effects on insects, fungi, vascular plants, moss, and lichen are yet not known. Moreover, the Contorta grows very rapid and have very impenetrable tree covers and might therefore effect negatively on species that are light dependent. (Skogsstyrelsen, 2011)

In the North Boreal part of Sweden the *Pinus Contorta* is estimated to contribute to 9 % of the recently established stands and about 4 %of the well-established stands (Stokland et al., 2003).The number for the young and well-established is around 5 percent. This results in a slight impact of 1, see Table 20.

Table 20. Proposed scale for the key factor "Introduction to alien species"(Michelsen 2008).

Amount of alien species	Impact	
0%	0	No impact
0-10%	1	Slight impact
10-25%	2	Moderate impact
>25%	3	Major impact

4.5.4 Assessment of Conditions for Maintained Biodiversity

In the case study Michelsen performed in his paper, the different key factors were not considered to have different impact to the biodiversity, instead they were considered to have the same impact (Michelsen, 2008). Therefor the same assumption was made for this calculation of CMB:

$$CMB = 1 - \frac{\sum_{i=1}^{n} KF_i}{\sum_{i=1}^{n} KF_{i.max}} = 1 - \frac{2+2+1}{3+3+3} = 0.4445$$

4.5.5 Spatial and Temporal Impact

The annual growth of conifer trees in productive forest is on average 3.7 m^3/ ha in Sweden (Stokland et al., 2003). Thus for the production of the functional unit of 1m^3 is needed which means that 0.27 ha/yr is needed.

4.5.6 Total Impact of Land Use

In the (Michelsen, 2008) paper, it is assumed that the forest already is altered due to centuries of forestry. The land use in the Norwegian case study represent a postponement of the natural processes that eventually will bring the area back to its natural state and quality (ESxEV) (Michelsen, 2008). He is also assuming that the relaxation time is equal to the rotation time in the forest.

Before the intervention (forest production)

$$Q_{t_0} = ES * EV * CMB_{t_0} = 0.535 * 1 * 1 = 0.535$$

After the intervention (forest production)

$$Q_{t_1} = ES * EV * CMB_{t_1} = 0.535 * 1 * 0.445 = 0.238$$

The quality difference ($\Delta Q = Q_{t_0} - Q_{t_1}$ =0.297)

Table 21 conveys the different possible cases for land use impact for forestry in the forest type *PA0608*- the Scandinavian and Russian taiga surrounding Piteå. The first case, *PA0608*, is based on the information gathered above and represents the current state and management of production forestry in Norrbotten. The second case, *PA0608 increased CMB*, represents a scenario when the conditions for maintained biodiversity have become better which means that either there are less alien species, more area set aside for conservation or more volume of dead wood. Lastly the third case *PA0608 decreased CMB*, represents that the conditions for maintained biodiversity have become worse through one of the key indicators is increased with one scale level. This could be due to more alien species, less area set aside for conservation or less volume of dead wood in the forest, and is assumed to lower the biodiversity and thus decreases the conditions for maintained biodiversity.

Table 21. Land use impact on biodiversity.

Case	ES*EV	CMB	ΔQ	ha*y	ΔQ* ha*y
PA0608	0.535	0.445	0.297	0.27	0.0803
PA0608 increased CMB	0.535	0.555	0.238	0.27	0.0643
PA0608 decreased CMB	0.535	0.333	0.357	0.27	0.0963

4.6 Analysis of the Michelsen Method

The Michelsen method analyses the tree biodiversity aspects *ecosystem scarcity*, *ecosystem vulnerability* and *conditions for maintenance of biodiversity* as a function of land use. In his case study the author analyses two different types of ecoregions found in Norway in order to evaluate the impacts from forestry on biodiversity. Only three aspects of conditions for maintenance of biodiversity were chosen. Although, he mentions that other aspects are as well important for maintenance of biodiversity in northern boreal forest.

Table 21 conveys the result from the case study, the first case represents the impacts on biodiversity from the forestry in the Norrbotten region and represent the possible impacts on biodiversity from producing biofuels that are based on forest products. ES*EV are intrinsic values of the ecoregion of Norrbotten- Scandinavian and Russian taiga (PA0608) and are therefore not possible to influence trough alternated forest management operations. The conditions for maintained biodiversity on the other hand, is an index that is possible to influence through changed forestry management operations. The delta Q represents the biodiversity quality and are due to changed conditions for maintained biodiversity when forestry activities have been introduced to the forest compared to a reference. The reference CMB value is set to 1, therefor represents that the condition for maintained biodiversity are as good as they can possible be since no intervention have occurred. The parameter ha*y are values that are necessary to have in order to include the aspect in the life cycle assessment, subsequently the land use impact from this forestry activity are given 0.0803 ΔQ*h*yr.

The result from this case study of Scandinavian and Russian taiga (PA0608) is the same as for the Norwegian case, which is no surprise due to a number of reasons. Ecosystem scarcity and ecosystem vulnerability are intrinsic values and are given identical factors due to that there are no more detailed information taken in to consideration despite the information given from WWF about the ecosystem status of (PA0608). In order to give a more local result from the case study and the method need more detailed information on local level is needed and more research have to be done. However it was possible to distinguished some differences between the Swedish (Norrbotten) case and Norwegian when it comes to conditions for maintenance of biodiversity. Hence, the status of the key indicators: amount of decay wood, area set aside and introduction of alien species, was not the same for Norrbotten and Norway, though they were given the same "score" due to the score intervals. The reason for the alternated results from the cases was only due to the difference in forestry intensity. In Sweden it is assumed that the increment of conifer trees in productive forest is on average 3.7 m^3/ha per year whereas it is slightly lower in Norway, 2.3 m^3/ha (Michelsen, 2008) and thus is given a lower land use impact than in Norrbotten which resulted in the land use impact of 0.0803 ΔQ*h*yr.

