Aquaculture in Lake Storsjön: an ecosystem services based investigation

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Abstract

The purpose of this thesis is to investigate if the application of the ecosystem services concept can provide decision makers and stakeholders with additional relevant information for decisions regarding establishing of aquaculture on a local level, using the Lake Storsjön as a case study. In order to provide this knowledge, three different tasks are carried out within this thesis: the identification of the main ecosystem services provided by Lake Storsjön, the understanding of ecosystem services that will be affected by the expansion of aquaculture and the identification of the services that will be used for a possible expansion of the aquaculture sector.

The CICES methodology (Common International Classification of Ecosystem Services) is used to identify the ecosystem services provided by Lake Storsjön. The understanding of the affected ecosystem services is carried out with the use of a Delphi-inspired approach. The identification of the services required for the establishment of aquaculture is driven by a cross-reference matrix.

Lake Storsjön provides thirty-nine out of the fifty-nine ecosystem services included in the CICES. About half of these will be effected by environmental impacts connected to operations of ecosystem management required by aquaculture expansion, mostly with a low or medium degree of impact. An increase in the implementation of aquaculture might cause detrimental trade-offs with these ecosystem services: “Wild animals”, “Genetic materials from all biota”, “Disease control”, “Maintaining nursery populations and habitats” and “Filtration/dilution/sequestration/storage/accumulation by ecosystem”.

An expansion of the aquaculture sector requires seven of the ecosystem services provided by Lake Storsjön. The vital services for this process are: “Surface water for non-drinking purposes”, “Filtration/dilution/sequestration/storage/accumulation by ecosystem” and “Chemical condition of freshwater”. These services have to be safeguarded and maintained in order to guarantee adequate conditions for an expansion of this sector.

At the same time the expansion of aquaculture supports the service “Animals from in situ aquaculture”. The benefits connected to the implementation of aquaculture shall be economically assessed and compared to the actual economic value delivered by the other ecosystem services in order to further understand the positives and negatives outcomes of aquaculture expansion in an ecosystem services perspective. This is considered to be a relevant step for strategic and decision making processes concerning aquaculture expansion in Lake Storsjön.

In addition to the economic perspective, it seems that the most relevant factor when discussing planning and development processes towards ecosystem services is the importance of not overshooting the resilience ability of the ecosystem in order to ensure the accessibility of the services to future generations. This belief is recommended to be applied to Lake Storsjön in order to guarantee a conscious expansion of the aquaculture sector on a social, economic and environmental level.

Key words: ecosystem services, aquaculture, CICES, Sweden, trade-offs.
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## Glossary of some specific Swedish words

Glossary 1: some specific Swedish words that are used and translated in the thesis. These words are generally used in Swedish since this thesis handles information about a specific Swedish location but to facilitate a better general understanding they are translated to English.

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<thead>
<tr>
<th>Swedish</th>
<th>English</th>
<th>Notes</th>
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<tr>
<td>Aborre</td>
<td>European Perch</td>
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<td>Bergsimpa</td>
<td>Alpine Bulledhead</td>
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<td>Bäckröding</td>
<td>Brook Trout</td>
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<td>Elritsa</td>
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<td>Gädda</td>
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<td>Harr</td>
<td>Grayling</td>
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<td>Indalsälven Vattenvårdsförbund</td>
<td>Indalsälvens Water Quality Association</td>
<td>Organisation</td>
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<td>Kanadaröding</td>
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<td>Landscape protected areas</td>
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<td>Organisation</td>
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<td>Roach</td>
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<td>Naturreservat</td>
<td>Natural reserve</td>
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<td>Organisation</td>
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<td>Nors</td>
<td>European Smelt</td>
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<td>Storsjödjuret</td>
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<td>Three-spined Stickleback</td>
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<td>Plan for the use of water of the Storsjön water-system</td>
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<td>The winter park</td>
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<td>Öring</td>
<td>Char</td>
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<td>Östersund Frösö Båt och Hamnföreningen</td>
<td>Östersund and Frösön Boat and Harbour Organization</td>
<td>Organisation</td>
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1. Introduction

The concept of ecosystem services has started to be recognized and explored on theoretical level but now a raising interest in identifying ecosystem services is shown by different institutions and agencies (TEEB, 2010; Millennium Ecosystem Assessment, 2005; Maes et al., 2014). Identifications of ecosystem services provide an evaluation of the level of ecosystem services delivered to people, considering both the ecosystems from which the services are derived but also the people who depend on and are affected from the supply of services. The European Environment Agency invites its members to develop a systematic identification of the ecosystem services delivered both on a national, regional or local level (Maes et al., 2013). In Scandinavia, some investigations have been carried out with a national perspective or referring to particular types of ecosystems, but there are not many cases of studies conducted on specific sites (Alahuhta et al., 2013; Naturvårdsverket, 2014; Maes et al., 2013). In Sweden, Naturvårdsverket supports the identification of ecosystem services in order to guide decision making and planning processes (Naturvårdsverket, 2013).

