Nordic Council of Ministers

BIODIVERSITY AND ECONOMIC MODELLING

Links, challenges and possible ways out

Biodiversity and economic modelling

Links, challenges and possible ways out

Steffen Brøgger-Jensen, Simon Laursen Bager,
Jesper Karup Pedersen and Michael Munk Sørensen

TemaNord 2018:531

Biodiversity and economic modelling
Links, challenges and possible ways out
Steffen Brøgger-Jensen, Simon Laursen Bager, Jesper Karup Pedersen and Michael Munk Sørensen

ISBN 978-92-893-5595-7 (PRINT)
ISBN 978-92-893-5596-4 (PDF)
ISBN 978-92-893-5597-1 (EPUB)
http://dx.doi.org/10.6027/TN2018-531

TemaNord 2018:531
ISSN 0908-6692

Standard: PDF/UA-1
ISO 14289-1

Cover photo: Unsplash.com

Print: Rosendahls
Printed in Denmark

5041 0457
Ecolabelled Printed Matter
Rosendahls

Nordic Council of Ministers/Publication Unit
Ved Stranden 18
DK-1061 Copenhagen K
Denmark
Phone +45 3396 0200
pub@norden.org

Nordic co-operation
Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and the Faroe Islands, Greenland and Åland.

Nordic co-operation has firm traditions in politics, economics and culture and plays an important role in European and international forums. The Nordic community strives for a strong Nordic Region in a strong Europe.

Nordic co-operation promotes regional interests and values in a global world. The values shared by the Nordic countries help make the region one of the most innovative and competitive in the world.

The Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen K, Denmark
Tel.: +45 3396 0200 www.norden.org

Download Nordic publications at **www.norden.org/nordpub**

Content

Preface ... 7
Summary ... 9
Background ... 9
Links ... 9
Conclusions and recommendations ... 10
List of abbreviations ... 15
1. Introduction ... 17
2. Analytical framework ... 21
2.1 Two-way link ... 21
2.2 DPSIR framework ... 22
2.3 Challenges ... 27
3. Starting point ... 31
3.1 Land use differs in Scandinavia ... 31
3.2 Biodiversity indicators ... 32
3.3 Macro-economic indicators ... 34
4. Possible ways for linking biodiversity indicators with economic models ... 39
4.1 From macro-economic indicators to biodiversity indicators ... 40
4.2 From biodiversity indicators to macro-economic indicators ... 52
5. Conclusions and recommendations ... 55
5.1 Conclusions ... 55
5.2 Recommendations ... 65
6. References ... 69
Sammenfatning ... 73
Baggrund ... 73
Sammenhængene ... 73
Konklusion og anbefalinger ... 74
Appendix 1: Glossary ... 79
Appendix 2: Biodiversity indicators: Three examples ... 81
The Norwegian Nature Index ... 81
SEBI – Streamlining European Biodiversity Indicators 2020 ... 83
OECD Biodiversity Policy Response Indicators ... 86
Appendix 3: From Drivers to States, Two examples ... 89
Example 1 – The skylark ... 89
Example 2 – Open land ... 95

Preface

While many other environmental problems, particularly energy use and air pollution, have been analysed through integration with and links to macro-economic models in the Nordic countries, this has proved much more difficult for biological diversity. Thus, to what extent such models can be used to describe the drivers and threats to changes in biodiversity diversity are therefore not evident.

This report investigates to what extent it is possible to establish and quantify a causal link between economic activities and biodiversity, in whole or in part, and what it would take in terms of data and model changes to do this where appropriate. However, it also considers the inverse link (i.e. how changes in biodiversity may affect the economic sectors and whether such a link may be quantified).

The report was funded by the Environment and Economy Group (MEG) and Terrestrial Ecosystem Group (TEG) under the Nordic Council of Ministers and prepared by COWI A/S.

September 2018
Signe Krarup
Chairman of the Working Group on Environment and Economy

Summary

Background

Economic activities impact on biodiversity – and changes in biodiversity impact on economy. However, our understanding of these links is still fairly limited. In the words of the report "Making the environment count" published by the Nordic Council of Ministers (NCM) in 2016 (TemaNord 2016:507, p. 102): "Biodiversity has proved among the more challenging environmental issues to link to macroeconomic models."

Against this background, the Environment and Economy Group (MEG) and Terrestrial Ecosystem Group (TEG) under the NCM have launched a project aimed at addressing the extent to which it is possible to establish links between macro-economic models and biodiversity indicators.

The objective of the project is to investigate to what extent it is possible to establish and quantify a causal link between economic activities and biodiversity, in whole or in part, and what it would take in terms of data and model changes to do this where appropriate. Actually, the link in question consists of two links, since the link between economic activities and biodiversity goes both ways.

The project focuses on the impacts of economic activities and changes therein on biodiversity. However, it also considers the inverse link (i.e. how changes in biodiversity may affect the economic sectors and whether such a link may be quantified).

Links

The causal link between economic activities and biodiversity is analysed using the so-called DPSIR framework, which systemises and structures the links between *Drivers*, *Pressures*, *States* (or *Environmental states*), *Impacts* and *Responses* within the environmental field. Each step (or stage) of which the DPSIR framework consists – and accompanying links – have their own indicators.

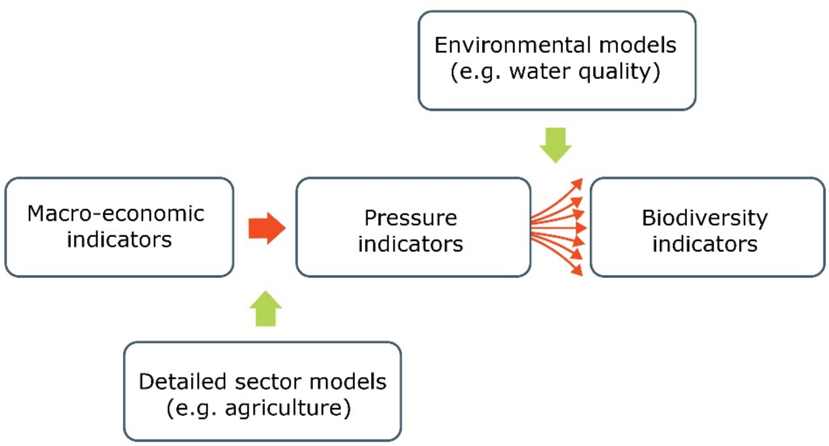
The link in question is divided into two links, namely: first, the link between *Drivers* (e.g. increase in forestry production) and *Pressures* (e.g. loss of natural forest), second, the link between *Pressures* and *States* (e.g. changes in living conditions in open land for certain birds). In this way, the analysis can be made more concrete, not least because it is becomes fairly easy to relate it to macro-economic indicators contained in various macro-economic models (of relevance for the first-mentioned link) and biodiversity indicators contained in various environmental models (of relevance for the latter link). For each of the two links, it is examined whether and to what extent it may be quantified applying macro-economic or environmental models. The causal link between biodiversity and economic activities is examined by looking at the link between *States* and *Impacts* (e.g., changes in recreational opportunities or natural values).

The project builds upon existing macro-economic and environmental models and associated indicators in the Scandinavian countries. However, it takes into consideration ongoing work in this field by international organisations such as the OECD.

Conclusions and recommendations

The overall conclusion is illustrated in Figure 1 below. Establishing the relation from macro-economic indicators to pressure indicators can be done through detailed sector models. Establishing the link from pressure indicators to biodiversity indicators is much more complex and it is unclear what the predictive strength of such a relation would be.

Figure 1: From macro-economic indicators to biodiversity indicators – from fairly straightforward links to complex links



It seems possible to construct quantitative models that can estimate changes in the pressure level (as recorded by selected pressure indicators related to *Pressures*) that originate from a certain macro-economic scenario (as recorded by selected macro-economic indicators related to *Drivers*). Such models would support policy assessments and answer questions like whether a given macro-economic scenario will increase or decrease the pressure on biodiversity.

However, how much biodiversity (measured by selected biodiversity indicators related to *States*) will be affected by a change in the pressure level would remain uncertain. The fact that biodiversity is not easily measured by a few indicators, the time lag from change in a pressure until the effects materialise and the spatial dimension of the pressures mean that only qualitative conclusions might be drawn about the link between *Pressures* and *States*.

Nevertheless, being able to estimate changes in the pressure level as a result of various macro-economic scenarios would be a significant step forward in the assessment of future development of biodiversity.

From Drivers to Pressures

The feasibility of linking drivers and pressures has been assessed for each of the main pressure types:

- Habitat loss and degradation.
- Climate change.
- Excessive nutrient load and other forms of pollution.
- Over-exploitation and unsustainable use.
- Invasive alien species.

Table 1 presents the conclusion regarding the feasibility of establishing a quantified relation between the economic sectors and each pressure.

Table 1: Pressures, economic activity and available models

Types of pressures	Type of economic activity (or sector)	Data and models
Habitat loss and degradation	Land use	No land-use models available. Feasible to develop such models. Through mapping and land-surveying detailed land-cover and land-use data can be expected to be available in the future.
Climate change	All sectors	Climate change depends on global emissions. Not relevant to link national GHG emissions and biodiversity.
Pollution	All sectors	Pollution module exists. They can estimate the emissions from a given macro-economic scenario.
Over-exploitation and unsustainable use	Fishery	Some models for over-exploitation of marine resources are available (e.g. fish stocks as function of fishing effort).
Invasive alien species	Trade and tourism	Limited knowledge about these links. It has not been investigated to what extent it is possible to link the pressures to the macro-economic indicators.

Table 2 presents an estimate of the number of biodiversity indicators affected by each of the main pressure types. Though it is not considered feasible to make quantified links from *Pressures* to *States*, it is most relevant to make such links, to the extent possible, from *Drivers* to *Pressures* and, hence, important to point out the main pressure types of particular importance to changes in *States.*

The assessment made in this report clearly points to habitat loss and degradations as the most import pressure type. It is followed by climate change and over-exploitation and unsustainable use.

Table 2: Number of biodiversity indicators affected by each main type of pressure (based on the Norwegian Nature Index 2015)

Type of pressures	Number of indicators affected
Habitat loss and degradation	207
Climate change	166
Pollution	62
Over-exploitation and unsustainable use	102
Invasive alien species	32

Note: Indicators might be affected by several pressures, hence total exceeds the total number of indicators.

Source: Framstad, E (ed.), 2015.

Table 3 summarises findings regarding feasibility and importance of the main pressure types for establishing a quantitative link between *Drivers* and *Pressures.* It helps identifying focus areas of future work aimed at establishing – and developing – such link.

Table 3: Main pressure types, feasibility and importance

Types of pressures	Importance	Feasibility
Habitat loss and degradation	High	High
Climate change	High	Low
Pollution	Low–medium	Medium
Over-exploitation and unsustainable use	Medium	High
Invasive alien species	Low	Low

This assessment points to habitat loss and degradation caused by land-use changes as the main pressure type that should be prioritised. Therefore, the main recommendation of the current project reads as follows:

Explore how to quantify the link between macro-economic sector indicators and habitat loss and degradation. This would imply to initiate work on a "land-use" model that could estimate the effects of sector activity on several aspects of habitat change.

Making the link between the macro-economic drivers and the land-use change would then allow qualitative assessments of many biodiversity indicators.

Several sectors contribute to changes in land and land cover, affecting terrestrial ecosystems and habitats. The pressure is the combination of the development in these sectors and therefore, having one land use and land cover model would significantly improve the understanding of this pressure.

From Pressures to States

The link between *Pressures* and *States* is the subject of biodiversity research. There is a need to continue improving the understanding and possibly be able to quantify some more of the relation. The recommendations are:

- Controlled studies in test areas, both open land and forests, aimed at identifying, assessing and quantifying the link (or rather links) between *Drivers* and *Pressures* and also between *Pressures* and *States.*
- Studies are required to establish better and more indicative relations between positive environmental change and biodiversity recovery, with special emphasis on response delays and other factors that inhibit full recovery.
- Relations between biodiversity richness and ecosystem functionality need to be established in more detail, as ecosystem functionality is essential for biodiversity resilience as well as for ecosystem services. A thorough understanding of biodiversity and ecosystem resilience and threshold levels of impacts that trigger changes in biodiversity richness and ecosystem functionality appears to be fundamental for a better integration with macro-economic modelling.
- Rather than establishing new biodiversity data gathering procedures it may prove beneficial to look into existing biodiversity monitoring programmes that provide regular data on biodiversity. Also, statistics and databases that hold information on e.g. land use, emission levels and other environmental elements should be exploited when testing new indicators and indices that can be used in sector models or macro-economic models.

As part of ongoing research activities on valuation of ecosystem services, more data will be established that could be used for improving the understanding of how macro-economic indicators are affected by changes in biodiversity. Hence, a separate, final recommendation is:

- Further development of valuation principles of biodiversity in order to add methodological approaches. This could include how the sector activity/output or value added is affected by changes in biodiversity.

List of abbreviations

AHTEG	Ad Hoc Technical Expert Group
BAT	Best available technology
CBD	Convention on Biological Diversity
CGE	Computable General Equilibrium
DMU	National Environmental Research Institute; it was closed in 2011, when Danish Centre for Environment and Energy was reorganized
DPSIR	Drivers, Pressures, States (or Environmental states), Impacts and Responses
ESS	Ecosystem services
EEA	European Environmental Agency
GDP	Gross Domestic Product
GHG	Greenhouse gases
IUCN	International Union for Conservation of Nature
MAES	Mapping and Assessment of Ecosystems and their Services
MEA	Millennium Ecosystem Assessment
MEG	Environment and Economy Group
na	Not available
NCM	Nordic Council of Ministers
NGO	Non-governmental organization
ODA	Official Development Assistance
OECD	The Organization for Economic Co-operation and Development
PES	Payment for Ecosystem Services
PM	Particulate matter
RIVM	National Institute for Public Health and the Environment
SEBI	Streamlining European Biodiversity Indicators
TEEB	The Economics of Ecosystems and Biodiversity
TEG	Terrestrial Ecosystem Group
UN	United Nations
UNCSD	United Nations Conference on Sustainable Development
USD	US Dollar

1. Introduction

Biodiversity is under pressure. It is true all over the world, including the Nordic countries, in which, especially, agriculture and forestry have contributed and contribute to the deterioration of biodiversity. It is considered a threat, not only to biodiversity, but also to human life by the world community. Consequently, actions have been taken at various levels to reverse this development. However, progress is not as fast as planned. Many of the 196 countries which are parties to the Convention on Biological Biodiversity from 1992 will hardly reach the so-called Aichi Biodiversity Targets for 2020 approved at the UN Biodiversity Conference in Japan in 2010.

Economic activities impact on biodiversity – and changes in biodiversity impact on economy. There is common agreement that the first-mentioned link is the key in any attempt to improve biodiversity and also that the latter link is important to keep in mind to the extent that it captures the impact of changes in biodiversity on human life.

However, our understanding of these links is still fairly limited. In the words of the report "Making the environment count" published by the NCM in 2016 (TemaNord 2016:507, p. 102): "Biodiversity has proved among the more challenging environmental issues to link to macro-economic models." Against this background, the Nordic Council of Ministers (NCM) has launched a project focusing on the possibilities of linking measures of biodiversity with macro-economic modelling.

The Environment and Economy Group (MEG) and Terrestrial Ecosystem Group (TEG) under the NCM has entrusted COWI A/S (henceforth: COWI) with the project. COWI has carried out the project in cooperation with members of the specially formed steering group established by MEG and TEG to supervise and direct the work.

The objective of the project is to investigate to what extent it is possible to establish and quantify a causal link between economic activities and biodiversity, in whole or in part, and what it would take in terms of data and model changes to do this where appropriate. Actually, the link in question consists of two links, it is a two-way link, since the link between economic activities and biodiversity goes both ways. In this context, it is worth emphasising that the project is conceptual in the sense that it aims at investigating to what extent it is possible to establish and quantify such links. No new models, indicators or data is provided.

What are the policy questions?

Basically, there are two types of policy questions:

Policy questions focusing on the impact of economic activity on biodiversity:

- How do current economic activities affect our biodiversity – and how will it affect it in the medium to long-term?
- Which economic activities especially impact on pressures on biodiversity?
- What are the drivers (e.g. demography, economic growth and urbanisation) that affect our biodiversity – and which of these are the most important?

Policy questions focusing on the impact of changes in biodiversity on economic activity:

- How may changes in biodiversity impact natural values, recreational opportunities and human life?
- How may changes in biodiversity impact framework conditions for selected eco-nomic sectors – through changes in biodiversity as an ecosystem service or natural resource or through new legislation aimed at protecting biodiversity?
- Which economic activities are especially sensitive to changes in biodiversity?

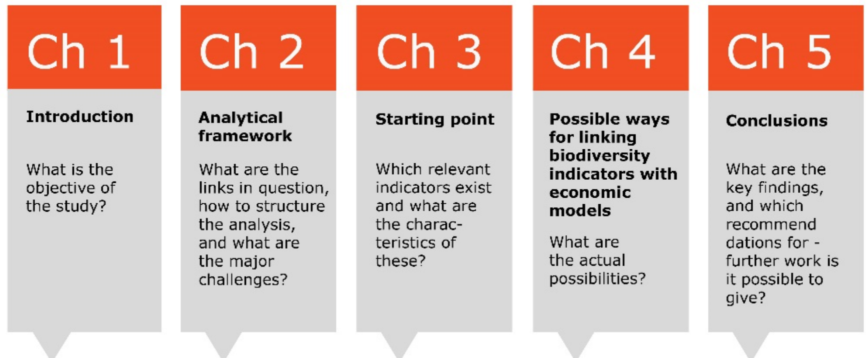
The project focuses on the impacts of economic activities and changes therein on biodiversity. However, it also considers the inverse link (i.e. how changes in biodiversity may affect the economic sectors and whether such a link may be quantified).

This report provides the findings of the project. It reviews and synthesises current knowledge of the possibilities of linking economic activities and biodiversity in a Nordic context, thereby addressing some of the prevailing policy questions in the Nordic countries and beyond regarding the links between economic activities and biodiversity.

The target group is fairly broad. It is the hope of the authors that the report is understandable and of potential use to politicians, the press and NGOs in the Nordic countries. At the same time it is the hope that it provides valuable input to the ongoing work in this field of international organisations (foremost OECD, the European Commission and the UN), ministries of finance and other ministries in the Nordic countries, and the academia.

The report consists of five chapters in addition to this one, and three appendices. Chapter six provides the references. Each of the other five chapters addresses a few questions, cf. Figure 2.

Figure 2: Structure of the report



Chapter 2 presents the analytical framework highlighting the two-way link between economic activity and biodiversity, the model applied to structure the analysis, and the well-known challenges in linking measures of biodiversity and economic modelling. The next chapter, Chapter 3, concerns the starting point of the analysis; foremost existing macro-economic indicators and biodiversity indicators. It provides a brief overview of the indicators applied in Denmark, Norway and Sweden. Subsequently, Chapter 4 presents the main analysis carried out on the basis of the above chapters. It describes and discusses how the links between economic activities (in particular, macro-economic indicators) and biodiversity (in particular, biodiversity indicators) can be established. It elaborates on the two different directions of the links – from economic activities to biodiversity and from biodiversity to economic activities. Chapter 5 provides an overview of the findings and makes a few recommendations for further work.

Hopefully, the findings and, not least, recommendations may serve as a valuable source of inspiration for the many people in the Nordic countries engaged with the establishment of possibly links between economic activities and biodiversity, taking into good account existing models, indicators and data.

2. Analytical framework

This chapter describes the applied analytical framework. Focus is on the two-way link between economic activity and biodiversity, the model applied to structure the analysis, and the well-known challenges in linking measures of biodiversity and economic modelling.

2.1 Two-way link

Much of current policy making is referring to and using macro-economic ana-lyses and macro-economic projections. New policy proposal are subject to macro-economic assessments indicating their impacts on economic growth and employment. Biodiversity is an example of an environmental policy area where the link to macro-economic assessment has not yet been developed. This is the point of departure for the current project and the basis on which its objectives have been defined.

As mentioned in Chapter 1, the objective of the project is to assess whether it is feasible to link economic activities and biodiversity and how it could be done. It is important to distinguish between the knowledge of a link and the ability to describe it in quantitative models.

More specifically, the project addresses the following two questions:

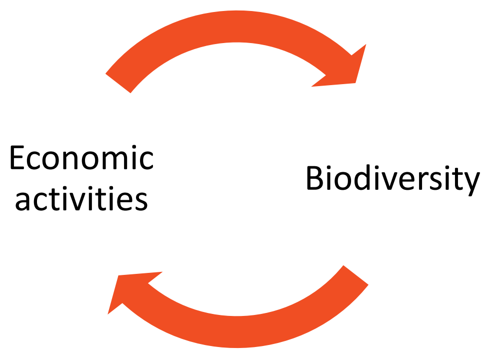
- Can we establish a link from macro-economic indicators to biodiversity indicators – and, if so, can we quantify it?
- Can we establish a link from biodiversity indicators to macro-economic indicators – and, if so, can we quantify it?

Figure 3 illustrates the two all-important questions to be addressed in the project, highlighting the fact that the link between economic activities and biodiversity is a two-way link.

There is no doubt that economic sectors and various economic activities, foremost production and consumption, associated with these affect biodiversity through the use of resources, modification of environments and ecosystems, and disposal of waste and other residues. The question is whether this link may be properly established and, not least, quantified. That is the first question.

The second question concerns establishing – and quantifying – the reverse link. Biodiversity underpins some economic activities and a loss of biodiversity (or in broader terms, ecosystems and their related goods and services) affects the functioning of the economic system. However, the exact impact on the economic activity depends on the type of changes in biodiversity experienced as well as the economic activity in question, with sectors such as agriculture or tourism being more affected than, for instance, banking or the automobile industry.

Figure 3: Economic activities impact on biodiversity – et vice versa



The second question concerns establishing – and quantifying – the reverse link. Biodiversity underpins some economic activities and a loss of biodiversity (or in broader terms, ecosystems and their related goods and services) affects the functioning of the economic system. However, the exact impact on the economic activity depends on the type of changes in biodiversity experienced as well as the economic activity in question, with sectors such as agriculture or tourism being more affected than, for instance, banking or the automobile industry.

As mentioned, the focus is on the first question in this project.

