Sveriges lantbruksuniversitet
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Department of Aquatic Resources

Assessment of freshwater ecosystem services – with a case study in river Arbogaån

Bedömning av ekosystemtjänster och effekter av klimatförändringar – med en fallstudie i Arbogaån

Emelie Möllersten

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Preface

This master thesis constitutes the end of my studies at the master program Soil and Water Management at the Swedish University of Agricultural Sciences. The 2 years spent in the program has deepened my understanding of the complex interactions found in nature. It has also furthered my passion for water management and environmental protection.

Several persons have contributed to the completion of this thesis. First, I would like to thank my supervisor Sara Bergek for her valuable input and support throughout the entire master thesis period. Furthermore, I would like to thank everyone involved in the Life IP Rich Waters project for appreciated insights and help along the way. Finally, I want to say thank you to my family and friends for supporting me along the way.

Den 28 juni 2018
Emelie Möllersten

Abstract

Humans are dependent on a large variety of services that come from the ecosystems around us. Some of these ecosystem services are provided by rivers and lakes and include for example drinking water, water for irrigation and industry, flood control, climate regulation, and recreation. Ecosystem services are increasingly threatened by human activities, including hydropower, forestry, agriculture and fisheries. Another threat is climate change which will lead to for example intensified rainfall, more frequent flooding, and higher temperatures. This study aims to contribute to the understanding of what indicators and methods that can be used for assessing freshwater ecosystem services, and to evaluate and describe how flooding might affect the condition of them. This was done by conducting both a literature review of previous research and a case study of the river Arbogaån. During the literature review 344 indicators were found that could be used for assessment of freshwater ecosystem services status. Different methods for assessing ecosystem services were also examined, for example expert judgements, case studies, qualitative vs quantitative methods, and citizen science. The review also gave an understanding of how climate change could affect freshwater ecosystem services, and the results showed that primarily drinking water and biological diversity are threatened in Europe. In the case study of river Arbogaån, a new method was developed for assessing flooding impacts on ecosystems services. The method consisted of a GIS overlay analysis and an assessment of flooding impacts based on previous research. The method can be used as a starting point for future research, when assessing the impacts of climate change on ecosystem services. The method was tested on six ecosystem services that are assumed to be sensitive to climate change (flooding) in river Arbogaån. The assessment indicated that biological diversity, drinking water, and habitat will be affected negatively by flooding in river Arbogaån. No change in condition was found for flood control or water for irrigation and industry, and not enough data was available to estimate the effects on regulation of eutrophication. Without knowledge on how climate change influence ecosystem services and how to assess it, it will be impossible to know when, where and what actions that are necessary to protect them. The findings presented in this master thesis provide a framework for future studies wanting to explore similar issues.

Keywords: ecosystem services, freshwater, climate change, flooding, assessment

Sammanfattning

Människor är beroende av en rad olika tjänster som kommer från ekosystemen som omger oss. Vissa av dessa ekosystemtjänster kommer från sjöar och vattendrag och inkluderar exempelvis dricksvatten, vatten för bevattning och industri, översvämningskontroll, klimatreglering, och rekreation. Ekosystemtjänster är allt mer hotade av mänskliga aktiviteter såsom vattenkraft, skogsbruk, jordbruk och fiske. Ett annat hot är klimatförändringar vilka kommer leda till mer intensiva skyfall, mer frekventa översvämningar, och högre temperaturer. Detta projekt syftar till att öka förståelsen för vilka indikatorer och metoder som kan användas för att utvärdera ekosystemtjänsters status, samt hur deras status påverkas av översvämningar. Detta gjordes dels genom en litteraturstudie av tidigare forskning samt genom en fallstudie av Arbogaån. Under litteraturstudien hittades 344 indikatorer som skulle kunna användas för att utvärdera ekosystemtjänsters status. Diverse metoder för utvärdering av ekosystemtjänster hittades också, till exempel expertbedömningar, fallstudier, kvalitativa vs kvantitativa metoder, och medborgarforskning. Studien gav också en förståelse för hur klimatförändringar kan komma att påverka ekosystemtjänster i sötvatten, och resultaten visade att främst dricksvatten och biologisk mångfald är hotade i Europa. Under fallstudien av Arbogaån utvecklades en ny metod för att bedöma översvämningars effekt på ekosystemtjänster. Metoden bestod av en GIS analys samt en bedömning av översvämningars påverkan baserat på föregående forskning. Metoden kan användas som en startpunkt för framtida studier som vill utvärdera klimatförändringars effekt på ekosystemtjänster. Metoden testades på sex ekosystemtjänster som antas vara känsliga mot klimatförändringar (översvämningar) i Arbogaån. Utvärderingen indikerade att biologisk mångfald, dricksvatten, och livsmiljö kommer påverkas negativt av översvämningar i Arbogaån. Ingen förändring av status hittades för skydd mot översvämningar eller vatten för bevattning industri, och otillräckliga data gjorde att tjänsten reglering av översvämning inte kunde bedömas. Utan kunskaper om hur klimatförändringar påverkar ekosystemtjänster så är det omöjligt att veta när, var och vilka åtgärder som är nödvändiga för att skydda dem. Resultaten som presenteras i detta masters projekt kan användas som ett ramverk för framtida studier som vill utforska liknande frågeställningar.

Nyckelord: ekosystemtjänster, sötvatten, klimatförändring, översvämning, bedömning

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Abbreviations

ASFA	Aquatic Science and Fisheries Abstracts
CICES	Common International Classification of Ecosystem Services
EEA	European Environment Agency
ESS	Ecosystem Services
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographical Information System
IPCC	Intergovernmental Panel on Climate Change
MAES	Mapping and Assessment of Ecosystems and their Services
MEA	Millennium Ecosystem Assessment
MSB	Swedish Civil Contingencies Agency
NLS	Swedish National Land Survey
SLU	Swedish University of Agricultural Science
SMHI	Swedish Meteorological and Hydrological Institute
SWAM	Swedish Agency for Marine and Water Management
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
WFD	Water Framework Directive

1 Introduction

Ecosystem services (ESS) are the direct or indirect benefits that humans gain from the ecosystems surrounding us, and have been defined by the Millennium Ecosystem Assessment (MEA) as *"...the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth"* (MEA, 2005). The MEA was initiated in the year 2000 by the then United Nations (UN) Secretary General Kofi Annan. The assessment was carried out by hundreds of scientists worldwide with the purpose of evaluating the consequences to human well-being from the degradation of ecosystems. The assessment found that ecosystems worldwide have been degrading at an increasingly higher speed over the past 50 years compared to any previous timespan in human history.

In 2011 the European Union (EU) adopted the EU Biodiversity Strategy to 2020. The strategy aims to stop the losses of biodiversity and the degradation of European ecosystems and their related ESS (European Commission, 2011). This strategy highlighted for the first time in an EU context the importance and value of ESS, and member states are with the help of the Commission requested to map and assess the status and value of services in their territories by 2020 (Maes *et al.*, 2016).

As a response to the EU Biodiversity Strategy the Swedish government adopted in 2014 a strategy on strengthening biodiversity and securing ecosystem services (Swedish Government, 2015). The environmental work in Sweden is guided by 16 environmental quality objectives. (Naturvårdsverket, 2017). According to the latest yearly follow-up in 2018 the objectives flourishing lakes and streams, thriving wetlands, zero eutrophication, and a rich diversity of plant and animal life, among others, will not be reached if no further action is taken (Naturvårdsverket, 2018). To enhance the chances of reaching the environmental quality objectives the government has established 28 milestone goals. One of these goals is that by 2018 the values of ESS should be commonly known and integrated within political decisions, economic considerations, and other relevant parts of Swedish society (Miljömål.se, 2017).

Indicators are an important tool for assessing ESS and for decision-making and management of ecosystems. Within the EU the Mapping and Assessment of Ecosystems and their Services working group (MAES) develops methods and ways for identifying and mapping ESS at EU and national level (EU, 2014). Indicators are needed to be able to quantitatively assess the characteristics and trends of the services, making it easier for policy-makers to understand the need for management (Layke *et al.*, 2012).

1.1 Freshwater ecosystem services

Rivers, lakes and wetlands are among the most important types of ecosystems considering the services they provide (MEA, 2005). Services from freshwater ecosystems include drinking water, water for irrigation and industry, flood control, climate regulation, and recreation. But, freshwater ecosystems are also among the most degraded on the planet, and the speed of degradation is faster than that of other ecosystems (MEA, 2005). This degradation is largely due to a fast-growing human population which require increasingly more provisioning services from freshwater ecosystems (Dodds *et al.*, 2013). Humans have also heavily altered freshwater ecosystems to work for their needs like irrigation, industry, and electricity generation. The construction of dams, drainage of wetlands, straightening of rivers and so forth has damaged many of the naturally occurring ecosystem services (MEA, 2005). Some ecosystem services have the ability to renew themselves (e.g. water supply) while others (e.g. biodiversity and genetic resources) might be lost forever (Dodds *et al.*, 2013). To protect and secure the future use of freshwater ESS it is important that they are brought to attention within water management both nationally and internationally. To be able to account for ESS in management decisions more knowledge is needed about how to classify them, how to assess their status, what indicators to use, and what pressures affect their delivery (Bergek *et al.*, 2017).

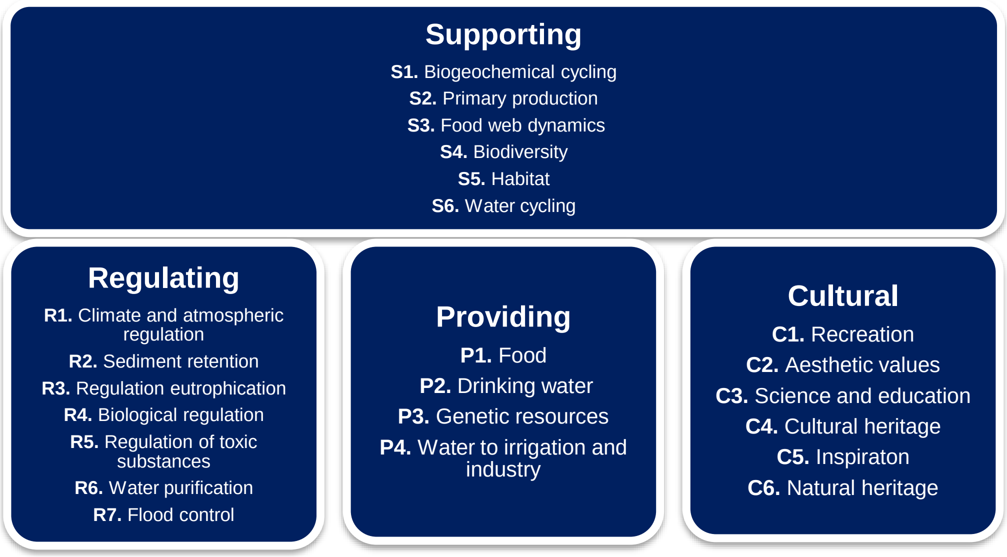

Figure 1: Classification of freshwater ecosystem services in Bergek et al (2017).

There are a couple of different frameworks for classifying ESS, but most of them are based on the system developed during the MEA. This classification subdivides services into four different groups: supporting, regulating, providing, and cultural (MEA, 2005) (Figure 1).

Supporting services provide the underlying and most fundamental functions of the ecosystem. Primary production, biodiversity and water cycling are examples of supporting services. These services are essential for other ESS to exist and function. Regulating services reduces the degree of various environmental problems by providing e.g. flood regulation, water purification, and sediment retention. Providing services deliver goods like food and drinking water for human consumption. Last the cultural services include recreation, inspiration and culture which give humans enjoyment and emotional well-being. Two other classification systems for ESS include The Economics of Ecosystems and Biodiversity (TEEB) and the Common International Classification of Ecosystem Services (CICES). The TEEB framework was adapted after the MEA, with the purpose of bringing more attention to the economic values of ESS. The CICES framework was developed by the European Environment Agency (EEA) with the purpose of providing standards of how ESS are described, this to enable especially economic accounting and comparisons between regions (La Notte *et al.*, 2017).

Bergek *et al* (2017) presented the first Swedish national compilation of ecosystem services and their current conditions in lakes and watercourses. This report was the first attempt made in Sweden to classify and assess national freshwater ESS and was conducted by researchers at the Department of Aquatic Resources at the Swedish University of Agricultural Science (SLU) together with the Swedish

Agency for Marine and Water Management (SWAM). The study identified 23 ESS provided by Swedish lakes and watercourses (Figure 1) and they were given preliminary status ratings as either poor, poor-moderate, moderate-good, or good. These status ratings were made in each of the five water districts within Sweden by using indicators currently collected within the EU Water Framework Directive (WFD), the Environmental Quality Objectives, the Species and Habitat Directive, and the Bathing Directive. The initial ratings based on indicators were then subject to expert judgements within each district for the final status assessment. The results of this study show that most ESS from Swedish freshwaters have moderate status, much due to eutrophication and physical alterations of waterways (Bergek *et al.,* 2017). The indicators used for the assessment were concluded to only partly be able to assess the status of ESS, and the expert judgements played a large role in the final assessment. Bergek *et al* (2017) highlights the difficulties of national status assessments of specific lakes and rivers and that better methodologies and indicators need to be developed.

There are many different pressures that could threaten the delivery of ESS from Swedish lakes and rivers. For sustainable water management it is important to identify these factors and what effects they will have on ESS (Grizzetti *et al.,* 2016). According to Bergek *et al,* (2017) there are 19 different pressures on ESS from lakes and rivers in Sweden. Among these are climate change, hydropower, forestry, agriculture and environmental toxins.

Many studies aiming to assess the status of ESS involve the assumption that an ecosystem with good ecological quality and health indicate that it delivers more services. This is in most cases considered to be a valid assumption, but more research is needed to investigate the relationship between ecosystem health, biodiversity and ESS (Maes *et al.*, 2016). A greater understanding of how to assess ESS condition and their potential pressures is needed for sustainable management and to secure the accessibility of them in the future.

2 Climate change

In this master thesis the effects of climate change on freshwater ESS was studied. During the last three decades the temperature on Earth's surface has continuously increased (IPCC, 2014). Climate change will also lead to changes in precipitation and runoff, with more intense rainfall events and more frequent flooding (SMHI, 2014). These changes have impacts on all ecosystems, including freshwater ecosystems and the services they provide (MEA, 2005).

In Sweden changes in precipitation is likely to vary depending on the location in the country, but most models point towards a greater increase in northern Sweden and during the winter months (SMHI, 2014). The predictions for the southernmost parts of Sweden are more uncertain, where some models point towards an increase and some towards a decrease in total precipitation. From the SMHI climate models it is also clear that the number of days with torrential rain will increase over the whole country, and the intensity of rain events are predicted to increase with 10-15% by the end of this century. Torrential rains will increase the occurrence of extreme flooding events, which pose a threat to many ecosystems, cities, roads, electrical infrastructure, and wastewater treatment plants. How extreme a flood event becomes depend on the soil saturation, evaporation, and the occurrence of dams to store excess water. The risk of flooding is predicted to vary throughout Sweden, with increased risks in primarily southern Sweden (SMHI, 2014).