Länsstyrelsen Jämtlands län (the Jämtland County Administration Board) is interested in the role played by ecosystem services in delivering benefits in the area of Lake Storsjön. Consequently an identification of the ecosystem services provided by Lake Storsjön is considered by the administrators within the Jämtland County Administration Board as an interesting task to provide relevant information and knowledge in order to understand the actual values delivered by the Lake’s ecosystem to the surrounding municipalities of Berg, Krokom, Östersund and Åre. Hence, the revealed interest in establishing aquaculture businesses in Lake Storsjön gives the opportunity to integrate ecosystem services reasoning in the planning and decision making processes as suggested by Naturvårdsverket (Cati, 2015a).

The expansion of aquaculture represents an interesting economic possibility for the County of Jämtland and, for this reason, this issue is widely debated (Cati, 2015a). In fact operations of ecosystem management, required by aquaculture, are recognized as possible harms for the ecosystem possibly causing trade-offs among other ecosystem services (Maes et al., 2014). But possible negative aspects have to be considered at the light of the positive effects that ecosystem services might have on aquaculture expansion. In fact, aquaculture might be supported by some of the services provided by Lake Storsjön. The role of aquaculture has to be investigated to identify major tradeoffs with other ecosystem services.

The outcomes of this work might be relevant for the ongoing project “Vattenanvändningsplan för Storsjön vattensystem”, carried out by the Jämtland County Administration Board in collaboration with the municipalities surrounding Lake Storsjön and the region Jämtland-Härjedalen. This project aims to develop a common strategy for the use of the Storsjön area and water (Länsstyrelsen Jämtlands län, 2015). The concept of ecosystem services is considered a relevant approach that should be also included in the project. Thus the work carried out in this thesis might be included into a wider framework concerning the development of a more sustainable society on the shores of Lake Storsjön.
1.1 Aim and purposes

The purposes of this thesis are to provide knowledge about the ecosystem services provided by Lake Storsjön and to explore limits and opportunities for the growing sector of aquaculture with regards to the ecosystem services concept. The aim of this thesis is to provide information to support decision makers in steering aquaculture expansion in Lake Storsjön in a conscious way. The specific knowledge intended to be provided answers the research questions reported in Section 1.2.

1.2 Research questions

1. Which are the main ecosystem services provided by Lake Storsjön?
2. Which ecosystem services will be affected by the expansion of aquaculture in Lake Storsjön?
3. Which ecosystem services will be used for the expansion of aquaculture in Lake Storsjön?

1.3 System boundaries

The generic system boundaries of this thesis are represented by Lake Storsjön, located in the County of Jämtland, Sweden. Some more detailed specifications are provided in the following sections.

1.3.1 Ecosystem services identification

The identification is carried out with regards to the Storsjön ecosystem. The Storsjön ecosystem is limited to the waterbody for what concerns provisioning, regulation and maintenance ecosystem services. When identifying cultural ecosystem services the boundaries of the Storsjön ecosystem are expanded in order to include its shores and activities or sites which are located inland in the proximity of the Lake. This enlargement is necessary since some of the cultural ecosystem services provided by Storsjön do not take place only within its waters. The identification of abiotic outputs considers the Indalsälven River into its boundaries.

1.3.2 Environmental impacts of aquaculture

The impacts considered, when discussing possible environmental impacts of aquaculture on ecosystem services, are those expected to be generated by operations taking place within the waters of Storsjön. Possible environmental issues connected to the use of motorboats are considered to be negligible. Environmental impacts that could be caused by operations and activities taking place on the shores of the Lake or inland (such as building of infrastructures or transportation) are not considered (Tajani & Olofsson, 2014). Furthermore environmental implications connected to the production and delivery of tools, materials and components necessary to aquaculture are not included too.

1.3.3 Conditions necessaries to the development of aquaculture projects

Developing aquaculture projects requires the consideration of a large number of environmental, legal, economic and social conditions or parameters to fulfil (Andersson et al., 2013; Naturvårdsverket,
1993; Tajani & Olofsson, 2014). Only environmental conditions are considered when assessing which ecosystem services will be needed by aquaculture expansion in Lake Storsjön.