2.2 DPSIR framework

When assessing the two-way link between economic activities and biodiversity, it is imperative to understand exactly how it works. To this end we have applied the so-called DPSIR framework. DPSIR is an abbreviation for *Drivers*, *Pressures*, *States* (or *Environmental states*), *Impacts* and *Responses*. It was developed by RIVM in the Netherlands and DMU in Denmark in the 1990s within the framework of a project carried out on behalf of the EEA (EEA, 1999). It systemises and structures the links between *Drivers*, *Pressures*, *States*, *Impacts* and *Responses* within the environmental field.

This section provides an overview of the DPSIR framework and information about the translation of the two-way link into the DPSIR framework. The link from macro-economic indicators to biodiversity indicators is further detailed using the DPSIR framework, as is the reverse link from biodiversity indicators to macro-economic indicators.

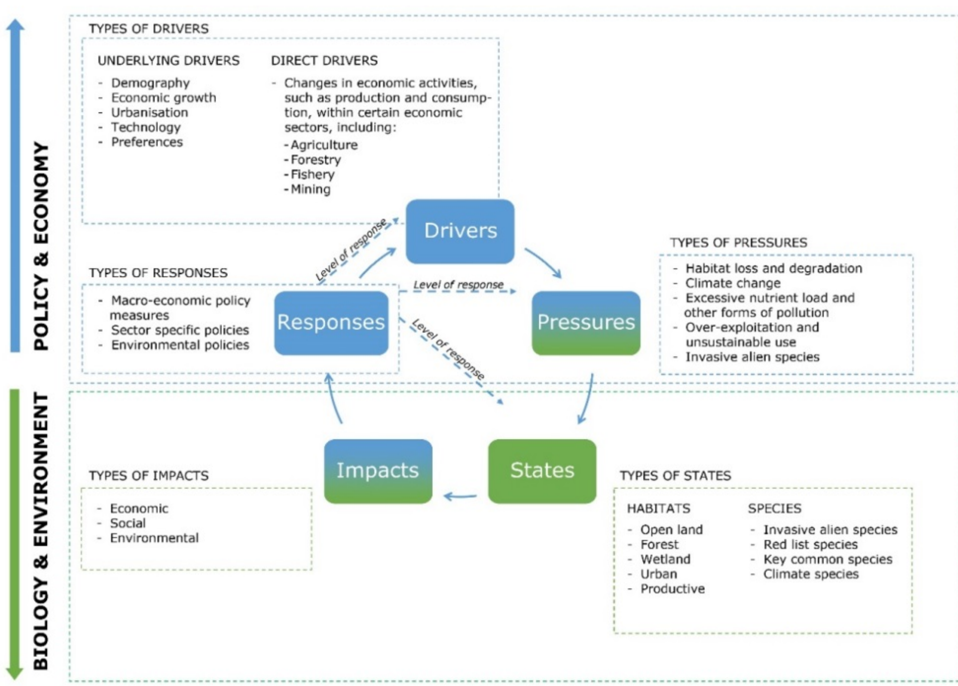
2.2.1 Overview

In order to understand how the economy affects biodiversity overall, it is necessary to understand the various ways in which the economic system affects land, air, and water quality and quantity, which in turn affect biodiversity. The DPSIR framework assists in developing this understanding.

Figure 4 provides an overview of the DPSIR framework adapted to biodiversity, highlighting the five steps (or stages) of which the DPSIR framework consists and providing information about the meaning of each step. The upper half of the figure (*Drivers*, part of *Pressures*, and *Responses*) relates mainly to policy and the economy, whereas the lower half of the figure (*States* and part of *Impacts*) mainly concerns biology and the environment, i.e. the actual changes that take place in nature, affecting ecosystems and the environment. The blue colour denotes relations to policy and economy, while the green colour denotes relations to the environment and biology.

It should be mentioned that a number of similar framework models exist – for instance, the Pressure-State-Response model developed by the OECD and the Driving Force-State-Response model used by the UNCSD (OECD, 2003) – and also that the DPSIR framework may be interpreted in different ways. In particular, the latter issue concerns the exact understanding and definition of *Pressures*, *States* and *Impacts*, respectively. When developing Figure 3, we took into consideration the fact that the Convention on Biological Diversity and its Secretariat refer to "five principal pressures", which have thus been included in the figure under the heading "Types of pressures" (Convention on Biological Diversity, 1992; Convention on Biological Diversity website).

Figure 4: DPSIR framework adapted to biodiversity



Source: Prepared by COWI on the basis of EEA, 1999; Convention on Biological Diversity (1992); Convention on Biological Diversity website; Geist & Lambin, 2002; Kristensen, P., 2004; MEA, 2005; OECD, 2003; Statistics Denmark, 2002.

The first step (*Drivers*) in the DPSIR framework on impacts on biodiversity of the economic system distinguishes between direct drivers and the underlying drivers, which drive changes in economic activity. Thus, the drivers of changes in biodiversity can be regarded as the result of multiple drivers occurring at various scales, temporal as well as spatial. The methodology follows that of Geist and Lambin (2002), which use a similar framework to describe changes to land use and causes of deforestation and land use change.

Direct drivers can be understood as specific economic activities leading to pressures on the environment, e.g. food production, transport of goods, infrastructure development, agricultural expansion and intensification of forest management. That is, the consumption, production, transport and disposal of goods, which take place in an economic system. A division can, of course, be made between various sectors of the economy, e.g. agriculture, industry, transport and services.

Underlying drivers are factors of the socio-economic system, which drive demand for commodities, products or services of the economy and lead to changes in the proximate causes. These include demographic factors such as population growth, economic factors such as market expansion, technological factors such as new harvesting techniques, political factors such as environmental policy enforcement or support for organic agriculture, and cultural factors such as changes in values or beliefs (e.g. renewed support for local food production).

In the model, drivers within the economy lead to specific activities taking place. This causes *Pressures* to be enacted on the environment through activity within various economics sectors. These pressures can be understood as conditions affecting the quality or quantity of the ecosystem or environment. This could be the release of pollutants (e.g. SO_2, NO_X, and particulate matter (PM)), loss of habitat (e.g. through conversion to farmland), fragmentation (e.g. through expansion of a road), intensification (e.g. due to increased industrial activity), and various other disturbances that place pressures on the environment. As mentioned, we have emphasised the "five principal pressures" highlighted by the Secretariat of the Convention on Biological Diversity.

The economic activities and the pressures caused by them affect the natural conditions (*States*) of the ecosystem or environment in question. Such changes in the states can be qualitative, i.e. affecting the quality of the state of an ecosystem or a habitat by reducing key species within this, or quantitative, i.e. affecting the area of a habitat or ecosystem. Further, the changes to the state of an ecosystem or habitat can affect the ecosystem services (ESS) provided by the ecosystem or habitat. Keeping in mind the focus on biodiversity, the types of changes involve changes to habitats or changes to species. The former concerns the type of habitat affected, which can be forest areas, open land habitats such as heath or meadows, wetlands such as marshes, urban areas such as parks or greenfields, or productive areas such as farmlands. As these different areas are home to different kinds of biodiversity, they are of importance to the impact on the biodiversity of economic activities. The changes to the state of the ecosystem also affect the species present in this, e.g. by introducing invasive species, by causing a loss or change in e.g. red-list species or key common species, or by introducing new species through qualitative changes to the ecosystem (e.g. through changes to the climate). The impact on biodiversity is thus the causal effect enacted by changes throughout the system beginning with a change to the *Drivers.*

The change in environmental states may have economic, social and/or environmental impacts (*Impacts*). Economic impacts concern economic opportunities, costs, and benefits derived from the environment, whereas social impacts concern health, the quality of life, security and ethics. The environmental impacts concern changes in the value of the ESS provided, such as changes in recreational opportunities and natural values.

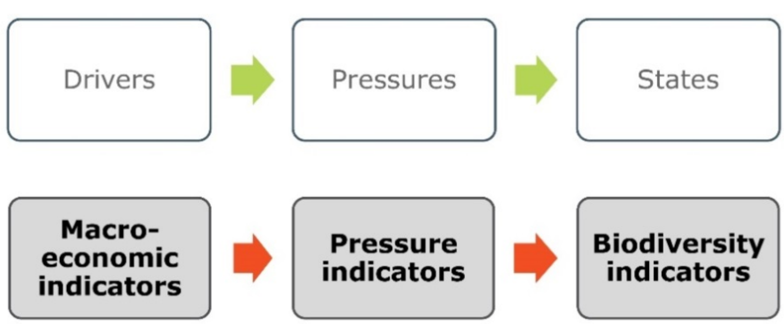
Consequently, impacts on society (often) call for actions (*Responses*). This usually involves policies or targets being set. The types of responses include macro-economic measures, sector-specific policies and environmental policies – applying hard regulation such as laws, as well as soft regulation such as taxes and tariffs.

The level of response determines where in the chain of events (*Drivers*, *Pressures* or *States*) the response is targeted as illustrated in Figure 4 by the dotted lines. Generally, the higher up the chain of events the response is targeted, the greater the effect. If the driver causing the loss of or change to biodiversity can be changed, the effect is greater than if only the state of the environment is sought changed. This is because in the latter case, the driver will still enact pressures, which will continue to cause changes to the state of the ecosystem or environment. However, the higher one moves up in the chain of events, the more difficult it becomes to pinpoint the exact factor that leads to the impact on biodiversity in the end, making the response difficult to design. It should be noted that this report does not deal with the response-part of the DPSIR framework, but focuses on the first four steps and links between them.

2.2.2 *From Drivers to States*

It follows from the DPSIR framework that the link from economic activities to biodiversity, in fact, consists of two links, namely a link from *Drivers* to *Pressures* and another link from *Pressures* to *States.* Furthermore, it follows that the steps and links between these may be converted into certain indicators. This is illustrated in Figure 5 below.

Figure 5: From Drivers to States



In terms of establishing the overall link between *Drivers* and *States*, the above figure presents our conceptual understanding. It illustrates the principal relation between macro-economic activity as the driver leading to pressures and how they affect environmental states, where biodiversity is one aspect of the environmental state. For example, an economic activity such as agriculture (a driver) leads to emissions (a pressure), which may reduce food supply and therefore lead to a reduction in population of some species (environmental state). The lower part presents how the relation could be quantified. Economic activity may be measured in physical or monetary terms and by applying an emission factor (tonnes of emission per unit of activity), the pressure can be estimated. The changes in emissions might be linked to the resulting change in the species in question (the biodiversity indicator) through an environment model of some form.

Ideally:

- Macro-economic indicators used in macro-economic modelling should be linked to pressure indicators.
- Pressure indicators should be linked to biodiversity indicators constituting a subset of environmental state indicators.

The major objective of this project is to assess the two types of links: from *Drivers* to *Pressures* and from *Pressures* to *State*.

The assessment in this project covers the current state of knowledge regarding those links. The approach is firstly to assess relevant biodiversity indicators, then identify the drivers, and having identified the drivers and the biodiversity indicators, alternative ways of implementing the above elements practically are described and discussed.

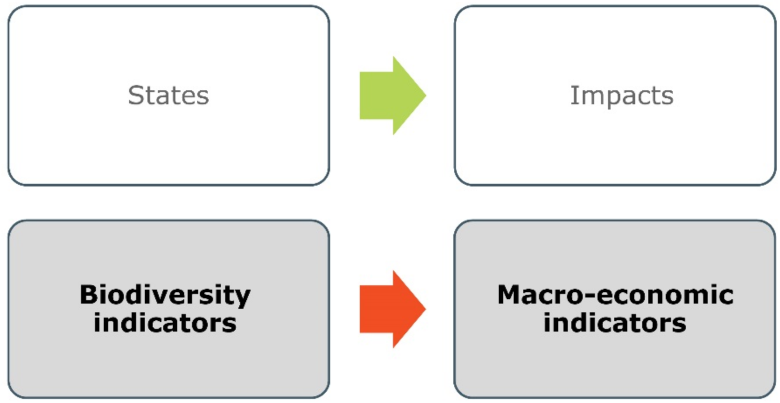
It is important to note that the project does not establish the links or answers the question of how macro-economic developments affect biodiversity. The objective is to assess the feasibility of providing quantitative links.

2.2.3 From States to Impacts

The link between biodiversity and economic activities can also be described using part of the DPSIR framework. Biodiversity is captured by *States,* whereas economic activities are captured by *Impacts*.

Figure 6 illustrates the link from *States* to *Impacts.* It highlights the fact that this link may be converted into a link between biodiversity indicators and macro-economic indicators.

Figure 6: From States to Impacts



To quantify the link, two issues need to be taken into consideration:

- How changes in biodiversity affect the provision of ecosystem services.
- How changes in ecosystem service provision affect sector activity and can be aggregated and incorporated into the macro-economic models.

This implies the application of the ESS approach. The main advantage of this approach seen from an economic point of view is that it portrays ecosystems as natural capital stocks and flows, providing goods and services for human societies, which can be valued using various economic valuation methods and thus accounted for using economic decision-making (Costanza and Daly, 1992; Costanza *et al.*, 1997; de Groot *et al.*, 2002; MEA, 2005; TEEB, 2008; TEEB, 2011b, 2012). Of the ecosystem services, provisioning services are the ones most often and easiest included in the economy as these constitute the direct products (food, lumber, etc.), which are produced by the ecosystem and which can be valued.

2.3 Challenges

There are a few well-known challenges in linking measures of biodiversity and economic modelling. These are dealt with in this section.

2.3.1 Diversity

Biodiversity is a measure of the richness of ecosystems and provides an indication of the number of species and habitats (and genetic variation) within a certain ecosystem or a certain geographical site. Biodiversity can be expressed by simple quantitative numbers and figures, but the importance of these numbers is justified only when the qualitative aspects of biodiversity are considered. Qualitative aspects include:

- The occurrence of red-listed or protected species and protected habitats.
- The occurrence of species that perform key roles in an ecosystem.
- Trends in biodiversity and the state of biodiversity relative to a pristine condition.

Management and policy-based attention to biodiversity, such as national nature protection legislation, will always be based on these qualitative aspects of biodiversity and hence social and legislative responses to pressures on biodiversity are not executed in a linear way.

Besides, it is noteworthy that numerous food chains – and trophic levels in these – exist. It contributes to the complexity of biodiversity.

2.3.2 Valuing biodiversity and ecosystem services

Putting a price tag on biodiversity and ESS is not always possible. It constitutes a challenge to the extent that one would like to quantify impacts in monetary terms, but not in non-monetary terms.

In many cases, studies on value of ESS (cf. e.g. Costanza *et al.*, 1997; Farber *et al.*, 2002; Salles, 2011; Costanza *et al.*, 2014) provide a value of the service in current dollars per area, e.g. per hectare. Economic activity can then change the area of the given ecosystem, e.g. a forest, and the value extracted for the forest can then be used to calculate the loss occurring due to economic activity. However, this rests on the assumption that the marginal and average value of the forest (or any other ecosystem) is similar (OECD, 2015). That is, the loss of the first two hectares of forest is equal to that of the last two hectares. From a biological perspective, this is likely to be false. Biodiversity is affected differently depending on the area of the ecosystem remaining, i.e. the first two hectares of forest loss affect the biodiversity of a given species different than the last two hectares leading to the complete loss of the forest, despite the per hectare value being similar. The latter case may lead to local extinction of the species (sic!), whereas the former may barely affect the number.

This is further complicated by the fact that the economic activity might not change the area of the ecosystem in question, but the quality, e.g. a forest, may be degraded by the location of a road or housing development in its proximity, or a grassland can be degraded by animal grazing. The per-area approach cannot be used in these cases, because the area remains unchanged, although in a qualitatively different state.

Finally, to some species, a tipping point might exist, i.e. the point at which a marginal change in area leads to a significant (more drastic) change in the living condition of the species. Such effects are also not accounted for in the per-area approach.

2.3.3 Time lag and resilience

A particular challenge is linked to the fact that biodiversity responses to environmental impacts are characterised by a time lag.

Many biodiversity indicators may respond swiftly to additional pressures on the environment. The loss of habitat will obviously result in a loss of species at the given site and hence species-based indicators will often demonstrate habitat loss immediately.

However, this response is not linear as the loss of the first fragments of a habitat may not be as readily exposed to biodiversity change as the loss of the last fragments.

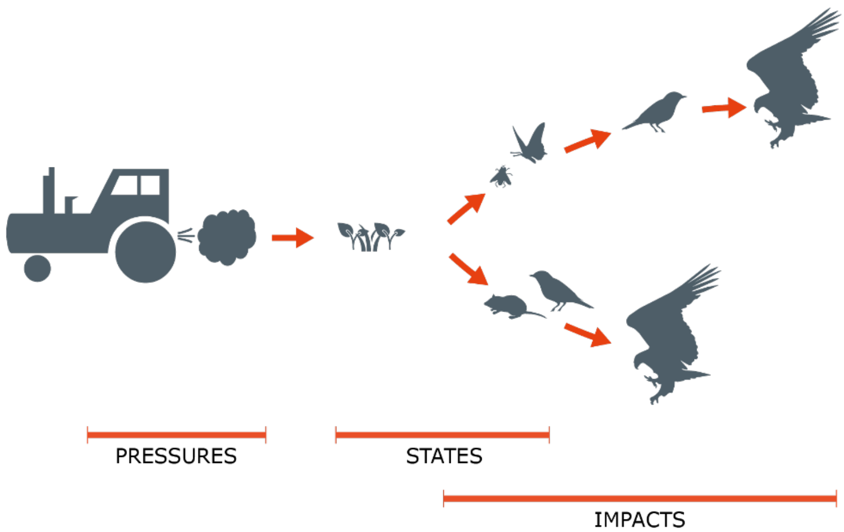
Similarly, the impacts of increased fragmentation and intensification may express themselves with some delay and different indicators may display different temporal responses to such impacts. The resilience in a given habitat or ecosystem cannot be predicted without detailed studies, but it is normally expected that a simple or depleted habitat or ecosystem displays less resilience than a more pristine or complex habitat or ecosystem. The response model is thus far from being linear and rather triggered by various ecological or functional thresholds that are likely to vary significantly from case to case.

In contrast to the response demonstrated by many biodiversity indicators when a habitat disappears or deteriorates, the responses to habitat improvements may show a very different pattern. In a fragmented landscape where the natural habitats may be rather small and mutually isolated, the dispersal of biodiversity elements between suitable habitats may be delayed, for some elements almost infinitely. Inter-dependency between species (such as butterflies and flowering plant species) and the lack of sufficient mobility in many species are among key reasons why biodiversity responses to positive habitat changes may be delayed to various levels. Because of the built-in system inertia, at least in fragmented landscapes, many studies that aim to demonstrate pressure-impact causality fail to distinguish between state and change in their conclusions. An indicator may be useful to demonstrate a certain state or even a clear causality, but it may be inferior when displaying change, at least a positive change.

Thus, ecosystems and biodiversity do not respond in a linear way to increased or reduced pressures, and this creates a particular challenge with regard to modelling effects of economic activities.

In this connection, it is worth mentioning that the prevailing time lags (or response times) in combination with the above-mentioned numerous food chains and trophic levels makes it anything but easy to sort out *States* and *Impacts*. This is illustrated in Figure 7, where weed is affected by a tractor, implying that two food chains are affected; in both food chains small birds are affected, but in one more directly than in the other. Whereas the delimitation of *Pressures* is fairly straightforward, the delimitation of *States* and *Impacts* is not because they overlap in time.

Figure 7: Anything but easy to sort out States and Impacts



2.3.4 Spatial aspects

Most economic models are Computable General Equilibrium (CGE) models or Partial Equilibrium Models, which do not feature a spatial component, which is needed to model ESS and/or biodiversity impacts. The importance of including spatial aspect into the modelling is stressed by the fact that the impacts of various pressures on the state of the ecosystem or habitat (and thus biodiversity) vary by spatial location.

As such, the spatial location of the *Drivers* matters a great deal to the impact on *Pressures* and, hence, *States*.

2.3.5 Integration versus mainstreaming

In a report by the OECD (2015) on the integration of ESS into economic modelling, a point is raised which warrants further consideration. Namely, that two approaches for considering biodiversity and the links to the economy (and vice versa) exist: One is to integrate biodiversity considerations into economic models. Another is to mainstream biodiversity into economic decision-making. The first can be considered a more quantitative approach, whereas the second is a more qualitative approach.

The quantitative approach is dealt with in Chapters 4 and 5.

The qualitative approach, i.e. mainstreaming biodiversity and economic decision-making is a softer approach, where the impact on biodiversity from economic activities is evaluated outside CGE and other models. The OECD, for example, suggests to evaluate the losses or gains to biodiversity to adjust the results provided by the models. In the words of the OECD (2015): "Alternative growth paths can be evaluated in terms of the losses or gains they imply for different ESS and these values can be used to adjust the estimated GDP growth rate, to give a 'corrected GDP'".

3. Starting point

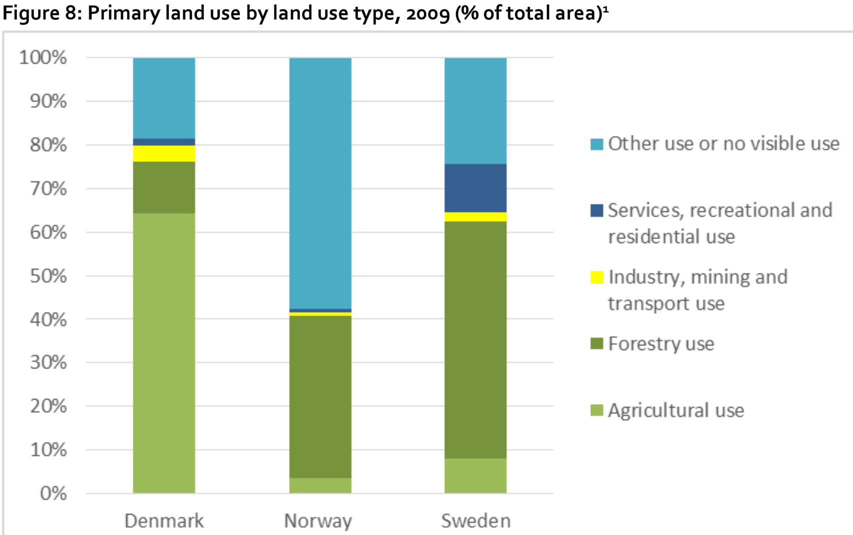
In this chapter, the focus is on the starting point when identifying, improving and establishing links between economic activities and biodiversity. We present examples of biodiversity indicators followed by a thoroughfare of macro-economic indicators. Emphasis is on the macro-economic models and accompanying models. In the subsequent chapter, these two "building blocks" – biodiversity indicators and macro-economic indicators – are used to assess how links may be established.