2.1 Climate change effects on freshwater ecosystem services

Global climate change is and will continue to modify the global water cycle by changing the spatial distribution, intensity, duration, and form of precipitation on Earth (Chang & Bonnette, 2016). These changes will vary by location and the impacts felt by humans will largely depend on the capacity of a regions social and biophysical system to adapt (Chang & Bonnette, 2016). Climate change is predicted to worsen the degradation of freshwater ecosystems and their biodiversity across the planet, which will lead to a reduction of the ESS that they provide (MEA, 2005). A study by Döll & Zhang (2010) evaluated the effects of climate change on freshwater ecosystems at a global scale. They concluded that extreme events, temperature and river flow alterations caused by climate change will have a larger negative effect on ESS than anthropogenic alterations have had in the past. River flow and temperature alterations have impacts on fish and water-bird populations as it effects their feeding, breeding, and spawning grounds. Invasive species could also become more common when the water conditions change. Wetlands are likewise vulnerable to changes in river flow, and wetlands in areas threatened by droughts or floods could disappear completely. Wetlands are important providers of ESS like flood control, water purification, and regulation of eutrophication (Döll & Zhang, 2010). Chang & Bonnette (2016) looked at climate change impacts on water-related ESS in California. They concluded that climate change in the region will have effects on both regulating, providing, and cultural ESS. Degradation of the provisioning service water supply is currently considered to be the greatest threat to human kind. An increasing number of floods will have negative impacts on e.g. water purification and sediment retention. Drinking water treatment costs will followingly go up as the turbidity of the water will be higher (Chang & Bonnette, 2016). Even though climate change is predicted to have significant impacts on freshwater ESS, there is considerably little research made and large knowledge gaps still exist, both concerning the effects and how to predict and measure them (Dunford *et al.*, 2015).

3 Project presentation

3.1 LIFE IP Rich Waters

This master thesis is carried out as a part of an action within the Swedish integrated LIFE-project LIFE IP Rich Waters. This action is led by the Department of Aquatic Resources at SLU together with the county administrative boards of Stockholm, Västmanland, and Västra Götaland. The aims of the action are to (i) identify a method for assessing freshwater ESS and how they are affected by climate change, (ii) identify suitable areas in the landscape for overflow during flooding, and (iii) evaluate the risks of contamination during flooding events (Havs- och vattenmyndigheten, 2017).

LIFE IP is an environmental program funded by the EU and Rich Waters is the first of its kind in Sweden. The project aims to improve the freshwater environment in Sweden, by supporting the implementation of the water framework directive. The main focus is the River Basin Management plan of the Northern Baltic River Basin district, which is situated in mid-Sweden.

This master thesis contributes to the project aiming to explore methods for assessing freshwater ESS and the effects on them by climate change. The master thesis is done in collaboration with the Department of Aquatic Resources at SLU.

3.2 Purpose

The purpose of this master thesis is to contribute to the understanding of methods and indicators for assessing freshwater ESS. The purpose is also to evaluate and describe how climate change might affect freshwater ESS. Both overall by making a literature study and in a study site, the river Arbogaån.

3.2.1 Research questions

The master thesis focuses on the following research questions;

1. What indicators and methods can be used to assess freshwater ecosystem services status?

2. What freshwater ecosystem services are affected by climate change?

3. How will ecosystem services in study site Arbogaån be affected by flooding?

3.3 Study site description

The catchment of Arbogaån is 3808 km^2 and spans over three counties, Örebro, Dalarna and Västmanland. The river system starts in small streams in southern Dalarna and makes its way through multiple lakes before it reaches lake Mälaren east of the town Arbogaån. The area is home to about 60’000 residents and consists of mainly forested and cultivated land. The river Arbogaån (Figure 2) and the areas surrounding it are sensitive to high flow events, and there have been multiple occurrences of flooding. The area around river Arbogaån is characterized by very flat terrain and the water holding capacity of the catchment is relatively low. The river also runs through multiple towns which are often situated in low lying areas and therefore especially sensitive to flooding (Arbogaåns Vattenförbund, 2008).

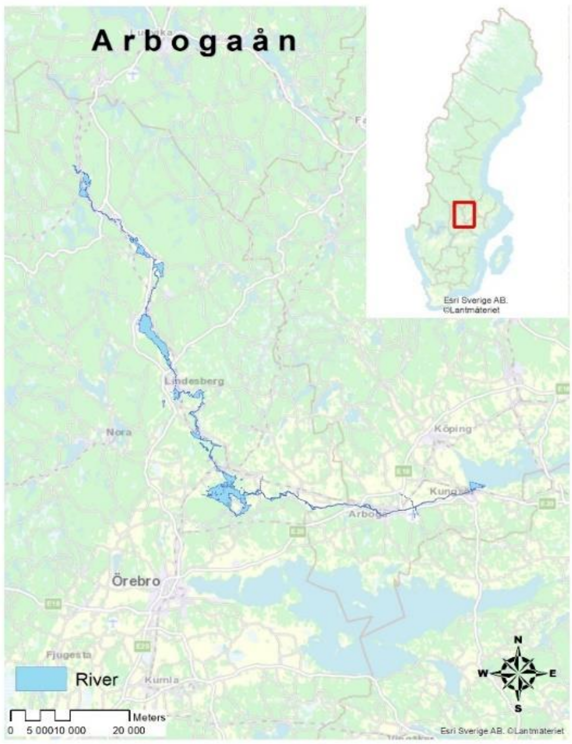

Figure 2: The river Arbogaån’s location in Sweden (GIS data from Lantmäteriet).

3.3.1 Flood risk in river Arbogaån

Extreme flooding events are predicted to become more frequent in a future climate (SMHI, 2014). The river Arbogaån have previously experienced extreme flooding in 1966, 1977, and 2000 (Arbogaåns Vattenförbund, 2008). To be able to estimate the impacts of flooding an analysis of flood risk zones along river Arbogaån has been made by the Swedish Civil Contingencies Agency (MSB) in 2013. The analysis resulted in maps showing the ranges of the 50-year flood, 100-year flood and the 'calculated highest flood'. The 50-year and 100-year flood have a 2% and 1% risk respectively of happening in any given year. The 'calculated highest flood' shows the highest possible water level for a river based on worst-case scenarios considering rainfall, snowmelt, soil saturation, etcetera. The scenario also considers the effects of climate change (MSB, 2013). According to their analysis the 'calculated highest flood' would cause road bridges in the city Arboga to be under water, the powerplant west of Arboga to be flooded, and a lot of land around the river Arbogaån to be under water (MSB, 2013).

3.3.2 Freshwater ecosystem services in river Arbogaån

Within the LIFE IP Rich Waters project, the importance of different ESS in river Arbogaån and how sensitive they are to climate change (primarily flooding) have been discussed by a group of local and regional water experts. The discussions led to a matrix showing the estimated demand and sensitivity to climate change for each of the 23 ESS included (Table 1). Six services were classified as being in high demand and under high threat from climate change, they were; biological diversity, drinking water, habitat, water for irrigation and industry, flood control, and regulation of eutrophication.

Biological diversity is a term describing the variety of species, genetic information, and functional groups in an area. It is highly important for the functioning of ecosystems, and biodiversity is a prerequisite for an ecosystem to deliver the services that humans depend upon. Habitat describes an area where one or multiple species live. A well-functioning habitat is essential for the reproduction and development of species that live there (Bergek *et al.*, 2017). Drinking water is by far the world's most important resource for human consumption. In Sweden we have a good supply of freshwater resources, contrary to many other countries on the planet. But, freshwater resources in Sweden are threatened by for example sea level rise and the occurrence of harmful substances (Bergek *et al.*, 2017). Water is also used in many industrial processes and for irrigation. Worldwide irrigation accounts for about 70% of the total amount of freshwater used by humans, industry about 20%, and municipal use about 10% (FAO, 2016). Mass and paper industry, steel and metals production, chemicals and pharmaceutical industry are examples of industry that use a lot of water in the world today. What specific industry is located around Arbogaån have not been considered in this project. Flood control is the ecosystems ability to reduce flooding risks, for example through lowering the water velocity in wetlands and by natural meandering. Regulation of eutrophication is an ecosystems ability to reduce the negative impacts of excess nutrients, by converting nitrogen to nitrogen gas, or by sedimentation (Cioffi & Gallerano, 2001).

Table 1: Demand for and sensitivity to climate change for freshwater ecosystem services in river Arbogaån as classified by an expert group in the LIFE IP Rich Waters project in 2017.

	Demand for ESS				**Sensitivity to climate change**			
Ecosystem Service:	None	Low	Medium	High	None	Low	Medium	High
Biogeochemical cycling				x			x	
Primary production				x			x	
Food web dynamics				x			x	
Biodiversity				x				x
Habitat				x				x
Climate and atmospheric regulation		x					x	
Sediment retention			x					x
Regulation eutrophication				x				x
Biological regulation		x						x
Regulation of toxic substances			x					x
Water purification			x					x
Flood control				x				x
Food			x				x	
Drinking water				x				x
Genetic resources	x					x		
Water to irrigation and industry				x				x
Recreational				x		x		
Aesthetic values				x		x		
Science and education			x				x	
Cultural heritage				x			x	
Inspiration				x			x	
Natural heritage				x				

4 Materials and methods

The method for this research project was divided between an overarching systematic literature review and a case study of the river Arbogaån (Figure 3).

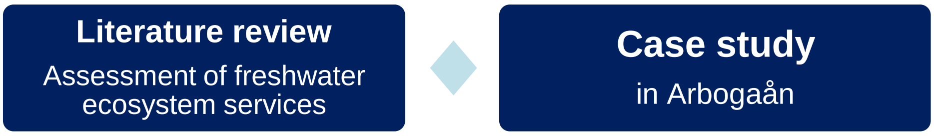

Figure 3: Visualization of methods for research project.

4.1 Literature review

The literature review focused on current knowledge within the academic research literature and related to two research questions: (i) What indicators and methods can be used to assess freshwater ecosystem services status? and (ii) What freshwater ecosystem services are affected by climate change?

The review was done systematically. A systematic literature review is according to Fink (2005) *"a systematic, explicit, and reproductible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners"*. The literature review for this study was conducted according to a method proposed by Fink (2005) and is divided into seven steps (Figure 4).

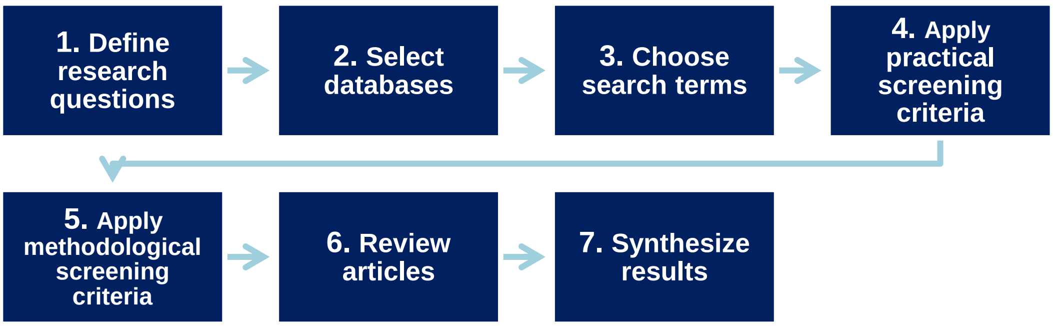

Figure 4: Visualization of method for systematic literature review.

Two online international journal databases were searched for literature: Web of Science and Aquatic Science and Fisheries Abstracts (ASFA). These databases were selected based on suggestions from the librarians at Ultuna Campus library. The database searches were carried out between January and February 2018 and two different sets of articles were collected, with the purpose of answering the two different research questions.

4.1.1 What indicators and methods can be used to assess freshwater ecosystem services status?

First some broad search terms were used to be able to identify the best keywords for finding relevant articles (Pickering & Byrne, 2014). They were 'assessment', 'water' and 'ecosystem services'. After a couple of trial searches the keywords that were used for collecting the first set of articles could be defined (Figure 5).

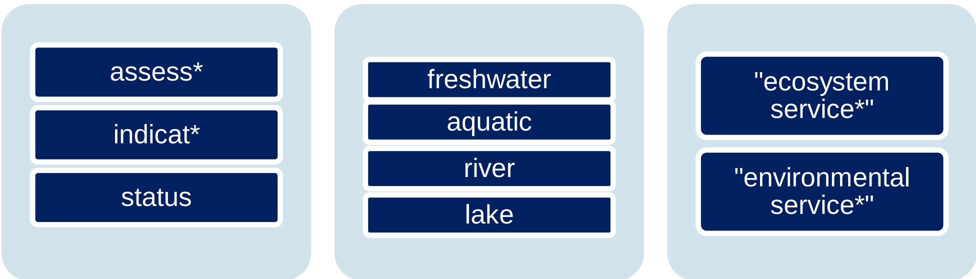

Figure 5*: Keywords used for the first literature search. Between each word in the columns the Boolean operator OR was used. Between the columns the Boolean operator AND was used.*

Between each word in the columns the Boolean operator OR was used and between columns the Boolean operator AND was used (Figure 5). Keywords were added one at a time to be able to see the resulting changes in number of search results, the relevance of the results, and to get an idea of what types of research have or have not been done.

4.1.2 What freshwater ecosystem services are affected by climate change?

For the second set of articles the broad search terms used were "climate change", "impact", "water" and "ecosystem service". After a couple of trial searches the keywords used for collecting the second set of articles were defined (Figure 6).

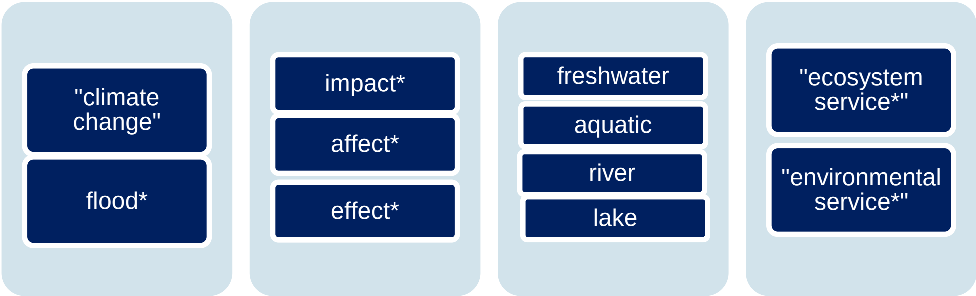

Figure 6: *Keywords used for the second literature search. Between each word in the columns the Boolean operator OR was used. Between the columns the Boolean operator AND was used.*

Between each word in the columns the Boolean operator OR was used and between columns the Boolean operator AND was used (Figure 6). Keywords were added one at a time to be able to see the resulting changes in number of search results, the relevance of the results, and to get an idea of what types of research have or have not been done.

4.1.3 Selection criteria

The two sets of articles were both selected based on the practical screening criteria, which were: (i) can answer the research questions (based on read titles and abstracts), (ii) only peer-reviewed articles, (iii) Published between 2008 and 2018, (iv) studies from Europe, (v) text in English or Swedish, and (vi) available electronically in full text. Limiting the search to the past 10 years was done because most relevant articles were found after the publication of the MEA in 2005, and by 2008 the articles found had more consistent use of terminology related to ESS. Limiting the search to European articles was done because the same directives and legislations related to water management apply to all EU member countries. The references of the articles that passed the practical screening criteria were also examined.