1.4 Background

1.4.1 Lake Storsjön

Lake Storsjön is located in the Swedish county of Jämtland and it is stretched among four municipalities: Östersund, Krokom, Äre and Berg. Storsjön is the fifth Swedish biggest lake with a waterbody extension of 456 Km²; the average water depth is 19.6 m and its deepest point is at 86 m (SMHI, 2015). Lake Storsjön is included in the drainage basin of the Indalsälven River that is also the only inlet and outlet of the Lake. There are four major islands located in the lake: Frösön, Norderön, Andersön and Verkön (Vatteninformationssystem Sverige, u.d.).

1.4.2 Aquaculture in the Jämtland County

Aquaculture is a growing sector within the Swedish food production (Hedlund et al., 2014; Jordbruksverket, 2014). This growth is supported by a national strategy that aims to achieve social, economic and environmental sustainable levels of aquaculture in the next years (Jordbruksverket, 2012).

A raised interest in aquaculture has been attested in particular in the northern Counties, such as Jämtland, because of different reasons. First, aquaculture can provide employment opportunities in sparsely-populated area. Second there is a large availability of freshwater bodies with oligotrophic characteristics located in sparsely populated areas. The aquaculture potential of these water bodies is greater than that of corresponding lakes in the southern areas of Sweden because they encounter less cultivated and populated catchment areas and consequently they are not deeply affected by pre-existing nutrients loads (Hedlund et al., 2014). Furthermore other chemical and ecological water parameters are often targeted as optimal for the establishment of aquaculture projects (Andersson et al., 2013).

During 2013, 3,262 tons of fish have been produced in the Jämtland Country, over a total national production of 11,663 tons (Jordbruksverket, 2014); consequently around 28% of the 2013 national production has been produced in Jämtland. The main species farmed belongs to the salmonid family such as Rainbow trout, Char and Salmon trout (Cati, 2015b; Jordbruksverket, 2014). Aquaculture usually occurs in closed cage systems placed in the waterbodies during the non-freezing period (Cati, 2015b). Jämtland has been targeted by different studies as a suitable county for supporting aquaculture expansion and The Jämtland County Administration Board has perceived an increase in the permits applications for the establishment of aquaculture projects (Andersson et al., 2013; Cati, 2015b; Hedlund et al., 2014). For the moment, most of the development has taken place in sparsely populated areas and in lakes whit a low degree of opposing interests, consequentially the development of this sector has been accepted on an overall level (Cati, 2015b). But the interest in expanding the production to higher levels (requiring larger water volumes) has led aquaculture companies in being interest in larger water bodies, such as Lake Storsjön.
1.4.3 Environmental impacts of aquaculture

No specific research has been carried out in order to evaluate the environmental impacts connected to the current aquaculture production of Lake Storsjön, but different studies have demonstrated which impacts are most likely to occur in similar conditions (Alanära & Andersson, 2000; Burridge et al., 2010; Findlay et al., 2009; Lalonde et al., 2015; Naturvårdsverket, 1993; Turchini & De Silva, 2008). The expansion of aquaculture could impact the ecosystem services of Lake Storsjön because of consequences and issues connected to: nutrients load, spread of alien populations, spread of diseases and parasites, spread of antibiotics, pesticides and chemicals and physical use of the landscape.

Nutrients load refers to the release of nitrogen and phosphorus both from the direct spread of fodder and from the release through fecal wastes (Naturvårdsverket, 1993). The consequences of nutrient loading are considered to possibly cause eutrophication issues, to affect the local biota and to change the chemical and ecological status of freshwater (De Silva, 2012; FAO, 2005; Naturvårdsverket, 1993).

Spread of alien populations refers to the uncontrolled escape of reared fishes by the cage system. Escapees can affect the local biota, because of genetic issues (connected to their reproduction with native species) and because of direct impacts caused on the local food chain and alterations of the local bio-ecological dynamics (Alanära & Andersson, 2000; FAO, 2005; Naturvårdsverket, 1993).

Spread of diseases and parasites refers to the diffusion of these nuisances both via direct contact between reared and wild fishes (escapees) and by the transportation via water (Alanära & Andersson, 2000; Naturvårdsverket, 1993).

Spread of antibiotics, pesticides and chemicals refers to the use of these substances because of aquaculture management operations and to their consequent dispersion in the aquatic environment. The dispersion of these agents could be particularly dangerous in terms of deterioration of water quality and bioaccumulation of harmful components in the local biota (Burridge et al., 2010; Chagnon et al., 2014; Lalonde et al., 2015).

Physical use of the landscape refers both to the visual intrusion of the cage system in the water system and to the direct occupation of a portion of the water surface. The visual intrusion can represent a threat to the landscape value while the direct use of the water surface can clash with opposing interests such as water transportation and water sports (Cati, 2015b).