But – before presenting and discussing the biodiversity indicators, it is relevant to highlight the differences between the Scandinavian countries in this context. The pressures on biodiversity are to a large extent related to land-use, and therefore the difference in land use in Scandinavia is addressed.

3.1 Land use differs in Scandinavia

The three Scandinavian countries differ a lot from each other with regard to land use. This becomes very clear by looking at the share of land used for agriculture, forestry and others, respectively, cf. Figure 8.

Figure 8: Primary land use by land use type, 2009 (% of total area)[1]



Note: [1] 2016 for Norway.

Source: Eurostat (online data code: lan_lu) and Statistics Norway www.ssb.no/statistikkbanken/selectvarval/saveselections.asp

Whereas agriculture is predominant in Denmark, amounting to 64% of land use, it is negligible in Norway and Sweden accounting for 2% and 8%, respectively. The opposite picture is evident with regard to forestry. In Denmark, forestry accounts for 12%, in Norway 37% and in Sweden 54%. In Norway, open firm ground amounts to 38% constituting a large share of the land use named "Other use or no visible use".

3.2 Biodiversity indicators

As mentioned in Chapter 2, biological diversity is immense. Hence, the number of biodiversity indicators is large.

The following list of biodiversity indicators is not exhaustive, but provides an overview of the most important biodiversity indicators in Scandinavia:

- The IUCN Red List of Threatened Species. It is an assessment of endangered species and the list is prepared in all three countries based on the IUCN principles.
- Conservation status. EU legislation on NATURA 2000 requires the Member States to assess the conservation status for habitats and species (Denmark and Sweden).
- The Danish Biodiversity Map.
- The Norwegian Nature Index (NNI).

The NNI is interesting as it provides an aggregated biodiversity measure. Appendix 3 includes a detailed discussion of this index. The aggregated index is based on 301 indicators from nine main ecosystems. The NNI was established in 1990 as an aggregated index that has been compiled by means of data from monitoring, model estimates and expert assessments. The majority of the indicators represent indicators of species' population levels and the number of indicators vary between the nine ecosystems. A number of public institutions provide the data, whether they are monitoring data (approximately 35% of all data), model-based estimates (approximately 19%) or experts' assessments (46% of all data). The NNI is published every five years. The discussion in Appendix 2 covers for example the uncertainty about the individual indicators.

The NNI illustrates the main complexity of measuring biodiversity:

- Diversity.
- Time lag and resilience.
- Spatial aspects.
- Uncertainty.

First of all, the diversity expressed by having about 300 individual indicators means that the feasibility of linking all these indicators to economic activity data will be challenging. This is discussed in further detail in the next chapter.

All over the world, a lot of work on the further development of biodiversity indicators is carried out. Two examples hereof are the SEBI and OECD Biodiversity Policy Response Indicators, cf. Appendix 2 for further details about this work and also the NNI.

Biodiversity indicators often house an inverse relation between robustness and measurability: The simpler the indicator and the easier it is to measure (and likely less costly), the less indicator *value* it may possess. And vice versa: The better and stronger the indicator, the more complex they are formulated – and the more difficult (and perhaps costly) they may be to measure in the field. The same challenge applies to indices, but with the added twist that the stronger the index (in terms of measuring biodiversity), the more complex it often appears – and the less transparent it may prove to be in terms of providing clear signals for reasons behind changes and trends.

A lot of efforts are constantly made and along many parallel tracks to develop meaningful, transparent and strong indicators and indices on the environment, biodiversity, land use and combinations of those elements. Obviously, any attempt to establish clear and transparent links between ecosystems and biodiversity with economic models will fail immediately if not based on intelligent indices. On the other hand, the idea of constructing intelligent indices also fails if the indices are constructed and aggregated on the basis of indicators that are difficult or costly to sample or if the underlying datasets are insufficient.

In the substantial work carried out by the EEA and the European Commission in establishing an integrated set of biodiversity and sustainability indicators, SEBI (Streamlining European Biodiversity Indicators), a detailed list of criteria for the selection of indicators was prepared as part of the process. Obviously, the individual criteria are applied to a varying extent in common national and regional monitoring programmes, and only in a non-existing ideal world will all criteria be applied equally when elaborating and using biodiversity indicators. However, the criteria do provide a useful checklist of factors to consider when searching for or establishing a new indicator or index.

The criteria for selection of biodiversity indicators developed as a part of the SEBI programme are as follows (SEBI 2012):

- *Policy-relevant and meaningful*: The indicators should send a clear message and provide information at a level appropriate for policy and management decision-making by assessing changes in biodiversity, related to baselines and policy targets.
- *Biodiversity-relevant*: The indicators should address key properties of biodiversity or related issues as pressures, state, impacts and responses.
- *Well-founded methodology*: The methodology should be clear, well-defined and relatively simple. Indicators should be measurable in an accurate and affordable way, and constitute part of a sustainable monitoring system. Data should be collected using standard methods with known accuracy and precision, using determinable baselines and targets for assessment of improvements and declines.
- *Acceptance*: The power of an indicator depends on its broad acceptance. Involvement of policy-makers as well as major stakeholders and experts in the development of an indicator is crucial.
- *Routinely collected data*: The indicators must be based on routinely collected, clearly defined, verifiable and scientifically acceptable data.

- *Cause-effect relation*: Information on cause-effect relation should be achievable and quantifiable in order to link pressure, state and response indicators. These relation models allow scenario analysis and represent the basis of the ecosystem approach.
- *Spatial coverage*: The indicators should ideally cover the entire region in focus.
- *Temporal trend*: The indicators should show temporal trends.
- *Sensitivity towards change*: The indicators should show trends and permit distinction between human-induced and natural changes. The indicators should thus be able to detect changes in systems in timeframes and on scales that are relevant to the decisions, but also be robust enough to measure errors that do not affect interpretation.
- *Representative*: The set of indicators provides a representative picture of the DPSIR chain.
- *Small in number*: The smaller the total number of indicators, the easier it is to communicate cost-efficiency to policy-makers and the public.
- *Aggregation and flexibility*: Aggregation should be facilitated at a range of scales.

Concerning the criteria "spatial coverage" and "temporal trend", it remains important to consider the geographical scale that is planned or expected to be covered, as well as the temporal scale with which the indicators are expected to be issued. When identifying suitable indicators for economic activities, it is assumed that the appropriate geographical scale is at the national level.

For the temporal scale, an annual reporting scheme will not be achievable and most likely not necessary in most cases. On a national scale, a 5-year monitoring and reporting scheme may be appropriate, even if other macro-economic indicators are prepared on a yearly scale.

3.3 Macro-economic indicators

Given that the objective is to investigate the feasibility of establishing quantified links between macro-economic indicators and biodiversity indicators, it is useful to consider what the most relevant macro-economic indicators are. This section describes such indicators. Furthermore, the reason for wanting to establish the link between macro-economic and biodiversity indicators is to be able to make forecasts and scenario simulations of how alternative macro-economic scenarios will affect biodiversity. Hence, it is relevant to consider macro-economic indicators like those included in existing macro-economic models used for economic projects and scenarios.

3.3.1 Identification of economic models in the Scandinavian countries

This section provides a description and brief assessment of the main macro-economic models applied in the Scandinavian countries. The models are described in relation to the characteristics most important for the feasibility of linking the macro-economic models with drivers of biodiversity change.

The macro-economic models are typically either econometrically estimated models or Computable General Equilibrium (CGE) models.

Below is a list of the main models currently used in the Scandinavian countries:

- Danish macro-economic models:
  - ADAM[1]
  - SMEC[2]
  - MONA[3]
  - MUSE[4]
  - DREAM[5]
  - REFORM[6]
- Danish sector models:
  - EMMA[7]
  - ESMERALDA[8]
- Norwegian macro-economic models:
  - MODAG[9]
  - KVARTS[10]
  - MSG[11]
- Swedish macro-economic models:
  - EMEC[12]
  - MARKAL-Nordic.[13]

Further information about these is provided in the tables below.

---

[1] http://www.dst.dk/da/Statistik/Publikationer/VisPub?cid=17987
[2] https://www.dors.dk/modeller-metoder/smec
[3] http://www.nationalbanken.dk/en/publications/Pages/2004/02/MONA.aspx
[4] https://www.dors.dk/modeller-metoder/muse
[5] http://www.dreammodel.dk/
[6] http://www.dreammodel.dk/dwn_REFORM.html
[7] https://ens.dk/service/fremskrivninger-analyser-modeller/modeller/oekonomiske-og-tekniske-modeller
[8] http://curis.ku.dk/ws/files/135687554/10.pdf.pdf
[9] https://www.ssb.no/forskning/beregningsmodeller/modag
[10] https://www.ssb.no/forskning/beregningsmodeller/kvarts
[11] https://www.ssb.no/forskning/beregningsmodeller/msg
[12] http://konj.se/var-verksamhet/miljoekonomi/emec-en-miljoekonomisk-allmanjamviktsmodell.html
[13] https://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/miljoarbete-i-sverige/regeringsuppdrag/2015/styrmedel-klimat-energi/150625-ru-strymedel-klimat-energi-bilaga.pdf

Table 4: Macro-economic models, Denmark

Model name	ADAM	SMEC	MONA	MUSE	DREAM	REFORM
Primary focus	The conse-quences of changes in economic policy	The conse-quences of changes in economic policy	The conse-quences of changes in economic policy	Analyses of the effect of environmen-tal taxes on income dis-tribution	Future government revenue and expenditure	Long-term conse-quences of changes in economic policy
Type	Econometric	Econometric	Econometric	CGE	CGE	Static multi-sector CGE model
Time horizon	Short-term	1–30 years	Short-term	Long-term	Long-term	Long-term
Time resolution	Yearly	Yearly	Quarterly	Yearly	Yearly	Yearly

Table 5: Sector models, Denmark

Model name	EMMA	ESMERALDA
Primary focus	Energy and electricity consumption projections	Analyses of interaction between agriculture and the environment
Type	Econometric	Econometric
Time horizon	Medium to long-term	Short-term
Time resolution	Yearly	Yearly

Table 6: Macro-economic models, Norway

Model name	MODAG	KVARTS	MSG
Primary focus	The consequence of changes in economic policy	The consequence of changes in economic pol-icy	The consequence of changes in economic policy
Type	Econometric	Econometric	CGE
Time horizon	Short to medium-term	Short to medium-term	Long-term
Time resolution	Yearly	Quarterly	Yearly

Table 7: Macro-economic models, Sweden

Model name	EMEC	MARKAL-Nordic
Primary focus	Analyses of the interaction between the economy and energy and environmental initiatives	Dynamic optimisation energy model
Type	CGE	Modelling of energy systems
Time horizon	10–20 years	Medium to long-term (up to 2050)
Time resolution	Static model (base and target year)	Yearly (and seasons)

3.3.2 *Assessment of macro-economic models*

The macro-economic models are fairly similar with respect to properties relevant for the issue of linking macro-economic drivers to biodiversity indicators.

The indicators from the models include annual economic sector activity in monetary terms. Activity in the included economic sectors is measured as total production values and/or total value added.

The sector aggregation level may vary across the models, but typically, they include sectors such as agriculture, forestry and fishery with no further disaggregation.

The following characterises all the models:

- They do not include a spatial dimension; they are defined as national models and the variables and parameters are "national".
- They do not include detailed biodiversity or ecosystem indicators or variables.
- There is no specific land-use description.
- They include aggregated agricultural variables on economic values, but no data on physical quantities.
- The econometric models used for business cycle analysis are typical of short run models covering projections 1–5 years ahead.
- The CGE models may be used for more long-term analysis.

Considering the type of drivers, pressures and states identified and described in the previous section, the macro-economic models do not directly provide data that can be used to project these DPSIR elements.

This does not mean that linking macro-economic models and biodiversity indicators is not feasible. It merely means that "something" is needed in between the output of the models or that the models need to be amended.

3.3.3 *Detailed sector models*

There are examples of specific sector models that can be used in connection with the standard main macro-models. An example of such a model is the Danish agricultural model ESMERELDA.[14] The ESMERELDA model includes data on disaggregated activities in the agricultural sector by including a number of specific inputs and outputs (products) and sub-sectors by type of farming. Therefore, it can be used to estimate and project the distribution by different crops including areas with permanent grass, pesticides and fertiliser use. Some of these model outputs are driver indicators and could therefore be used to establish a link. This is discussed further in the next chapter.

Other examples include energy and emission models. Emission data and emission modelling is included in for instance EMMA. It is a model that covers the energy use in sectors and households at a more detailed level and it allows for estimation of emissions of the main air pollutants.

[14] There are similar models covering the Swedish Agricultural Sector, e.g. SASM or CAPRI.

These examples show that there are specific sector models that utilise the outputs of the macro-economic models and project the effects of the general economic development on the specific sector. They are also used to assess the effect of specific sector policies on the general economic development. These "pre" or "post" models with detailed sector description could potentially be applied when linking the macro-economic models and biodiversity indicators.

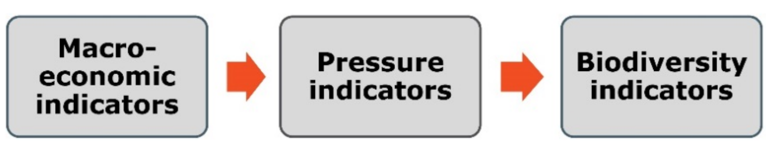
4. Possible ways for linking biodiversity indicators with economic models

This chapter presents the feasibility analysis of linking macro-economic indicators and biodiversity indicators. The previous chapter described the availability of biodiversity and macro-economic indicators. Recalling that the objective of this study is to assess the feasibility of establishing: i) links between macro-economic indicators and biodiversity indicators; and ii) links between biodiversity indicators and macro-economic indicators, with emphasis on the former link.

Initially, it is important to note that by assessing the feasibility of establishing links, we mean the feasibility of establishing quantified relations. This would be in the form where the relation between the economic and biodiversity indicators are represented by mathematical functions allowing for calculating the effects of changes in one set of indicators on the other set of indicators.

The assessment applies the DPSIR approach, linking economic drivers to pressures, further to environmental state and finally to biodiversity impacts. It should be noted that a detailed causal relation might include several steps. Figure 9 illustrates the elements of each link.

Figure 9: From macro-economic indicators to biodiversity indicators



The assessment describes each of the “arrows” as one element in establishing the links. For each type of link, the assessment covers different segments of biodiversity and considers the specific drivers and how they could be linked to the macro-economic models. The assessment is organised to addresses the following elements:

- Data availability: Is the currently collected data, the necessary data that could be used to underpin the links?
- Existence of statistical or functional relations: Is it necessary to develop pre- or post-models to the existing macro-economic models?
- Expected strength of the relations: If statistical analysis will establish relations, what is the explanatory power?

The first element concerns what additional data would be required and what the costs of collecting and maintaining the necessary data would be. The second element considers whether it is necessary to develop additional models in order to link economic variables and biodiversity indices. Finally, as conclusion, the strength of the expected explanatory power of the relation is discussed.

4.1 From macro-economic indicators to biodiversity indicators

4.1.1 *From macro-economic indicators to pressure indicators*

The assessment describes each step at a time. Starting from how the macro-economic indicators and drivers can be linked to the pressures that affect biodiversity.

Figure 10: From macro-economic indicators to pressure indicators

The typical outputs of the current available macro-economic models are aggregated sector data and therefore, there is a need for linking the macro-economic model output to what is the "real" economic driver. The main type of drivers include:

- Sector and subsector activity.
- Technologies by sector.
- Regulation (that defines certain technologies in each sector).

The detailed sector activity is driven by many factors and therefore economic models that include price and or demand factors are required to model and project future disaggregated activity levels. Disaggregated sector activities affect the level of pressures. Taking for instance emissions as an example of pressure, the quantification could include the following parameters or indicators:

- Emissions = Sector production * emission factor.
- Emission factors = f (technology, regulation).

Technology and regulation influence the level of pressures either directly or through effects on the economic drives. It means, in the example of emissions as a pressure, that the emissions can be estimated by an emission factor applied to the sector output. This emission factor depends on the choice of technology. Both technological development and regulation can affect the choice of technology and thereby change the emission level.

Specific regulations often define standards for maximum emissions.[15] Policies could also affect the sector production.

For other types of pressure related to land use, fishery etc. there are similar relations. The total pressure is proportional to changes in activity levels with a given technology. The general development in technologies and more specifically, regulatory requirements to the use of technologies will affect the pressure level.

Often the effects of technology and regulation are more important than sector activity (production/output). While the sector activity may vary a few percentage points each year, regulation might require substantial changes, affecting the pressure level or completely removing the pressure.

The assessments of data and model availability by economic sector are dealt with in the following.

As the links between macro-economic activities and biodiversity are not established, there is no objective way to define which economic sectors are the most important in relation to biodiversity. However, based on the considerations made in Chapter 2 and the description of the starting point in Chapter 3, the following economic sectors are identified as relevant for biodiversity:

- Agriculture.
- Forestry.
- Fishery.
- Tourism.
- Transport.
- Energy (hydropower).

Manufacturing industries and energy production (non-hydropower) might be relevant as generators of emissions (air pollutants, GHGs and water pollutants). The emission levels might be linked directly to the aggregated outputs and then there is not so much need for more detailed sector models.

As explained in Chapter 2 on the DPSIR framework, the five principal pressures on biodiversity as defined and used in the Convention on Biological Diversity are:

- Habitat loss and degradation.
- Climate change.
- Excessive nutrient load and other forms of pollution.
- Over-exploitation and unsustainable use.
- Invasive alien species.

For each of the six economic sectors, the most important pressures are described under the above headings.

---

[15] For example the requirements to use Best Available Technology (BAT) as required by EU legislation on industrial emissions.

Agriculture

There will be a need for an "intermediate" model that links total agricultural output to specific driver and pressure indicators. The development in the agricultural sector is determined by a complex mixture of factors. Specific models, such as the Danish ESMERALDA, model the agricultural output based on world market prices, technology and regulation as input parameters.

Agricultural pressures include:

- Habitat loss and degradation:
  - Habitat areas.
  - Crop mix (farmed area with different crops).
  - Field size (indicator for small habitats).
- Excessive nutrients load and other forms of pollution:
  - Emissions: pesticides and nutrients.
- Over-exploitation and unsustainable use:
  - Conventional or ecological farming.

The table below summarises an assessment of the availability of data and models for each of the specific pressures.

Table 8: Pressures, Agriculture, Data availability

Pressure	Data availability	Comments
Emissions		
- Nutrients	Data available	It could be argued that the use of fertilisers is more of a driver (kg N/ha), and the run-off from the fields is the pressures.
- Pesticides	Data available	-
Crop mix	Data available	-
Field size	Detailed land-cover and land-use maps are being developed.	For example, the very detailed land-cover maps for Denmark include data for 2001 and 2016, indicating that it might be difficult to establish a long-time series of data.[1]
Type of farming (conventional or ecologic)	Data available	-
Habitats area	Data might be available	Areas of Natura 2000 sites are available. Detailed land-cover data, as mentioned above, no long-time series are available.

Note: 1) Cf. http://dce2.au.dk/pub/TR95.pdf

Collecting data is the first element in quantifying a link between the activity in the agricultural sector and the pressures. As mentioned above, an increase in the agricultural sector output can be generated in multiply ways. To have a simulation model where a given macro-economic policy is assessed would require a detailed agricultural model. Such models exist and could be applied to quantify some of the pressures. Habitat pressures such as field size and areas of small habitats such as hedges and borders etc. would not be produced by any of the existing models. It means that it would require further studies to determine whether these pressures can be linked to the existing agricultural output indicators included in sector models.

Forestry

Forest constitutes a very important type of habitat in the Nordic countries. A large share of species live in forests and the share of red-listed species in forests is high. The below table shows the share of red-listed species that have forests as their primary habitat.

Table 9: Red-listed species, Primary habitat

	Denmark	Norway	Sweden
Forests as primary or only habitat	44%	48%	42%
Farmland as primary or only habitat	Na	24%	33%

Source: Denmark: Petersen, A.H., *et al.* (2016). Norway: Henriksen, S. and Hilmo, O. (2015). Sweden: ArtDatabanken, Rödlistade arter i Sverige 2015. ArtDatabanken SLU, Uppsala.

For forests, the type of forest and whether they are used for commercial forestry are important for pressure on biodiversity. Contrary to agriculture, the species that are grown change over a very long time span. Although there are less changes to biodiversity from a given area of forest, there is often a long time lag from a change in the habitat until all the biodiversity effects can be observed. The typical monoculture plantations have relatively less biodiversity than other types of forests. The forestry practices are very important, for example leaving dying or dead trees as habitats for species of insects and sponges. Forestry pressures include:

- Over-exploitation and unsustainable use:
  - Areas with different types of species of trees.
  - The amount of dead wood.
  - Type of forestry (degree of sustainability etc.).
- Habitat loss and degradation:
  - Forestry area (e.g. deforestation).

The table below summarises an assessment of the availability of data and models for each of the specific pressures.

Table 10: Pressures, Forestry, Data availability

Pressure	Data availability	Comments
Area with different types of forests	Data available	As with other land-use and land-cover data, the issues is lag of long time series
Area with types of forestry	Data available	
Area of Nature 2000 forests	Data available	
The amount of dead wood could be an indicator of the pressure	Data might be available or could be estimated	-

In contrast to the case of agriculture, the possibility of linking the economic forestry activities to the pressures seems more feasible. For forests, the area of forest not used for commercial forestry is a key pressure indicator. It could relatively easily be described by a forestry sector model.

Fishery

For fishery, the effects of the sector's activity on biodiversity is rather complex. The amount of catches by species is regulated, but still the quotas could be too high. Another driver is the amount of bycatches depending on the fishing technologies. The fishing technologies, for example the use of bottom trawls, can affect the seabed habitants.

Fishery pressures include:

- Over-exploitation and unsustainable use:
  - Total volume of catches by species.
  - Volume of by-catches by species.
  - Use of fishing technology.

Table 11: Pressures, Fishery, Data availability

Pressure	Data availability	Comments
Total volume of catches by species	Data available	-
Volume of by-catches by species	Data available	-
Use of fishing technology	Data partly available	While the use of different fishing equipment is known, there is less data available on the impact on marine habitats

For fishery, the volume of fish-catches is the key pressure and it seems relatively feasible to link the volume of catches and the sector activity. The fishery policy should be integrated as the volume of catches is often regulated by quotas.

Tourism

Tourism can affect biodiversity in protected areas such as Natura 2000 sites and national parks etc. To what extent this is an important pressure is subject to debate. If the number of visitors means that physical degradation takes place or breeding or nesting species are disturbed, then it is a pressure; it is not the case, there might be limited effects from recreational activities.