The two final sets of articles to be reviewed and further analysed were selected based on the methodological screening criteria. The methodological screening criteria for the articles selected with the purpose of answering the first research question were: (i) can answer the research question (based on read full texts), and (ii) include a discussion on methods or indicators for assessing freshwater ESS. The methodological screening criteria for the articles selected according to the second research question were: (i) can answer the research question (based on read full texts), and (ii) analyse climate change effects on freshwater ESS or water quality.

The two final sets of articles were further analysed in detail based on the corresponding research question. A synthetization of publication year, study area, purpose, methods, results, and conclusions was done for each set of articles.

4.2 Case study of river Arbogaån

A new methodology had to be developed to answer the third research question: (iii) How will ecosystem services in study site Arbogaån be affected by flooding? The method was developed based on knowledge gained from the literature review and on what data was available for the study site at the start of the project. The developed method consisted of a Geographical Information System (GIS) overlay analysis of flood risk zones, and an assessment of how freshwater ESS will be affected by flooding. The effects of climate change on ESS in river Arbogaån were estimated by looking at the flooding risks in the area, hence changes in for example temperature and precipitation were not considered.

The method was tested on the six freshwater ESS in river Arbogaån that were assessed as begin in high demand but also under high threat from climate change by the expert group within LIFE IP Rich Waters (Table 1). These were biodiversity, habitat, regulation of eutrophication, flood control, drinking water, and water to irrigation and industry. To evaluate the effects of flooding on these ESS it was decided to focus on four substances: nitrogen, phosphorus, sediments, and toxins. These four substances were selected because they are often referred to in literature as under risk of leaching during flooding events (Arheimer *et al.*, 1996; Bloomfield *et al.*, 2006; Ulén & Johansson, 2009; Oeurng *et al.*, 2011; Øygarden *et al.*, 2014; Baborowski & Einax, 2016; Ockenden *et al.*, 2016; Peraza-Castro *et al.*, 2016; Rankinen *et al.*, 2016). The developed method generally consisted of four steps (Figure 7). Each step is explained in detail below.

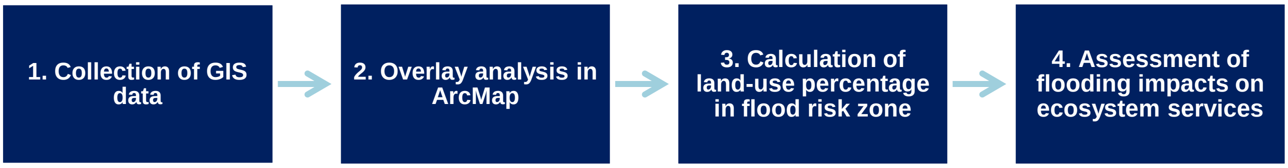

Figure 7:Visualization of method used for the case study.

4.2.1 Collection of GIS data

The first step towards evaluating the effects of flooding in river Arbogaån was to investigate what land-use would be impacted by the ‘calculated highest flood’. Spatial data on the land-use categories cultivated land, forest, open land/other, wetland, industry, and buildings were obtained from Lantmäteriet - the National Swedish Land Survey (NLS). Spatial data on wetlands was obtained from Länsstyrelserna - the County Administrative Boards. Spatial data on flood risk zones along river Arbogaån, the ‘calculated highest flood’, was collected from Myndigheten för Samhällsskydd och Beredskap - the Swedish Civil Contingencies Agency (MSB). Table 2 provides a description of the different land-use layers used.

Table 2: Description of land-use layers used for the overlay analysis in ArcMap. (Source: (Lantmäteriet, 2018; Naturvårdsverket, 2009)

Land-use	Description of land-use layer
Cultivated land	Land that has been plowed for cultivation of cereals, ley, oil plants, vegetables, kitchen plants and energy forest.
Forest	Land with coniferous or deciduous trees. Includes clear cut forest areas.
Open land/other	Land with vegetation under 1.5 meters. Includes overgrown arable land, pasture, grassland, gardens, beaches, heath acide, etc.
Wetland	Land where water during a large part of the year is close to or right above the land surface. Includes water areas covered with vegetation.
Industry	Land with primarily industrial activities.
Buildings	Land covered by buildings.

4.2.2 Overlay analysis in ArcMap

The method for finding what land-use types around river Arbogaån that are threatened by flooding consisted of an overlay analysis of spatial data in ArcMap 10.6. With the spatial data on land-use and flood risk zones introduced in step 1 used as input data, the software was used to produce output data in the form of overlaying maps. All overlay analysis was done in the geographic coordinate system GCS_SWEREF99, from which all the data was obtained.

The geoprocessing tool “Intersect” was used to select the land-use areas that would be affected by the flood. The tool computes two layers intersection (land-use and calculated highest flood) and yields a new layer showing where the two layers overlap. In that way the land-use areas at risk of being flooded were obtained as the output features. Lastly the tool “Select by Attribute” was used to get cultivated land, forest, open land/other, wetland, industry, and buildings affected by the flood into individual layers. The “Select by Attribute” tool makes it possible select polygons and create new layers based on an attribute query.

4.2.3 Calculation of what land-use are in the flood risk zone

For each of the new layers showing land-use affected by flooding a new field ‘Area’ was added to their attribute tables. On the ‘Area’ field the tool ‘Calculate Geometry’ was used to get the area of each land-use category in the flood risk zone. After that the area of all the land-use types in the risk zone were added together. Then a percentage for each land-use category within the flood risk zone was obtained by dividing their individual areas with the total flooded area multiplied by 100.

4.2.4 Assessment of flooding impacts on ecosystem services

The six freshwater ESS considered in this project had all been estimated as being in high demand in the study area and with an expected high sensitivity to climate change (primarily flooding) (Table 1). To assess the impacts of flooding on these ESS, cause-effect relationships were constructed between flooding of the land-use categories and leaching of nitrogen, phosphorus, sediments and toxins, and for each substance impacts on ESS. Based on the cause-effect relationships found in literature and on personal judgement an assessment of each land-use category’s impact on ESS could be made. It was decided to look specifically at the substances nitrogen, phosphorus, sediments and toxins because they are often referred to as under risk of leaching during flooding (Arheimer *et al.*, 1996; Bloomfield *et al.*, 2006; Ulén & Johansson, 2009; Oeurng *et al.*, 2011; Øygarden *et al.*, 2014; Baborowski & Einax, 2016; Ockenden *et al.*, 2016; Peraza-Castro *et al.*, 2016; Rankinen *et al.*, 2016).

The literature searches were made in Web of Science, ASFA, and Google Scholar. The first search was done by combining keywords describing the land-use categories, flooding, and keywords for nitrogen, phosphorus, sediment, and toxins. The second search was done by combining keywords describing the ESS with keywords for nitrogen, phosphorus, sediment, and toxins.

To assess the impacts on ESS, a conceptual flowchart was developed and followed. Each land-use category was analysed separately for its respective impacts on ESS. The developed flowchart consisted of three steps (Figure 8) which are explained in detail below. After each land-use category's impact on ESS had been evaluated, an overall assessment was made on how flooding affect ESS status in the river Arbogaån. This was done by combining the impacts on ESS from every land-use and seeing what impact was most dominant.

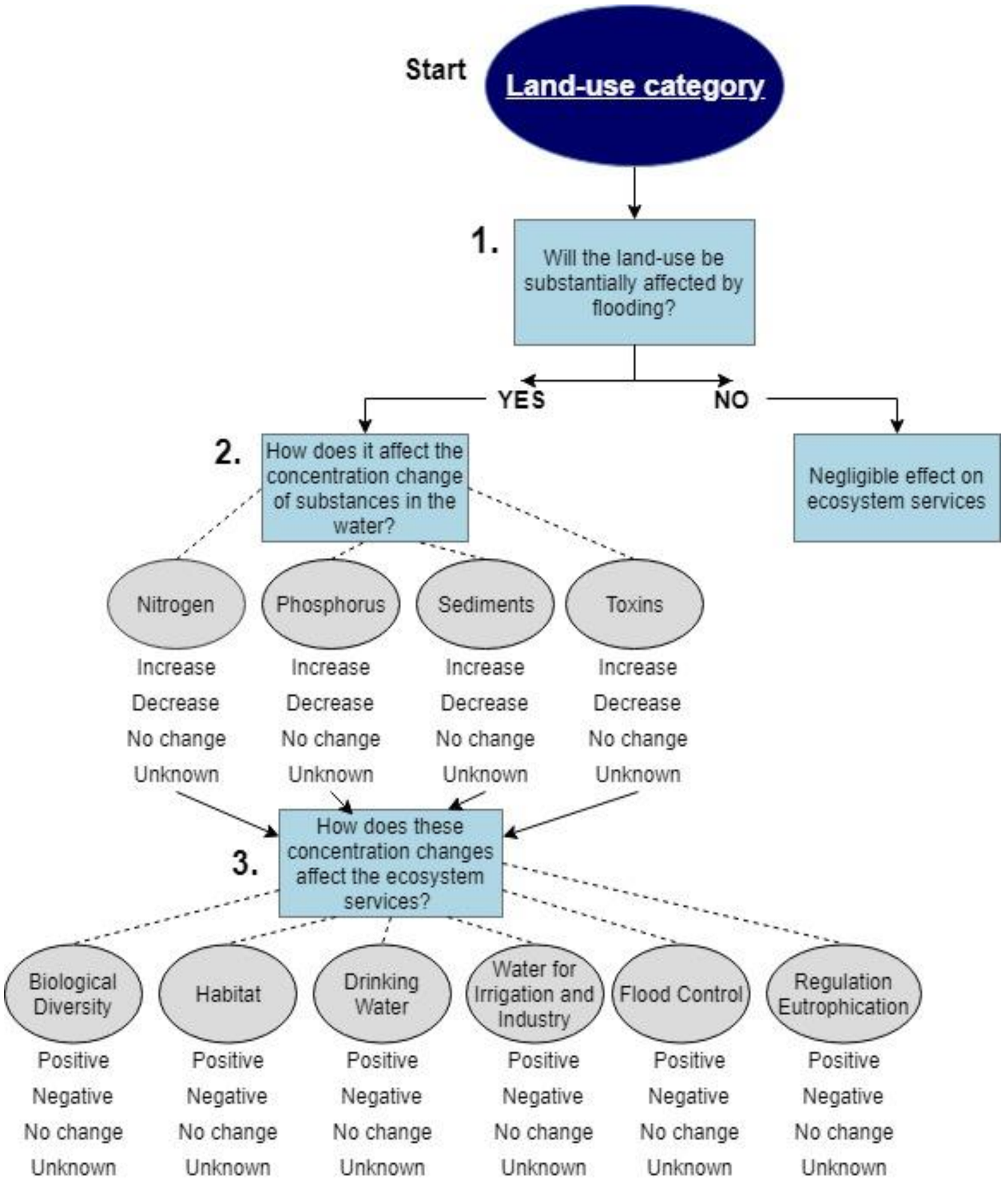

Figure 8: Conceptual flowchart showing method for assessment of substances concentration changes during flooding, and impacts on ecosystem services status.

Start: Each land-use category in the flood risk zone was analysed separately for its impacts on ESS status in river Arbogaån.

Step 1: If the land-use category covered a large part (>1%) of the flood risk zone, it was considered to influence leaching or uptake of one or more of the substances during flooding. The answer to the first question was in that case yes. If the land-use category only covered a minor part (≤1%) of the flood risk zone, it was considered to have negligible effects on ESS status and the answer was no.

Step 2: In the second step an assessment was made for the land-use category's effect on leaching or uptake of nitrogen, phosphorus, sediment, and toxins during flooding. This assessment was based on relationships found in research, and the leaching was classified as either increased, decreased, no change or unknown.

Step 3: In the last step the status change of ESS due to flooding of the land-use category was assessed. Based on the concentration changes found in step 2 and the cause-effect relationships found between substances and each ESS, the effects on ESS were assessed as either positive, negative, no change or unknown.

5 Results

5.1 Literature review

The database searches together with the practical screening criteria resulted in 32 articles found that could potentially answer the first research question. For the second research question the practical screening criteria resulted in 23 articles.

5.1.1 What indicators and methods can be used to assess freshwater ecosystem services status?

For answering the first research question 11 articles were found that passed the methodological screening criteria. The articles had different spatial scales, everything from EU-wide, national, regional, local, to studies of specific watersheds, rivers, and lakes. The two databases gave different search results depending on what search terms that were used (Figure 9 and 10). In Web of Science more articles were found that matched the search terms compared to in ASFA. In general, when the word 'aquatic' was added to the search query increasingly more articles were found. There was no change in number of results when the word 'environmental service' was added to the query. However, when the words 'lake' and 'river' were added more articles were found.

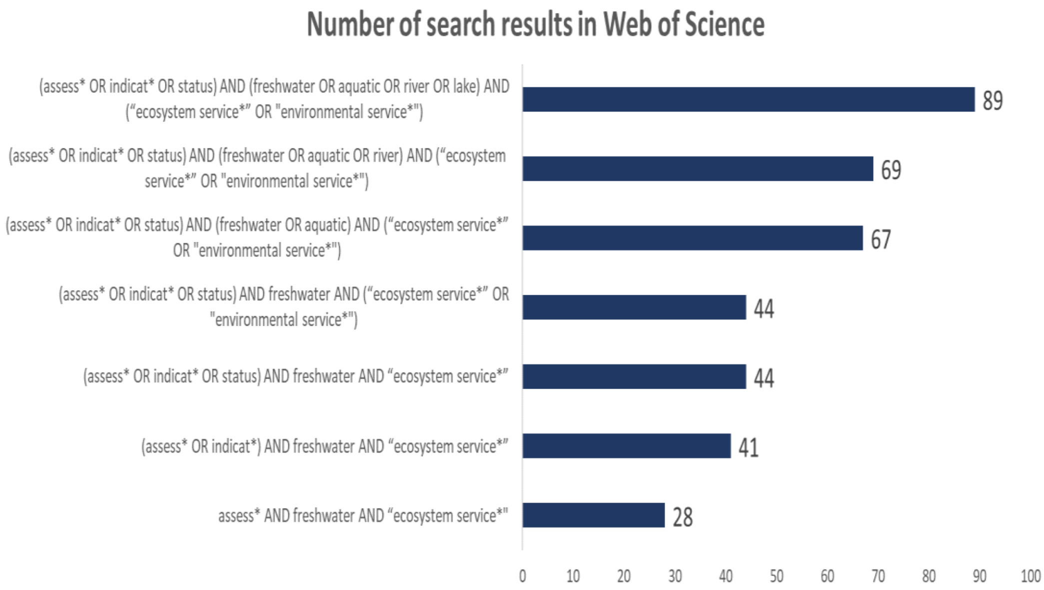

Figure 10: Number of search results in Web of Science by using different search queries. The search queries were combinations of the words assess, indicat*, status, freshwater, aquatic, river, lake, 'ecosystem service' and 'environmental service'. They were combined by using the Boolean operators AND or OR.*