1.4.4 Environmental conditions necessary to aquaculture development

When developing aquaculture the environmental conditions that are mostly required concern the chemical, ecological and hydrological status of the selected water body (Alanära & Andersson, 2000; Andersson et al., 2013; Hedlund et al., 2014; Naturvårdsverket, 1993). Specifically, these conditions refer to the waterbodies’ area, average depth, average water flow, nutrient loads (phosphorus and nitrogen), temperature, dissolved oxygen level, pH, hardness levels, salinity, metal concentrations and amplitude (Alanära & Andersson, 2000; Andersson et al., 2013). Specific parameters for these conditions are required in order to establish aquaculture according to the forecasted production or species to rear. For instance, a pH level higher than 5.5 is considered to be necessary to maintain the farming of salmonid species (Alanära & Andersson, 2000).
1.4.5 Ecosystem Services

Different studies and classification systems often use different terms for describing and classifying ecosystem services (Maes et al., 2013, 2014; Millennium Ecosystem Assessment, 2005; TEEB, 2010). This thesis approaches the concept of ecosystem services according to the guidelines of the European Environment Agency and consequently to the CICES (Common International Classification of Ecosystem Services) (Haines-Young & Potschin, 2013; Maes et al., 2013, 2014).

Ecosystem services represent the flow of services and goods for which there is demand and from which, in turn, people benefit. Ecosystem functions represent the potential that ecosystems have to deliver services, irrespective whether or not they are useful for humans (Maes et al., 2013). Consequently, without any human implication it is impossible to detect ecosystem services, in that case is so necessary to use the concept of ecosystem functions.

Ecosystems with a good health status possess the full potential of ecosystem functions but it is possible that operations of ecosystem management are carried out in order to improve the delivery of a certain service. Ecosystem management refers to the labour, capital, operations or energy needed to obtain certain benefits. But operations of ecosystem management can lower the amount or quality of other services that ecosystems are or could be delivering or at the cost of the state of ecosystems (Maes et al., 2013).

This implies the concept of trade-offs; ecosystem services trade-offs derive from management choices made by society, which can change the type, magnitude, and relative mix of services provided by ecosystems. Trade-offs occur when the provision of one ecosystem service is reduced as a consequence of increased use of another one. In some cases, a trade-off may be an explicit choice, but often trade-offs arise without premeditation or awareness about them (Rodriguez et al., 2006). Trade-offs among provisioning and regulation and maintenance services are a known issues but often they are not effectively included into policy making and planning or development processes (Tuvendal, 2012).

It is possible to apply the concept of trade-offs to aquaculture. Aquaculture is in fact considered to be an ecosystem service. As mentioned before, operations of ecosystem management can be required in order to improve the delivery of a certain service. For instance the service of aquaculture needs external inputs of chemicals in order to manage hygienic issues within the cage system. But as stated before these operations might have consequences both on the ecosystem and on other ecosystem services. So the chemical inputs might endanger the ecosystem itself or the delivery of other services. The environmental impacts reported in Section 1.4.3 are consequences of operations of ecosystem management required by aquaculture and are addressed as possible drivers of trade-offs among ecosystem services.

1.4.6 The Common International Classification of Ecosystem Services

The Common International Classification of Ecosystem Services (CICES) is a method developed by the European Environment Agency in order to standardize nomenclature use in ecosystem services identifications (Haines-Young & Potschin, 2013). In the same way of the Millennium Ecosystem Assessment and The Economics of Ecosystems and Biodiversity systems, the CICES divides
ecosystem services into three categories: provisioning, regulation & maintenance and cultural. Provisioning services include all material and biota-dependent energy outputs from ecosystems; they are tangible things that can be exchanged or traded, as well as consumed or used directly by people in manufacture. Regulation and maintenance services include all the mechanisms thanks to which ecosystems control or modify biotic or abiotic parameters that define the environment of people (Maes et al., 2013). These are ecosystem outputs that are not consumed but affect the performance of individuals, communities and populations and their activities (Haines-Young & Potschin, 2013). Cultural services include all non-material ecosystem outputs that have symbolic, cultural or intellectual significance (Maes et al., 2013). These major “Sections” are in turn expanded into “Divisions” which are composed by a series of “Groups”, “Classes” and “Classes type”. This structure provides a clear and easy to follow approach that is considered to include, in a systematic way, the most important ecosystem services provided by a specific ecosystem.

It is important to note that abiotic environmental outputs, which often affect ecosystems and their services, are not included in the main approach but are addressed in a separate ‘Complementary classification table’ (Haines-Young & Potschin, 2013).

The CICES is adopted in this thesis since guidelines from the EEA recommend its use in order to carry out similar tasks; furthermore it is considered to be a useful and appropriate tool according to the purposes and aims of this thesis.
2. Methods

This thesis applies different methods in order to answer each of the three research questions in Section 1.2. In the following sections the different techniques, tools and methodologies applied are described in relation to the research question for which they are used.