Tourism pressures include:

- Over-exploitation and unsustainable use:
  - Number of visits to protected areas.

Table 12: Pressures, Tourism, Data availability

Pressure	Data availability	Comments
Number of tourists	Data available	-
Number of visits to protected areas	Data might be available	Not all nature sites would be covered, so assessment is required to estimate the total numbers

The pressure on nature sites might be linked to the number of visitors. So the activity in tourism could be linked to the pressure. It might not be a proportional relation, so it would be necessary to investigate this pressure in further detail before a quantified link can be established.

Transport

Transport affects mainly by contributing to the fragmentation of the habitat. This can be approximated by the length of the road and rail network. Ideally, the effect depends on where the network is expanded, so the better indicator would be changes to the length (or areas) of transport network affecting different types of habitats.

Transport pressures include:

- Length of road network (including crossings of protected habitats, etc.).
- Length of rail network (including crossings of protected habitats, etc.).

Table 13: Pressures, Transport, Data availability

Pressure	Data availability	Comments
Length of road network	Data available	-
Length of rail network	Data available	-
Length of road network crossing nature habitats	Data can be estimated	It might be possible to estimate data from the detailed land-cover maps, though no long time series would be available
Length of road network crossing nature habitats	Data can be estimated	

A transport sector model could be developed and based on primarily infrastructure investments, the pressures on habitats area and fragmentation could be estimated. As with the other sector models, it would have to include a "policy" element where the exact type of the investments in question has to be specified. As an example, take investments in road construction; Here, it is important to make a distinction between the construction of new roads and the enlargement (or widening) of existing roads. The first type affects biodiversity much more than the second type.

Energy

The energy sector activity affects biodiversity through emissions, but that is similar to the effects of all other sectors contributing to air pollution, cf. the above discussion. Hydropower additionally affects freshwater biodiversity in rivers and streams.

Energy pressures include:

- Excessive nutrient load and other forms of pollution:
  - Air pollutants.
- Habitat loss and degradation:
  - Hydropower production.
  - Number of hydropower stations.

Table 14: Pressures, Energy, Data availability

Pressure	Data availability	Comments
Emissions of air pollutants	Data available	-
Number of hydropower stations	Data available	-
Total production by hydropower stations	Data available	-
Number of fish passes at hydropower stations	Data may be available	If not recorded, it can be collected

For hydropower, hydro-economic models that can be used to estimate the pressure on the water environment already exist. For air pollution, there are also models and modules that estimate the air pollution from economic sectors including energy production.

4.1.2 From pressure indicators to biodiversity indicators

In order to establish the link between *Pressures* and *States*, it is useful to organise the assessment by the different habitat types and describe the extent to which there are models describing *States*. Modelling of the relation between pressures and environmental state indicators is typically related to specific habitats or ecosystems.

Figure 11: From pressure indicators to biodiversity indicators

Based on for example the EU MAES ecosystem typology, the following habitats or ecosystems can be distinguished:

- Terrestrial:
  - Subtypes.
- Freshwater:
  - Subtypes.
- Marine:
  - Subtypes.

For each of the main types, key drivers and state indicators are presented. It is not possible to give an overview of all "environmental" models that might link the drivers and the state indicators. There are many research projects where such models have been developed for specific locations and habitats/ecosystems. Instead, a more broad description of what has been done and where data and models can be found are presented.

Terrestrial ecosystems/habitats

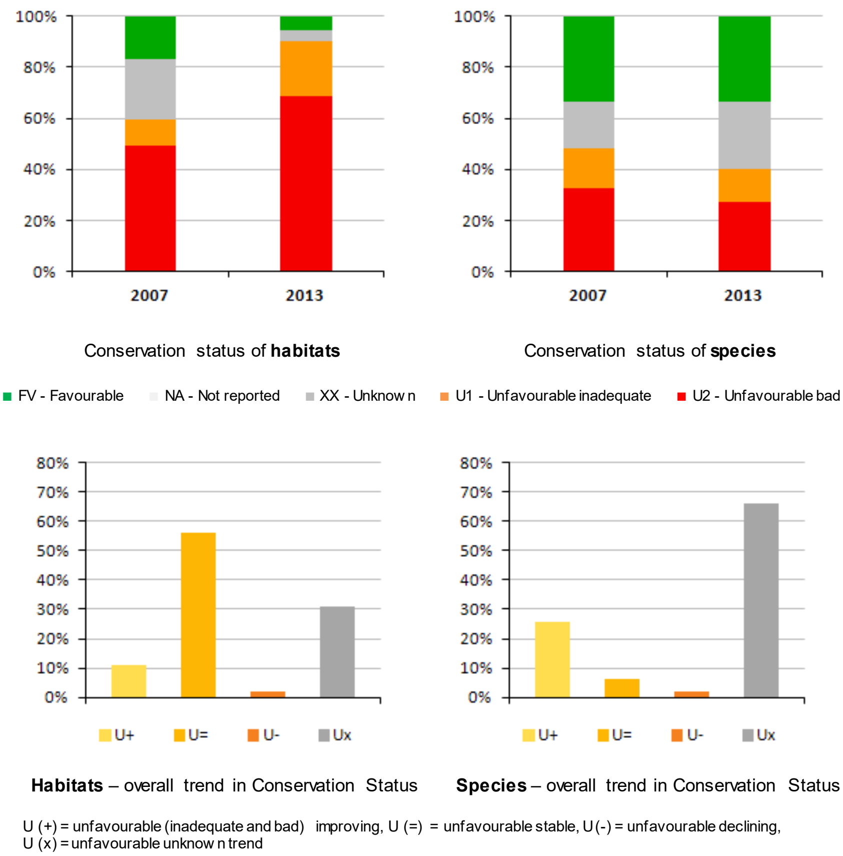
Terrestrial ecosystems/habitats are affected by all of the following key pressures:

- Habitat loss and degradation.
- Climate change.
- Excessive nutrient load and other forms of pollution.
- Over-exploitation and unsustainable use.
- Invasive alien species.

There are models that describe how the drivers affect the environmental state. In relation to the habitats designated under the EU Habitats and Birds Directives – the Nature 2000 sites – there is a definition of conservation status. This is a state definition based on a number criteria where biodiversity indicators are included. The aim of the directives is to bring all these habitats into so-called favourable conservation status.

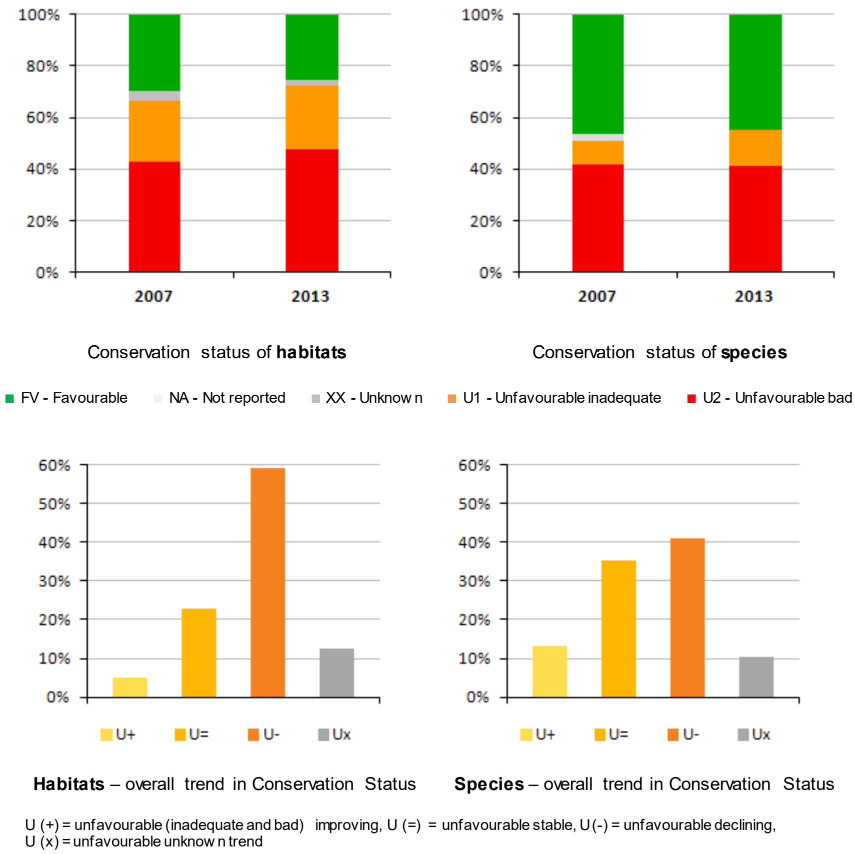
Favourable conservation status is defined for each Member State and typically includes indicators for the presence and abundance of certain species. Member States have to determine the conservation status for all the designated areas. The current conservation status for Natura 2000 sites in Denmark and Sweden is illustrated below.

Figure 12: Conservation status for Nature 2000 sites in Denmark



Source: National Summary for Article 17 – Denmark (National Summary 2007–2012). Available at: https://circabc.europa.eu/sd/a/ae61e78c-c1b1-46f4-abc3-ebf892b30c03/DK_20140528.pdf

Figure 13: Conservation status for Nature 2000 sites in Sweden



Source: National Summary for Article 17 – Sweden (National Summary 2007–2012). Available at: https://circabc.europa.eu/sd/a/eb343c64-d847-46f7-a970-8238dae3ae41/SE_20140528.pdf

Overall, the situation regarding the current conservation status is slightly better in Sweden than in Denmark. However, for both countries, the figures illustrate that the share of habitats having a favourable status has decreased from 2007 to 2013.

The Member States have had to develop action plans to describe how to improve the conservation status. The plans do not include specific modelling. The measures are supposed to improve the situation, but there is no quantitative estimation of when a favourable conservation status will be achieved or what it will take to achieve that situation.

The example of the conservation status classification illustrates the challenges related to quantification of biodiversity impacts. The conservation status is based on a number of indicators.

Many of the indicators are biodiversity-related. Using the example of the skylark as an indicator for the biodiversity segment of common species, the above assessment points to a causality between skylark breeding population levels and the two factors of food availability and nesting site availability. While food availability could be approximated by the application of pesticides, nest site availability is primarily a result of structural changes such as field sizes, availability and extent of small habitats with (semi-) natural vegetation. It might be possible to estimate a relation if the data series can be established for nesting site availability. Such data is not directly available and hence it would require further research to estimate a long time series.[16]

Freshwater and marine ecosystems

These ecosystems and habitats are affected by:

- Pollution (eutrophication).
- Intensive fishing.
- Hydro-morphological changes.

Taking eutrophication as an example, the Water Framework Directive requires achievement of good ecological status in all water bodies. To develop the plans to achieve this target, models that simulate the effect of reduced pollution with nutrients have been developed. They also take into account the expected changes in economic activity, for instance changes in the agricultural sector.

Water habitats are required to achieve a good ecological status by the Water Framework Directive.[17] Good ecological status is measured based on the following elements, among others:

- Composition, abundance and biomass of phytoplankton.
- Composition and abundance of other aquatic flora.
- Composition and abundance of benthic invertebrate fauna.

For each of the elements, one or more indicators are used and the link to the pressures are established:

- Modelling or regression analysis linking the emissions of nutrients to nutrient concentrations and resulting impacts on state indicators such as:
  – Mean summer concentration of Chlorophyll a, benthic fauna (fauna composition and eelgrass; Secchi depth as a proxy for potential eelgrass depth limit).
- Calibration of status classification between Member States leading to definitions of indicator values corresponding to status classification.

In the case of Denmark, there are more than 100 coastal water bodies, and models have been made for about half of the water bodies. For the rest of the water bodies, the impacts are defined by extrapolation from the model assessment.

[16] See for example recent research on farmland bird species: HELDBJERG, H., SUNDE, P., & FOX, A. (2017). Continuous population declines for specialist farmland birds 1987-2014 in Denmark indicates no halt in biodiversity loss in agricultural habitats. Bird Conservation International, 1-15. doi: 10.1017/S0959270916000654.

[17] The definition in the WFD is "water body".

What should be noted in this respect is that the models are very complex, so it is not a simple task to estimate whether a certain reduction in nutrients will actually achieve the improved ecological status.

As discussed above in respect of drivers, the link between drivers and pressures on the water environment is affected by:

- Changes in economic activities.
- Introduction of specific nutrients and emission policies.

The effects of changes in agricultural activity that will follow from a macro-economic model projection are most likely of minor importance. The changes in economic activity from one year to another are typically a few percentage points. It means that the effect on eutrophication of such changes will be of minor importance. What will matter are the effects of the specific measures. This includes measures to change agricultural practices (equivalent to changing the production technology in manufacturing industries).

As the implementation of measures to reduce pressures is still ongoing, it is not yet possible to monitor whether the effects will be improved biodiversity or not.

The assessment of ecological status in water bodies or habitats is an example where the quantification has been taken very far. Still, there are factors not included in the advanced hydrological water quality models. As it is too early to compare monitoring data and the model results, the strength of the relation cannot be assessed.

Fishing can reduce certain species as a result of overfishing. In addition, there are other effects such as degradation of seabed habitats due to fishing technologies (bottom trawl).

There are models used to determine the amount of fishing as input to determine the quotas that regulate EU fisheries. As fishing is regulated, changes in macro-economic activity should not affect the volume of catches. So, this link might be less important.

Availability of environmental models that links pressure and state

While data on environmental states is available to some extent, there are fewer environmental models that can link pressure and state indicators. There are many such models, but they cover specific locations.

Table 15: Availability of environmental models, Overview

Habitat types	Model availability	Comments
Terrestrial	Only for selected locations or for selected species	Generally no estimated causal relation
Freshwater	Water quality models are more broadly available	Used for assessing compliance with the WFD
Marine		
- Coastal	Many models	Used for assessing compliance with the WFD
- Non-coastal	Few models available	-

The above sections describe the data and model availability for the two elements in linking macro-economic indicators and biodiversity indicators. The next section completes the assessment by considering the feasibility of further development of models that contain quantified causal/statistical relation.

4.1.3 Strength of causal relations

Relations between drivers and pressures

The relation between macro-economic indicators and pressure indicators is based on technological and behavioural relations. The technological relation, for example emissions in kg per economic activity in DKK, can be established researching the technologies as applied by the economic sectors.

To establish behavioural relations, time series or cross sectional data series would be needed. While the most ideal data sets may not always be available, in general it will be possible to establish such relations.

Relations between pressures and state

The relation between a given level of a pressure and the resulting state including biodiversity indicators are naturally science-based. While it is possible to describe causal relations, specific functional relations are more challenging. The examples dealt with in previous sections indicate that there are instances where the relation has been estimated and instances where they have not.

For the pressure "Habitat loss and degradation", which is related to land use, historical data is not available. There are examples where historical data for a few years has been created, but long time series are generally not available. It seems, therefore, very difficult to estimate a statistical relation between habitat conditions and biodiversity indicators.

Hence, the estimation of functional relations that can be used to predict how much a change in a given pressure will affect a specific biodiversity indicator is going to be very challenging. With the existing knowledge, qualitative relations will be much more feasible.

The next section summarises the findings regarding the link from economic drivers via pressures to environmental state, including biodiversity.

4.2 From biodiversity indicators to macro-economic indicators

This section discusses how to establish the link from biodiversity to macro-economic modelling.

Biodiversity can affect the activity in economic sectors directly or indirectly. Directly, if the population of a certain species changes, for example in fishery. Indirectly, through its effect on ecosystem functioning. Therefore, using the concept of ecosystem services, which include all ecosystem effects, will facilitate the assessment. Furthermore, it applies an approach being increasingly widely used. Specifically, we will use the EU MAES approach, which applies the CICES definition of ecosystem services. They include:[18]

- Provisioning.
- Regulating and maintaining.
- Cultural.

Based on the ecosystem service concept, the linking of biodiversity and macro-economic indicators is discussed.

Biodiversity is an integrated part of the functioning of all ecosystems. Reduced biodiversity affects the functioning of the ecosystems and hence the services provided, and reduced functioning of the ecosystems affects biodiversity. The complexity of ecosystem functioning makes it difficult to estimate the exact impacts of reduced biodiversity.

The impact on the economy of changes to biodiversity comes through the three types of ecosystem services.

The first type has to do with the fact that, reduced biodiversity could mean that certain species are less abundant, affecting commercial use of these species or the ecosystem within which the species perform specific functionalities. Reducing the populations of key species may result in unexpected, negative consequences in habitats and ecosystems such as outbreak of pest species when populations of regulatory species have been depleted.

The impact of reduced biodiversity is more long-term and if the gene pool is reduced, the long-term stability of ecosystems could be threatened. This effect on long-term regulation and maintenance of the ecosystems is the second type of ecosystem services. And in this case, changes to biodiversity affect this long-term stability.

The third and last type of ecosystem service is cultural services. In this respect, changes in biodiversity might have a direct effect if a certain species is reduced in numbers or becomes extinct.

For agriculture, there are direct and indirect effects. One effect that has been discussed is pollination, where reduced plant species biodiversity could reduce the number of bees which again will impact on the crops that depend on pollination, or if bee populations are being depleted there will be less pollinators. Indirect effects are numerous and related to the loss of inherent regulatory mechanisms within ecosystems when species are lost from the ecosystem. A lack of natural regulatory mechanisms leads to instability, loss of ecosystem resilience and frequently to outbreak of pest species.

For forestry, the same mechanisms are in play, though the effects in economic terms may differ due to the much longer crop rotation scheme.

---

[18]Cf. http://biodiversity.europa.eu/maes/common-international-classification-of-ecosystem-services-cices-classification-version-4.3

For both sectors, the more long-term risk is that a reduction of the number of plant species (or sub-species) could imply that the currently grown crops become subject to diseases and that the lower genetic variation result in less resistant species.

From a valuation perspective, these effects are difficult to assess. Reduced output due to lower level of biodiversity is the impact that is easiest to value as the market price of the crops times the reduced volume constitutes the impact.

Valuation of a reduced gene pool is one of the challenging effects to assess. Potentially, it could be very significant. It includes effects on the pharmaceutical industry as plants and animals are used to develop new medicine, and hence the possible losses from reduced biodiversity could be very significant. Loss of genetic variation can prove disastrous if, as a result, commercially important species lose the ability to adapt to changing environmental conditions, like climate change.

The impact on cultural services could affect tourism if it is associated with certain species. For example, safari tourism in Africa would decline if big game species become extinct. There are probably fewer species with the same importance in the Nordic countries, though for example bird watching or angling could be examples.

Studies suggest that society shows significant willingness to pay for protection of biodiversity. This effect is not relevant in the context of traditional macro-economic indicators. It could, however, be relevant in the context of a green GDP. Overall, in the context of for example TEEB, there is much literature and studies on valuation of ESS.[19]

[19] See for example: http://www.teebweb.org/

5. Conclusions and recommendations

In this chapter, we highlight the conclusions and findings of this study and put forward a few recommendations for further work.

5.1 Conclusions

The previous sections have discussed the availability of data and models that could be used to quantify the link between macro-economic and biodiversity indicators and the reverse link between these.

In the following, the conclusions and findings are presented for each direction of the link starting with the feasibility of quantifying the link between macro-economic indicators and biodiversity indicators.

5.1.1 Conclusion on the link between macro-economic indicators and biodiversity indicators

Referring to the illustration in the figure below, there are two elements in the link:

- Macro-economic indicators to pressure indicators.
- Pressure indicators to biodiversity indicators.

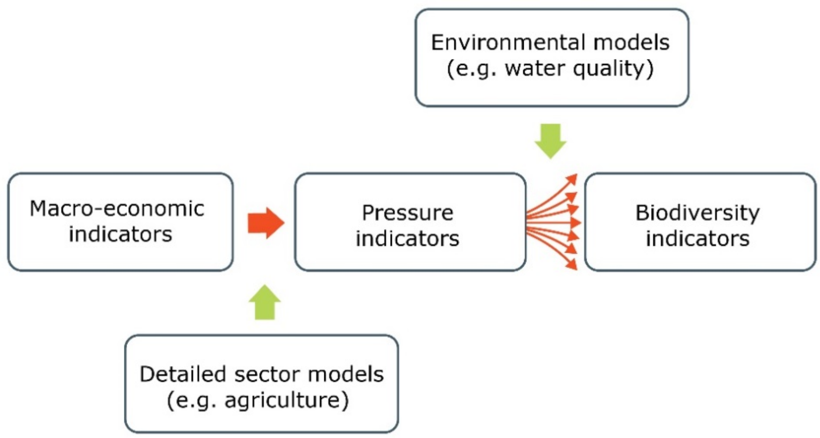
The conclusions address each of the two elements and are based on the criteria of data availability, functional relations and their strength.

The overall conclusion is that it seems feasible to link macro-economic indicators to the pressure indicators. The review in the previous chapter has indicated that for most of the main pressures, there are available indicator data. However, the specific relation between the macro-economic indicators and the pressure indicators needs to be developed. For most pressures, it would have to be done through economic sector models where the aggregated macro-economic indicators are broken down on more specific sector activity or output indicators.

Linking the pressure indicators and biodiversity indicators is more challenging. There are only few examples. One is the assessment of nutrients in the aquatic ecosystem, where models capable of estimating the effects of changes in the load of nutrients in fresh and marine water environments have been developed.

This overall conclusion is illustrated in the figure below. Establishing the relation from macro-economic indicators to pressure indicators can, as mentioned above, be done through detailed sector models. Regarding the link from pressure indicators to biodiversity indicators, it is much more uncertain whether it can be done and what the predictive strength of such a relation would be.

Figure 14: From macro-economic indicators to biodiversity indicators, From fairly straightforward link to complex link



The implication of these conclusions is that it might be possible to "build" models that can estimate the "pressure" level from a given macro-economic scenario. It means that it could be possible to support policy assessments of whether a given macro-economic scenario will increase or decrease the pressure on biodiversity. How much biodiversity would be affected would remain uncertain. The fact that biodiversity is not easily measured by a few indicators, the time lag from change in a pressure until the effects materialise and the spatial dimension of the pressures mean that only qualitative conclusions can be drawn. Being able to summarise the pressure level would, however, constitute a significant step forward in the assessment of future development of biodiversity.

In the following sub-sections, the conclusions on the feasibility of establishing these links are further elaborated. The text box on the skylark provides an example that overall illustrates the challenges and issues, cf. also Appendix 3.