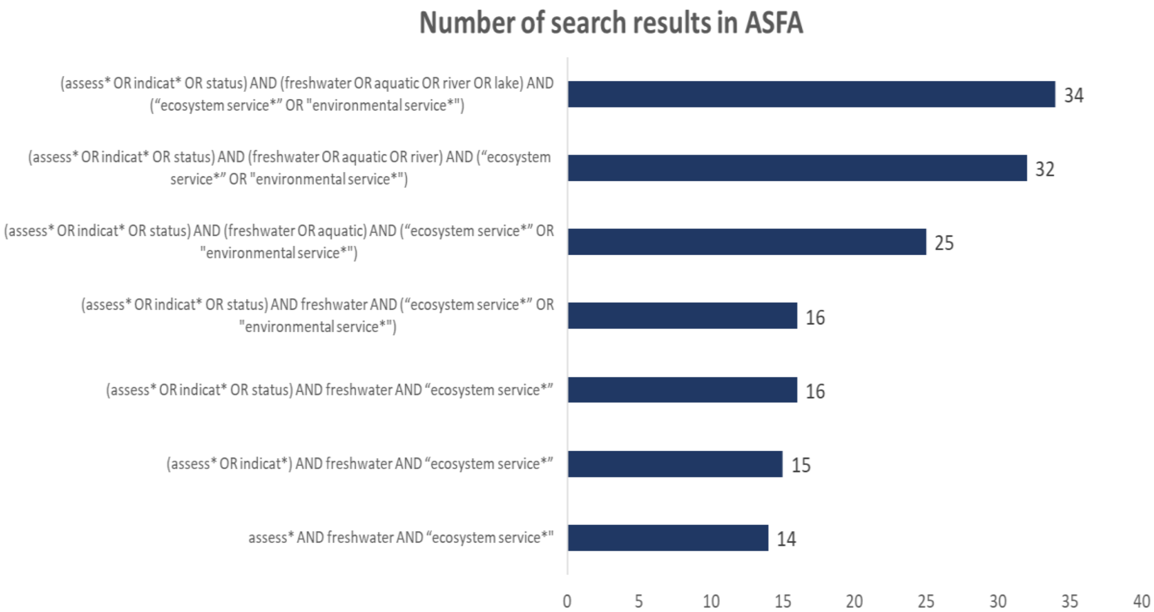

Figure 9: Number of search results in ASFA by using different search queries. The search queries were combinations of the words assess, indicat*, status, freshwater, aquatic, river, lake, 'ecosystem service' and 'environmental service'. They were combined by using the Boolean operators AND or OR.*

The 11 articles analyzed had used a variety of approaches for selecting ESS and evaluating indicators and methods that could be used for assessing them. The methods used by the studies were predominantly literature reviews, expert judgements, and case studies. Among the studies, five had based their classifications of ESS on already existing frameworks (Albert *et al.*, 2016; Maes *et al.*, 2016; Mononen *et al.*, 2010*;* Kettunen *et al.*, 2012; Vidal-Abarca *et al.*, 2013). The frameworks used by these studies were alterations of either the MA, CICES, or the TEEB framework. The remaining six studies based their selections of ESS on either literature reviews or expert judgements (Tolonen *et al.*, 2014; Grizzetti *et al.*, 2016; Vidal-Abarca *et al.*, 2016; Harrison *et al.*, 2010; Busch *et al.*, 2012; Schröter *et al.*, 2017). Four of the peer-reviewed articles had a focus solely on freshwater related ESS, the other seven studies had a broader focus on both terrestrial and aquatic ESS. Most of the studies based their identification of ESS indicators on previous literature, the indicator's ability to communicate information about the services, data availability, continuity of data, and relevant temporal and spatial scale of the data. Some of the studies also used expert groups and case studies for selecting and evaluating indicators. Out of the 11 peer-reviewed articles, seven of them provided lists of proposed indicators for assessment of freshwater ESS. These indicators have been synthesized and referenced (Appendix 1, Table 5). In general, fewer possible indicators were found for supporting and cultural services, while regulating and provisioning services had more. Many of the indicators could be categorized as measuring aspects of either ecological status (according to the WFD), hydrology, meteorology, pollution, biodiversity, water use, erosion, or activities related to water (Appendix 1, Table 5).

Three of the studies (Tolonen *et al.*, 2014; Maes *et al.*, 2016; Vidal-Abarca *et al.*, 2016) evaluated the possibility of using data that is already reported at EU and national level for assessing the status of freshwater ESS. Especially, data reported under the WFD for evaluating ecological status was considered. All three studies concluded that there is possibility of using these existing data for assessing ESS and that it would be both time and resource saving to be able to use these datasets for more than one purpose. But, all three studies also concluded that the knowledge of relationships between WFD indices, ecosystem functions and the status of ESS is limited. They proposed to focus research on finding linkages between specific freshwater ESS and ecological status indicators.

Vidal-Abarca Gutiérrez and Suárez Alonso (2013) used a mix of indicators and expert judgements for estimating the effects of pressures on freshwater ESS. They looked at data series of 139 indicators of freshwater ESS and interpreted the direction and slope of each indicator. They then classified each ESS indicator into seven classes as either improving, some improvement, no net change, improvement and/or deterioration, some deterioration, deterioration, or unknown. In this way the status change for ESS could be estimated. Another study evaluated trends in ESS services status by using information from literature and scientific experts (Harrison *et al.*, 2010). The experts interpreted information from literature and various reported proxies of ESS status like changes in habitat area, water abstraction, urbanization, agricultural expansion, pollution, and eutrophication to assess the ESS status change.

One study tested in what situations quantitative versus qualitative methods are best suited for assessing ESS (Busch *et al.*, 2012). Their findings show that quantitative methods are generally good for in-depth analysis of specific and local ESS, with good data availability. Quantitative methods are also good for putting monetary value on services. The quantitative methods discussed included computer-based modelling, GIS, and physical modelling where the information can be measured and communicated with numbers. Qualitative methods were generally better for comprehensive analysis of ESS and for identifying changes to ecosystem health and status. By using for example expert judgments and interviews, qualitative methods are less dependent on data availability. Qualitative methods include estimations based on causal linkages, reviews of literature, questionnaires, etc.

Schröter *et al* (2017) looked at the potential of using citizen science as a tool for measuring ESS. Citizen science is when citizens engage themselves voluntarily and typically without payment in research activities. They concluded that citizen science can be a good tool for assessing cultural ESS, especially with the help of today's sensory and mobile technologies available for the civic society. By involving citizens, it might also help raise the awareness of ESS and their values in society (Schröter *et al.,* 2017).

Many of the articles discussed that it is often hard to find indicators that directly measure the ESS provided, and that for some the use of proxy indicators is necessary (Kettunen & Vihervaara, 2012; Vidal-Abarca Gutiérrez & Suárez Alonso, 2013; Maes *et al.*, 2016). Proxy indicators are indirect measures that reflect the ESS status in absence of a direct measure. These proxy indicators could for example be measures of land cover, number of private wells, or number of flood-events per year.

Many studies highlighted large gaps in data for being able to develop statistically and scientifically acceptable indicators for freshwater ESS (Maes *et al.,* 2015; Mononen *et al.,* 2011; Vidal-Abarca *et al.,* 2016; Kettunen *et al.,* 2012). They also talked about the need for more research on the linkages between biodiversity, ecological status and the delivery of ESS. The relationship between good ecological status and ESS delivery need more attention, especially since this assumption is commonly made in the literature (Maes *et al.*, 2016).

5.1.2 What freshwater ecosystem services are affected by climate change?

For answering the second research question seven articles were found that passed the methodological screening criteria. The articles had different spatial scales, both EU-wide and national. The two databases gave different search results depending on what search terms that were used (Figure 11 and 12). In Web of Science more articles were found that matched the search terms compared to in ASFA. Many more articles were found in the databases when the words ‘aquatic’ and ‘river’ were added to the search query. It did not make a big difference considering the number of search results if the words ‘effect’ and ‘affect’ were added as alternatives to ‘impact’. It also did not make a big difference if ‘environmental service’ was added.

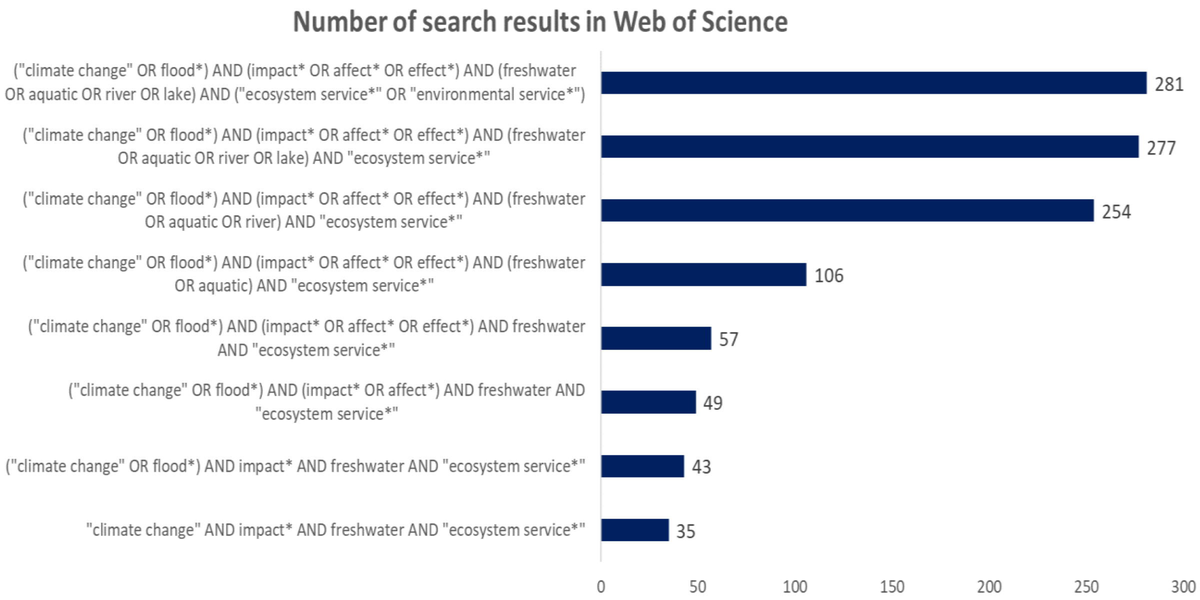

Figure 11: Number of search results in Web of Science using different search queries. The search queries were combinations of the words 'climate change', flood, impact, affect*, effect*, freshwater, aquatic, river, lake, 'ecosystem service' and 'environmental service'. They were combined by using the Boolean operators AND or OR.*

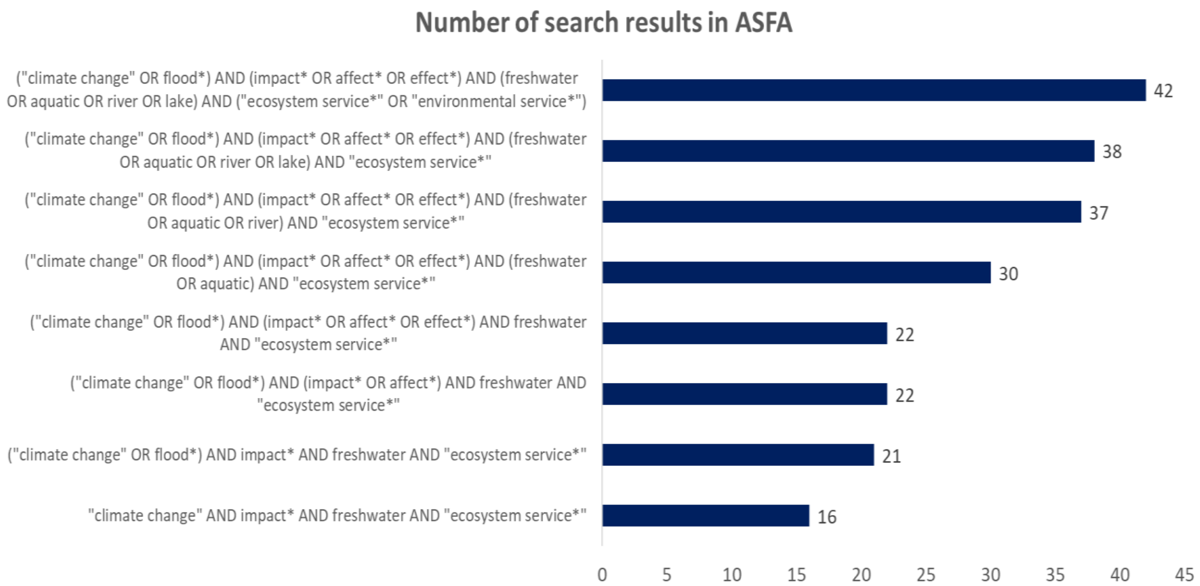

Figure 12: Number of search results in ASFA using different search queries. The search queries were combinations of the words 'climate change', flood, impact, affect*, effect*, freshwater, aquatic, river, lake, 'ecosystem service' and 'environmental service'. They were combined by using the Boolean operators AND or OR.*

To find research articles that specifically addressed climate change effects on freshwater ESS was a challenge. The seven articles that in some way identified and highlighted this issue were analyzed. Three of the studies used computer based models for assessing the effects of climate change on ESS and freshwater water quality. (Jeppesen *et al.*, 2009; Bangash *et al.*, 2013; Dunford *et al.*, 2015). Jeppesen et al, 2009 found that in northern latitudes climate change is likely to lead to increased nutrient runoff resulting in eutrophication and declining ecological status. Bangash *et al* (2013) looked at climate change effects on water provisioning and sediment retention and their results showed that both services are threatened by climate change. Dunford *et al* (2015) concluded that climate change will have significant effects on ESS delivery in Europe, especially water provisioning and biological diversity.

Another study used spatial data of climate change and ESS to calculate the vulnerability of European freshwater ESS using ArcGIS (Tzilivakis *et al.*, 2015). They considered drinking water, water purification, biological diversity, flood control, and sediment retention to be the ESS which are most sensitive to climate change in Europe. Moor *et al* (2015) correlated wetland species functional traits to ecosystem processes and ultimately the provisioning of ESS from wetlands. They found that in northern latitudes the ESS flood control and nutrient retention could increase due to taller and faster growing wetland plant species.

All studies agree that climate change will have impacts on freshwater ecosystems and/or the services they provide (Jeppesen *et al.*, 2009; Bangash *et al.*, 2013; Dunford *et al.*, 2015; Whitehead *et al.*, 2009; Moor *et al.*, 2015; Tzilivakis *et al.*, 2015; Terrado *et al.*, 2014). Climate change will have impacts on surface water quality in Europe and the possibility of water bodies to reach good ecological quality under the WFD (Whitehead *et al.*, 2009). Higher temperatures will have effects on aquatic organism's habitats, evaporation, oxygen saturation, and the speed of chemical and biological processes. Intensified rainfall and flooding will cause erosion, and consequently higher loads of suspended solids, nutrients, contaminants and toxic substances to freshwater systems (Whitehead *et al.*, 2009). As a response to these changes drinking water supply will be threatened and biodiversity is likely to decrease across Europe. Other threatened ESS include water purification, flood control and sediment retention. (Jeppesen *et al.*, 2009; Whitehead *et al.*, 2009; Dunford *et al.*, 2015). Some of the impacts on freshwater ESS largely depend on location, where southern and northern Europe will experience different effects of climate change. In southern Europe carbon sequestration, and food and timber production is predicted to decrease, whereas these services including flood control and nutrient retention are predicted to increase in northern Europe (Dunford *et al.*, 2015).

5.2 Case study of the river Arbogaån

The results from the GIS overlay analysis showed that the lower part of the river, consisting of primarily cultivated land, will be affected by flooding the most. Out of the six ESS analyzed, a negative status change as a response to flooding was projected for half of them, and no change or unknown status change for the remaining ones (Table 4). The results are presented in closer detail below.