The numbers used for the calculations can also be questioned; the data used for amount dead wood is up to date, whereas the data for invasion of alien species and land set aside might not be as accurate. Currently there are no national requirements for area set aside, instead the action is encouraged through FSC, but it is mandatory to maintain areas with high conservation values or areas where red-listed species are found. Subsequently it was interesting to see how the result differed with changed result in CMB. If the conditions for maintenance of biodiversity were improved, it resulted in a lower CMB and the impacts on biodiversity were therefore lower than the original case. Whereas if the condition for maintenance of biodiversity was worse, the result was a higher CMB and Q and subsequently the effects were larger on the biodiversity. Furthermore it is questionable how correct the assumption is that these three key indicators have equal impact on biodiversity and if the indicators are the most important aspects. Other aspects that could have been included are amount of coarse and old trees, diversity in tree species, and occurrence of stumps to name a few.

The reliability and completeness of the method is important to analyse. The methods used for calculating ecosystem scarcity as well as ecosystem vulnerability factors are rather incomplete. Ecosystem scarcity calculations are based on how widespread the type of land use are and are calculated on ecoregion level in this case. Ecosystem vulnerability are merely based on a tree grade scale provided by World Wildlife Fund. There are alternative methods to calculate these factors, which were presented in Michelsen (2008) though due to lacking data availability, these calculations can be difficult to compute.

The Michelsen method can be used as a good complement to the Koellner method that only take species richness in to consideration in that method. The combination of these two methods provides a better picture of the different aspects complexity of biodiversity.

Another aspect that might be of importance is the possibility to compare different land use types with each other based on this methodology. Different land use types will have different key factors for maintained biodiversity. For this reason it might be difficult to compare.

5 Analyse of the Other Methods

In addition to analysis of the methods examined in the case study, the remaining methods presented in Table 12 are analysed in the following section. Moreover, some of the findings from the literature study are as well analysed.

5.1 ReCiPe

The characterization factors that ReCiPe provides do not only include land use impacts on biodiversity (ecosystem damage), but also the midpoint impact categories; climate change, terrestrial acidification, freshwater eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, and natural land transformation. For this reason ReCiPe is a good tool to investigate a products impact on biodiversity since it enables investigation of which impact categories that are contributing most to the endpoint category ecosystem damage. Hence, a product can have a large impact on biodiversity even if the product does not have a large land demand.

Moreover, land use impact is the impact category that have been proven to be the dominate driver of biodiversity loss in terrestrial ecosystem. For this reason it is important that ReCiPe include these impacts as correctly and sophisticated as possible. In (Allacker et al., 2014) ReCiPe were among other methods examined to include land use impacts in the construction sector. When they tried to include the effects from transforming “forest” to “forest, intensive” no impact were distinguished even if the land were changed in to another type of forest with much lower biodiversity. Moreover, ReCiPe do not differentiate between transformations of different natural land use types such as transformation of forest to shrubland, nor from non-natural land transformation in to another non-natural land use, such as agriculture to urban. Since the transformation impact is proven to be the dominate impact on biodiversity it is important that that impact is differentiated and not set to zero (the transformation impact is calculated as the land use type before the activity minus the land use type during the occupation).

5.2 Functional Diversity

The methodology that de Souza et al. (2013) proposes by including functional traits of species and how they are linked to each other in an ecosystem, enables a broader view of biodiversity to be included in the characterization factor.

The method only calculates the effects from occupational impacts, since most of the studies used for developing the methodology did not have information about the previous land uses state. Moreover information about the ecosystems recovery was not included. In the de Souza et al. (2013) study both functional diversity (FD) and species diversity (SD) characterization were calculated and compared. A significant difference between the SD and FD characterization factors could only be found for a few land use types. However, FD indicators represented a closer mechanistic link between biodiversity loss and resulting impacts in ecosystem stability and functioning (de Souza et al., 2013).

Moreover the sample size may influence the result, since the small samples may not represent the number of communities in each land use type. Ecosystem processes result from the interactions among species and the higher sample size the better it is to distinguish the difference between the presence or absence of a species versus the functional change in the ecosystem characteristics (de Souza et al., 2013).

The authors concludes that FD characterization factors allows a more precise detection of community response to environmental changes and ecosystem processes (de Souza et al. 2013). Moreover, the FD factor is also less sensitive to changes and more conservative than SD factors. More detailed land use types such as different forest or agriculture types in LCIA are needed to better correspond to the level of detail in biodiversity data available. What is needed for the development of this method is a good functional knowledge of the species, which is not needed for calculating SD factors (de Souza et al. 2013).

5.3 EPS

The EPS method includes biodiversity as one of the impact categories trough Normalized EXtiontion. The NEX value for a specific land use on global scale and a mean value of number of red listed species threatened by the different specific land use type divided by that land use type area is the value.

The land use types that are connected bio biofuel production are: Renewable energy, Logging and wood harvesting, and Wood and pulp plantations. These are defined for global share of threatened red-listed species connected to these different land use types. This division is not very useful if the purpose is to compare different biofuels with regards to biodiversity. In order to use a more local value for a specific land use type it is possible to only use those numbers, which then have to be looked up. This may be time consuming and difficult but may say a little bit more than a global average number.

5.4 Biodiversity Indicators

The purposes of performing a life cycle assessment of a product can be many. It could be to investigate the environmental impact from the product for its whole life cycle, in order to make improvements of whole value chain. Another purpose can be to enable comparison between products in order to distinguish which product is best of a range of products for different environmental categories. In order to be able to do this an indicator that is applicable for a wide range of products is needed. For biodiversity this can be a bit tricky since different land use types can be sensitive to different type of interventions and subsequently result in different indicators.

The most common indicator for biodiversity is species richness and is mainly measured in vascular plant species. However, studies have shown that only 10-11% of the variation in species richness of one taxonomic group can be predicted by the change of in richness of another group (Michelsen, 2008). Furthermore, different species respond differently between and within different taxonomic group (Immerzeel et al., 2014). For this reason it is important to include other taxonomic groups as well within the species based biodiversity indicators.

Umbrella-species is a concept that have been developed through the need to define how much of a specific habitat the most indigent species require to survive in the landscape (Angelstam and Mikusinski, 2001). This could require quality of the biotope, the total area of the biotope and other natural disturbance processes such as fire. For the north Boreal forest in Sweden this umbrella species could be for example nattskärra, trädlärka or blålkråka. By protecting these species one have a protecting umbrella for other species in the same habitat (Angelstam and Mikusinski, 2001).