Skylark

The skylark (Alauda arvensis) is a common bird in the agricultural landscape and other open landscapes. The skylark is adapted to areas with low-growing and sparse vegetation where it feeds on plant seeds, and during the breeding season also insects. The nest is located on the ground, on arable land as well as in natural habitats.

Traditionally, the skylark has been used extensively as an indicator on the environmental quality of the agricultural landscape, as its breeding population tends to fluctuate with key characteristics of agricultural activities.

The suitability of a skylark habitat depends on a number of factors, of which food resources and nest site quality generally are considered the most important as regard the environmental quality of the breeding habitat. As a predominantly migratory species, winter conditions play an insignificant role on the breeding grounds even if the species arrive in late winter and early spring on the breeding grounds, where weather conditions can be harsh.

Based on these key characteristics of the skylark ecology, it appears that pressures on the skylark breeding population can stem from two significantly different factors: Food availability and nest site quality.

Food availability in the agricultural landscape is likely to be determined primarily by two different factors: Availability (and quality) of plant seeds and production of insects and other invertebrates. Nest site quality depends rather on the physical environment of the skylark breeding site. If it is assumed that the nest site quality can be measured in terms of the survival rate of eggs and nestlings and that survival can be expected to increase if the nest is located in suitable vegetation outside the arable fields, then nest site quality will be correlated with the availability of natural habitats in the agricultural landscape.

5.1.2 From macro-economic indicators to pressure indicators

The assessment in Chapter 4 focused on the main economic sectors that are drivers for the key pressures. The assessment also looked at different habitats and how the pressure affects state.

The analysis of the feasibility of linking drivers and pressures was made for each of the main pressure types:

- Habitat loss and degradation.
- Climate change.
- Excessive nutrient load and other forms of pollution.
- Over-exploitation and unsustainable use.
- Invasive alien species.

Table 16 summarises the findings regarding the feasibility of establishing a quantified link between economic activity (or economic sectors) and each main pressure type.

Table 16: Pressures, economic activity and available models

Types of pressure	Type of economic activity (or sector)	Data and models
Habitat loss and degradation	Land use	There are generally no land-use models or modules available that can estimate the changes in habitats as a result of a given macro-economic scenario. Such models could be developed. They would require other factors than "pure" macro-economic indicators to be included. An example: Investment in transport infrastructure may increase the area used for such infrastructure, but the investment could also merely be modernisation of existing infrastructure. Therefore, policy variables that would define more specifically the type of investments would have to be included. Mapping and land-surveying use for aerial surveys allow the production of high-resolution digital maps which can be used to estimate land-cover and land use. Therefore, detailed land-cover and land-use data can be expected to be available in the future. There are examples of studies that have assessed the historical development. Caspersen et al. (2016) is an example, where the historical development in for example field size and small biotopes from 1954 until now has been assessed. Based on historical aerial photos and subsequent digitalisation, the landscape feature has been estimated. The study covers eight selected locations and includes generalisations based on the sample sites. The study illustrates that detailed land-use and land-cover data may be estimated, though there are no systematically recorded data except for the most recent years.
Climate change	All sectors	There are data and models that estimate the contribution to GHG emissions from economic sectors. However, the effect of climate change on biodiversity is related to the climate conditions. They depend on global emissions. Therefore, it is of limited interest to link national GHG emissions and biodiversity.
Pollution	All sectors	There are already some pollution modules that can estimate the emissions from a given macro-economic scenario. They provide a quite direct indicator output. Increased emissions are the same as increased pressure. It should be noted that in many cases the data needs to be calculated or estimated. Emissions are typically not "measured" or monitored for each and every source. So, they need to be estimated based on activity data and emission factors. Emissions are affected by technological change and specific sector or environmental policies – often more crucial for the level of pressure than economic activity in itself.
Over-exploitation and un-sustainable use	Fishery	Over-exploitation of marine resources could lead to their depletion. There are models for the development in the fishery stocks as a function of fishing effort. As most fishery is regulated through international quotas, the development is less linked to the macro-economic development.
Invasive alien species	Trade and tourism	While increased numbers of invasive alien species are related to trade and tourism, it needs to be investigated whether the pressures are proportional to international transport of goods and passengers. It has not been investigated to what extent it is possible to link the pressures to the macro-economic indicators.

As indicated in the above discussion on the assessment of ecosystems and compliance with EU directives on birds, habitats and waters, status categories that in broad terms describe the environmental state have already been defined. In most cases, the state description is based on a set of indicators and many of those indicators are biodiversity indicators. Therefore, the categories of favourable conservation status and good ecological status could be used as indicators for biodiversity.

The disadvantage of such an approach is that there are only few status categories. It means that changes are not recorded unless they result in a change of status category classification. For the Natura 2000 sites, they are either characterised as one of the two unfavourable status classifications (inadequate or bad) or as favourable status classification.

The above assessment has addressed the feasibility of linking macro-economic and pressure indicators. Before considering whether the links could made, it is also worth to consider the relative importance by types of pressure.

One indicator for the importance could be the number of biodiversity indicators affected by each type of pressure. The Norwegian Nature Index comprises 301 individual indices, and it has been assessed how the main types of pressures affect these individual indicators.

The table below concerns the number of individual indicators that are affected by each of the main pressure types. Though the overall assessment is that it is not very feasible to make quantified links from the pressures to the biodiversity indicators, it is relevant to make links to macro-economic indicators to the pressure types that have the largest impact.

The assessment clearly points to habitat loss and degradations as the most import pressure type. It is followed by climate change and over-exploitation and un-sustainable use.

Table 17: Number of biodiversity indicators affected by main types of pressures, Example from Norway[1]

	Habitat loss and degradation	Climate change	Pollution	Over-exploitation and unsustainable use	Invasive alien species	Indicators, Total
Seabed	17	29	2	28	0	33
Sea, pelagic	5	27	2	18	2	34
Coastal water, bottom	9	34	11	21	5	37
Coastal water, pelagic	3	27	3	15	9	37
Freshwater	29	8	18	3	8	33
Wetlands	31	3	6	1	3	33
Forest	67	16	11	10	1	87
Mountain	21	18	0	6	0	31
Open lowlands	25	4	9	0	4	29
Total	207	166	62	102	32	

Note: [1] Number of indicators that are medium or very sensitive for various main types of pressures in the various eco-systems. Note that many indicators are sensitive to more than one main type of pressure, and also that some indicators are part of more than one eco system.

Source: Adapted by COWI on the basis of Framstad, E. (ed.), 2015.

The results of the assessment of feasibility and the above indication of the relative importance of the different pressures indicate where the future work should be focused.

The next table presents for each type of pressure, the ranking of importance and feasibility.

Table 18: Main pressure types, Feasibility and importance

	Feasibility	Importance
Habitat loss and degradation	High	High
Climate change	Low	High
Excessive nutrient load and other forms of pollution	Medium	Low–Medium
Over-exploitation and unsustainable use	High	Medium
Invasive alien species	Low	Low

This assessment points to habitat loss, degradation and land-use changes as the types of pressure that should be prioritised. Making the link between the macro-economic drivers and the land-use change would allow qualitative assessments. This can be illustrated using the above example of the skylark. The population of skylark being an example of species indicator that is affected by land-use. If an economic development means further loss of habitants, the population is likely to decrease. This kind of qualitative assessments could be made if the link between macro-economic and land-use is established.

For the other important pressure – climate change – the feasibility is low. While the level of GHG emissions is considerably affected by macro-economic indicators, the resulting climate change impacts are the result of the global emissions. Hence, the links between macro-economic indicators in the Scandinavian countries and climate changes are going to be very weak.

Having concluded that it is feasible to develop the link between macro-economic indicators and pressure indicators, the question is how it should be done.

5.1.3 How to establish the link between macro-economic indicators (drivers) and pressure indicators?

Given that none of the existing macro-economic models in the Scandinavian countries includes variables directly describing environmental drivers, the alternative ways forward to establish the link could be by:

- Amendments of macro-economic models.
- Development and tests of interface models (detailed sector models, land-use models or environmental pressure-state models).

In principle, macro-economic models could be amended so that biodiversity effects would be integrated as part of the models. There are few examples of corresponding models. For example, energy and climate change models, where the energy consumption and the associated GHG emissions are integrated in the macro-economic models. Energy is used across all economic sectors, and changes in energy prices or introduction of carbon measures have macro-economic impacts.

Given the many dimensions and elements of biodiversity and biodiversity change, a full integration with current macro-economic models would be challenging.

Instead of amending the existing macro-economic models, the assessment of biodiversity could be done by linking the output or input of macro-economic models to detailed sector models.

The advantages and disadvantages of the two different approaches are summarised in Table 19 below.

Table 19: Amending existing macro-economic models vs applying sector and environmental models

	Amend existing macro-economic models	Apply sector and environmental models
Resource need	High	Medium
Flexibility	Low	High
Overall feasibility	Low	Medium

5.1.4 From pressure indicators to biodiversity indicators

Biodiversity richness and biodiversity populations fluctuate over time for a number of reasons. Biodiversity indicators yield a snapshot of the state of biodiversity and do not reveal any information about causes and effects behind the observed level and status of the biodiversity, and many impact elements are in play. This means that the explanatory or indicative power would be low and be of almost qualitative nature. For example, if the use of pesticides increases, the population of skylarks is likely to decrease although it is not possible to predict by how much. On the other hand, by attempting to estimate the quantitative relation, the relative influence of different factors on the skylark population might be revealed and thereby valuable information can be recorded in a model that supports policy development.

Further items include:

- Many "natural" factors affect the environmental state, implying it is challenging to make predictive models.
- Time lag between *Drivers* and *Pressures* and the effects hereof on *States*, as some biodiversity effects will only very gradually materialise, means that models need to cover very long time periods to capture all effects and impacts.
- For freshwater/coastal waters, the WFD means that some quantitative assessment is possible.
- For terrestrial habitats there are no general models with predictive power.

These considerations do not point to a clear conclusion. It might be possible to establish links between economic activity and several biodiversity indicators, but it will require additional data collection and especially analysis as well as further development of models in order to establish functional relations between economic drivers and biodiversity change.

Given the complexity of the relations between *Drivers* and *Impacts*, there is a risk that the outcome of quantified models may provide qualitative results only. On the other hand, the process of quantification might reveal important information that serves to elucidate the relative magnitude of *Drivers* and the ensuing *Pressures* and *Impacts* on biodiversity.

The following factors should be considered before starting to develop the links between pressure and state indicators:

- Establishment of suitable indicators and indices that build on relevant biodiversity data and fulfil criteria for biodiversity indicators; for example, criteria such as those in the SEBI programme (SEBI 2012).
- Estimation and pilot tests of functional relations between pressures and state of biodiversity.
- Test and analysis of indicative significance of functional and causal relations.

Despite the numerous biodiversity indicators and indices that have been developed for a highly diverse array of purposes over time, the present study has demonstrated that the specific criteria required for an indicator suitable of sampling macro-economic effects are not easily met. There are several reasons for this. Some of these are:

- Biodiversity indicators sampling *Drivers* and, especially, *Pressures* are not easily identified, as the causal relation between *Pressures* and *States* is complex and far less studied. Presently, suggestions for biodiversity indicators addressing *Drivers* tend to prescribe indirect measures and indicators such as policies and funds targeting environmental change. Not only are policies, funds and reserves likely to show effects on a very broad biological and geographical scale, but effects may emerge with considerable delay.
- Simple and transparent one-factor indicators may show strong correlation with environmental change, but may fail under a closer scrutiny regarding actual causal explanation, whereas more complex, aggregated indicators may appear more robust as regards causal relevance, but may fail in terms of transparency and communicative strength. Strongly aggregated and complex indices like the Norwegian Nature Index may perform strongly on communication parameters, but without any disintegration into basic components and elements it will lack transparency and scientific indicator value. Indicators that primarily serve awareness raising purposes may not demonstrate strong and clear relations between pressures and environmental state and vice versa.
- Biodiversity indicators may highlight qualitative or quantitative changes in the environment and a clear focus on the difference and frequent lack of separation between the two must be maintained in order to understand the indicative value and direction of any given indicator. The rather simple and well-known biodiversity indicator – the skylark, as a typical representative of the environmental quality in the agricultural landscape – fails to provide any indications of whether population trends can be explained by qualitative or by

quantitative aspects of environmental change. Hence, comprehensive indicators should preferably be able to point to both aspects, such as a species (e.g. the skylark) and a geophysical indicator (e.g. area of natural habitat) in order to provide a stronger and transparent indicative functionality.

Based on the example of the skylark, cf. text box above on the skylark and Appendix 3, the estimation of quantified relations might not allow us to estimate the effect of a 10% decrease in the use of pesticides. However, it might allow an estimation of whether the change in pesticide use is more or less important relative to other factors that affect a population of skylarks, including habitat developments that affect the availability and quality of suitable skylark breeding sites.

5.1.5 Conclusion on the link between biodiversity indicators and macro-economic indicators

Establishing the link between biodiversity indicators and macro-economic indicators is challenging, but could be feasible. Overall, there are only a few economic sectors where there would be immediate and direct impact of changes in biodiversity. For example for fishery, the abundance of commercially utilised species affects the volume of catches, and thereby the economic values generated in the sector.

For tourism, there could also be a direct impact if certain species or types of habitats are more or less abundant.

For other sectors, it is less clear how changes in any biodiversity would lead to economic impacts. It might happen more indirectly. Changes in biodiversity affect the functioning of ecosystems and thereby all the services that ecosystems provide.

Establishing the link from biodiversity to macro-economic indicators is somewhat related to the issue of a green GDP and, hence, green national accounts paving the way for a green GDP. A green GDP is about expanding the elements included in traditional economic welfare as expressed by GDP and similar macro-economic indicators. As an example it means including changes in biodiversity. A green GDP could measure the subjective change in welfare for the citizens, due to changes in biodiversity, through willingness-to-pay analyses.

In an assessment conducted by the OECD (2015) on the economic feedback of loss of biodiversity and ESS, a number of general problems in linking biodiversity or ESS indicators to economic models are presented and discussed. They are the following:

- The valuation methods used to obtain the value of the services provided by the ecosystem service in question (e.g. protection against flooding) depend on techniques that involve large uncertainty and high margins of error. It is especially true with regard to valuation methods, where preferences are stated and not elicited.
- When assigning values to ecosystem services, local factors (i.e. on the specific biome, its quality, and the quantity/size and quality/type of services delivered) need to be taken into account. This means that generic values for ESS cannot necessarily be applied to areas other than those where this value was extracted.

For example, a given value in USD for e.g. coastal protection extracted in a north-western United States context is not (necessarily) relevant to coastal protection for Norway, despite similar climatic conditions and ecosystems, as other local factors will affect the value.

- The models of ESS do not cover all biomes equally, as more data and studies exist on some biomes. Further, marine ecosystems are generally less studied than terrestrial ecosystems.
- The ESS framework does not capture the values associated with biodiversity to the extent that sufficient distinction can be made at spatial levels required and between species and biomes. However, the OECD notes that some progress has been made to address this gap.

These caveats aside, the OECD suggests that potential "margins of error" in assessing the value of biodiversity or ESS should not prevent these values from being included in economic models, noting that "similar errors in other aspects of socio-economic modelling" occur (OECD, 2015).

In relation to a green GDP, the OECD (2015) suggests a four-step plan to overcome some of the barriers that exist regarding the integration into or linking of biodiversity indicators and economic models, namely:

1. Set up a database with state-of-the-art estimates of the value of ESS at a spatially differentiated level so the disaggregated database can be used in conjunction with the economic models.
2. Calculate the losses of ESS associated with alternative growth paths and use these figures to calculate an adjusted GDP figure for each path, indicating the effect that the losses have on "true GDP".
3. Initiate work on integrating ESS into the economic models. This could be done first for agriculture and forestry where there is considerable information on how economic growth affects ESS through its impacts on pollution, climate change etc., and on how reduced output in these sectors feeds back into the other economic sectors. Then one could work to incorporate water-related ecosystems and finally marine ecosystems.
4. Combine the work on adjusted GDP with that on sectoral production links to produce an integrated system that includes both the effects of economic growth on ESS and the effects of decline in ESS on growth.

5.2 Recommendations

Based on the conclusions, we present the below recommendations. The starting point is that it seems feasible to develop the link from macro-economic indicators to pressure indicators. Developing models that would be able to estimate the effects of a given macro-economic scenario on the main pressure categories could be a valuable contribution to improved biodiversity policy making.

The specific recommendations are provided by the different types of link that have been analysed.

5.2.1 The link from macro-economic to biodiversity indictors

As the assessment has shown, it is more feasible to develop the first part of this link, that is the relation between *Drivers* and *Pressures*. The main recommendation would be to further explore how that could be done:

- Explore how to quantify the link between macro-economic sector indicators and habitat loss and degradation. This would imply to initiate work on a land-use model that could estimate the effects of sector activity on several aspects of habitat change.

Several sectors contribute to change in land and land cover, affecting terrestrial ecosystems and habitats. The pressure is the combination of the development in these sectors therefore, having one land use and land cover model would significantly improve the understanding of this pressure.

It is likely that such work would have synergies with what is required for complying with the EU biodiversity strategy and with the EU Birds and Habitats Directives. There are requirement to improve biodiversity, but there seems to be few tools that can support a quantification of the efforts.

Regarding the other main pressure categories, the following is noted:

- Pollution – nutrients: There are already water quality models that can be used to assess both the link between the sectors and the pressures (load of nutrients) into the water environment, but also models that estimate the effects on a number of indicators for the environmental state including biodiversity.
- For air pollutants there are emission models that can simulate the effect of alternative macro-economic scenarios. Moreover, the air pollution polices have reduced the emissions, so this pressure is diminishing.
- Climate change: While this is an important pressure with increasing effect on many ecosystems, it not directly linked to the macro-economic indicators. It is the global level of emissions that changes the climate, which then affects the ecosystems. It is important to understand the effect of change climate on biodiversity, but it is and should be the subject of environmental research.

- Over-exploitation and unsustainable use: It is mainly for fishery that the issue of over-exploitation is an important pressure. Fishery models are already used for the assessment of quotas. It is less likely that additional work can improve the understanding of this pressure so no action is recommended.
- Invasive alien species: There is a need to understand this pressure better. It is related to global transport which is mainly caused by trade and global tourism. Whether the relation can be quantified is unknown. It could be considered to investigate the importance of this pressure further.

Regarding the link between the pressure and state indicators, this is subject of biodiversity research. There is a need to continue improving the understanding and possibly be able to quantify the relation further. Hence, the following recommendations:

- Launch of controlled studies in test areas, both open land and forests, with the purpose of identifying, assessing and quantifying the link (or rather links) between *Drivers* and *Pressures* and also between *Pressures* and *States*. Most probable such studies may provide valuable input to ongoing work in this field by the European Commission and other international organisations – not least, because such studies may provide very detailed, area specific insight into the complex causal relations that exist.
- Studies are required to establish better and more indicative relations between positive environmental change and biodiversity recovery, with special emphasis on response delays and other factors that inhibit full recovery.
- Relations between biodiversity richness and ecosystem functionality need to be established in further detail as ecosystem functionality is essential for biodiversity resilience as well as for ecosystem services. A thorough understanding of biodiversity and ecosystem resilience and threshold levels of impacts that trigger changes in biodiversity richness and ecosystem functionality appears to be fundamental for a better integration with macro-economic modelling.
- Rather than establishing new biodiversity data gathering procedures, it may prove beneficial to look into existing biodiversity monitoring programmes that provide regular data on biodiversity. Also, statistics and databases that hold information on e.g. land use, emission levels and other environmental elements should be exploited when testing new indicators and indices that can be used in sector models or macro-economic models.

5.2.2 The link from biodiversity to macro-economic indicators

As part of ongoing research activities on valuation of ecosystem services, more data will be established that could be used for improving the understanding of how macro-economic indicators are affected by changes in biodiversity. Hence, a separate, final recommendation is:

- Valuation of biodiversity: Further development of valuation principles of biodiversity in order to add methodological approaches. This could include how the sector activity/output or value added is affected by changes in biodiversity.

6. References

ArtDatabanken 2015. Rödlistade arter i Sverige 2015. Available at: https://www.artdatabanken.se/globalassets/ew/subw/artd/2.-var-verksamhet/publikationer/22.-rodlistan-2015/rodlistan_2015.pdf

Admiraal, J. F., Wossink, A., de Groot, W. T., & de Snoo, G. R. (2013). More than total economic value: How to combine economic valuation of biodiversity with ecological resilience. *Ecological Economics*, *89*, pp. 115–122.

Bakkes, J. A., P.R. Bosch, A.F. Bouwman, H.C. Eerens, M.G.J. den Elzen, M. Isaac, P.H.M. Janssen, K. Klein Goldewijk, T. Kram, F.A.A.M. de Leeuw, J.G.J. Olivier, M.M.P. van Oorschot, E.E. Stehfest, D.P. van Vuuren, P. Bagnoli, J. Chateau, J. Corfee-Morlot, & Y-G. Kim (2008) Background report to the OECD Environmental Outlook to 2030: Overviews, details, and methodology of model-based analysis. Report 500113001. Netherlands Environmental Assessment Agency and OECD, Paris, France: OECD.

Biala, K., S. Condé, B. Delbaere, L. Jones-Walters & Amor Torre-Marín, 2012: Streamlining European Biodiversity Indicators 2020: Building a future on lessons learnt from the SEBI 2010 process. EEA Technical Report No. 11/2012.

Ole Hjorth Caspersen og Patrik Karlsson Nyed Andersen (2016): Udvikling i Agerlandet 1954–2025 – Kortlægning af markstørrelse, markveje og småbiotoper. Institut for Geovidenskab og Naturforvaltning, Københavns Universitet. 67 s. ill.

Collen, B., J. Loh, S. Whitmee, L. McRae, R. Amin & J.E.M. Baillie, 2007: Monitoring Change in Vertebrate Abundance: the Living Planet Index. Conservation Biology 23: 317–327.

Convention on Biological Diversity (1992). Text of the convention. Available at: https://www.cbd.int/convention/text/

Costanza, R. & Daly, H. (1992). Natural capital and sustainable development, *Conservation Biology, 6*, pp. 37–46.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M. & Hannon, B. (1997). The value of the world's ESS and natural capital, *Nature*, *387*, pp. 253–260.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., & Turner, R. K. (2014). Changes in the global value of ecosystem services, *Global Environmental Change, 26*, pp. 152–158.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., & Pejchar, L. (2009). ESS in decision making: Time to deliver, *Frontiers in Ecology and the Environment, 7*, pp. 21–28.

Daly, H. (1996) Beyond Growth: the Economics of Sustainable Development. Boston, MA, USA: Beacon Press.