5.2.1 Overlay analysis in ArcMap

The overlay analysis resulted in maps showing what area and land-use categories that would be affected by the "calculated highest flood" (Figure 13-19). Most of the flooded land is located around the lower parts of the river.

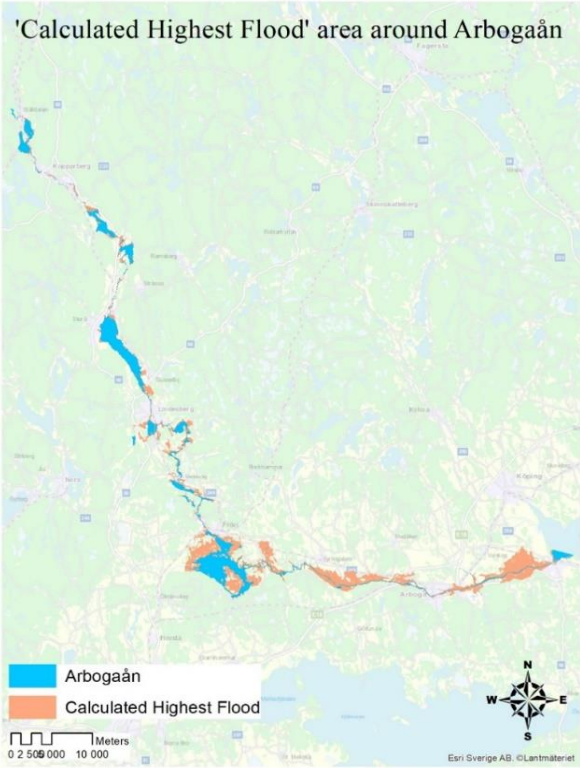

Figure 14: Map showing area affected by the 'calculated highest flood' along study site Arbogaån (GIS data from Lantmäteriet and MSB).

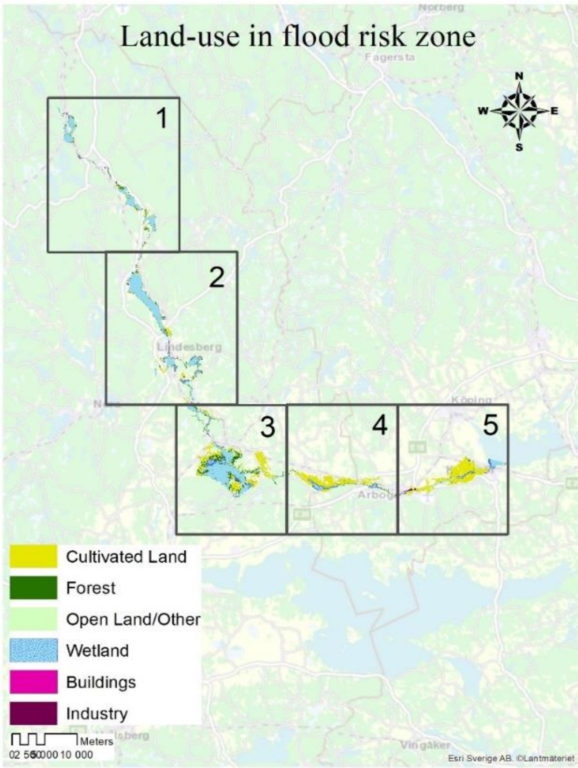

Figure 13: Map showing land-use affected by the 'calculated highest flood' along study site Arbogaån (GIS data from Lantmäteriet, MSB and Länsstyrelserna).

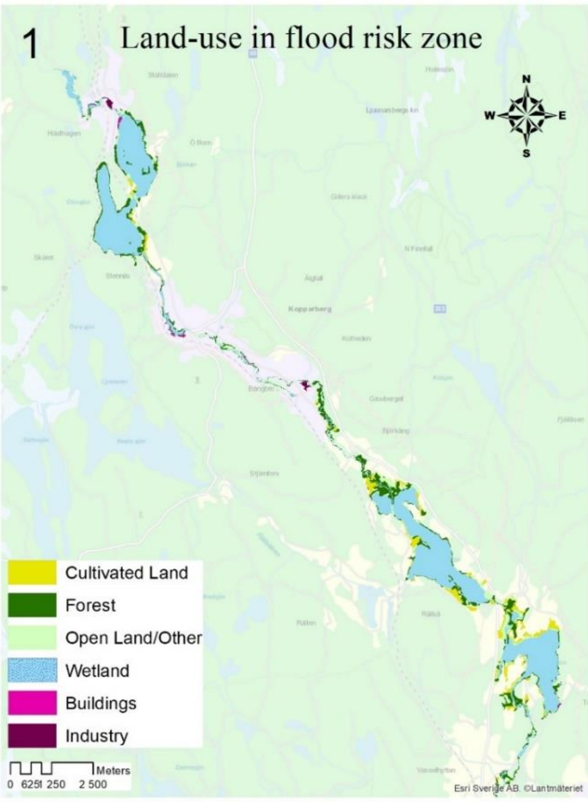

Figure 15: Map showing land-use affected by the 'calculated highest flood' along study site Arbogaån (GIS data from Lantmäteriet, MSB and Länsstyrelserna).

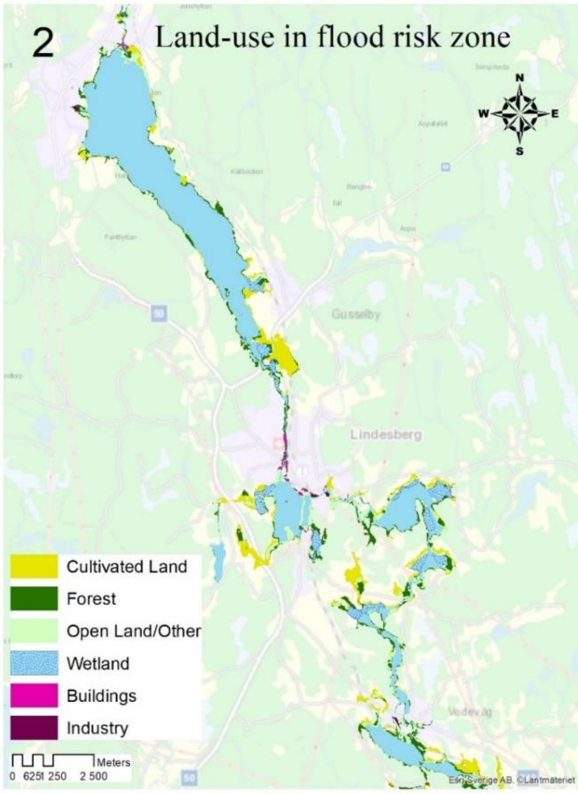

Figure 16: Map showing land-use affected by the 'calculated highest flood' along study site Arbogaån (GIS data from Lantmäteriet, MSB and Länsstyrelserna).

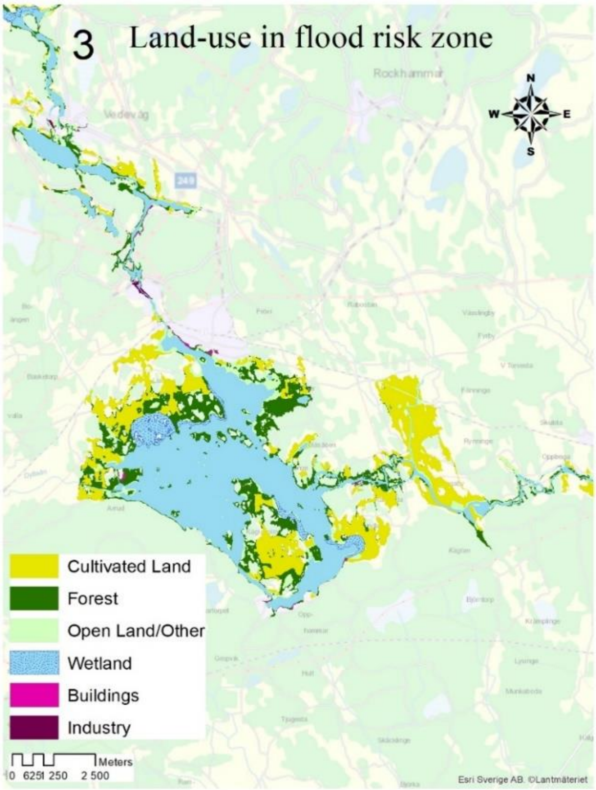

Figure 18: Map showing land-use affected by the 'calculated highest flood' along study site Arbogaån (GIS data from Lantmäteriet, MSB and Länsstyrelserna).

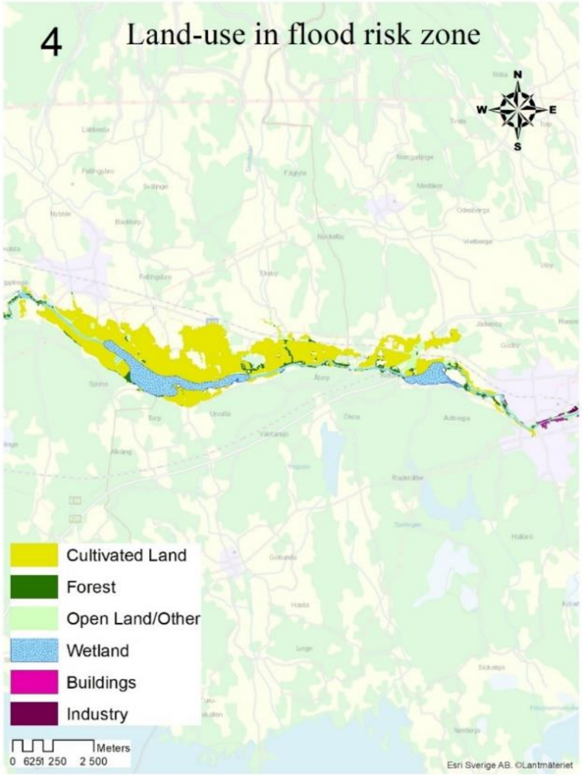

Figure 17: Map showing land-use affected by the 'calculated highest flood' along study site Arbogaån (GIS data from Lantmäteriet, MSB and Länsstyrelserna).

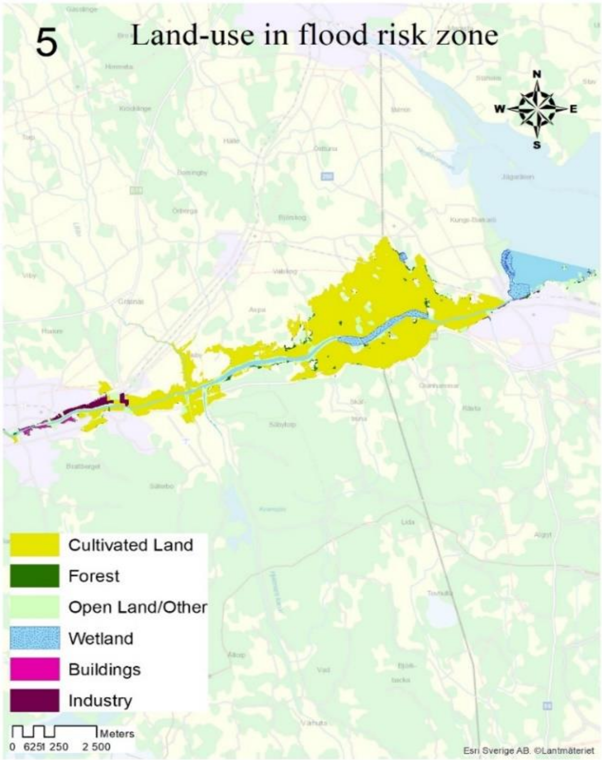

Figure 19: Map showing land-use affected by the 'calculated highest flood' along study site Arbogaån (GIS data from Lantmäteriet, MSB and Länsstyrelserna).

5.2.2 Land-use percentage in flood risk zone

The land around river Arbogaån that would be flooded by the "calculated highest flood" consisted primarily of cultivated land, which covered 58% of the flood risk zone. Forests covered 20%, open land/other covered 14%, wetlands covered 7%, buildings covered 1%, and industry covered 1% of the flood risk zone (Figure 20).

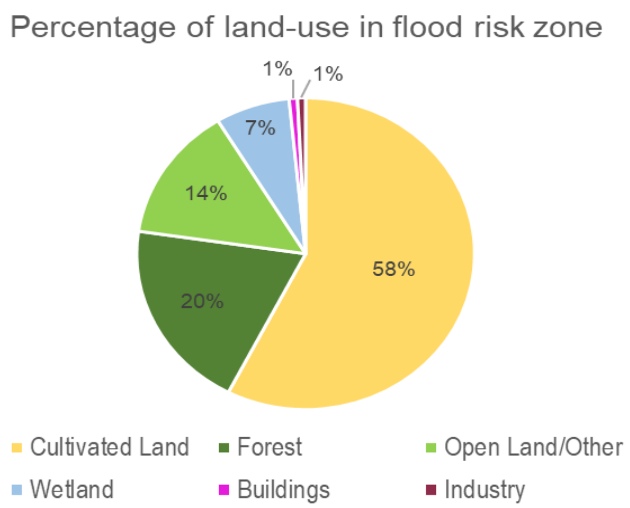

Figure 20: Pie diagram showing total percentage of land-use in the flood risk zone around river Arbogaån.

5.2.3 Substances effect on ecosystem services

In previously published studies, evidence was found on the cause-effect relationships between nitrogen, phosphorus, sediment, and toxins and impacts on freshwater ESS (Table 3). The evidence of cause-effect relationships show that nitrogen, phosphorus, sediments and toxins have negative effects on the ESS biological diversity, habitat and drinking water. For the ESS water for irrigation and industry and flood control the substances have no effect. Not enough evidence was found in previously published literature to form cause-effect relationships between the substances and regulation of eutrophication.

Table 3: Table showing cause-effect relationships between nitrogen, phosphorus, sediments, and toxins and impacts on the freshwater ecosystem services biological diversity, habitat, drinking water, water for irrigation and industry, flood control, and regulation of eutrophication.