For the boreal forest it has been found that the number of old trees, dead wood and a high diversity of tree species are good indicators for biodiversity, see section 3.3.3. Measuring these indicators as well as investigate different umbrella species could therefore be a good way of measuring the biodiversity impacts from the forestry and the products produced from the forest raw material. Though problems arises when the products produced from the forest material is to be compared to another product originating from the forest, such when comparing two biofuels, e.g. one forest based and one produced from an energy crop.

In these situations it is necessary to perform a comparison based on the same indicator and thus same characterization factors. For this reason it is important to develop a methodology that enable these requirements:

- Generally applicable across different products and human activities
- Organized in a hierarchy that ensure consistency when combining local-scale indicators with indicators on national, regional, or international as well as the different spatial levels: genetic, species, ecosystem, biotope, biome level.

Weidema (2008) concludes that preferable biodiversity indicators for these criteria's; have the ability to distinguish between endemic and exotic species as well as be able to distinguish between anthropogenic and natural variation. Moreover, Weidema (2008) expresses that the biodiversity indicator should "indicate particularly sensitive elements, thus providing early warning of change"(Weidema, 2008).

5.5 Biodiversity in Business

Two examples of strategies on how biodiversity can be incorporated in a company's strategic work is by analysing the recommendations from the TEEB (TEEB, 2012) and Eco4Buz- Ecosystem services and biodiversity tools to support business decision-making (WBCSD, 2013). The economics of Ecosystem and Biodiversity (TEEB), is a series of reports from United Nations on how ecosystem services, especially connected to biodiversity, can be evaluated in monetary terms and how these evaluations can be used in decision making for companies among others. The main point from these reports is that ecosystem services must be included in economic analyses even though it is not possible to put a monetary value of the service.

WBCSD (2013) argue in line with TEEB, "what gets measured gets managed", and provides a guide and a structured overview of existing tools and approaches for assessing biodiversity aspects into the business area. The aim with their report is to help companies make better informed decisions about what tools the companies can use to manage and assess different ecosystem impacts and dependencies. The question that WBCSD wants the corporate managers to answer in order to decide which approach and tool should be used, are:

- At what scale would you like to carry out an assessment; e.g. global, landscape or product level?
- What outputs would best support decision-making, e.g. map (including supporting reports) a quantitative value, or a score showing priority areas? (WBCSD, 2013)

However due to the time limitation further analysis could not be performed.

6 Discussion

6.1 How can biodiversity aspect quantitatively be included in LCA?

There are many ways of including biodiversity aspects in LCA. The most widespread approach is to include land use impact by having a characterization factor based on species richness. By analysing species richness the number of species in a specific land use type is related to a reference to see what status of the biodiversity in that specific land use type is as well as it enables comparing between different land use types. This reference varies between the different methodologies, although the majority uses a close to nature reference. By using a close to nature reference, different land use types will never have a negative value – and thereby not indicate a positive effect on the biodiversity. The reference Koellner uses for his Ecosystem Damage Potential is a regional average species richness and can however result in a negative EDP values for those land use types that have higher species richness than the regional average. This can be problematic if the regional average species richness is very low and therefor might signalize that the majority of the EDPs are positive for the biodiversity since there is a negative value. For this reason it might be better to use the EDPs calculated with a close to natural or natural potential vegetation reference such as the natural forest in the case study.

One important finding from the case study in the Koellner part, was how complicated the calculations of the characterization factor were. The first problem was the availability of usable data. The data used were collected from Riksskogstaxeringen and they receive their data through inventory of among others, vascular species found in the inventory area. They inventory 268 different species in the different inventory areas, whereas approximately 445 vascular forest species and additional 85 red-listed vascular forest species exists within the Swedish forest. This means that only 50% of the vascular species were inventoried. Most of the vascular species that are not inventoried are red-listed species and thus very rare, but may as well be important for the accuracy in the species richness estimations.

Furthermore, most characterization factors are additionally only based on vascular species richness. There are many studies that argue that changes within the vascular species may not say anything about the species richness change within another taxonomic group since species may respond differently to different kind of impacts within different taxonomic groups. Against this background, an inclusion of other taxonomic groups such as birds, mammals, insects for examples is vital to convey and detect impacts on biodiversity. Merely calculating number of vascular species in an area may not indicate any effects on the ecosystem function and subsequently the effects on the biodiversity.

Moreover, a majority of the currently existing characterization factors are at the moment mainly based on data from Europe, e.g. Koellner use data from Switzerland and Germany, except for de Souza et al. (2013) that uses data from America. For this reason the available characterization factors are not applicable for different geographic locations, they are only valid for the specific geographic location on which they are based on.

The available characterization factors for different land use types neither contain many different land use types nor differentiate between different types of forest or agriculture arable land use types. The biodiversity of a natural forest in the boreal zone will differ from a tropical zone and therefore a change in land use may have much more impact on the biodiversity closer to the equator for example. Moreover, different arable lands are neither differentiated; some characterization factors include different intensification levels of the land use types, though differentiation on crop level is still missing in the characterization factors for land use types.

The species richness calculations in the case study were based on the rarefaction equation that is dependent on number of samples and number of species found in the samples. It was noticed that the more samples found or used for one land use type, the larger area and the higher species number were generated in the species richness estimation for 100 m^2. This depends on the nature of the equation, the species-area concept and also by the abundance theory. Relative abundance says that few species are very abundant and few are very rare, most species are moderate abundant. The species area relationship concept states that the larger area, the more species can be found, which means that if one land use type has many samples, this land use type will have a large area, and thus more species can be found in this land use type due to the large area. Moreover, since the rarefaction curve is very steep for these cases, there must be many moderate abundant species and few rare species, since the last samples do not increase the species number remarkable. For the other land use types, such as for the case with data collected from natural parks, a higher biodiversity is expected and thus more rare-species found. This leads to a less steep rarefaction curve, which means that the additional species are evenly spread, and therefore indicates many rare species.