Dansk Ornitologisk Forening (2017): Overvågning af de almindelige fuglearter I Danmark. Årsrapport for Punkttællingsprogrammet.

de Groot, R. S., Wilson, M. & Boumans, R. (2002). A typology for the description, classification and valuation of ecosystem functions, goods and services. *Ecological Economics, 41*, pp. 393–408.

Edwards, P. J. & Abivardi, C. (1998). The value of biodiversity: where ecology and economy blend. *Biological Conservation*, *83*(3), pp. 239–246.

Ejrnæs, R., A.H. Petersen, J. Bladt, H.H. Bruun, J.E. Moeslund, P.Wiberg-Larsen & C. Rahbek, 2014: Biodiversitetskort for Danmark. Københavns Universitet, Aarhus Universitet. Videnskabelig Rapport fra DCE, nr. 112.

European Environment Agency (1999). Environmental indicators: typology and overview. Technical Report no. 25/1999. Copenhagen, Denmark: European Environment Agency.

European Environment Agency (2012). Streamlining European biodiversity indicators 2020. Copenhagen, Denmark.

Farber, S. C., Costanza, R. & Wilson, M. A. (2002). Economic and ecological concepts for valuing ecosystem services. *Ecological economics*, *41*(3), 375–392.

Fenger, M., T. Nyegaard & M.F. Jørgensen, 2016: Overvågning af de almindelige fuglearter I Danmark 1975–2015. DOF Rapport 19, Dansk Ornitologisk Forening.

Framstad, E. (ed.) (2015). Naturindeks for Norge 2015. Tilstand og utvikling for biologisk mangfold.

Geist, H. J. & Lambin, E. F. (2002). Proximate Causes and Underlying Driving Forces of Tropical Deforestation, *BioScience, Vol. 52*(2), February 2002, pp. 143–150.

Gómez-Baggethun, E., de Groot, R., Lomas, P., and Montes, C. (2010). The history of ESS in economic theory and practice: From early notions to markets and payment schemes, *Ecological Economics, 6*, pp. 1209–1218.

Gómez-Baggethun, E. Ruiz-Perez, M. (2011) Economic valuation and the commodification of ecosystem services, *Progress in Physical Geography, 35*(5), pp. 613–628.

Gowdy, J. M. (1997). The value of biodiversity: markets, society, and ecosystems. *Land Economics, Vol. 73*(1), pp. 25–41.

Henriksen, S. and Hilmo, O. (2015). Hvor finnes de truete artene? Norsk rødliste for arter 2015. Artsdatabanken (http://www.artsdatabanken.no/Rodliste/HvorFinnesDeTrueteArtene). Retrieved on 10/10//2017.

Howarth, R. B., & Farber, S. (2002). Accounting for the value of ecosystem services. *Ecological Economics*, *41*(3), 421–429.

Jones-Walters, L., & Mulder, I. (2009). Valuing nature: The economics of biodiversity. *Journal for Nature Conservation*, *17*(4), pp. 245–247.

Kristensen, P. (2004). The DPSIR Framework, Paper presented at the 27–29 September 2004 workshop on a comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya. Available at: http://wwz.ifremer.fr/dce/content/download/69291/913220/file/DPSIR.pdf

Laurila-Pant, M., Lehikoinen, A., Uusitalo, L., & Venesjärvi, R. (2015). How to value biodiversity in environmental management?. *Ecological indicators*, *55*, pp. 1–11.

Millennium Ecosystem Assessment (2005) Millennium Ecosystem Assessment: Ecosystems and Human Wellbeing: Current State and Trends. Washington DC, Island Press.

OECD (2003). OECD Environmental Indicators – Development, Measurement and Use – Reference Paper. Paris.

OECD (2015). The Economic Feedbacks of Loss of Biodiversity and Ecosystem Services, ENV/EPOC(2014)16/FINAL. Paris.

OECD (2017). Glossary of Statistical Terms. Available at: https://stats.oecd.org/glossary/index.htm

Pedersen, B., S. Nybø & O. Skarpass, 2013: Naturindeksens økologiske rammeverk. En mer stringent tilnærming til fastsetting av referanseverdier og utvalget av indikatorer. NINA Minirapport 428.

Petersen, A.H., T.H. Lundhede, H.H. Bruun, J. Heilmann-Clausen, B.J. Thorsen, N. Strange og C. Rahbek (2016): Bevarelse af biodiversiteten i de danske skove. En analyse af den nødvendige indsats, og hvad den betyder for skovens andre samfundsgoder. Center for Makroøkologi, Københavns Universitet.

Salles, J. M. (2011). Valuing biodiversity and ecosystem services: Why put economic values on Nature? *Comptes rendus biologies*, *334*(5), 469–482.

Statistics Denmark (2002). Informationsgrundlaget for integreret miljøplanlægning. Available at: http://www.dst.dk/da/Statistik/Publikationer/VisPub?cid=4558

TEEB (2008) The Economics of Ecosystems and Biodiversity: An Interim Report. European Commission, Brussels.

TEEB (2009) The Economics of Ecosystems and Biodiversity, Climate Issues Update. 32p.

TEEB Foundations (2010) The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Edited by Pushpam Kumar. Earthscan, London.

TEEB in National Policy (2011a) The Economics of Ecosystems and Biodiversity in National and International Policy Making. Edited by Patrick ten Brink. Earthscan, London.

TEEB in Local Policy (2011b) The Economics of Ecosystems and Biodiversity in Local and Regional Policy and Management. Edited by Heidi Wittmer and Haripriya Gundimeda. Earthscan, London.

TEEB (2012), The Economics of Ecosystems and Biodiversity in Business and Enterprise. Edited by Joshua Bishop. Earthscan, London and New York. Earthscan, London.

UNDESA/SEEA (2003). Handbook of National Accounting: Integrated Environmental and Economic Accounting. Available at: http://unstats.un.org/unsd/envaccounting/seea2003.pdf

UNDESA (2017) Environmental-Economic Accounts, United Nations Department of Economic and Social Affairs, Statistics Division. Available at: http://unstats.un.org/unsd/envaccounting/default.asp

University of Aarhus, GEUS and Ministry of Environment and Food in Denmark (2016). Vandmiljø og natur – NOVANA. Available at: http://svana.dk/media/210311/sr211.pdf

Van Winkle, C., Karousakis, K., Bark, R., and van der Heide, M. (2015) Biodiversity Policy Response Indicators, OECD Environment Working Papers, No. 90, Paris, France: OECD Publishing.

Sammenfatning

Baggrund

Økonomiske aktiviteter påvirker biodiversiteten – og ændringer i biodiversiteten øver indflydelse på økonomien. Vores indblik i disse relationer er imidlertid stadig forholdsvist begrænset. Som det hedder i rapporten "Making the environment count", der blev udgivet af Nordisk Ministerråd i 2016: "Biodiversity has proved among the more challenging environmental issues to link to macroeconomic models."

Samtidig gælder, at biodiversiteten er under pres. Det er tilfældet overalt, også i de nordiske lande, hvor navnlig landbrug og skovbrug har bidraget og stadig bidrager til tilbagegangen i biodiversitet. Hertil kommer, at mange af de 196 lande, der har tiltrådt FN's Biodiversitetskonvention fra 1992, næppe vil nå de såkaldte Aichi-mål for 2020, mål som blev vedtaget på FN's biodiversitetskonference i 2010 i Japan.

På den baggrund har Miljø- og Økonomigruppen (MEG) og Terrestre Økosystemgruppen (TEG) i Nordisk Ministerråd igangsat et projekt, der har til formål at belyse, i hvilket omfang det er muligt at etablere nogle sammenhænge mellem makroøkonomiske modeller og indikatorer for biodiversitet.

Mere præcist er formålet at undersøge, i hvilken udstrækning det er muligt at etablere og kvantificere en kausal sammenhæng mellem økonomiske aktiviteter og biodiversitet, helt eller delvist, og hvad det i givet fald vil kræve af data og modelændringer. Sammenhængen består ret beset af to sammenhænge, idet sammenhængen mellem økonomiske aktiviteter og biodiversitet går begge veje.

Projektet fokuserer på konsekvenserne af økonomiske aktiviteter og ændringer heri for biodiversiteten, men ser også på konsekvenserne af ændringer i biodiversiteten for de økonomiske aktiviteter.

Sammenhængene

Den kausale sammenhæng mellem økonomiske aktiviteter og biodiversitet undersøges ved hjælp af den såkaldte DPSIR-tilgang, der systematiserer og strukturerer sammenhængene mellem *Drivers*, *Pressures*, *States* (eller *Environmental states*), *Impacts* og *Responses* på miljøområdet. Den nævnte sammenhæng opdeles i to sammenhænge, nemlig for det første sammenhængen mellem *Drivers* (f.eks. øget produktion inden for skovbrug) og *Pressures* (f.eks. tab af naturskov) og for det andet sammenhængen mellem *Pressures* og *States* (f.eks. ændringer i levevilkår for bestemte fugle). På den måde kan analysen gøres mere konkret, ikke mindst fordi den let lader sig relatere til makroøkonomiske indikatorer indeholdt i diverse makroøkonomiske modeller (af betydning for førstnævnte sammenhæng) og biodiversitetsindikatorer indeholdt i diverse miljømodeller (af betydning for sidstnævnte sammenhæng). For hver af de to sammenhænge undersøges det, om og i hvilken udstrækning den lader sig kvantificere ved hjælp af makroøkonomiske modeller eller miljømodeller.

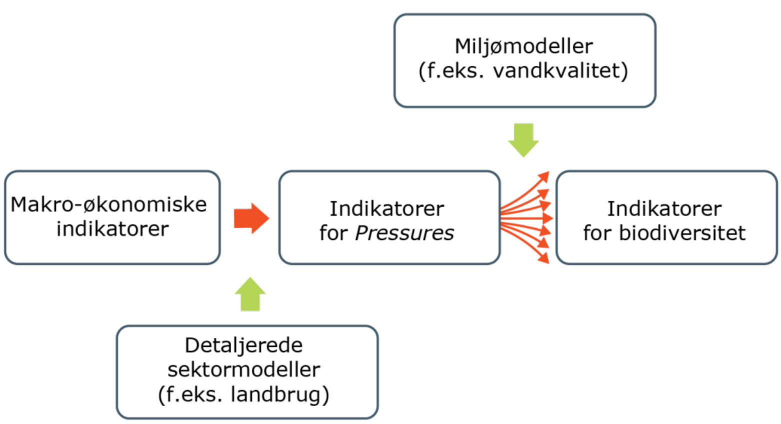
Den kausale sammenhæng mellem biodiversitet og økonomiske aktiviteter undersøges ved at se på sammenhængen mellem *States* og *Impacts* (f.eks. ændrede rekreative muligheder eller naturværdier).

Projektet baserer sig på eksisterende makroøkonomiske modeller og miljømodeller og tilhørende indikatorer i de skandinaviske lande, om end igangværende arbejder på området i internationale organisationer, såsom OECD, inddrages.

Konklusion og anbefalinger

Figur 15 nedenfor illustrerer analysens hovedkonklusion. Analysen har vist, at det vil være muligt at etablere kvantificerede sammenhænge mellem makroøkonomiske indikatorer og de påvirkninger, som det giver anledning til. Det kan ske gennem detaljerede sektormodeller. Derimod vil det være forbundet med store udfordringer at etablere de kvantitative årsagssammenhænge mellem påvirkningsindikatorer og biodiversitets indikatorer. Det vil næppe være muligt at etablere sammenhænge, som har stor forudsigelseskraft.

Figur 15: Fra makroøkonomiske indikatorer til biodiversitet indikatorer – fra simple til komplekse kvantitative sammenhænge



Analysen har vist, at det vil være muligt at opstille kvantitative modeller, som kan beregne ændringer i påvirkninger – målt ved påvirkningsindikatorer som følge af ændringer i makroøkonomiske forhold – målt ved ændringer i makroøkonomiske indikatorer. Sådanne modeller ville understøtte politikudvikling og besvarer spørgsmål, som hvordan en given makroøkonomisk politikfremskrivning vil øge eller mindske presset på biodiversiteten.

Derimod vil det ikke være muligt at kvantificere, hvor meget biodiversiteten vil ændre sig ved en given makroøkonomisk politik. Det skyldes, at biodiversitet ikke kan måles ved nogle få indikatorer, at der er eller kan være en lang tidsforskydning fra påvirkning og til konsekvens, samt at den rumlige dimension gør, at man skal kende de nøjagtige geografiske forhold, hvilket betyder, at man kun vil kunne drage kvalitative konklusioner.

Det er i denne sammenhæng vigtigt at understrege, at hvis man kan etablere kvantitative sammenhænge mellem makroøkonomiske indikatorer og påvirkningsindikatorer, så vil det give et væsentligt bidrag til vurderingen af, hvordan alternative politikker vil påvirke den fremtidige biodiversitetudvikling.

Fra Drivers til Pressures

Muligheden for at etablere sammenhænge mellem drivkraftfaktorer *(Drivers)* og påvirkningsfaktorer *(Pressures)* er blevet vurderet for de vigtigste påvirkningsfaktorer, nemlig:

- Tab og forringelse af habitater.
- Klimaforandringer.
- Udledning af næringsstoffer og andre typer af forurening.
- Overudnyttelse af naturressourcer.
- Invasive fremmede arter.

Tabel 20 sammenfatter konklusionerne om muligheden for at etablere kvantitative modeller til etablering af en sammenhæng mellem økonomiske aktiviteter og påvirkningsfaktorer, idet der tages udgangspunkt i ovennævnte fem påvirkningsfaktorer.

Tabel 20: Påvirkningsfaktorer, økonomiske aktiviteter og tilgængelige sektormodeller

Påvirkningsfaktorer	Økonomiske aktiviteter (sektorer)	Data og modeller
Tab og forringelse af habitater	Arealanvendelse	Der findes ikke umiddelbart modeller for arealanvendelse. Det vil være muligt at udvikle arealanvendelsesmodeller. En øget brug af avanceret fotobaseret kortproduktion vil give flere detaljerede arealanvendelsesdata.
Klimaforandringer	Alle sektorer	Klimaforandringerne afhænger af globale emissioner. Ikke relevant at etablere kvantitative modeller af sammenhæng mellem nationale GHG-emissioner og biodiversitet.
Udledning af næringsstoffer og andre typer af forurening	Alle sektorer	Der findes modeller, som beregner effekten af både luft- og vandforurening. Disse modeller kan beregne emissionen fra et givet makroøkonomisk scenarie.
Overudnyttelse af naturressourcer	Fiskeri	Der findes i et vist omfang modeller, som beskriver udnyttelse af marineressourcer (f.eks. modeller for fiskebestande som funktion af fiskeriindsatsen).
Invasive fremmede arter	Handel og turisme	Begrænset viden om årsager til fremkomsten af invasive fremmede arter. Vanskeligt at vurdere om der kan skabes en årsagssammenhæng.

Tabel 21 viser antallet af biodiversitetsindikatorer, som kan relateres til hver af påvirkningsfaktorerne. Tabellen viser, at tab og forringelse af habitatområder er den væsentligste påvirkningsfaktor, idet den er relevant for to tredjedele af alle de biodiversitetsindikatorer, som er med i det norske naturindeks. De næstvigtigste påvirkningsfaktorer er klimaforandringer og overudnyttelse af naturressourcer.

Tabel 21: Antal biodiversitetsindikatorer påvirket af forskellige påvirkningsfaktorer (baseret på det norske naturindeks for 2015)[1]

Påvirkningsfaktorer	Antal påvirkede biodiversitetsindikatorer
Tab og forringelse af habitater	207
Klimaforandringer	166
Udledning af næringsstoffer og andre typer af forurening	62
Overudnyttelse af naturressourcer	102
Invasive fremmede arter	32

Note: [1] Indikatorer kan påvirkes af flere faktorer, hvorfor det samlede antal påvirkede indikatorer fordelt på påvirkningsfaktorer overstiger det samlede antal indikatorer.

Kilde: Framstad, E (red.), 2015.

Tabel 22 sammenfatter vurderingen af vigtigheden af og muligheden for at konstruere kvantitative modeller til etablering af en sammenhæng mellem makroøkonomiske indikatorer og påvirkningsfaktorerne (sammenhængen mellem *Drivers* og *Pressures*). Vurderingen bidrager til identifikationen af, hvor det vil være mest relevant at igangsætte udviklingsprojekter.

Tabel 22: Vigtighed og mulighed for at kvantificere sammenhængen mellem økonomiske indikatorer og påvirkningsfaktorer

Påvirkningsfaktorer	Vigtighed	Mulighed (gennemførlighed)
Tab og forringelse af habitater	Høj	Høj
Klimaforandringer	Høj	Lav
Udledning af næringsstoffer og andre typer af forurening	Lav–middel	Middel
Overudnyttelse af naturressourcer	Middel	Høj
Invasive fremmede arter	Lav	Lav

Vurderingen og analysen peger på, at det vil være mest interessant at fokusere på arealanvendelsen som påvirkningsfaktor. Derfor er den vigtigste anbefaling fra dette studie:

- Igangsættelse af en undersøgelse af, hvordan man kan kvantificere sammenhængen mellem makroøkonomiske indikatorer og tab og forringelse af habitater. Det vil kræve, at der udvikles modeller for arealanvendelsen, og hvordan denne afhænger af aktiviteten i de økonomiske sektorer.

Hvis der udvikles modeller, som kan simulere ændringer i arealanvendelse som følge af den makroøkonomiske udviklinger, vil de kunne bruges til kvalitative vurderinger af, hvordan biodiversitetsindikatorer vil påvirkes af den makroøkonomiske udvikling.

Der er mange sektorer, som bidrager til ændringer i arealanvendelsen og dermed påvirker terrestriske økosystemer og habitater. Påvirkningen af økosystemerne og habitaterne afhænger ofte af sammenspillet med aktiviteten i de forskellige sektorer. Derfor vil der være stor gevinst ved at have en model, som kan beskrive arealanvendelsen som følge af alle relevante sektoraktiviteter.

Fra Pressures til States

Sammenhængen mellem påvirkningsfaktorer og miljøstilstand er genstand for megen forskning. Der arbejdes hele tiden med at øge forståelsen af disse sammenhænge. Anbefalingerne er, at:

- Udføre kontrollerede forsøg i testområder (habitater), både i det åbne land og i skove, med det formål at identificere, analysere og kvantificere sammenhængende mellem påvirkningsfaktorer og biodiversiteten.
- Gennemføre studier af sammenhængene mellem positive miljøforbedringer og genskabelse af biodiversitet med fokus på forsinkelsesfaktorer og andre barrierer for genskabelse af biodiversitet.
- Forsætte forskning i sammenhængen mellem biodiversitetsmangfoldighed og økosystemfunktionalitet, idet økosystemfunktionalitet er afgørende for biodiversitetstabilitet/-modstandsdygtighed og for omfanget økosystemtjenester. En dyb forståelse af biodiversitet- og økosystemstabilitet og tærskelværdier for ændringer er afgørende for en bedre integration med økonomiske modeller og indikatorer.
- I stedet for indsamling af nye data om biodiversitet kunne det være nyttigt at vurdere eksisterende programmer, som måler og registrerer data om biodiversitet.

Som en del af eksisterende forskning i værdisætning af økosystemtjenester må der forventes at komme nye og bedre data. De kan medvirke til at forbedre beskrivelsen af, hvordan makroøkonomiske indikatorer påvirkes af ændringer i biodiversitet. En separat anbefaling for sammenhængen mellem biodiversitet og makroøkonomiske indikatorer (den modsatrettede påvirkningskæde i forhold til den, som er diskuteret ovenfor) er derfor:

- Videreudvikling af værdisætningsprincipper og metoder for biodiversitet, som beskriver hvordan de økonomiske sektorer påvirkes af ændringer i biodiversiteten.

Appendix 1: Glossary

Table 23: Glossary

Term	Definition
Biodiversity	Biodiversity (or biological diversity) refers to the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.
Biodiversity indices (or indicators)	Biodiversity indices (or indicators) are measures of species diversity expressed as ratios between numbers of species and "importance values" (numbers, biomass, productivity and so on) of individuals. The term may also refer to genetic diversity and diversity of habitats or communities.
Economic model	A simplified representation of economic reality showing the interrelation between selected economic variables.
Ecosystem	Ecosystem means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.
Ecosystem services	ESS cover the provision of ecosystem inputs, the assimilative capacity of the environment and the provision of biodiversity.
Green GDP	A GDP that takes the value of environmental and resource changes into account. For example changes in the value of natural capital or the costs of environmental degradation.
Green national accounts	Accounts that describe environmental and resource flows or stock. They can be in physical units or in monetised values. They are not the same as the green GDP, but the accounts are often the first step in estimating the green GDP.
Habitat	A habitat is a place or type of site where an organism or population (human, animal, plant, microorganism) naturally occurs.
Macro-economic model	A macro-economic model is an economic model designed to describe the operation of the economy of a country or a region. Attention is paid to production of services and goods, consumption, investments, income, employment and prices.
National accounts	National accounts are a coherent, consistent and integrated set of macro-economic accounts, balance sheets and tables based on a set of internationally agreed concepts, definitions, classifications and accounting rules. National accounts provide a comprehensive accounting framework within which economic data can be compiled and presented in a format that is designed for purposes of economic analysis, decision-taking and policy-making.
Species	Species are all the individuals and populations of a particular kind of organism, maintained by biological mechanisms that result in their breeding only with their own kind.

Source: Convention on Biological Diversity website; OECD, 2017.

Appendix 2: Biodiversity indicators: Three examples

This appendix provides three examples on biodiversity indices and indicator systems providing insight into the features of and challenges in developing biodiversity indicators. The three examples are:

- Norwegian Nature Index.
- SEBI.
- OECD Biodiversity Policy Response Indicators.

In the following, these are presented and reviewed – one by one.

The Norwegian Nature Index

The Norwegian Nature Index (NNI) has been established as a means to demonstrate the state and trends in biodiversity in Norway, with the purpose of providing a condensated reporting of the state of Norwegian nature to policy makers and the public.

The specific purpose of the NNI has been to provide an answer to the question: Is the biodiversity declining or is it stable or increasing? Based on 301 indicators from nine main ecosystems and defined by 85 specialists, the NNI was established in 1990 as an aggregated index that has been compiled by means of data from monitoring, model estimates and expert assessments. The majority of the indicators represent indicators of species population levels and the number of indicators vary between the nine ecosystems. A number of public institutions provide the data, whether they are monitoring data (approx. 35% of all data), model-based estimates (approx. 19%) or experts' assessments (46% of all data). The NNI is published every five years.