2.1 Which are the most important ecosystem services provided by Lake Storsjön?

In order to define the most important ecosystem services provided by Lake Storsjön, an ecosystem services identification is required. The identification is carried out following the scheme of the Common International Classification of Ecosystem Services (CICES, version 4.3).

The information used for the identification are obtained via literature research but also thanks to personal communications. The literature research is oriented towards previous CICES reports and scientific articles that analyse specific ecosystem services provided by lakes with similar characteristics to Storsjön. This task is carried out using web-based tools such as portals and databases to reach the material required. Personal communications are performed via meetings, phone calls and e-mails; they are structured as discursive and format-free interviews in which the respondents are asked to assess the availability of a certain service and to provide relevant information about it (i.e. number of people accessing the service). A detailed list of the people contacted is available in Appendix 1.

Some modifications to the original CICES method are developed for this thesis. Only services that are totally dependent on abiotic sources are reported in the “Accompanying classification of abiotic outputs from natural systems”. The services that could be considered to be both biotic and abiotic or partially dependent on abiotic resources are reported with the biotic services. Furthermore the services of “Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants and animals”, “Filtration/sequestration/storage/accumulation by ecosystems” and “Dilution by atmosphere, freshwater and marine ecosystems” are discussed together in the same sections. This choice is made because for the specific case of Lake Storsjön some of these actions are at the same time carried out by biotic-abiotic components as well as by a joint action of the components of the ecosystems (micro-organisms, algae, plants and animals). Consequently these services are summarized into the single service “Filtration/sequestration/storage/accumulation/dilution by micro-organism, algae, plants, and by ecosystem” that doesn’t distinguish in detail which exact component of the ecosystem is carrying out a specific action.

2.2 Which ecosystem services will be affected by the expansion of aquaculture in Lake Storsjön?

A Delphi inspired approach is used in order to identify which and to what degree ecosystem services will be affected by aquaculture expansion in Lake Storsjön.
2.2.1 The Delphi approach

This approach is inspired by the original Delphi method but it has some differences. In principle it aims to collect and harmonize the opinions of a panel of experts on the issue (Börjeson, et al., 2005). The panel is set up according to the competences and the qualifications of the experts, which are connected to the fields of water chemistry, aquaculture, water protection, spatial planning and environmental science. The following experts are selected: Massimo Cati, Anders Hagström, Ingemar Näslund from Länsstyrelsen Jämtlands län and Erik Olofsson from the company Storsta AB (See Appendix 1 for more detailed information concerning the panel). The panel is asked to fill the matrix (See Section 2.2.2) with numerical values that reflect the magnitude of the possible impact of aquaculture over the ecosystem services provided by Lake Storsjön. The panel is asked to carry out this task according to its personal knowledge and view of the issue. In contrast to the original procedure of the Delphi method, the results are collected and a mathematical average is calculated for each impact over each service. So the approach used in this thesis does not aim to obtain a consensus forecast or judgement (as the original Delphi does) but aims to extrapolate a generic trend from the different opinions of the panel. Furthermore this approach is based on surveys sent individually to the panel and does not include any consultation among the experts involved, in contrast to the original Delphi method (Börjeson et al., 2005).

2.2.2 The matrix

The matrix used in the Delphi approach is designed in order to establish links between the identified ecosystem services of Lake Storsjön and the discussed environmental impacts from the potential expansion of aquaculture. So the results provided by the CICES identification of the ecosystem services of Lake Storsjön are linked to the environmental impacts described in the Section 1.4.3 and established according to the limitations reported in Section 1.3.2.

Only thirty out of the thirty-nine services identified are insert in the matrix.. The service “Animals from in situ aquaculture” is not included because there is no direct environmental impact of aquaculture on aquaculture itself. The services “Filtration/sequestration/storage/accumulation by micro-organism, algae, plants and animals”, “Filtration/sequestration/storage/accumulation by ecosystems” and “Dilution by atmosphere, freshwater and marine ecosystems” are summarized by the service “Filtration/dilution/sequestration/storage/accumulation by ecosystem”. Then abiotic outputs a part from “Renewable abiotic energy sources” are not included because of a too wide degree of uncertainty concerning their identifications.

The experts are asked to fill in the matrix according to Table 1, which shows the evaluation scale to use when assessing the magnitude of the impact over the service.
Table 1: Evaluation scale used in the matrix sent out to the expert panel of the Delphi approach for assessing the possible impact of aquaculture on ecosystem services.