The nature of the equation was therefore another difficulty with the calculations of the EDPs. Since the different cases had different number of samples and thus varying species number, the standardize species number varied massively depending on which standardized area was used for the calculations. It was noticed that the EDP values for the different land use types gave completely different results if they were calculated for 100 m^2 or for 1 hectare, and gave subsequently contradicting results. When the standardized area was 100 m^2 the monoculture pine case was the one with highest damage potential with a value of 0.288 for the linear equation, close followed by the National park case with a value of 0.25 and the case that represented a typical production forest had an ecosystem damage potential of 0.126. Whereas when the standardised area increased to 1 hectare, National park case was the one with lowest ecosystem damage potential and resulted in a value of -0.343. The pine monoculture received the highest value with 0.183, and the typical production forest was now the case with the next highest ecosystem potential with 0.0287, see Table 14. If this methodology shall be used to calculate characterization factors for biodiversity, it is necessary to have guidelines of how to handle these calculation difficulties.

Another important aspect to discuss when including land use impacts in the life cycle assessments is how to handle land transformation allocation. The largest biodiversity impact occurs when natural land is transformed into any type of land use. This allocation situation is difficult for most agriculture and silviculture situations, and due to the long-time perspective for forestry it is even more problematic there. The question is when and where should this transformation be taken in to consideration. There are no consensus regarding this matter. Michelsen argues that due to the historical land transformation, this is not needed to be taken into consideration. The Koellner method on the other hand, shows that one can take this as well as restoration time into consideration.

Additionally, there are as presented in the methodology matrix many other methodologies for including biodiversity aspects in LCA, but all having serious limitations.

6.2 Suitable Indicator for the Bio-DME Case

The purpose with the case study was to test two methodologies for calculating characterization factors for biodiversity. The case was based on the Bio-DME project between Volvo and Chemrec, which produced the DME in Piteå. The raw material used in the bio-DME production in this case is black liquor produced from a pulp mill. Instead of using the black liquor for heat and power to pulp mill, forest residues, stumps and bark are used. The biomass used for the pulp production consisted mainly of recycled fibres but 25 % are taken from virgin sources. These are harvested from immature trees from forest clearing and forest residues such as tree tops and branches. The biomass and raw material were assumed to be harvest in the surrounding area of Piteå, the location of the production plant. If the forest residues and the stumps would be left in the forest, these substrates would eventually start decomposing and become dead wood.

An increased forest-based biofuel production may lead to not only are forest residues are collected to meet the biomass demand for the production, stump harvesting might also increase. Stumps provides around 80 % of the deed wood found in the managed forest and forms habitat for insects among others. Removal of these substrates would have large negative effects on the biodiversity due to increased heterogenization.

Moreover, since the amount of dead wood is strongly linked to the status of the biodiversity of the forest, it could be suitable to include that aspect in the characterization factor for biodiversity aspects of boreal forest. The method Michelsen proposes includes this. It might be difficult to include the amount of dead wood directly in a inductive method such as the Koellner method, but if the taxonomic groups that are direct dependent on that type of structure were included in the characterization factor as species richness, the loss of these species relative a reference would indicate low levels of dead wood and a declined biodiversity.

A complementary approach to analyse the quality of the biodiversity could be to investigate the status for the different important indicators for biodiversity in boreal forest such as number of large and old trees, diversity of tree species, amount of dead wood, but also analyse the presence of these umbrella species can be a good indicator for the quality of the biodiversity.

6.3 What is needed to enable this quantitative inclusion in LCA?

It is difficult to evaluate if the quantitative inclusion of biodiversity aspects in life cycle assessments is the most efficient way of taking biodiversity aspects in to consideration when evaluating biofuels, and other products for that matter. The method Koellner has developed have many weaknesses; very coarse estimations when calculating the relative species richness for different land use types, the data availability for reproducing the calculations, lack in consensus how the calculations shall be performed (in terms of proper data amount and data quality, and standardized area for calculating species richness), and only vascular plants are included in the calculations and these may not represent the other taxonomic groups.

To develop and improve the characterization factors, a framework is needed. This should include how these species-area relationships can be fitted and transformed from rarefaction curves to the power model $S=cA^z$, which set criteria's on lowest and highest number of samples required for performing these calculations would be a step forward. The framework should also define which standardized area size should be used for calculating the species richness since it was clear that the area size strongly influenced the species number for the EDP calculations in the case study. More data are also needed so that other taxonomic groups can be included in the characterization factors. The more species groups that are included, the more the characterization factors will say about the impact on the biodiversity.

Against this background, more research, monitoring and data collection are needed to including other aspects than species richness in the characterization factors. If one species is lost may not say anything about the quality of the ecosystem and may not affect the ecosystem functions. The more biodiversity aspects that are included in the characterization factor, the more will the characterization factor (CF) be able to say about the respond to the ecosystem and status of the biodiversity. The aspects that are of importance to be incorporated are relative abundance, evenness and functional diversity.

Larger data samples are also necessary, the larger areas analysed the easier is it to enable analysis of ecosystem response to species loss.

The last aspect that is important is the development of more land use specific characterization factors as well as more geographical specific CFs. The current CFs that are available does not make it possible to compare different arable land, hence they do not differentiates between e.g. a rapeseed production land and a wheat production land. Subsequently if the purpose is to compare different biofuels produced by these crops, it is vital to have CFs that differentiates between different crops and the production country. The species richness is as aforementioned much larger the closer to the equator.

The methodology Michelsen proposes is of a completely different nature compare to the Koellner method since its core is evaluating key factors for maintained biodiversity for the land use type studied. These are varying between different land use types and may therefore not be used when comparing between different land use types or products that uses different land use types.