The NNI is built on the basis of the principles of the Mean Species Abundance Index (MSA), which means that the values of the individual indicators are scaled against their estimated value in a pristine or near-pristine reference condition that holds an intact biodiversity in a satisfying state. For ecosystems that have been changed and affected by man over a very long time, such as farmland areas, the reference state is defined as areas in a satisfying state. The NNI includes a common conceptual basis for setting reference values across ecosystem so that a specific reference state is defined for each of the nine ecosystems, even if the degree of how pristine they appear varies across the ecosystems.

The NNI is calculated for the major ecosystems in specific regions and for a given year, and the calculations are made by means of a number of mathematical transformations of observed or estimated primary data. The NNI can take on values between 0 and 1, where 1 equals the reference state and 0 the totally deteriorated ecosystems. So far, no attempts have been made to define precise thresholds for ecosystem functionality or vulnerability or good or bad ecological status.

One key challenge with an MSA based index is that the less pristine an area appears due to long-term human intervention (e.g. Western European farmland practise), the more problematic it is to define a reference state. For large parts of the Western World, indeed including Northwest Europe, outside the mountain areas humans have intervened and transformed the landscape over centuries and lately another antropogenic effect must be added as a pressure to the biodiversity: Climate change. This makes MSA based indices difficult to establish with any certainty in regions with dense human populations.

The indicators in the NNI are a selection of indigenous species found in the specific ecosystems, or groups of species characteristics of the individual ecosystems. Some of the indicators compile information about several species and are included in the NNI as indices. The NNI also includes indirect indicators that represent important resources for species, such as dead wood that makes up an important habitat for several forest species.

While the NNI may be attractive as a simple, one-figure expression of the average biodiversity state in each of the nine ecosystems, the complex aggregation of the large number of indicators makes it next to impossible to link trend in NNI with changes in environmental drivers and pressures. During the intricate calculations, the transparency of simple indicators has been lost and the final results yield no understanding of cause and effects. The single-figure index will obviously also cover numerous opposite trends in individual species or groups of species within the same ecosystem.

Hence, the importance of the NNI is to be able to convey a simple message about trends in Norwegian ecosystems though at the costs of not being able to provide any messages about causal links. As such, the NNI and similar types are not suitable to inform relations within the DPSIR cycle, and the NNI makes no attempt to describe temporal changes. Due to the single-figure summary, there is a significant risk that actual changes and transformations within the ecosystems are indicated over a rather long time span – and only then will it be reasonable to start detailed studies in order to attempt to understand causal relations. So, even if the purpose of the NNI is to answer a very simplified question (cf. above), there is a notable risk that even such a simple question cannot be answered within a horizon of even a few years.

Given the laborious work that lies behind simplifying data from 301 indicators into just nine single figures, the NNI covers an enormous amount of data and information about biodiversity in Norway. A vast amount of information that is likely to hold significant value for researchers and others who may want to establish a causal link between pressures and the state of biodiversity can be found within the institutions that are responsible for the NNI. As such, even if the NNI – and similar types of highly aggregated indices – appear unsuitable for use as biodiversity indicators of economic activities, the ecological framework and understanding of ecological functionality, data sets, calculations and data management that lie behind the NNI are highly significant for further studies into the DPSIR links.

SEBI – Streamlining European Biodiversity Indicators 2020

In 2003, the UNECE adopted a resolution on biodiversity – the Kiev Resolution on Biodiversity – calling upon European countries to halt the loss of biodiversity by 2010. Following this resolution, a process named Streamlining European Biodiversity Indicators 2020 (SEBI) was launched by the European Environmental Agency (EEA) and the European Commission together with other European partners to develop a set of biodiversity indicators with which it would be possible for European countries to follow the progress of the member states towards the UNECE target.

The SEBI process was launched in 2005 with the aim of providing a streamlined and workable set of biodiversity indicators, building on current monitoring programmes and available data to complement and not replace other biodiversity sampling efforts at a comparable scale. The result was a list of 26 indicators, which was published by EEA in 2007, cf. Figure 16 below. The SEBI indicators were subsequently checked against the 20 Aichi targets and new EU biodiversity targets following the launch of the EU strategy on biodiversity in 2011. It was agreed that the SEBI indicators can be used to measure progress also against these targets.

Figure 16: The 26 SEBI indicators organised against CBD focal areas

CBD focal area	Headline indicator	SEBI 2010 specific indicator
Status and trends of the components of biological diversity	Trends in the abundance and distribution of selected species	1. Abundance and distribution of selected species a. Birds b. Butterflies
	Change in status of threatened and/or protected species	2. Red List Index for European species
		3. Species of European interest
	Trends in extent of selected biomes, ecosystems and habitats	4. Ecosystem coverage
		5. Habitats of European interest
	Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance	6. Livestock genetic diversity
	Coverage of protected areas	7. Nationally designated protected areas
		8. Sites designated under the EU Habitats and Birds Directives
Threats to biodiversity	Nitrogen deposition	9. Critical load exceedance for nitrogen
	Trends in invasive alien species (numbers and costs of invasive alien species)	10. Invasive alien species in Europe
	Impact of climate change on biodiversity	11. Impact of climatic change on bird populations
Ecosystem integrity and ecosystem goods and services	Marine Trophic Index	12. Marine Trophic Index of European seas
	Connectivity/fragmentation of ecosystems	13. Fragmentation of natural and semi-natural areas
		14. Fragmentation of river systems
	Water quality in aquatic ecosystems	15. Nutrients in transitional, coastal and marine waters
		16. Freshwater quality
Sustainable use	Area of forest, agricultural, fishery and aquaculture ecosystems under sustainable management	17. Forest: growing stock, increment and fellings
		18. Forest: deadwood
		19. Agriculture: nitrogen balance
		20. Agriculture: area under management practices potentially supporting biodiversity
		21. Fisheries: European commercial fish stocks
		22. Aquaculture: effluent water quality from finfish farms
	Ecological Footprint of European countries	23. Ecological Footprint of European countries
Status of access and benefits sharing	Percentage of European patent applications for inventions based on genetic resources	24. Patent applications based on genetic resources
Status of resource transfers	Funding to biodiversity	25. Financing biodiversity management
Public opinion (additional EU focal area)	Public awareness and participation	26. Public awareness

Source: EEA, 2012.

The SEBI indicators have been devised in order to monitor trends in biodiversity on a regional level, specifically as an accumulated result of biodiversity conservation efforts undertaken nationally as well as on a wider European scale. Hence, the indicators were not established with the purpose of monitoring the consequences of policy decisions in specific economic sectors, though the underlying EU biodiversity strategy specifically addresses the main drivers of biodiversity loss as well as the need to ensure a streamlining of environmental policies and initiatives in major EU policy sectors such as agriculture, fisheries, energy etc.

As a part of the indicator development process, an elaborated set of criteria for selection of indicators was developed; it was rather rigorously applied to the proposed indicators.

The SEBI indicators were established to sample a wide range of subjects or areas, following the CBD Strategic Plan, outlined as CBD focal areas, cf. Figure 16. Basically, the SEBI indicators can be separated into two major groups, one covering direct impacts to and status and trends in biodiversity and another covering indirect impacts by means of sampling sustainability issues. When selecting suitable indicators for measuring effects from macro-economic decisions and policies, we recommend focusing primarily on the first group of indicators, corresponding to the following three CBD focal areas:

1. Status and trends of the components of biological diversity.
2. Threats to biodiversity.
3. Ecosystem integrity and ecosystem goods and services.

The SEBI indicators in these groups include indices for species and habitats in Europe in widespread use on national levels as well as indicators on fragmentation, trophic index and environmental quality. Most of these indicators are rather easily obtainable and accessible, such as indicators on abundance and distribution of species of birds and butterflies (SEBI indicator no. 1), as well as red-list index (SEBI indicator no. 2) and invasive alien species in Europe (SEBI indicator no. 10).

Other indicators will require substantial additional work before they can be launched as biodiversity indicators. An example of this is the indicator on fragmentation of natural and semi-natural areas (SEBI indicator no. 13), which includes a type of information that is most likely not readily available in any European country.

Some of the indicators are established in order to measure effects of activities in the economic sectors rather than the subsequent effect on biodiversity. These indicators include SEBI indicator no. 15, Nutrients in transitional, coastal and marine waters, SEBI indicator no. 17, Forest growing stock, increment and fellings and SEBI indicator no. 19, Agriculture nitrogen balance. These indicators may represent a close link to economic activities, but they may not be ideal for measuring effects on biodiversity.

The more steps of immediate correspondence and causal effects there are between the actual economic activity and the ensuing effect on elements of biodiversity, the less transparent the biodiversity indicator will appear and the less indicator strength will it demonstrate. On the other hand, as has been demonstrated elsewhere, simple and transparent indicators on biodiversity such as single species population indices may not readily be ascribed to specific economic activities.

In conclusion, the SEBI indicators represent a strong source of suitable indicators of which a subset of indicators may be applied for use in macro-economic modelling. The individual indicators have been prepared in order to serve a diverse set of purposes in different geographic regions, and it is anticipated that their status as indicators in active use in the individual European countries may differ significantly. Before further application, this should be carefully analysed as indicators that are not in regular use in a specific region might be replaced by a similar indicator well-known in that particular region.

OECD Biodiversity Policy Response Indicators

The OECD Biodiversity Policy Response Indicators were published in an OECD publication in 2015 (Van Winkle et al., 2015) as a part of an effort in identifying indicators that can be used to monitor progress towards the achievement of the Aichi Biodiversity Target 3 on Incentives and Target 20 on Resource Mobilization under the Convention of Biological Diversity. Given the specific contents of this framework for the objectives of this OECD study, it may be expected that the findings and recommendations of this OECD study may be applicable to the present study on biodiversity indicators in economic modelling.

The OECD study also undertook an examination of existing OECD datasets and monitoring systems that could be used for the purposes of the response indicators. Basically, the OECD analysed a number of existing OECD databases in the search for suitable data material that may be applied as indicators for the given Aichi Targets.

The point of departure of the OECD study is that environmental indicators are used to help assess, track and communicate environmental trends along three general categories: pressures, states (environmental conditions) and responses (societal responses). As such, the study follows the structure of the overall approach taken in the present study with the use of (part of) the DPSIR framework. The OECD study acknowledges the complexity of the relations between the state of the environment and the ensuing state of the biodiversity due to the multidimensionality of the physical environment, the multitude of ecosystems and the multiple pressures that have an effect on their state.

In the study, the OECD defines response indicators as indicators that:

1. Refer to actions that are being undertaken to help address the pressure on the environment.
2. Monitor the effects of response policies issued by society.

The OECD suggests a comprehensive set of criteria for selecting environmental indicators and further defines a so-called SMART concept for the indicators (SMART stands for Simple, Measurable, Accessible, Realistic and Timely). While the individual criteria appear sound and reasonable, it is also implied that not all criteria can be applied to each specific indicator for a variety of reasons.

The OECD makes little effort in defining the geographical and temporal scope of the indicators and while this may be fully acceptable – and perhaps even the only way forward due to a general lack of options for demonstrating spatial and temporal targets of individual policies – it causes a series of problems when identifying specific biodiversity indicators. As a consequence, indicators defined on this basis will generally appear fairly broad, and causal relations between policies and effects on biodiversity and ecosystems may be very difficult – if not impossible – to establish.

The OECD has presented a table of indicators proposed by the Ad Hoc Technical Expert Group (AHTEG) under CBD, cf. Figure 17. In its analysis of the significance of these indicators, the OECD takes a top-down approach starting with the databases that are available at OECD, assessing to which extent the datasets at OECD can provide data that can be used to construct suitable indicators for the given Aichi Targets. This approach is somewhat contrary to the opposite, bottom-up approach where the state of the biodiversity (or environment in broader terms) or biodiversity loss is described by means of specific indicators. Typical indicators for this sample biodiversity levels, population levels, habitat extent etc. as seen in the SEBI indicators and in many other examples.

While a key criteria for any operational indicator is that it has to be based on a suitable, updated and maintained dataset, it appears rather demanding to establish clear links between biodiversity loss and indicators of the type proposed by AHTEG and presented in Figure 17. Indicators presented in this table appear very broad with very few or even no clear links to the state of biodiversity. While the indicators may be useful for sampling policies and streams of funds, they appear rather unsuitable for sampling the actual effects of these policies and funds. Hence, the effects on biodiversity may never or only in a long-term perspective be traced, and links between specific impacts – positive or negative – on biodiversity appear problematic to establish.

Figure 17: Aichi Biodiversity Target indicators (Target 3 and 20, headline and operational indicators), as proposed by AHTEG, a working group under the CBD

Target 3	Headline	Trends in integration of biodiversity, ecosystem services and benefits sharing into planning, policy formulation and implementation and incentives
	Operational	Trends in the number and value of incentives, including subsidies, harmful to biodiversity, removed, reformed or phased out Trends in identification, assessment and establishment and strengthening of incentives that reward positive contribution to biodiversity and ecosystem services and penalize adverse impacts
Target 20	Headline	Trends in mobilization of financial resources
	Operational	1. Aggregated financial flows, in the amount and where relevant percentage, of biodiversity-related funding, per annum, for achieving the Convention's three objectives, in a manner that avoids double counting, both in total and in, *inter alia*, the following categories: a. Official Development Assistance (ODA) b. Domestic budgets at all levels c. Private sector d. Non-governmental organizations, foundations, and academia e. International financial institutions f. United Nations organizations, funds and programmes g. Non-ODA public funding h. South-South cooperation initiatives i. Technical cooperation. (see Annex I for the full list of 15 operational indicators)

Source: Documents UNEP/CBD/COP/DEC/X/3 and UNEP/CBD/COP/DEC/XI/3, available at CBD website (www.cbd.int).

For the bottom-up approach – sampling the state of biodiversity – the ensuing challenge is to ascribe the biodiversity and habitat loss to economic activities, policies and streams of funds. However, for this purpose, the OECD analysis of biodiversity policy response indicators does not point to appropriate ways forward.

It can be concluded that the OECD in this study pursues indicators and indicator opportunities in the present OECD data sets and databases that may reveal trends in incentives and resources made available for biodiversity conservation purposes. This may be a valid approach and one that implies a number of advantages at policy level (levels close to *Responses* and *Drivers* in the DPSIR framework). However, the OECD concludes that the development of suitable indicators depends on the availability of suitable databases and that additional work is needed to develop underlying databases with further information, so that appropriate indicators can be developed. This may be a fully justified conclusion if focusing solely on OECD datasets. However, given the multitude of publicly accessible and relevant databases outside the OECD and from which a plethora of relevant biodiversity indicators has been and can be developed, it may be questioned if the conclusion provided by OECD is valid in the broader perspective.

Appendix 3: From Drivers to States, Two examples

In this appendix, we provide two examples on the links between *Drivers*, *Pressures* and *States* in the DPSIR framework.

One example concerns a common species (the skylark), another example a habitat (open land).

The two examples serve the purpose of highlighting the multifaceted links that exist, thereby emphasising the challenges facing the researcher (or rather group of researchers, since different disciplines are required), who wants to establish such links that in the end may contribute to the establishment of links between measures of biodiversity and economic modelling.

The skylark example underlines the fact that while the link between *Drivers* and *Pressures* is fairly straightforward, the link between *Pressures* and *States* is very complex. The open land example pays particular attention to the link between *Drivers* and *Pressures*. It underlines the fact that developments in agriculture seriously affect biodiversity in the areas affected by agriculture.

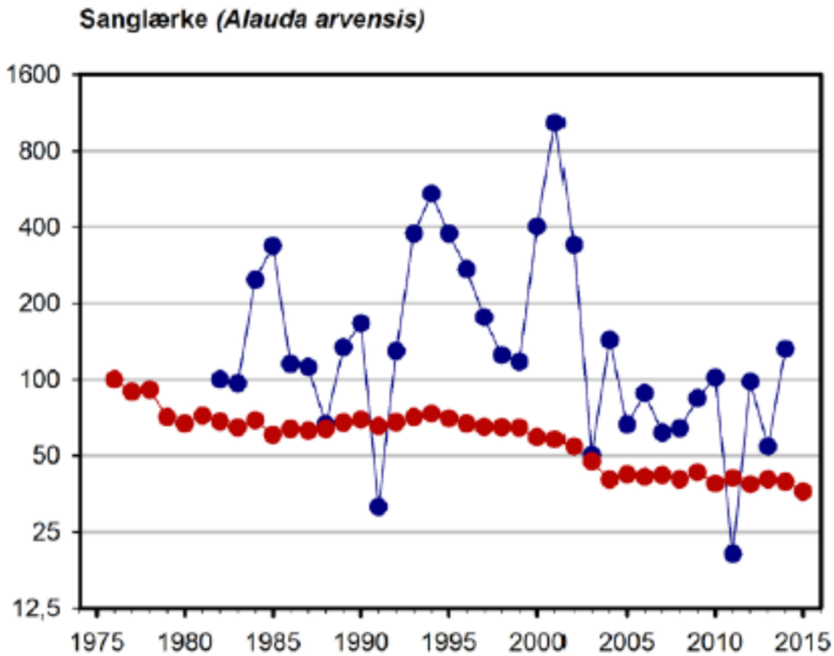
As part of the skylark example, selected biodiversity indicators and indices are presented.

Example 1 – The skylark

The skylark (Alauda arvensis) is a common bird in the agricultural landscape and other open landscapes. The skylark is adapted to areas with low-growing and sparse vegetation where it feeds on plant seeds and during the breeding season also insects. The nest is located on the ground, on arable land as well as in natural habitats.

Traditionally, the skylark has been used extensively as an indicator of the environmental quality of the agricultural landscape, as its breeding population tends to fluctuate with key characteristics of agricultural activities. Studies have documented that skylarks have higher breeding population densities on organically farmed land compared to agricultural areas where pesticides are applied regularly.

Figure 18: Development in breeding population (red dots, index, baseline index 100 is 1976) and winter population (blue dots, index, baseline index 100 is 1982) of Danish skylarks since 1976 and 1982, respectively



Source: Dansk Ornitologisk Forening, 2017.

The suitability of a skylark habitat depends on a number of factors, of which food resources and nest site quality generally are considered the most important as regards the environmental quality of the breeding habitat. As a predominantly migratory species, the winter conditions play an insignificant role at the breeding grounds even if the species arrives in late winter and early spring on the breeding grounds, where weather conditions can be harsh.

The preferred food resources for the skylark consist primarily of plant seeds and insects. Outside the breeding season, the skylark feeds on plant seeds and other plant material whereas nestlings are fed with insects.

The quality of the nest site is determined by factors such as predation and disturbance. The nest is located on the ground and is vulnerable to predation by crows, magpies and mammals such as foxes, martens etc. Hence, in order to complete a successful breeding period, the skylark needs to be able to locate its nest sufficiently concealed in the ground vegetation. The nest is also vulnerable to disturbance including traffic with agricultural vehicles. When located in the arable fields, the nest may be destroyed by vehicles and other agricultural equipment used in the cultivation of the fields. If the nest is located in permanent habitats such as field edges and road sides etc. between the fields, permanent grassland and meadows, the risk of nest destruction is much reduced.

Based on the above key characteristics of the skylark ecology, it appears that pressures on the skylark breeding population can stem from two significantly different factors: Food availability and nest site quality.

Food availability in the agricultural landscape is likely to be determined primarily by two different factors: Availability (and quality) of plant seeds and production of insects and other invertebrates. To some extent, both elements are controlled by the chosen agricultural scheme: Organic farming or intensive farming. In organic farming, no pesticides are applied and thus there is no control of the availability and production of non-crop plants and invertebrates. With the application of pesticides, a negative correlation will eventually develop between the amount of pesticides used and the availability of skylark food resources.

Hence, it is expected that a breeding population of skylark will diminish with increased application of pesticides, and vice versa increase with reduced use of pesticides. As such, the food availability is considered to be a result of the chemical environment of the skylark breeding site. Nest site quality depends rather on the physical environment of the skylark breeding site. If it is assumed that the nest site quality can be measured in terms of the survival rate of eggs and nestlings and that survival can be expected to increase if the nest is located in suitable vegetation outside the arable fields, then nest site quality will be correlated with the availability of natural habitats in the agricultural landscape.

In Denmark and other countries and regions where agriculture remains a key economic sector, there has been a long-term trend of increasing field size and reducing the numbers and coverage of natural and seminatural habitats. This trend has resulted in the loss of typical farmland habitats and hence the loss of biodiversity found in open, permanent habitats in farmland areas.

However, based on this two-pronged causality between skylark breeding population levels and farmland characteristics, it is not evident which of the two main factors determines the level of the breeding population, food availability or nest site quality. Food availability is primarily determined by the level of agricultural intensification when measured on the basis of the application of chemical substances, whereas nest site quality is primarily a result of structural changes such as field sizes, availability and extent of small habitats with (semi-) natural vegetation.

Causality not easily understood

Despite the widespread understanding that a single species with a strong and clear habitat affinity like the skylark represents a useful and representative indicator for farmland habitat quality, a closer examination of the causal relation between its indicator value and underlying drivers and pressures reveals that the causality is not easily understood. The skylark is – unsurprisingly – affected by a multitude of environmental factors and even if only the key factors are highlighted there are at least two fundamentally different factors affecting the population levels and conservation status of the skylark: Breeding habitat availability and habitat quality as expressed by food availability. Whereas the first is mainly a result of physical changes and land use in the farmland landscape, the second is a result of the agricultural practise and intensification level (specifically a result of the application of pesticides).

In order to overcome such challenges, it may be useful to look for an additional indicator that may supplement e.g. the skylark and provide more information about the causality.

An example could be the butterfly small copper (Lycaena phlaeas) which is widespread in open land in large parts of Europe. Like birds, butterflies are generally easily sampled and monitored and do as such fulfil a number of the indicator criteria put forward in Section 3.3. This species is associated with nutrient-poor, low-growing vegetation rich in flowering plants, a type of high-quality habitat that signals low-intensity and low-input agricultural activities.

The small copper is not associated with farmland fields as is the skylark and hence one significant environmental factor differs between these two species, which could facilitate a better understanding of environmental impacts and their causality in the open land. However, as a butterfly, the small copper introduces another explanatory challenge as butterflies are associated with flowering plants of certain species. Butterflies may have an acceptable dispersal ability provided suitable habitats are available, but many plant species show a very poor dispersal rate. This means that plants – and hence butterflies – in many cases respond poorly to habitat improvements in a fragmented landscape (as is often the case in farmland landscapes). The dispersal inertia may blur the response mechanisms and indeed the understanding of causality.