	Nitrogen	Phosphorus	Sediments	Toxins
Biological Diversity	**Negative effect** Increased nutrient concentrations can lead to e.g. eutrophication and losses of biological diversity (Peter et al., 1997)	**Negative effect** Increased nutrient concentrations can lead to e.g. eutrophication and losses of biological diversity (Peter et al., 1997)	**Negative effect** Suspended solids degrade aquatic habitats and is a threat to biodiversity (Newcombe & Macdonald, 1991; Ian & Jorge, 2009)	**Negative effect** Toxins released into the water during flooding can have direct negative and deadly effects on biota (Fleeger et al., 2003)
Habitat	**Negative effect** Increased nutrient concentrations can have large negative effects on freshwater habitats (Bergek et al, 2017 and Smith et al., 1999).	**Negative effect** Increased nutrient concentrations can have large negative effects on freshwater habitats (Bergek et al, 2017 and Smith et al., 1999).	**Negative effect** Suspended solids degrade aquatic habitats and is a threat to biodiversity (Newcombe & Macdonald, 1991; Ian & Jorge, 2009)	**Negative effect** Toxins can have deadly effects on biota and would have negative effects on their habitat (Fleeger et al., 2003).
Drinking Water	**Negative effect** Nitrogen and phosphorus losses to freshwater ecosystems can put the drinking water quality at risk (Schröder *et al*. , 2004).	**Negative effect** Nitrogen and phosphorus losses to freshwater ecosystems can put the drinking water quality at risk (Schröder *et al*. , 2004).	**Negative effect** Sediments in water makes the drinking water treatment process less efficient and more costly (Delpla *et al*. , 2009).	**Negative effect** Toxins all pose a risk to human health if found in drinking water sources (Delpla et al., 2009).
Water for Irrigation and Industry	**No change** As the most important factor for the ESS water for irrigation and industry is water quantity changes in nitrogen concentration was estimated to have no effect (Bergek et al, 2017).	**No change** As the most important factor for the ESS water for irrigation and industry is water quantity changes in phosphorus concentration was estimated to have no effect (Bergek et al, 2017).	**No change** As the most important factor for the ESS water for irrigation and industry is water quantity changes in sediment concentration was estimated to have no effect (Bergek et al, 2017).	**Negative effect** As toxins can have deadly effects on biota is was estimated to have a negative effect on water for irrigation (Fleeger et al., 2003).
Flood control	**No change** As the most important factor for the ESS flood control is the morphology of the river nitrogen was estimated to have no effect (Bergek et al, 2017).	**No change** As the most important factor for the ESS flood control is the morphology of the river phosphorus was estimated to have no effect (Bergek et al, 2017).	**No change** As the most important factor for the ESS flood control is the morphology of the river sediments was estimated to have no effect (Bergek et al, 2017).	**No change** As the most important factor for the ESS flood control is the morphology of the river toxins was estimated to have no effect (Bergek et al, 2017).
Regulation Eutrophication	**Unknown** No research was found on nitrogens impact on the ESS regulation of eutrophication.	**Unknown** No research was found on phosphorus impact on the ESS regulation of eutrophication.	**Unknown** No research was found on sediments impact on the ESS regulation of eutrophication.	**Unknown** No research was found on toxins impact on the ESS regulation of eutrophication.

5.2.4 Impacts on ecosystem services from flooding of different land-use

Cultivated Land

Cultivated land was assessed to have a negative effect on the ESS biological diversity, habitat, and drinking water, to have no effect on water for irrigation and industry and flood control, and with an unknown effect on regulation of eutrophication during flooding (Figure 21) The answers to the questions in the flowchart were based on evidence found in literature.

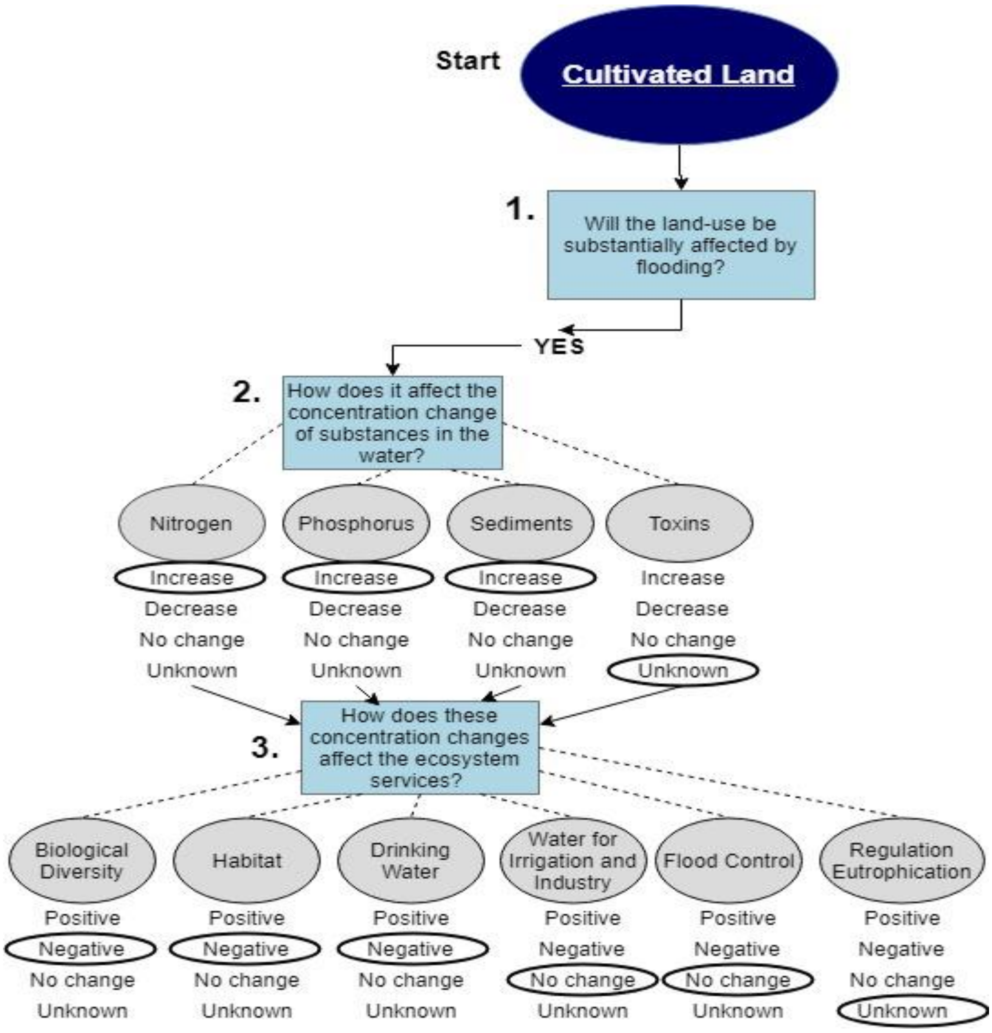

Figure 21: Flowchart showing the assessment of how cultivated land could affect ecosystem services status in study site Arbogaån in case of flooding.

Step 1:
Since cultivated land cover 58% of the impacted area, it was judged to have a substantial impact on the leaching or uptake of substances during flooding. Hence the answer to the first question was yes.

Step 2:
According to previously published research nitrogen, phosphorus, and sediment losses from cultivated land is likely to increase during flooding events (Ulén & Johansson., 2009; Øygarden *et al*., 2014; Ockenden *et al.*, 2016). Few studies have been made on the leaching or uptake of pesticides during flooding from cultivated land, and the effects that flooding will have are likely very variable (Bloomfield *et al.*, 2006). No research was found on the leaching or uptake of other toxins from cultivated land during flooding. Based on the references presented above it was assessed that the concentrations of nitrogen, phosphorus and sediments in the water would increase during flooding of cultivated land. As little research was found on leaching or uptake of toxins from cultivated land during flooding, its concentration change was assessed as unknown (Figure 21).

Step 3: According to the cause-effect relationships found in preceding literature increased concentrations of nitrogen, phosphorus and sediments will have negative effects on the ESS biological diversity, habitat and drinking water, but no effect on the ESS water for irrigation and industry or flood control (Table 3). The substances effect on regulation of eutrophication was assessed as unknown due to lack of evidence from previous research. As the concentration change of toxins was assessed as unknown, its effect on ESS have not been considered.

Forest

Forests were assessed to have a negative effect on the ESS biological diversity, habitat, and drinking water, to have no effect on water for irrigation and industry and flood control, and with an unknown effect on regulation of eutrophication during flooding (Figure 22). The answers to the questions in the flowchart were based on evidence found in literature.

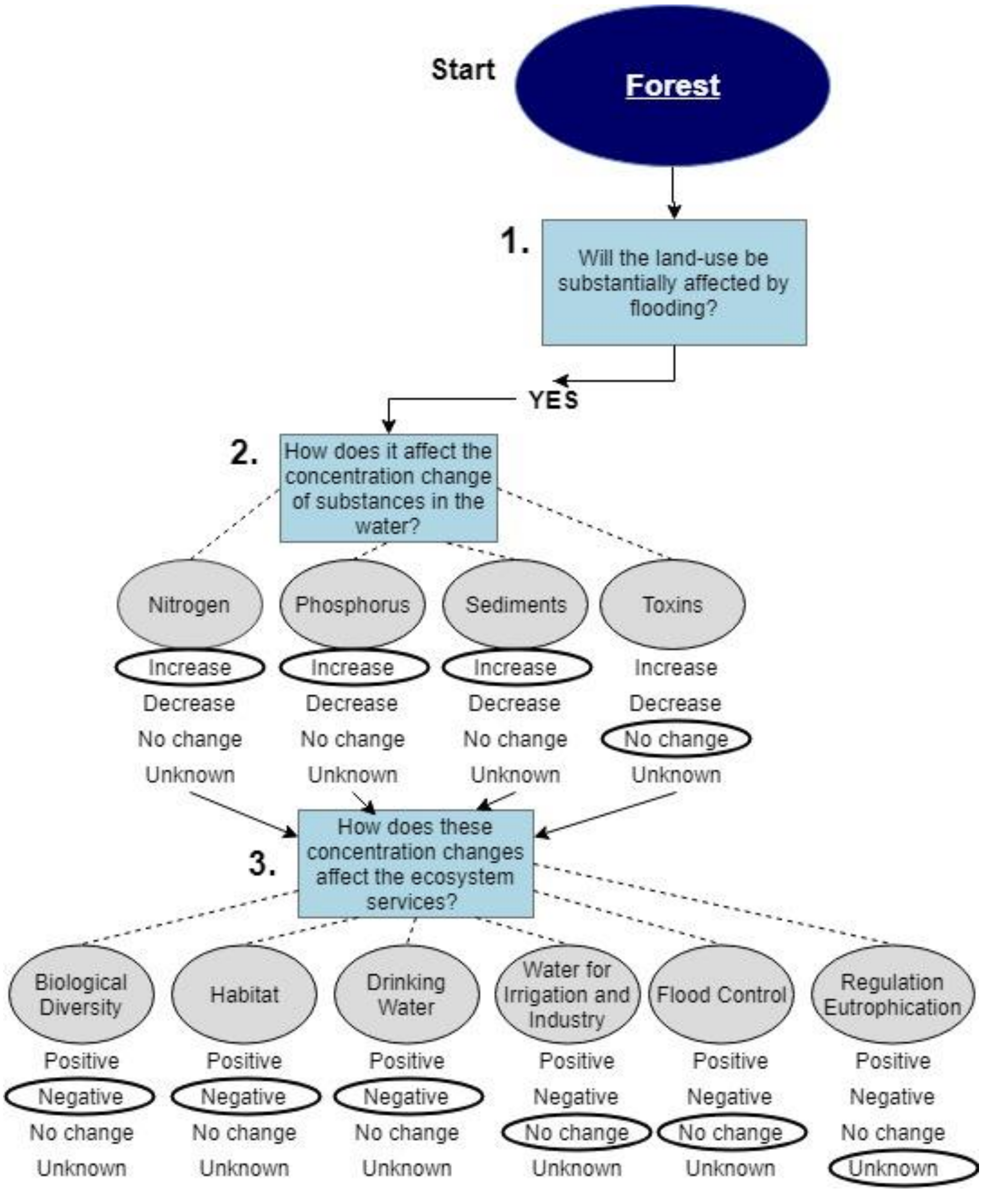

Figure 22: Flowchart showing assessment of how forests could affect ecosystem services status in study site Arbogaån in case of flooding.

Step 1:
Since forests cover 20% of the impacted area, they were judged to have a substantial impact on the leaching or uptake of substances during flooding. Hence the answer to the first question was yes.

Step 2:
According to previously published research there is an increased risk of nitrogen leaching from forests in Sweden under climate change scenarios with more frequent flooding, higher temperatures, and intensified precipitation (Akselsson *et al.*, 2010). Peraza-Castro *et al* (2016) evaluated the effect of floods on the transport of suspended sediments from a forested catchment. They conculded that flood events were responsible for transporting 91% of sediments from forests over a three-year period. No specific research was found on phosphorus or toxins leaching or uptake from forests during flooding. But, as phosphorus often binds to sediment it was assessed that it would be under risk of leaching as well (Wölz *et al.*, 2009). Based on the references presented above it was assessed that the concentrations of nitrogen, phosphorus and sediments in the water would increase during flooding of forested land. As no research was found on leaching or uptake of toxins from forested land during flooding, its concentration change was assessed as unknown (Figure 22).

Step 3: According to the cause-effect relationships found in preceding literature increased concentrations of nitrogen, phosphorus and sediments will have negative effects on the ESS biological diversity, habitat and drinking water, but no effect on the ESS water for irrigation and industry or flood control (Table 3). The substances effect on regulation of eutrophication was assessed as unknown due to lack of evidence from previous research. As the concentration change of toxins was assessed as unknown, its effect on ESS have not been considered.

Open Land/Other

No assessment was possible for the land-use category Open Land/Other (Figure 23). The assumptions for this conclusion is described in the different steps below.

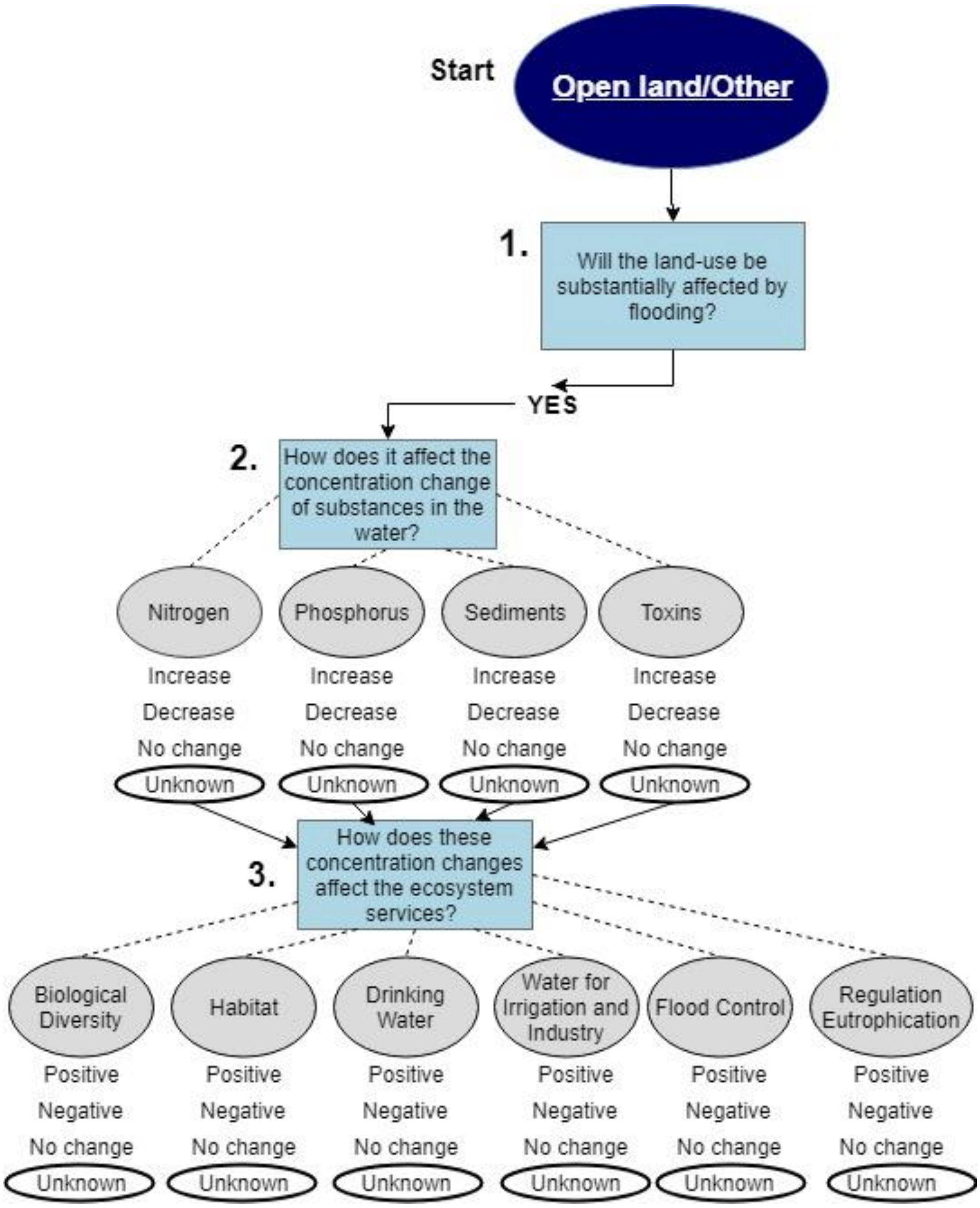

Figure 23: Flowchart showing assessment of how open land/other could affect ecosystem services status in study site Arbogaån in case of flooding.