<table>
<thead>
<tr>
<th>Value</th>
<th>Magnitude</th>
<th>Description</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No impact</td>
<td>No consequences for the ecosystem service</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Low impact</td>
<td>Small affection for the ecosystem service</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Medium impact</td>
<td>Relevant affection of the ecosystem service</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>High impact</td>
<td>Possible depletion of the ecosystem service</td>
<td></td>
</tr>
</tbody>
</table>

A numeric value (from “zero” to “three”) corresponding to a magnitude (from “no impact” to “high impact”) is given to the cross between every impact and every service of the matrix. The single results are then averaged with the others and in the end translated into a color indicator in order to facilitate the understanding of the matrix for the reader.

2.3 Which ecosystem services will be used for the expansion of aquaculture in Lake Storsjön?

The selection of the ecosystem services required by aquaculture uses as its starting point the results of the CICES identification of Lake Storsjön. These ecosystem services undergo the same selection explained in Section 2.2.2 thus not all of the services identified are included in this task. After this selection the services are inserted in a chart to assess the degree of dependence of aquaculture over each service.

The identification is carried out by the author considering the environmental conditions usually necessary for aquaculture implementation reported in Section 1.4.4 and established according to the limitations reported in Section 1.3.3. The evaluation of the degree of dependence of aquaculture on a specific service is evaluated according to Table 2 which shows the evaluation scale to use when assessing the degree of dependence of the requirement over the service.

Table 2: Evaluation scale used in the Table 8 for assessing the possible dependence of aquaculture on ecosystem services.

<table>
<thead>
<tr>
<th>Value</th>
<th>Degree of dependence</th>
<th>Description</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No dependence</td>
<td>The service is not needed by aquaculture</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Partial</td>
<td>Aquaculture is partially dependent on the service</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Total</td>
<td>The service is fundamental for aquaculture</td>
<td></td>
</tr>
</tbody>
</table>

A numeric value (from “zero” to “three”) corresponding to the degree of dependence (from “null” to “total”) is given to the cross between every requirement and every service of the matrix.
3. Results

3.1 Ecosystem Services Identification

The results provided by the identification of the main ecosystem services provided by Lake Storsjön is reported in this section. The Tables from 3 to 6 include all of the services of the CICES and they show their availability for Lake Storsjön. The description of the ecosystem services available is reported into the specific sections in Appendix 2, Ecosystem services delivered by Lake Storsjön.

Table 3: Provisioning Ecosystem Services of Lake Storsjön.

<table>
<thead>
<tr>
<th>Division</th>
<th>Group</th>
<th>Class</th>
<th>Present in Lake Storsjön</th>
<th>Appendix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrition</td>
<td>Biomass</td>
<td>Cultivated crops</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reared animals and their outputs</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wild plants, algae and their outputs</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wild animals and their outputs</td>
<td>YES</td>
<td>See 2.1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plants from in-situ aquaculture</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Animals from in-situ aquaculture</td>
<td>YES</td>
<td>See 2.1.2</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>Surface water for drinking</td>
<td>YES</td>
<td>See 2.1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground water for drinking</td>
<td>YES</td>
<td>See 2.1.4</td>
</tr>
<tr>
<td>Materials</td>
<td>Biomass</td>
<td>Fibers and other materials from plants, algae and animals for direct use or processing</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Materials from plants, algae and animals for agricultural use</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Genetic materials from all biota</td>
<td>YES</td>
<td>See 2.1.5</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>Surface water for non-drinking purposes</td>
<td>YES</td>
<td>See 2.1.6</td>
</tr>
<tr>
<td>Energy</td>
<td>Biomass-based energy sources</td>
<td>Ground water for non-drinking purposes</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Mechanical energy</td>
<td>Plant-based resources</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Animal-based resources</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Animal-based energy</td>
<td>NO</td>
<td>-</td>
</tr>
</tbody>
</table>

According to Table 3, Lake Storsjön provides six of the sixteen provisioning services included in the CICES. The role of Storsjön in supplying provisioning services is mostly relevant for what concerns the use of its waters. In particular the provisioning of “Surface water for drinking” is a relevant service since most of the Municipalities surrounding the Lake are totally dependent on this service for the supply of this vital resource. The abstraction of “Ground water for drinking purposes” and of “Surface water for non-drinking purposes” still represent important services especially in the Municipality of Östersund, in particular for the provisioning of water for the snowmaking system of the Frösön ski slopes or for the cooling of a CHP plant. The provisioning of “Wild animals” generated by fishing is a partially important food source on a local level. The relevance of the provisioning of
“Genetic materials from all biota” is hard to assess and analyze, further research is required in order to investigate this service on a more detailed level.

Table 4: Regulation and Maintenance Ecosystem Services of Lake Storsjön.