Accordingly, caution must be paid even when applying seemingly useful and strong indicators as the real causal relations between the given biodiversity elements and the underlying drivers and pressures may appear more complex when subject to a closer analysis. An awareness of such reservations is beneficial for further work on biodiversity indicators.

Selected indicators and indices

Indicators and indices for biodiversity are being developed by a plethora of institutions and organisations on a global scale. Ranging from single species indicators to complex and intricate indices for habitats, ecosystem or even nations and regions, indicators and indices have been defined and established in order to fulfil a huge range of tasks within environmental planning and management. Hence, the availability of indicators and indices on a global scale is overwhelming and the diversity in their structure and applicability is enormous.

Impacts of environmental loads and physical changes in land use, natural resources exploitation and degradation and fragmentation of habitats and ecosystems may reveal themselves along a variety of temporal and spatial gradients. Environmental and ecological impacts may cause instant effects on the biodiversity or measurable effects may be delayed, showing up in an indirect manner or even appearing at a physical distance from the place of direct impact.

An index like the MSA (Mean Species Abundance), which bases a significant part of the information on an assessment of the relative state of the biodiversity, may prove useful in regions dominated by pristine or near-pristine habitats and ecosystems. In regions marked by significant long-term land use with large-scale transformations like the arable parts of Western Europe such index may prove less valuable as the definition as well as the assessment of pristine or near-natural biodiversity becomes difficult to clarify.

Further, a number of valuable habitats now considered important for biodiversity have been created because of long-term farming activities such as meadows and permanent, dry grassland.

Indicators and indices that build on species populations may appear more transparent and easier to access and operate, but they will obviously inform less – or nothing – about habitat drivers.

As a consequence, indicators and indices that add habitat or ecosystem indicator elements (such as MSA) may provide much more direct knowledge about the state of the environment – but hence less transparent knowledge about actual, resulting biodiversity trends.

As a consequence, indicators and indices that add habitat or ecosystem indicator elements (such as MSA) may provide much more direct knowledge about the state of the environment – but hence less transparent knowledge about actual, resulting biodiversity trends.

Hence, different indicators are probably needed for monitoring impacts, raising awareness and analysis purposes. Indicators that are suitable for monitoring policies typically track a single area or parameter and can often – though not always – be simple in their presentation though not in their interpretation.

Complex, aggregated indicators established on the basis of an assemblage of individual indicators are typically primarily appropriate for awareness raising. The data requirement can be substantial and only rarely is data provided regularly on the appropriate geographical scale and with the necessary frequency. Therefore, in order to provide the necessary data basis, actual sampled data must be supplemented by estimations and modelling, all of which decrease transparency, replicability and perhaps even validity or precision.

For the purpose of testing biodiversity indicators and indices for their suitability in macro-economic modelling, we have tentatively identified indicators and indices that are currently being applied in the Nordic countries and which cover a range of spatial and temporal scales. Further, the indicators and indices cover a range of complexity, from simple single species indicators to complex and modelled indices of biodiversity.

In addition to the Norwegian Nature Index and SEBI already mentioned in Section 3.2 and presented in Appendix 2, three indices may be emphasised in this context, namely the Biodiversity Map of Denmark, Living Planet Index and Breeding Bird Index, Denmark. All of these may be applied when linking economic activities and biodiversity. Table 24 overleaf provides an overview of the five indices.

Table 24: Five selected biodiversity indicators and indices

Items	Norwegian Nature Index	SEBI	Biodiversity Map for Denmark	Living Planet Index	Breeding Bird Index, Denmark
Type of index: - Spatial coverage - Country or countries covered	Index, composite National Norway	Indicators National, EU EU	Index, composite National, local Denmark	Index Global Global	Indicators, combined to indices. National, regions within Denmark. Denmark
Temporal aspects: - How often is data collected? (E.g. yearly, bi-yearly, decadal, etc.) - How long a historic period does the index cover?	Some indicators yearly, some infrequent. Updated every 5 years. Thematic indices updated with shorter intervals.	Some indicators yearly, some infrequent.	Infrequent data collection. No temporal reference for the index.	Bi-yearly, but based on a range of indicators with different updating schedules.	Yearly, since 1976.
Robustness, reliability	Robustness and reliability cannot be readily assessed. Robustness highest in freshwater and marine systems and lowest in forest and open lowland.	Simple and robust indicators and aggregated indices. Also complex indicators especially for sustainable use.	Complex index, robustness and reliability cannot be readily assessed, but probably high.	Complex index, robustness and reliability cannot be readily assessed.	Simple and robust indicators and combined indices.
Knowledge and information gathering: - Which type of information (e.g. scientific and other types of knowledge) is incorporated in the index?	Index based on 301 indicators, of which some are monitored yearly/regularly, some are estimated and some are modelled.	Combined simple and aggregated indicators as well as complex indices, based on a range of indicators on a European scale. Primarily constructed on the basis of national indicators and indices.	Complex index based on a range of indicators on high nature value areas/habitats, species diversity indicators, occurrence of red-list species.	Complex index based on a range of indicators on a global, regional scale.	Data on population trends of breeding birds in Denmark, calculations of yearly trends. Single species indicators can be combined to species groups indices.
Scope of index: - Systems assessed - Habitats assessed - Species and species groups assessed - Ecosystems services assessed	Species, habitats, ecosystems.	Species groups, habitats, ecosystems, sustainability.	Species groups (red- list species) and habitats, indicating richness of biodiversity (gridnet).	Species groups, habitats, ecosystems.	Species and species groups.
Does the index/measure include: - Drivers of change in systems and services? - Impacts of change in services on human well-being? - Explicit consideration of the role of biodiversity in the systems covered by the index?	No No No	No No No	No No No	Yes Yes Yes	No No No
Data availability: - Is data used in the measure/index open access? - How frequently is the data updated? - Are there any restrictions to using or updating the data?	Data is partly open access and partly not open access (?). Infrequent updating (varies among selected indicators).	Data is partly open access and partly not open access. Infrequent updating (varies among selected indicators).	Data is partly open access and partly not open access. Infrequent updating (varies among selected indicators).	Not known.	Data is not open access. Database belongs to Birdlife DK. Indicators/indices are open access. Data is updated yearly.
Review: - Is the index peer-reviewed? - If yes, when and by whom?	Peer-reviewed process in NINA (responsible institution). Strong scientific credibility.	Peer-reviewed process when the indicator system was developed. Yearly or regular quality assurance of individual indicators at a national level (details unknown).	Peer-reviewed process in DCE and CMEC (responsible institutions). Strong scientific credibility.	Peer-reviewed by publishing institutions.	Data analysis/indicators undergo quality assurance prior to publication, carried out by staff in Birdlife DK.
Indicative assessment	Complex and aggregated index with a good indicator value, but a lack of transparency and combined single indicators leave the overall indicator strength somewhat depleted in terms of response abilities.	Strong indicator set for biodiversity trends and change. High transparency for some/most of the individual indicators.	Strong indicator for biodiversity distribution. Not developed for asserting change and trends, but for potential distribution and occurrence and for demonstrating a potential biodiversity baseline.	Highly complex and aggregated index with some indicator value, but a lack of transparency leaves the overall indicator strength almost insignificant.	Strong indicator set for biodiversity trends and change. High transparency.
Usefulness in relation to economic modelling	Partly useful	Useful	Not useful	Partly useful	Useful

Source: Pedersen, B. *et al.*, 2013; Biala, K. *et al.*, 2012; Ejrnæs, R. *et al.*, 2014; Collen, B. *et al.*, 2007; Fenger, M. *et al.*, 2016.

Example 2 – Open land

In this context, open land habitats cover natural, semi-natural and man-made habitats in the open land, primarily in the agricultural landscape, but also in other open landscape types where economic activities may leave direct and indirect impacts. Generally, the characteristics and quality of the habitats in the open land will predominantly be determined by agricultural activities including structural changes, crop use and intensification. Also, infrastructural developments such as road network developments, establishment of power lines, wind farms etc. have an effect on the ecological quality of open land habitats, directly or indirectly. In more pristine open landscapes, such as open upland landscapes in northern Scandinavia, agricultural activities do not play a significant role (though extensive grazing with reindeer may locally result in notable impacts on the habitats). Instead, infrastructure developments may appear much more visible and critical in landscape and habitat impacts.

Specifically, the open land habitats cover the following types:

- Meadow and permanent grassland.
- Upland areas.
- Heathland types.
- Dunes (covered with vegetation).
- Small-scale habitats in farmland areas.
- Arable land.

The ecological quality of these habitats is directly influenced and determined by a range of factors, including:

- Livestock grazing.
- Crop selection.
- Organic vs conventional farming.
- Farming intensification.
- Emissions and pollution.
- Field size and land allocation.
- Infrastructure development, including roads, rail, power lines and wind farms.
- Urbanization.

It appears from this list that open land habitats can be affected by changes and developments in a multitude of factors and that causal links between economic drivers and habitat quality are complex and potentially interacting.

Below, we give an individual overview of each of the above mentioned factors.

Livestock grazing

Livestock grazing on meadows and grassland areas are an important element in supporting biodiversity in open areas dominated by low-growing vegetation. A high number of plant species and species of birds and animals are related to meadows and permanent grasslands that are kept open and low-growing by grazing animals. In many Western European countries, the number of grazing livestock has been significantly reduced and concentrate on many fewer, but larger farms. In Denmark alone, the number of farms keeping cattle has decreased from 96,000 to 12,000 in the same period, with the average number of cattle in each farm increasing from 12 to 55. If grazing is discontinued or if the grazing pressure is reduced, the natural succession processes will lead to overgrowing of the meadow vegetation with taller grasses, herbs and shrub. The biodiversity of tall-growing vegetation is lower than that in the open, grazed areas.

Suitable biodiversity indicators include population level indices for species closely connected with low-growing, exposed vegetation. A large number of plant species, bird species and some insects are regularly monitored within their areas of distribution and used as indicators for the occurrence and quality of grazed meadows and grassland. Such species typically include a number of red-listed species as a consequence of meadows and permanent grasslands having become significantly reduced in area in Western Europe over the last 40–50 years. Thus, many species closely dependant on such habitats have become rare and threatened over the course of the same period.

Trends in single-species based indices will indicate the combined effects of those pressures that apply to meadows and grassland as habitats and will thus not specifically reveal whether the effects are caused by changes in total area or changes in ecological and environmental quality. In order to strengthen the indicator value of single-species based indices, they may be combined with statistics of total area. Still, fragmentation and edge effects will not be identified by such aggregated indicators as factors that can influence the overall habitat quality.

Crop selection

The suitability of arable land as a habitat for biodiversity depends heavily on crop selection. Arable land rarely provides a suitable habitat for many species, but crop selection may still be a significant differentiator for species found in farmland areas. A common farmland species like the skylark is widespread on arable fields, but requires a low and dense vegetation such as wheat or barley crops during the breeding season, whereas maize and soy beans do not provide adequate nest cover and grow too tall early in the breeding season. Species of grass grown for hay or seeds may provide a satisfying habitat for several species of birds, but as the grass is harvested rather early during the breeding season of birds, nests and nestlings may be lost during the harvest.

Crops from the cabbage family attract large numbers of butterflies from the Pieris family (especially large white and small white) and hence the occurrence of white butterflies may fluctuate a lot spatially and temporarily.

Suitable indicators are few, but include common species like the skylark and large and small white butterflies. Few other easily monitored species are directly connected with arable land. The population levels of the skylark is significantly affected by the available food resources which again are governed by the amount of pesticides applied. Thus, the population trends in the skylark do not necessarily indicate crop type, but rather other aspects of the agricultural scheme like the use of pesticides.

Indicators for crop type are likely better represented by agricultural statistics and statistics of seeds trade.

Organic and conventional farming

The biodiversity quality difference between organic and conventional farming relates primarily to the environmental and ecological effects of the use of pesticides and fertilizers in conventional farming. Other factors may apply to varying extent, but the predominant factor remains the application of non-natural substances to the fields. In general, structural differences are small and may not have major effects on the biodiversity.

Suitable indicators include typical farmland biodiversity elements, notably bird species like the skylark, barn swallow, partridge, insects like wild bees and bumblebees and a number of plant species. As discussed elsewhere none single bird species indicator will in itself yield a clear and unique indication of the farming type as they are affected by a few or a number of factors of which the effect of non-natural substances like pesticides is just one. Plant species may demonstrate a clearer one-stringed relation with their environment and as such turn out as providing stronger indication of the ecological quality of their environment. However, as plant dispersal may be very slow in particular in a highly fragmented farmland landscape, the suitability of plant species as indicators of habitat quality may be inferior to other biodiversity elements. This also means that invertebrates and other organisms closely connected with plants may turn out as inferior indicators as well. This applies to bees and butterflies, which are otherwise frequently used as biodiversity indicators.

Farming intensification

Farming intensification represents a gradual change or development in farming practises that have less significant ecological impacts on a short-term scale whereas on the longer term, the impacts on ecology and biodiversity can be momentous. Farming intensification can show up as gradual land allocations, enlargement of field sizes, removal of paths and small biotopes and an increase in the application of fertilizers and pesticides.

Farming intensification signifies a common, widespread and long-term process that can be exemplified by the fact that in Denmark the number of farms has decreased from 200,000 in 1920 to 42,000 in 2010 even if the overall area of arable land in Denmark has remained roughly constant. In parallel to this process, which has seen a very large number of small-scale natural habitats disappear in the farmland landscape, the diversity of the farming activities on the individual farms has decreased significantly as well, resulting in much more specialized farms. As an example, the number of farms raising pigs has decreased from 120,000 in 1970 to 4,600 in 2011 and the average number of pigs per farm has increased from 70 to 2800 in the same period. As mentioned above, the number of farms keeping cattle has decreased from 96,000 to 12,000 in the same period, with the average number of cattle at each farm increasing from 12 to 55. At the same time, there has been an increasing tendency to keep livestock inside all year around.

This intensification of the agricultural activities has obviously had a profound effect on farmland biodiversity even if the year-to-year changes have remained much more subtle on the bigger geographical scale. Large-scale changes to farmland habitats and biodiversity have been documented over time by means of various measures and indicators. Monitoring of yearly changes is problematic due to the gradual and/or small-scale changes on the individual farms, and because of the multi-layered effects such changes may have on the farmland biodiversity.

Hence, due to the multitude of types of changes involved in a gradual intensification process, the effects on biodiversity are difficult to uncover using typical biodiversity indicators at least on a short term basis. Effects are obvious on longer terms although challenging to link directly to individual factors and elements. It may not be useful to apply simple indicators and indices to gradual changes occurring over a short-term scale as it appears unlikely that simple indicators will be able to bring attention to the relevant causal relations between change in farming practise and change in biodiversity.

Emissions and pollution

Emissions and pollution from industries, agriculture and transport constitute a significant if not diffuse impact on the ecological quality in the open land. Emissions of nitrogen-based substances from industries and farms have resulted in a widespread eutrophication of otherwise nutrient-poor habitat types which leads to enrichment of the habitats. The consequences have been that the growth conditions for the plant species that are closely adapted to a nutrient-poor environment have changed in favour of taller-growing plant species that are better at exploiting an environment richer in nutrients.

Drainage water and surface water run-off from fertilized fields contribute to a widespread enrichment of wetlands and water courses, which subsequently affect the biodiversity connected with these habitats. In both cases, the loss of species from a habitat which is being affected by eutrophication due to various sources may happen rather quickly and can as such be documented with standard biodiversity indicators, even if the response time may be protracted. If the environmental conditions are improved and thus re-establishing suitable growth conditions for plant species that are adapted to a nutrient-poor environment, it may take much longer for these plant species to reappear at the specific site. There may be several reasons for this, but one major reason is the fact that the dispersal of many plant species can be very slow.

Thus, the absence of specific plant species that may hold indicator value for the particular habitat or site may not indicate a poor growth environment, but rather that the plant species has not been able to re-enter its former site. With the absence of plant species typical for such habitats and sites, these sites will also be void of insects and other invertebrates which are dependent on the plants. It can be concluded that the inertia in the response processes following changes in a given habitat and at a given site may distort the picture of species of plants and invertebrates expected to be present at the site or in the habitat.

Despite the above constraints, suitable if not optimal biodiversity indicators for emissions and pollutions may include a number of specific plant species typically found at nutrient-poor sites and at sites that may be polluted due to emissions or by water.

Field size and land allocation

Farmland structure parameters such as field size and land allocation belong to the group of pressures that have an effect of the physical extent and configuration of the natural habitats in the open landscape. With an increase in field size, the actual amount of non-arable, small-scale habitats such as field edges, hedges and wild corners of the fields will decrease. Together with other small-scale farmland habitats, field edges, hedges and field corners that are left without regular cultivation make up a network of small, natural habitats that have profound effect for the occurrence and distribution of biodiversity in the farmland landscape. A rather large number of species of birds, invertebrates and plants as well as a few species of mammals are closely connected with such habitat structures, in most cases originally found in steppe or dry grassland habitats. Fields under regular cultivation hold just a fraction of the biodiversity generally found in farmland landscapes.

With an overall trend towards larger field sizes resulting from the use of larger machinery and a need to develop more efficient farming practises, the farmland biodiversity has decreased over the last 50 or more years in significant parts of Western Europe. With an increased fragmentation and reduction in size of natural and semi-natural habitats in the farmland landscape, it has become increasingly difficult for farmland biodiversity to persist in the gradually smaller and fewer suitable habitats and to spread between habitats of sufficient quality to maintain viable populations.

On the individual farms, changes may be sudden and significant from year to year, but on a regional scale, changes in field size and land allocation follow a much more gradual process and may be next to impossible to detect on a year-to-year basis.

Suitable biodiversity indicators include a long array of species typically found in the small natural habitats at field edges, in hedges and the wild field corners. Species groups including birds, plants and butterflies are relatively easy to sample and should be included in indicators or indices for farmland structure parameters, but it may be questioned how indicators based on these species groups track structural changes in the landscape. Effects of decreasing area with suitable habitat may be tracked easily as species disappear and population levels decrease, but because of highly varying dispersal rates, the actual recovery of biodiversity following e.g. a re-establishment of suitable habitat positive structural changes may not be tracked as straightforward and may show significant delay. Dispersal in a fragmented landscape may hold a significant degree of inertia that effectively postpone the recovery of a habitat-specific biodiversity at newly created or restored sites.

More precise indicators would be statistics on area, distribution and fragmentation of natural and semi-natural habitats in the open landscape, but such parameters are only rarely sampled on a regular basis.

Infrastructure development

Structural changes in the open landscape following new infrastructural developments may include fragmentation and reduction in the total area of natural habitats, disturbances and pollution from traffic, and infrastructure elements like high-voltage power lines and wind turbines pose a specific risk for birds and to some extent bats, which are known to collide fatally with power lines and wind turbines.

The effects on biodiversity of fragmentation and loss of natural habitat due to infrastructure development cannot clearly be distinguished from changes in field size, land allocation and other structural changes caused by changed farming practise (cf. section above). Disturbances due to increased traffic or caused by rotating turbine blades in wind farms can render areas near roads, rails and wind turbines less usable to species even if there are no physical changes to the habitat.

Fatal collisions with power lines and wind turbines do occur regularly, but only very rarely will the mortality be measurable on a population level. Hence, the effects of the risk of fatal collisions can basically be neglected on a larger scale.

Urbanization

The effects of urbanization can be equalled with other structural changes in the open landscape that result in loss of natural and semi-natural habitat as urbanization primarily entails land reclamation. On a regional scale, the effects of urbanization on biodiversity may be insignificant and impossible to measure on a short time scale. Also, urbanization processes mainly take place near bigger cities as the human population growth currently concentrates in the largest cities. In the Nordic countries, growth is realised in the capital cities and a limited number of bigger cities only.

One of the side effects of the urbanization processes is the negative growth in the human population in rural areas. A large share of small, rural villages are encountering a net loss of inhabitants and an increasing number of single houses and farms are being abandoned. As a result, some rural areas are becoming less busy and less disturbed and some small-scale natural habitats are beginning to emerge where gardening and farming usually took place. In all, urbanization may also result in slightly improved open landscape biodiversity although it may be measured only in the longer term and not on a fine geographical scale.

Summary

Sampling changes and trends in open land habitats may appear rather easy to accomplish, but due to significant covariance between drivers of impacts and biodiversity indicators, the causal relations may require further analysis in order to be understood correctly.

Many biodiversity indicators may respond swiftly to additional pressures on the environment. Loss of habitat will obviously result in a loss of species at the given site and hence species-based indicators will demonstrate habitat loss immediately. On the other hand, the impacts of increased fragmentation and intensification may express themselves with some delay and different indicators may display different temporal responses to such impacts. The resilience in a given habitat or ecosystem cannot be predicted without detailed studies, but it is normally expected that a simple or depleted habitat or ecosystem displays less resilience than a more pristine or complex habitat or ecosystem.

In contrast to the response demonstrated by many biodiversity indicators when a habitat disappears or deteriorates, the responses to habitat improvements may show a very different process. In a fragmented landscape where the natural habitats may be rather small and mutually isolated, the dispersal of biodiversity elements between suitable habitats may be delayed, for some elements almost infinitely. Interdependency between species (such as butterflies and flowering plant species) and a lack of sufficient mobility in many species are among key reasons why biodiversity responses to positive habitat changes may be delayed to various levels.

Because of the built-in system inertia, at least in fragmented landscapes, many studies that aim to demonstrate pressure-impact causality fail to distinguish between state and change in their conclusions. An indicator may be useful to demonstrate a certain state or even a clear causality, but it may be inferior when displaying change, at least a positive change.

The examination above of open land pressures further demonstrates that the impact of habitat loss versus loss of habitat quality may show very differently in open land biodiversity. While biodiversity elements may be exposed to both physical changes and quality changes, the responses may vary significantly.

Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen K
www.norden.org

Biodiversity and economic modelling

Is it posible linking biodiversity to macro economic models, thereby increasing our understanding of how economic activities affect biodiversity – et vice versa? It is the key question that this report aims at answering on the basis of existing statistics, indicators and models in the Scandinavian countries.

The economic sectors identified as relevant for biodiversity are: agriculture; forestry; fishery; tourism; transport; and energy (especially, hydropower). The main pressure types analysed include: habitat loss and degradation; climate change; excessive nutrient load and other forms of pollution; over-exploitation and unsustainable use; and invasive alien species.

A set of recommendations for further work are made focusing on impacts of economic activities on biodiversity.

9 789289 355957