However, even though more research needs to be put in this matter, the question will still be if it will be possible to completely include and convey the complexity of biodiversity aspects in LCA and if attempting to include biodiversity aspects in LCA is the a suitable method to analyse biodiversity aspects linked to the production of different products. Biodiversity is a very complex concept and clearly difficult to measure and the result from the case study in the Koellner test, conveyed that it is not easy to perform these calculations. More importantly, the results may not say so much about the land use impact on biodiversity, and will an inclusion of other aspects such as other biodiversity indicators or other taxonomic groups, ever be able to convey the complexity of biodiversity and be possible to include in the life cycle assessment. Species responds to different intervention in different ways and scientist also argue that there can be a long response delay of these interventions, which makes it even more difficult to predict an effect from a human intervention. Life cycle assessments on the other hand, are seen as a linear and a rather straight forward quantitative approach that focus on figures and numbers. Against this background, one may question the possibility and suitability to achieve this inclusion, or if a complementary method should be performed to analyse biodiversity aspects connected to a products life cycle.

The complementary research question to what is needed to enable an inclusion of biodiversity aspects in LCA was “Or is a complementary method to LCA needed to analyse biodiversity in a better way?”. This research question have been difficult to answer due to the time limitation. Nevertheless, some things can be said about this matter. It have been quite clear from the case and literature study that an inclusion of biodiversity aspects in a life cycle assessment are a difficult mission. For this reason it might be easier to evaluate biodiversity separately and not try to insert it into the LCA. This might be by performing an investigation of the land use type the product one investigating, biofuel in this case, may affect the biodiversity. However, more research must be put in complementary methods together with research for inclusion of biodiversity aspects in life cycle assessments to be able to answer these questions.

6.4 How can biodiversity be taken in to consideration in business decisions?

Due to the time limitation, it was not possible to completely answer this research question. First of all, more information about how Volvo wants to incorporate biodiversity in business decisions would be needed. In addition to this, more research on good examples visualizing how biodiversity can be included into companies is needed. The focus on this thesis has been on life cycle assessments and biofuels, and therefore this research question might be outside the core scope for the thesis and was therefore not fully prioritized.

Some suggestions can however be presented from the findings in the literature study and case study. Since life cycle assessments is an important tool to analyse the environmental impacts within Volvo, biodiversity can be incorporated by include land use in all assessments. This has been done for previous LCA on biofuels, but is not included at the moment for other LCAs. This does not necessarily mean that characterization factors for biodiversity must be included; including the area demand for the products may be enough to predict if the product may have a negative impact on biodiversity. However this will not be able to convey how large the negative impacts are, merely that one can expect negative impact on the biodiversity.

One way for Volvo to take biodiversity aspects into consideration is to make sure that the companies and organizations that Volvo interacts with, in as large extent as possible, are environmental certified and have biodiversity certifications. This would mean, make sure all forest products used within the organization, are FSC certified to name one example. Another way is to start including ecosystem services in the economic analyses even if it is not possible to put monetary value to the service, as TEEB recommends. This would mean including environmental damage cost in annual reports with all the other external expenses. If it is not included, the ecosystem service and thus biodiversity will not be considered as service with a value for the human consciousness.

6.5 Other Aspects

The scope of this thesis enables discussion of an enormous wide range of aspects since biodiversity and biofuels are two very complex subjects. One aspect that is of importance to discuss is the role legislation have for biodiversity impacts. It is rather clear from the literature that legislation and certifications systems control how the production forest are managed and therefore indirectly have an impact on biodiversity. It was noticed that the Swedish FSC have stricter demands than the Swedish Forestry Act. About half of the production forest in Sweden is certified with FSC which means that they have more obligations to follow in their management compare to the other non-certified productions forest. With that said, this do not mean that the non-certified must be worse than the certified. Whereas if the Swedish Forestry Act changed from voluntary actions to concreate obligations, all forest owns would have to prioritize biodiversity maintenance despite former interest in these matters.

Moreover, studies on the continued expansion of first generations biofuels and their direct and indirect effects in the environment and biodiversity are needed. This is important since the expansion of first generations biofuels are expected to continue in the future, and the land competition between food crops and other crop usage will increase massively due to the increased population on Earth. Investigating the indirect effects from land competition are thus extremely difficult measure. It is very difficult to predict what the outcome will be by increasing the production of one biofuel from a specific energy-crop, though due to the limited land availability, though the probability for displacement are rather high. How large the effects from this displacement would be on the biodiversity are for this reason very difficult to forecast since it depends on where the displacement occur and the on initial land use type and this cannot be predicted.

Lastly, another aspect that is important to discuss is the importance not only to analyse the impacts that different biofuels have on biodiversity, but also current fossil fuels. If the focus only is put on the different negative aspect the different biofuels may have on the environment and especially biodiversity, and similar analysis are not performed for diesel and petrol, the effects from these may be neglected.

7 Conclusions and Recommendations

Since no efficient methods for including biodiversity impacts in life cycle assessments currently exist, but the need for including theses aspects is important and should be taken in to consideration a guide of how these aspects can be taken in to consideration will be presented.

Because land use is the main driver to biodiversity loss, the inclusion of land use is the most important aspect to interpret if a products life cycle may have a negative impact on biodiversity or not. If one is interested in comparing products with each other with regards to biodiversity, the first thing is to include and compare the land area demand the different products require. After that, the land use type must be investigated, what geographic location that land use occur and if it is possible, what the previous land use type was, in other words have a land transformation initiated connected to the product or not. As previously mentioned, the most dramatic form of habitat and biodiversity loss occurs when a species diverse community, such as a rainforest are replace with a one single crop, such as a monoculture plantation. Against this background, if it is possible, these types of land uses should be avoided.

Measuring human interventions impacts on biodiversity and inclusion of biodiversity aspects in lifecycle assessment are a very complex mission. Due to the complexity there is no consensus on how biodiversity most accurately is measured, and therefore there is a wealth of methodologies with different approaches that attempts to include biodiversity, some are more credible than others. For this reason it is very difficult to draw any conclusion from the literature study and case study, of which approach and methodology was most suitable for including biodiversity aspects in lifecycle assessments. This might mean that an inclusion of biodiversity in the life cycle assessment is not even possible, and a complementary method to LCA is needed to investigate a products life cycles impact on biodiversity.

What is clear from the case and literature study is however that more research on how biodiversity can be included in life cycle assessment is needed.