<table>
<thead>
<tr>
<th>Division</th>
<th>Group</th>
<th>Class</th>
<th>Present in Lake Storsjön</th>
<th>Appendix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mediation of waste, toxics and other nuisances</td>
<td>Mediation by biota</td>
<td>Bio-remediation by microorganisms, algae, plants and animals</td>
<td>YES</td>
<td>See 2.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Filtration/sequestration/storage/accumulation by micro-organism, algae, plants, and animals</td>
<td>YES</td>
<td>See 2.2.2</td>
</tr>
<tr>
<td></td>
<td>Mediation by ecosystems</td>
<td>Filtration/sequestration/storage/accumulation by ecosystems</td>
<td>YES</td>
<td>See 2.2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dilution by atmosphere, freshwater and marine ecosystems</td>
<td>YES</td>
<td>See 2.2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mediation of smell/noise/visual impacts</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td>Mediation of flows</td>
<td>Mass flows</td>
<td>Mass stabilization and control of erosion rates</td>
<td>YES</td>
<td>See 2.2.3</td>
</tr>
<tr>
<td></td>
<td>Liquid flows</td>
<td>Buffering and attenuation of mass flows</td>
<td>YES</td>
<td>See 2.2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrological cycle and water flow maintenance</td>
<td>YES</td>
<td>See 2.2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flood protection</td>
<td>YES</td>
<td>See 2.2.6</td>
</tr>
<tr>
<td></td>
<td>Gaseous/air flows</td>
<td>Storm protection</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ventilation and transportation</td>
<td>YES</td>
<td>See 2.2.7</td>
</tr>
<tr>
<td>Maintenance of physical, chemical, biological</td>
<td>Lifecycle maintenance, habitat and gene pool protection</td>
<td>Pollination and seed dispersal</td>
<td>YES</td>
<td>See 2.2.8</td>
</tr>
<tr>
<td>conditions</td>
<td></td>
<td>Maintaining nursery populations and habitats</td>
<td>YES</td>
<td>See 2.2.9</td>
</tr>
<tr>
<td></td>
<td>Pest and disease control</td>
<td>Pest control</td>
<td>YES</td>
<td>See 2.2.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disease control</td>
<td>YES</td>
<td>See 2.2.11</td>
</tr>
<tr>
<td></td>
<td>Soil formation and composition</td>
<td>Weathering processes</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decomposition and fixing processing</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Water conditions</td>
<td>Chemical condition of freshwaters</td>
<td>YES</td>
<td>See 2.2.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical conditions of salt water</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Atmospheric composition and climate regulation</td>
<td>Global climate regulation by reduction of greenhouse gas concentrations</td>
<td>YES</td>
<td>See 2.2.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Micro and regional climate regulation</td>
<td>YES</td>
<td>See 2.2.14</td>
</tr>
</tbody>
</table>

According to Table 4, Storsjön provides sixteen of the twenty-one regulation and maintenance services included in the CICES. Storsjön plays a relevant role in the regulation and maintenance of liquid, materials and air flows. The Lake regulates both the quality and the quantity of a high amount of water. In particular the accumulation, retention and dilution of both nutrients, organic matter, metals and hazardous substances is important in ensuring an overall good water quality in the Lake and in the maintenance of acceptable ecological and chemical parameters. The Lake is extremely
important in supporting the balancing of the water flows in the region, also considered it connection to the Indalsälven catchment area. In these terms the “Flood control” action naturally carried by Storsjön (in collaboration with the effect of the dam located in its outlet) is relevant considering possible catastrophic events such as possible failures in the dam system located in the Indalsälven’s upstream tributaries. The regulation of material flows has physical and chemical consequences on a regional level. In particular nutrients and organic matters movement within the Storsjön and Indalsälven catchment area are regulated and slow down thanks to sedimentation processes. The maintenance of air flows enhance also the regulation of the local climate together with other factors such as humidity and temperature control. A series of complementary services support the maintenance of a well-functioning ecosystem such as the “Maintenance of nursery populations”, “Pollination or seed dispersal” and “Pest control”. The service of “Disease control” seems to be vital as it has been demonstrated by the Cryptosporidium outbreak in 2010 (Östersunds Kommun, 2012). The service of “Global climate regulation by reduction of greenhouse gas concentrations” has an interesting environmental value but issues connected to carbon cycling for the specific case of this Lake have to be assessed and integrated into a more reliable and complex model.

Table 5: Cultural Ecosystem Services of Lake Storsjön.