Step 1:

Since open land/other cover 14% of the impacted area, it was judged to have a substantial impact on the leaching or uptake of substances during flooding. Hence the answer to the first question was yes.

Step 2:

As the land-use category open land/other consist of many different land-use types (Table 2) it was impossible to draw any general conclusions on the leaching or uptake of substances during flooding. Hence the answers to question 2 in the flowchart were unknown (Figure 23).

Step 3:

As the concentration changes of the substances from open land/other were assessed as unknown, the effects on ESS could not be estimated. Hence, they also had to be classified as unknown (Figure 23).

Wetland

It was assessed that wetlands don't have any impact on the analyzed freshwater ESS status (Figure 24). The answers to the questions in the flowchart were based on evidence found in literature.

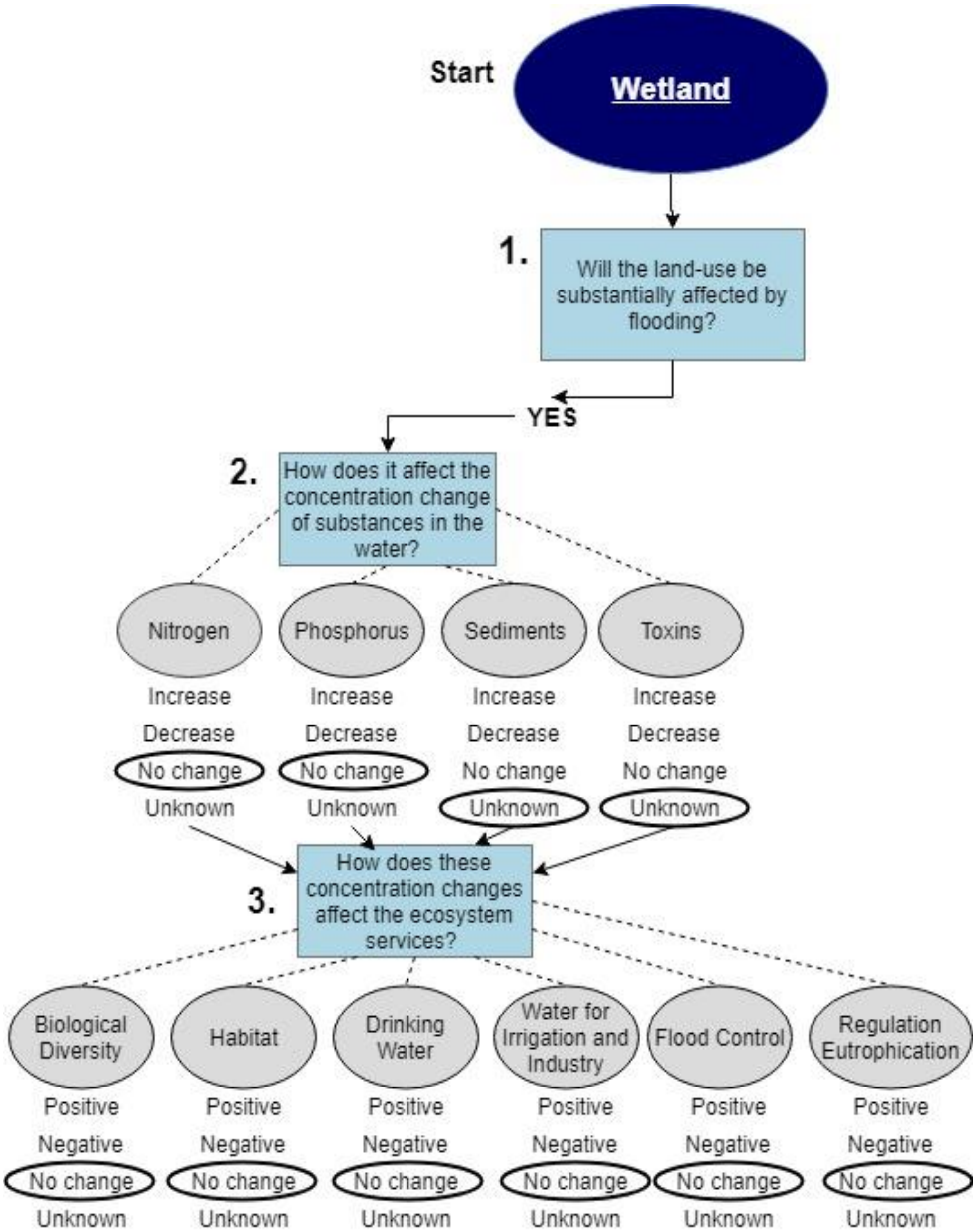

Figure 24: Flowchart showing assessment of how wetlands could affect ecosystem services status in study site Arbogaån in case of flooding.

Step 1:
Since wetlands cover 7% of the flooded area, they were judged to have a substantial impact on the leaching or uptake of substances during flooding. Hence the answer to the first question was yes.

Step 2:
According to previously published research wetlands in agricultural and forested catchments are effective at removing nutrients from runoff both during base flow and storm flow situations (Fink & Mitsch, 2004). But, no research was found on leaching or uptake of substances by wetlands during flooding. During flooding the whole wetland would be covered by water and it was assessed that it would then lose its ability to remove nutrients. But, it was also assumed unlikely that wetlands would leach any substances when flooded. No literature was found on the effects of flooding on sediment and toxin leaching or uptake from wetlands. Based on the judgements presented above it was assessed that the concentrations of nitrogen and phosphorus in the water would not change during flooding of wetlands. As no research was found on leaching or uptake of toxins or sediments from wetlands during flooding, their concentration changes were assessed as unknown (Figure 24).

Step 3: According to preceding research flooding of wetlands wouldn't cause leaching or uptake of nitrogen and phosphorus, and hence it was assessed that there would be no impact on ESS status (Figure 24). But, as the concentration changes of toxins and sediments was assessed as unknown, their effect on ESS have not been considered.

Buildings

Buildings were assessed to have no effect on freshwater ESS (Figure 25). The assumptions for this conclusion is described in step 1 below.

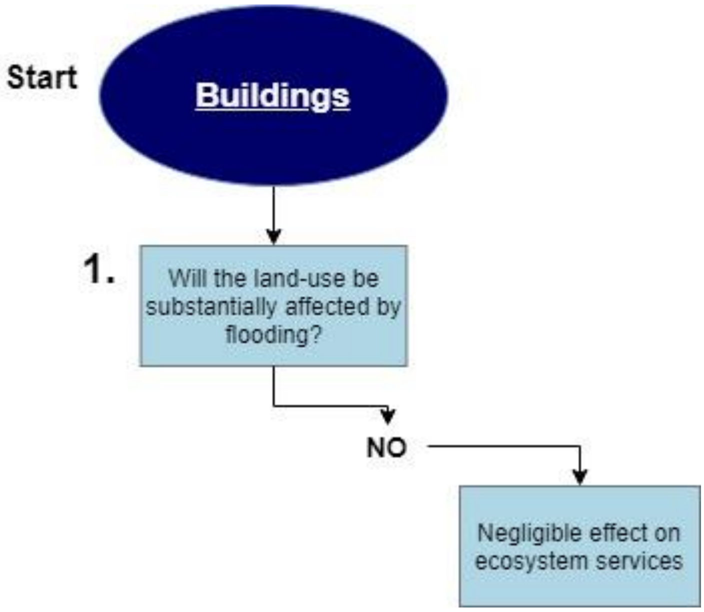

Figure 25: Flowchart showing assessment of how buildings could affect ecosystem services status in study site Arbogaån in case of flooding.

Step 1: Because the land-use category buildings only cover 1% of the flood risk zone it was judged to have negligible effects on the overall status of ESS in river Arbogaån (Figure 25).

Industry

Industry was assessed to have no effect on freshwater ESS (Figure 26). The assumptions for this conclusion is described in step 1 below.

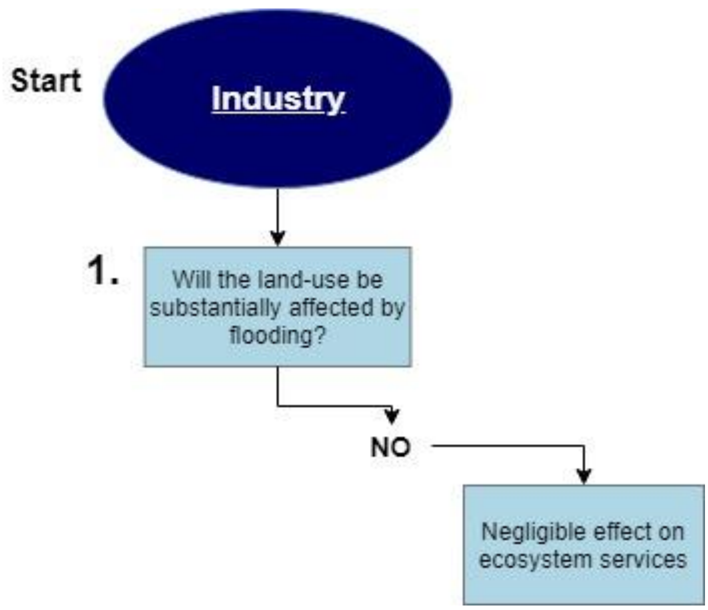

Figure 26: Flowchart showing assessment of how industries could affect ecosystem services status in study site Arbogaån in case of flooding.

Step 1: Because the land-use category industry only covers 1% of the flood risk zone it was judged to have negligible effects on the overall status of ESS in river Arbogaån (Figure 26).

5.2.5 Combined impacts on freshwater ESS statuses in the river Arbogaån

The combined impacts on ESS statuses in river Arbogaån due to flooding were obtained by combining the results from each flowchart (Figure 21-26).

It was assessed that biological diversity's status would be affected negatively by flooding of cultivated land and forests. Flooding of wetlands was assessed to have no impact on biological diversity, and open land/other was assessed to have an unknown effect on biological diversity's status. When combining these impacts on biological diversity the most prevalent impact was negative (Table 4).

The results showed that habitat and drinking water would be affected in the same way as biological diversity. The combined impacts on habitat and drinking water's statuses were also negative (Table 4).

Water for irrigation and industry's and flood control's statuses were not affected by flooding of river Arbogaån. The most prevalent impact was no change (Table 4).

For the ESS regulation of eutrophication no assessment was possible due to lack of evidence from previous research. Hence the combined impact on its status was unknown (Table 4).

Table 4: Combined impacts on ecosystem services status in the river Arbogaån due to flooding.

	Cultivated Land	**Forest**	**Open Land /Other**	**Wetland**	**Combined impacts on ESS status due to flooding of Arbogaån**
Biological Diversity	Negative	Negative	Unknown	No change	➡ **Negative**
Habitat	Negative	Negative	Unknown	No change	➡ **Negative**
Drinking Water	Negative	Negative	Unknown	No change	➡ **Negative**
Water for Irrigation and Industry	No change	No change	Unknown	No change	➡ **No change**
Flood control	No change	No change	Unknown	No change	➡ **No change**
Regulation Eutrophication	Unknown	Unknown	Unknown	No change	➡ **Unknown**

6 Discussion and conclusions

The purpose of this master's thesis was to contribute to the understanding of methods and indicators for assessing freshwater ESS status and to investigate what effects climate change could have on them. This was done by conducting both a literature review and a case study of the river Arbogaån.

6.1 Literature review

The literature review showed that there are indicators and methods for assessing freshwater ESS status presented in previous research. But, it also became clear that many of them are not supported by enough data to be able to make statistically significant assessments. This could lead to water managers and politicians making decisions based on false results. In turn this might cause a lot of resources being spent at the wrong place when they could have been better spent elsewhere.

Few indicators were found in previous research for the supporting ecosystem services. This is probably because they are hard to grasp and span over large areas. For the cultural services inspiration and natural heritage no indicators were found in previous literature. These services are valuable to human well-being but could also be hard to quantify.

For the scope of this study the 344 indicators found have not been analyzed individually, and the validity of them have hence not been investigated. The identified indicators have however brought an understanding to what types of indicators that can be used for assessing ESS status, and they could be useful for future research projects as a point of reference for ESS status assessments.

Some of the studies used previous literature and expert judgments for identifying possible indicators (Dunford *et al.*, 2015 and Mononen *et al.*, 2015). Others based their identification of indicators on data availability and data continuity (Tolonen *et al.*, 2014 and Vidal-Abarca *et al.*, 2016). For example, data collected under the WFD could be used for assessing the status of some freshwater ESS (Tolonen *et al.*, 2014 and Maes *et al.*, 2016). Using already existing data would be both a resource and time efficient way of assessing ESS status. However, a drawback of using existing data could be that ESS research gets biased and directed towards EU wide or national monitoring programs (Maes *et al.*, 2016). The linkages between WFD indices and ESS status also needs to be further understood (Vidal-Abarca *et al.*, 2016), and it is recommended that future research focus on this before WFD indices are used to assess ESS status. Using previous literature might be good for comparative analysis between different regions, as the same indicators and methods would be used. A drawback could be that no new and potentially better indicators would be developed. Expert judgements could be a good way of selecting and evaluating ESS indicators when available data is limited. It is however important to remember that they are subjective and dependent on the observer. One study looked at the use of citizen science for assessing ESS (Schröter *et al.*, 2017). This might be a good alternative for specific services like recreation or biodiversity that have easily quantifiable indicators, like number of recreational paths or number of fish caught. Citizen science could also raise the awareness of ESS and citizens involvement in protecting them. The pros and cons of using quantitative versus qualitative methods has also been investigated (Busch *et al.,* 2012). It was found that quantitative methods are better for evaluating specific ESS and for putting monetary value on them, hence the results from quantitative methods might be easier for water managers and policy makers to comprehend and to integrate into economic decisions. Qualitative methods on the other hand were found better for comprehensive analysis of ESS and for estimating changes in ecosystem health. These methods might then be better suited for assessing trends in ESS status over time and for situations where data is limited.