- Data on more taxonomic groups
- Data from more geographic locations and on different spatial scales
- Inclusion of other biodiversity aspects than species richness, such as functional diversity, relative abundance and different ecological responds
- Develop a framework on how to perform calculations for different methods and strive for consensus regarding which method should be used for certain situations
- Develop method that enables comparison between different corps on different land use types

First and foremost more data on different taxonomic group are needed in order to link species loss to biodiversity impact. There is also a need of more geographical spread data and for different spatial scales which enables analysis on different scales. In addition to this, framework on how the calculations shall be performed to enable reproducible methodologies as well as consensus on which methods that are appropriate and which are not, are also vital. Furthermore, development and research of characterizations factors that enables comparison between different land use types connected to different biofuels and products produced at different continents and from different types of crops are as well desirable.

For this reason it is difficult to evaluate whether the Koellner method or the Michelsen method can be considered to be good or bad regarding including biodiversity aspects in lifecycle assessments or if LCA is a suitable tool to use for evaluating biodiversity effects, however what can be said is that more research is needed.

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Appendix

A1 Data Collection

The vascular species and area data required to calculate the biodiversity and land use characterization factor for the Koellner case was gathered from Riksskogstaxeringen. Riksskogstaxeringen is a part of SLU that inventory data and information about the Swedish forest in so called inventory areas. The data used in the case study was gathered from different sample-areas in northern Sweden, Norrbotten and Västerbotten, number 2^1 and 1 in Figure A1. Every sample-area has a number id and each area is inventoried in a ten year interval. For this reason were data from 2004-2013 collected. Riksskogstaxeringen inventory approximately 268 different vascular species and specify the sample areas according to the following categories:

Figure A1. Region division of Sweden.

- The year the inventory was preformed
- Vegetation area.
- Differed area. Area that was damaged or had a trail through it, which decreased the area possible for vegetation.
- If the area had been exposed of ground intervention and how large that area would be
- Observed area, the actual area with vegetation that is considered in the inventory. This is the area used in the method (0-100m^2).
- Which district the sample area occurred.
- Stand age. Stand age is defined by the mean age of the total age of the stand. Total age of a tree is the amount of years that passed from that the seed was starting to grow until the year before the measuring time. At production forests are not seed-trees, under grown trees or dead trees taken in to consideration when estimating the stand age (SLU, 2014a).
- Mean height of the trees
- Cover of tree crown (0-100%)
- Pine tree share. Contorta share. Spruce share, birch share, aspen tree share, beech share, and other softwood (0-100%)
- If the sample area was inventoried in a National park or similarly protected areas.
- Name of the inventoried species (268 species)
  - 23 different ground layer species (lichens and mosses), of which 7 of the species are labelled “other lichens” or “other mosses” and 2 of the species are labelled “ renlavar”
  - 201 field layer species, of which 4 species are labelled “lumrar”, 3 labelled “high fern[12]”, 11 are labelled “broad leafed grass”, 3“thin leafed grass”, 2 “kovaller”, and approximately 50 are labelled “others”
  - 44 bushes and tree species

The species registrations are performed on sample-areas which are located in a specific district. The district can either be a permanent registration area or a temporary. In half of the permanent areas are land-inventory performed and in the other half are vegetation-inventory performed. The samples-areas

[12] Ormbunke

are divided into corridor areas, which are always inventoried, and intermediate stumps that are only inventoried when deforestation have occurred in that division during season 1 (SLU, 2014a).

Table A1. Description of sample-areas

Temporary district	Permanent district
Corridor areas (7 meter radius)	Corridor areas (10 meter radius)
Intermediate Stump areas (7 meter radius)	Intermediate Stump areas (7 meter radius)

The sample areas are divided in different categories: YV, AVM and MBA. Section 12.2 in the handbook (SLU, 2014a). The abbreviation stands for different limitations of the inventoried sample area. The original size of the sample area were 100 m^2, thus due to different obstacles, most of the sample areas were decreased to a smaller size. In the calculations was the sample size 99m^2 therefor used.

For northern Sweden the age division look as following: seen in Table A2. Due to this aged division for production forest the whole age span between 0-80 will be included in the calculations for the characterization factors for the different land use types.

Table A2. Productive forest area for different age classes 2009-2013 (Nilsson and Cory, 2014).

2011	Forest land	0-	3-	11-	21-	31-	41-	61-	81-	101-	121-	141-
Produktiv skogsmark	**1000 ha**	**% av produktiv skogsmarksareal** % of productive forest area										
Norrbotten	3491	2.4	6.0	6.8	8.4	10.0	18.8	12.6	9.0	6.3	7.4	12.2
Västerbotten	3002	3.6	7.7	8.0	11.4	9.2	15.4	11.1	9.2	8.8	7.4	8.1
Västernorrland	1656	6.2	6.4	10.5	13.1	13.1	16.3	6.9	7.9	8.2	6.1	5.3

Stand age of the forest can also imply where in the succession the forest is occurring. Studies have shown that mid-succession is the time when the species richness have reach its maximum, this occur somewhere between the succession age of zero and the age of steady state (old forest). This can be explained by that there is an overlap between species that belongs to pioneer state and climax state (Schmidt, 2008).

Deforestation in production forest includes “final felling”, weeding. clearance and some other felling interventions (SLU, 2014a).

Definition of production forest is a forest that is suitable for forest production and that is not used for other objectives in to larger extents. Natural forest can be divided in to different categories. The first level of natural forest is characterized of the existence of coarse dead trees and no interventions have occurred during the past 25 years (SLU, 2014a).

The data collected for calculating plant species richness in this case study was inventory data collected from following criteria’s, see table A3. Norrbotten coastland between the years 2004-2013, sample area of 99 m^2 was chosen, stand age of 0-80years. In order so say anything from the rarefaction curve it is recommended to have a minimum of 20 samples (Gotelli and Colwell, 2010). Hence, data that met these requirements since the number of samples used were between 40 and 100.

Information is also given on which the sample area is found in a national park, that criteria are used for calculating “potential natural vegetation”.

Table A3. Data criteria for the EDP calculations

Year	Pine-share	Contorta-share	Spruce-share	Birch-share	Stand age	County division	Studied vegetation area
2004-2013	0-100	0-100	0-100	0-30	0-80	Norrbotten and Västerbotten coastland and highland	99

Beyond the inventory of the above criteria's, Riksskogstaxeringen inventory habitat, amount of dead wood, among other forest information..

A2 Visual Basic for Application Excel Code

In the following section the Excel code for calculating the rarefaction function is conveyed :

```
Function rarefaction(S As Integer. K As Integer. Ki As Range. n As Integer)


Dim sum As Double

'K= number of samples. in other words number of inventory- sample- areas

'Ki= number of samples where species i  occur. which is displayed in a range

'n= sample number

'S= total number of species

'Combin= "Returns the number of combinations for a given number of items. Use COMBIN to determine the total possible
number of groups for a given number of items"

'rarefaction= expected number of species based on n number of samples

sum = 0

For i = 1 To S

  If K - Ki(1. i) >= n Then

   sum = sum + WorksheetFunction.Combin(K - Ki(1. i). n)

  End If

Next i


rarefaction = S - (sum / WorksheetFunction.Combin(K. n))

End Function
```

The function can thereafter be used to calculating the number of expected species in regard to number of samples. See Table A4 below.

Table *A4*. Example of how the expected species number is calculated as a function of number of samples.

		Area	sample	Expected species. E(S)

number of samples (606)		99	1	20.60726
number of species (144)		198	2	29.87806
		297	3	35.87038
		396	4	40.30523
		495	5	43.82227
		594	6	46.73661
		693	7	49.22881
		792	8	51.41156
		891	9	53.35899
		990	10	55.12179
		1089	11	56.73579
		1188	12	58.22703
		1287	13	59.61495
		1386	14	60.91443

A3 Plotting rarefaction curve

When the expected species number is calculated with the rarefaction function, the rarefaction curve could be plotted, see Figure A2.

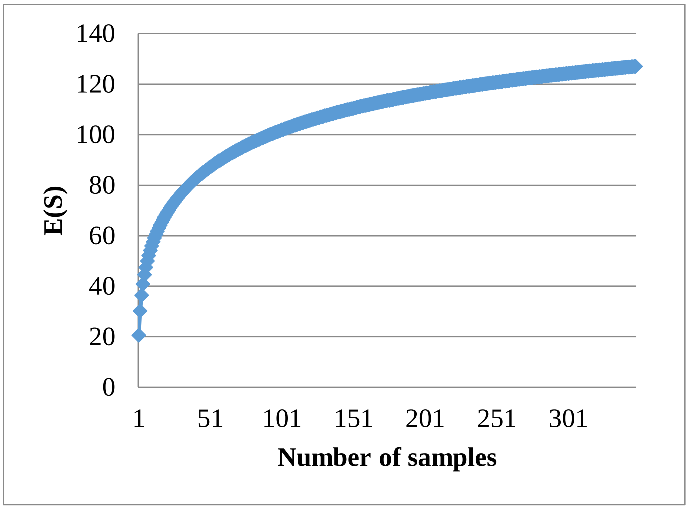

Figure A2. Rarefaction curve with estimated number of species as a function of number of samples for the regional average, N=348.

A4 Calculating EDP

A4.1 EDP with Regional Average Species Richness (384 samples)

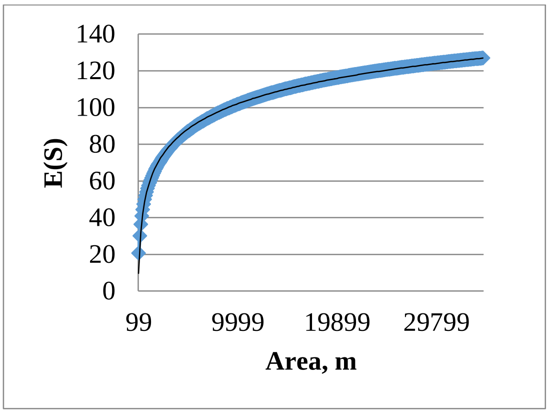

Figure A3. Rarefaction curve for "regional average", E(S) = 20,05ln(A/99) +9,5952
R² = 0,9974, N=348

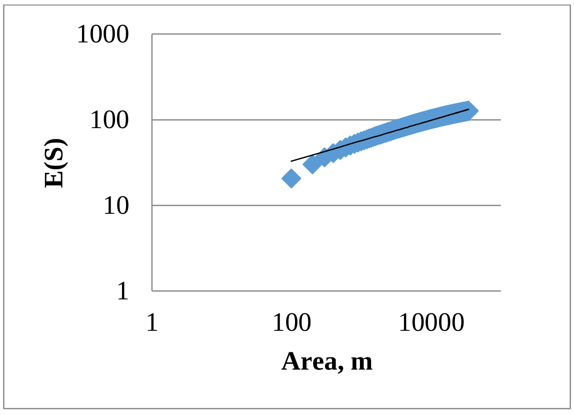

Figure A4 Estimated species for "regional average" against sample areas, fitted power equation
$E(S) = 10{,}981A^{0{,}2384}$
$R^2 = 0{,}9703$, N=348

If one only analyses the samples from Norrbotten and Västerbotten coastland instead, the plots in Figure 3 and Figure A4 are received. The sample numbers have now decreased to 348 and thus give other parameter values. Thus because of the nature of the rarefaction function, that it calculates the estimated specie richness depending on the number of samples, the more samples the more likely it is that a new species is identified and the higher estimated species number. This will benefit the land use types with many sample plots and identified species,

Another reference state was also computed for 52 of the plots from the total 606 plots. This was done in order to analyse the influence in sample number and species numbers. Those samples had a high species number and gave therefor high values for approximated species richness, see next section.