By limiting the literature review to only scientific literature, other forms of literature, e.g. reports and projects presentations, were excluded. One example of literature that have not been analyzed is the MEA report (MEA, 2005). This project and other similar forms of literature might have contained information on ESS indicators and climate change impacts as well, and they could be considered in future studies. The literature search was also limited to studies from Europe, but relevant research could also be found elsewhere. The search terms used in the online databases also had an impact on the articles found and broader search terms would have given more results. For example, when the keyword “aquatic” was added to the search queries, many more articles were found compared to when only “freshwater” was used. This is probably because “aquatic” included marine waters as well.

From the literature review many potential methods and indicators were identified that could be used for assessing freshwater ESS status. The different methods have both pros and cons, and they should be carefully considered by future research projects.

Climate change will have a significant effect on freshwater ecosystem services and the benefits that they provide to humans (Dunford *et al.*, 2015). Potential impacts of climate change on freshwater ecosystems found in the literature include higher temperatures, intensified rainfall and more frequent flooding events (Whitehead *et al.*, 2009; Bangash *et al.,* 2013; Tzilivakis *et al.,* 2015). These changes affect freshwater

ESS by altering aquatic habitats, oxygen saturation, erosion, leaching of contaminants, and so on (Whitehead *et al.*, 2009).

From the analyzed literature it became clear that especially the freshwater ESS drinking water and biological diversity are threatened by climate change in Europe (Bangash *et al.,* 2013; Terrado *et al.,* 2014*;* Dunford *et al.,* 2015). By conducting this literature review it was also highlighted how complex ecosystems are and how hard it is to estimate climate change effects on them. It is often hard to pin-point exactly what processes that underlie the delivery of an ESS and most ESS depend on a variety of different processes (Moor *et al.,* 2015). The results on what ESS are threatened by climate change also vary depending on what region is studied. For example, food and fiber production, flood control and carbon sequestration were found to increase in northern Europe while they were found to decrease in southern Europe (Dunford *et al.,* 2015; Moor *et a.l.*, 2015). Because of this it ought to be extra important that mitigation measures are taken where they are most needed and that there is good communication and cooperation between countries and regions.

The results from the literature review show that research on climate change effects on freshwater ESS is scarce (Dunford *et al.*, 2015). This means that there is little evidence to serve as decision basis for water managers and politicians. To be able to manage water resources effectively and to make sure that action is taken in the right place, more research is needed on the topic. It is recommended that future research focus on finding cause-effect relationships between climate change and specific freshwater ESS status.

6.2 Case study of the river Arbogaån

The results from the case study of river Arbogaån, where six ESS were analyzed, show that flooding could have negative impacts on ESS that are of high importance to humans. The results indicate that the statuses of the ESS biological diversity, habitat, and drinking water are threatened by flooding events. Biological diversity is the variety of life on earth and is highly important to human well-being. Every organism in an ecosystem (including humans) have an important role to play. Biodiversity help in maintaining the balance of ecosystems which provide us with food, freshwater, medicine, pest control, recreation and so forth (Cresswell & Murphy, 2016). Drinking water is the most important resource for human consumption, and is essential for all life on earth. Habitat describes an area where one or multiple species live. A well-functioning habitat is essential for the reproduction and development of the species that live there. Effects on biological diversity and species habitat could have far reaching impacts on entire ecosystems which humans rely on for e.g. food resources and recreation (MEA, 2005). A negative status change for drinking water would have negative effects for the cities and towns along river Arbogaån that rely on it. From this study no change in status was expected for the ESS water for irrigation and industry or flood control. This was mainly because these two ESS were found to rely more on water quantity than the concentrations of nitrogen, phosphorus, sediment, and toxins. The change in status for the ESS regulation of eutrophication could not be estimated due to lack of evidence from previous research.

To do the assessment of ESS status change in river Arbogaån due to flooding a new method had to be developed. As this was a first attempt to develop such a method, the result is exploratory. The developed method only considers a few aspects of an immensely complex natural system. Apart from leaching or uptake of nitrogen, phosphorus, sediments, or toxins during flooding there are many other substances and factors that could play a role, as well as combined effects. Some other factors include changes in river morphology, water velocity, oxygen saturation, and light penetration. The developed method only looked at flooding of different land-use categories and their potential impacts on ESS status. Other aspects of the land like soil type, slope, and potentially contaminated sites could also influence the status assessment of ESS. But, it would be impossible to consider all aspects and the results from this study should be seen as an indication of effects that flooding could have on ESS status.

During the GIS overlay analysis, the "calculated highest flood" was used as the flood risk zone. This flooding event is a predicted worst-case scenario which considers the effects of climate change. There are other types of flood predictions such as the 50-year and 100-year flood, but they were not studied in this project. From the overlay analysis it became clear that most of the flood impact areas are located in the lower part of the river. This means that the leached substances would also affect lake Mälaren which is located downstream river Arbogaån. It is understood that the impacts on ESS could be more significant in the lower parts of the river compared to the upper and that they could also differ locally. For this study however, the leaching of substances from all parts of river Arbogaån were considered to influence ESS statuses in the whole river. In addition, the assessment made by Bergek *et al* (2017) for ecosystem services importance and sensitivity to climate change (primarily flooding) was made for the whole catchment of Arbogaån, but for this study it was assumed that the same assessment would be true for the river Arbogaån itself too.

By using the flowcharts developed to assess flooding impacts on ESS status, the land-use categories buildings and industry were considered to have negligible impacts because they only cover 1% each of the flood risk zone (Figure 20). This judgement was made because all land-use categories had to be treated on equal terms based on their respective percentages in the area. But, even though the "calculated highest flood" would impact such small areas of industry and buildings they could still have impacts on ESS. This may be especially true for industry where relatively high concentrations of toxic material could be washed away. For future research it might be beneficial to develop a weighted risk factor for each land-use category, which would not only consider their respective areas in the flood risk zone but also their respective leaching risks.

The assessments of leaching or uptake of substances and the subsequent impacts on ESS were based on evidence found in literature and on informed judgment. When doing this type of assessment, it is impossible to be completely objective and impartial. This subjectivity was however limited by strictly following the developed flowchart and by supporting the assessments with literature. The affects that nitrogen, phosphorus, sediments, and toxins have on ESS status is also relative. Maybe small amounts of nutrients would actually benefit biological diversity, but for simplicity more general conclusions of their impacts had to be made.

In this study the new developed method was only tested on six ESS out of the 23 identified by Bergek *et al* (2017) (Table 1). But, the remaining 17 freshwater ESS could also be affected by flooding in river Arbogaån. The LIFE IP Rich Waters expert group estimated that an additional four ESS had a high sensitivity to climate change, but these ESS were not analyzed in this study as the demand for them was only low or medium high.

For future studies it should be considered if additional factors also need to be included in the assessment. In this study the impacts of flooding were assessed, but climate change will also lead to higher temperatures and intensified rainfall. These factors could also influence ESS status, and their combined effects could be even more important. It could also be tested if specific land areas could be used as indicators for ESS in the overlay analysis. Maybe areas like Natura2000, national parks, and water protection areas could indicate the status of freshwater ESS. The method developed during this project can be used as a starting point for future research of flooding impacts on freshwater ESS status.

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Appendix 1

Table 5: List of ecosystem service indicators and data sources found during the literature review.

Ecosystem Service:	Indicators found in literature:	References:
Supporting		
Biogeochemical cycling	N deposit, Chelation, P runoff, Use of fertlizer	*Kettunen & Vihervaara (2012)*
Primary production	Net primary production, Leaf Area Index	*Kettunen & Vihervaara (2012)*
Food web dynamics	Number of key functional traits, number of keystone species, number of top predators	*Kettunen & Vihervaara (2012)*
Biodiversity	Species diversity, Number of populations, Share of endangered species, Mean species abundance	*Maes et al (2010)* *Kettunen & Vihervaara (2012)*
Habitat	Ecological status, Morphological status, Chemical status, Number of habitats, Species diversity, Share of endangered species, Spawning, nursery and feeding areas, Macrophyte species richness	*Vidal-Abarca et al (2016)* *Grizzetti (2016)* *Maes et al (2010)* *Kettunen & Vihervaara (2012)*
Water cycling	Soil water, Groundwater recharge, Number and area of glaciers, Snow, Hydrological state index, Regulated water reservoirs, Water stored in reservoirs, Water lossess in distribution channels, Recycled water, Water transfer	*Vidal-Abarca & Suárez-Alonso (2013)*
Regulating		
Climate and atmospheric regulation	Annual precipitation, Annual average temperature, Evapotranspiration, Evaporation from reservoirs, Humidity index, CO2 & CH4 & N2O emissions from wastewater, C sequested by Populus, Organic C stored in fluvisols, C sequestered in riparian biomass, C balance, Avoided cost of negative climate impact, C in soil or sediment, Dissolved organic matter, Ecological status, Drought frequency	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)*
Sediment retention	Undisturbed soils, Risk of gully erosion, Sediment accumulated in reservoirs, Specific degradation index, Areas with steep slopes, Sandy areas, Erosion risk, Regulation in place to prevent erosion, Buffer zones, Soil erosion rate, Geomorphology, Riparian vegetation distrubition, State of fluvial habitat and macrophytes	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)* *Albert et al (2016)*
Regulation eutrophication	Undisturbed habitat, Improved water quality, Nutrient retention rate, N fixing vegetation, Avoided cost of fertilized use and water protection	*Mononen et al (2016)*
Biological regulation	Frequency of pest/disease outbreaks, Biodiversity status, Number of alien species, Population affected by water related diseases, Ecological status, Introduced aquatic invertebrated and plants, Economic cost of invasive species	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)*
Regulation of toxic substances	Ecological status, Nutrient loads, Area of riparian forest, Number of treatment plants, Decomposition in waste in biological processes, Improvement of water quality, Avoided cost of water treatment	*Vidal-Abarca et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)* *Albert et al (2016)* *Maes et al (2010)*

Water purification	Point source pollution, Fertlizer use, BOD5, P & N concentration, Salinity, Ecological status, Number of tratment plants, Point source pollution, Cost of water purification, Financial investmnet in water quality, Retention of N by water bodies and riparian areas, Buffer zones, Area of riparian forest, Area of wetlands, Nutrient removal by wetlands, Nutrient loads	*Vidal-Abarca et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)* *Grizzetti et al (2016)*
Flood control	Number of floods, Deaths caused by floods, Economic losses from floods, Status of river banks, Urbanized surfaces, Sediment retention, Flood risk maps, Undrained habitats, Detention time, Avoided cost of flood prevention and damages, Water retention capacity, State of riparian and fluvial habitat, Wetlands area, Probability of flood, Percentage of population living in flood risk areas	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)* *Albert et al (2016)* *Maes et al (2010)*
Providing		
Food	Ecological status, Total catch of river and lake fish, Value of fish production, Employment, Number of species in commersial use, Population size of commersial fish, Status of fish population, Fish produces sustainably, Percent of fish in humans diet	*Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)*
Drinking water	Surface water availability, Renewable water resources, Runoff, Provisioning of drinking water, Water consumption by drinking, Water Exploitation Index, Value of water, State of surface water, River salinity, Water storage capacity, Water-stressed population	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)* *Albert et al (2016)* *Maes et al (2010)*
Genetic resources	Genetic variance, Biodiversity of vertebrates and invertebrates, Number of LIFE-Nature projects for protection of species	*Vidal-Abarca et al (2016)* *Mononen et al (2016)*
Water to irrigation and industry	Surface water availability, Renewable water resources, Runoff, Provisioning of water, Water use per sector, Water Exploitation Index, Value of water, State of surface water, River salinity, Water storage capacity, Area water logged by irrigation, Volume of desalinated water	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Maes et al (2010)*
Cultural		
Recreation	Number of fishing licenses, Number of river beaches, State of surface water, Water sports, Number of visitors, Proximity to areas of scenic rivers or lakes, Avoided medical cost, Natural events, Accessiblity to natural areas, Tourism revenue, Employment, Area of protected land, Length of nature trails, Time spend outdoors, National parks and Natura 2000 sites	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)* *Albert et al (2016)* *Maes et al (2010)*
Aesthetic values	Scenic rivers or lakes, Number of visitors to national parks, Length of river altered by dams, Length of riparian area affeced by land-use change, UNESCO world heritage sites	*Vidal-Abarca & Suárez-Alonso (2013)* *Kettunen & Vihervaara (2012)*
Science and education	Number of scientific projects and articles, Number of courses and thesis related to water, Number of organizations that focus on water, Monitoring sites, National parks and Natura 2000, Number of visitors, UNESCO world heritage sites, State of surface water, Number of green areas, Proximity to lakes and rivers, Financial expenditure on research	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Kettunen & Vihervaara (2012)* *Mononen et al (2016)* *Maes et al (2010)*
Cultural heritage	Natural heritage and cultural sites, National species, Festivals related to water, Religious places related to rivers, Words related to water, Number of visitors, Incentives to maintain cultural landscapes, State of surface water	*Vidal-Abarca et al (2016)* *Vidal-Abarca & Suárez-Alonso (2013)* *Grizzetti et al (2016)* *Maes et al (2010)*
Inspiration	x	
Natural heritage	x	

Popular science summary

Freshwater ecosystem services are the benefits that humans gain from rivers and lakes in our surrounding environment. These services include for example drinking water, food, biological diversity, climate regulation, water for irrigation, and recreation, and are all very important to human life and well-being. The services that freshwater ecosystems provide are currently threatened by both human activities and climate change. Climate change will lead to more extreme weather events and is already causing higher temperatures, droughts, intensified rainfall, and more frequent flooding. These changes could impact freshwater ecosystems and the services that they provide us with. To know how to best protect these ecosystem services, it is essential to find indicators and methods that can tell us if and why an ecosystem service is threatened.

The purpose of this master thesis was to investigate what indicators and methods that could be used to assess ecosystem services status and change of status related to climate change in terms of flooding. First a literature review was made where previous research was searched for information. The review resulted in a list of indicators that could be used for assessing ecosystem services status. The review also gave a better understanding of how climate change could affect freshwater ecosystem services status. Climate change is likely to impact many of the services that humans rely on, for example drinking water and biological diversity are often referred to as threatened.

The second part of this master thesis was a case study of the river Arbogaån located in mid-Sweden. This work was related to one of the sub-actions within LIFE IP Rich Waters, an EU funded project that started in Sweden 2017 with the purpose of improving water management in Sweden. The sub-action studies ecosystem services and impacts of climate change. In this project an initial method was developed for how to assess flooding impacts on ecosystem services. The method was tested on six ecosystem services that within the LIFE IP project had been assessed as being of high importance to humans in river Arbogaån, but also under high threat from climate change. They were: drinking water, biological diversity, water for irrigation and industry, flood control, regulation of eutrophication, and habitat. The assessment indicated that flooding could have serious consequences on services that are important for human societies. It was estimated that flooding has a negative impact on biological diversity, drinking water, and habitat.

Biological diversity is the variety of life on earth and is highly important to human well-being. Every organism in an ecosystem (including humans) have an important role to play. Biodiversity help in maintaining the balance of ecosystems which provide us with food, freshwater, medicine, pest control, recreation and so forth. Drinking water is the most important resource for human consumption, and negative impacts on this ecosystem service could lead to huge societal problems. Habitat describes an area where one or multiple species live. A well-functioning habitat is essential for the reproduction and development of the species that live there.

The developed method could be used as a reference and starting point for future research projects. It is important that we prepare for climate change and are aware of the impacts that it could have on ecosystem services. Without this knowledge it will be impossible to know when, where and what measures that are necessary for protecting them.