Table A5.Fitted parameters for the regional average reference

	Total nr of species	Total Area [m²]	Nr of Samples	Species/samples	c	z	R^2	$E(S)=c100^z$	$E(S)=c10000^z$
Regional average less sample	127	34000	348	0.36	10.98	0.2384	0.97	33	171

Table A6. EDP calculations with Norrbotten and Västerbottens coastland as reference (348 samples)

	$EDP_{local\_linear,E(100)}$	$EDP_{local\_non\text{-}linear,E(100)}$	$EDP_{local\_linear,E(10000)}$	$EDP_{local\ non\text{-}linear,E(10000)}$
Norrbotten coast-pine	0.274	0.086	0.200	0.060
Norrbotten coast-"total forestry	0.108	0.031	0.0468	0.013
Forest in "National parks" (NPV)	0.235	0.0723	0.0787	-0.074

If one instead use the 384 sample based reference the result do not differ noticeable to the previous calculated EDPs with 606 samples.

A4.2 EDP with Regional Average Species Richness (52 samples)

In this section are the regional average species richness calculated based on only 52 samples. This was done by to see how the result changed when the number of samples changed. As can be seen in Table A7 are the species richness number quite high for both 100 m^2 and 1 hectare.

Table A7. Parameters from the fitted power equation for the regional average species richness plot with 52 plots.

	Total nr of species	Total Area [m^2]	Nr of Samples	c	z	R^2	$E(S)=c100^z$	$E(S)=c10000^z$
Regional average less sample	82	5148	52	6.4542	0.3025	0.9762	25.99	210.06

In Table A8 are the EDPs calculated based on this reference.

Table A8. EDP for the different cases based on average species richness with 52 samples

	$EDP_{local\_linear.E(100)}$	$EDP_{local\_non\text{-}linear.E(100)}$	$EDP_{local\_linear.E(10000)}$	$EDP_{local\ non\text{-}linear.E(10000)}$
Norrbotten coast-pine	0.080451667	0.022645621	0.34946063	0.116087
Norrbotten coast-“total forestry	-0.129163055	-0.032798709	0.226152052	0.069223
Norrbotten coast-“clearcut”	0.044261528	0.012223161	-0.265138532	-0.0635
Forest in “National parks” (NPV)	0.031121413	0.008536312	0.078652043	-0.01832

A4.3 Dead Wood

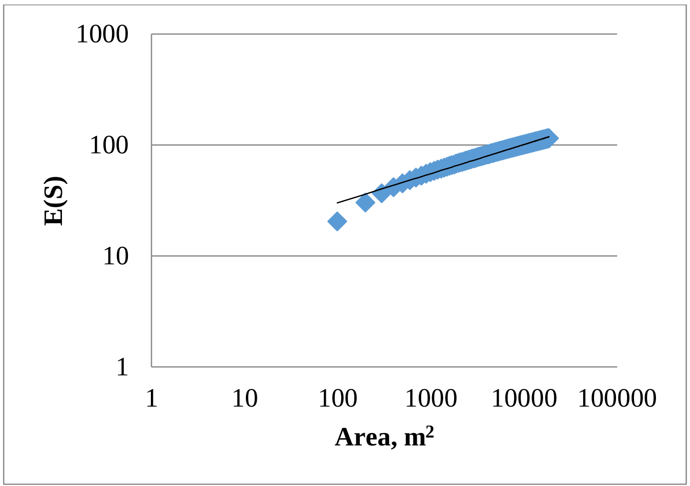

Figure 30.Estimated species number and area in a log-log plotted function with fitted power trend line with equation: E(S) = $9{,}0435A^{0{,}2618}$
$R^2 = 0{,}9762$

In this case samples that includes the whole stand age distribution from 0 to 285 years were selected in Norrbotten coastland. This resulted in 187 plots with 115 species. The estimated standardized species richness for 100m^2 was 30 species and 184 species for 1 hectare.

A.5. Calculating Standardized Species Richness and EDP with Semi log Equation

In this section the parameters from the semi-logarithmic equation are used to calculate the standardized species richness for 100 m^2 and 1 hectare, see Table A9.

Table *A9*. Overview of the parameters from the rarefaction curve used for calculate E(S).

	Total nr of species	Total Area [m²]	Nr of Samples	c	z	R^2	E(S)=c+z*ln(100)	E(S)=c+z*ln(10000)
Regional average 606	144	59994	606	0.4096	22.214	0.9939	0.6329	102.93
Regional average 384	127	34452	384	9.5952	20,05	0.9974	9.80	194.46
Norrbotten – "pine forestry"	61	5148	52	20.284	10.568	0.9953	20.39	69.058
Norrbotten - "total forestry"	171	9999	101	15.056	16.587	0.9975	15.22	91.61
Forest in "National parks" (NPV)	85	5346	54	16.294	17.018	0.9972	16.47	94.84
Forest with high volume of dead wood	91	7623	77	15.904	17.051	0.9959	16.07537	133.8595

In Table A10 are the standardised species richness calculations for 10m² and 1 hectare used to calculate the ecosystem damage potential. As can be seen, the result vary enormously and are therefore not very dependable and shall therefore not be used.

Table *A10*. EDP for different type of forestry in Norrbotten with "regional average" 606 samples as reference situation and semilog species area relationship.

	$EDP_{local\_linear.E(100)}$	$EDP_{local\_non\text{-}linear.E(100)}$	$EDP_{local\_linear.E(10000)}$	$EDP_{local\ non\text{-}linear.E(10000)}$
Norrbotten coast-pine	-31.2192529	-0.937592331	0.329095098	0.107764527
Norrbotten coast-"total forestry	-23.053903	-0.858680263	0.110008804	0.031466801
Norrbotten coast-"clearcut"	-26.9400543	-0.899116551	0.048802495	0.01350906
Forest in "National parks" (NPV)	-25.016958	-0.87986211	0.078652043	0.022117728

In Table A11, are the EDP calculated based on the NPV as a reference, these values result as well in questionable result and can therefore not be used.

Table *A11*. EDP for different type of forestry in Norrbotten with "NPV" as reference situation and semi log species area relationship.

	$EDP_{local\_linear,E(100)}$	$EDP_{local\_non\text{-}linear,E(100)}$	$EDP_{local\_linear,E(10000)}$	$EDP_{local\ non\text{-}linear,E(10000)}$
Norrbotten coast-pine	-0.23839432	-0.057730221	0.271822445	0.085646799
Norrbotten coast-"total forestry	-0.23839432	-0.057730221	0.271822445	0.085646799