<table>
<thead>
<tr>
<th>Division</th>
<th>Group</th>
<th>Class</th>
<th>Present in lake Storsjön</th>
<th>Appendix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical and intellectual interactions</td>
<td>Physical and experiential interactions</td>
<td>Experiential use of plants, animals and land/seascapes in different environmental settings</td>
<td>YES</td>
<td>See 2.3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical use of land/seascapes in different environmental settings</td>
<td>YES</td>
<td>See 2.3.2</td>
</tr>
<tr>
<td>Spiritual symbolic and other interactions</td>
<td>Intellectual and representative interactions</td>
<td>Scientific</td>
<td>YES</td>
<td>See 2.3.3</td>
</tr>
<tr>
<td>with biota, ecosystems, and land/seascapes</td>
<td></td>
<td>Educational</td>
<td>YES</td>
<td>See 2.3.4</td>
</tr>
<tr>
<td>(environmental settings)</td>
<td></td>
<td>Heritage, cultural</td>
<td>YES</td>
<td>See 2.3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Entertainment</td>
<td>YES</td>
<td>See 2.3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aesthetic</td>
<td>YES</td>
<td>See 2.3.7</td>
</tr>
<tr>
<td></td>
<td>Spiritual and emblematic</td>
<td>Symbolic</td>
<td>YES</td>
<td>See 2.3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sacred and/or religious</td>
<td>YES</td>
<td>See 2.3.9</td>
</tr>
<tr>
<td></td>
<td>Other cultural outputs</td>
<td>Existence</td>
<td>YES</td>
<td>See 2.3.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bequest</td>
<td>YES</td>
<td>See 2.3.11</td>
</tr>
</tbody>
</table>

According to Table 5, Lake Storsjön provides all of the eleven cultural services included in the CICES classification. The cultural services provided ranges from “Physical use of land/seascapes in different environmental settings” comprehending activities such as kayaking or ice-skating to “Symbolic interactions” such as the cultural influence of the monster of the Lake into local traditions and art crafts. The “Aesthetic intellectual and representative interactions” play a relevant role in characterizing the local and regional landscape and promote the development of different activities connected to the enjoyment of the scenery offered by Lake Storsjön such as golf clubs or restaurants. Lake Storsjön also provides the service of “Experiential use of plants, animals and land/seascapes in
different environmental settings” that guarantees many different areas for recreation activities. The Lake has intrinsic values providing the services of “Existence cultural outputs” or “Bequest cultural outputs”. Further cultural services are: “Sacred interactions” represented by churches located in a scenery in which the Lake plays a relevant role or “Scientific intellectual and representative interactions” consisting of scientific projects, organizations and initiatives connected to Lake Storsjön. Other cultural services provided are “Educational intellectual and representative interactions”, “Entertainment intellectual and representative interactions” and “Heritage, cultural intellectual and representative interactions”. These service seem to be variegated and hard to fully assess but they indicate how high the cultural value of Lake Storsjön is.

Table 6: CICES Accompanying Classification of Abiotic Outputs of Lake Storsjön.

<table>
<thead>
<tr>
<th>Section</th>
<th>Division</th>
<th>Group</th>
<th>Present in Lake Storsjön</th>
<th>Appendix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic provisioning</td>
<td>Nutritional abiotic substances</td>
<td>Mineral</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-mineral</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Abiotic materials</td>
<td>Metallic</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-metallic</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td>Regulation &amp; maintenance by natural physical structures and processes</td>
<td>Energy Mediation of waste, toxics and other natural nuisances</td>
<td>Renewable abiotic energy sources</td>
<td>YES</td>
<td>See: 2.4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-renewable energy sources</td>
<td>NO</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>By natural chemical and physical processes</td>
<td>YES</td>
<td>See: 2.2.1, 2.2.2</td>
</tr>
<tr>
<td></td>
<td>Mediation of flows by natural abiotic structures</td>
<td>By solid (mass), liquid and gaseous (air)flows</td>
<td>YES</td>
<td>See: 2.2.3, 2.2.4, 2.2.5, 2.2.6, 2.2.7</td>
</tr>
<tr>
<td></td>
<td>Maintenance of physical, chemical, abiotic conditions</td>
<td>By natural chemical and physical processes</td>
<td>YES</td>
<td>See: 2.2.8, 2.2.9, 2.2.10, 2.2.11, 2.2.12, 2.2.13, 2.2.14, 2.2.15, 2.2.16</td>
</tr>
<tr>
<td>Cultural settings dependent on abiotic resources</td>
<td>Physical and intellectual interactions with land-/seascapes (physical settings)</td>
<td>By physical and experiential interactions or intellectual and representational interactions</td>
<td>YES</td>
<td>See: 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.3.5, 2.3.6, 2.3.7, 2.3.8</td>
</tr>
<tr>
<td></td>
<td>Spiritual, symbolic and other interactions with land-/seascapes</td>
<td>By type</td>
<td>YES</td>
<td>See: 2.3.8, 2.3.9, 2.3.10, 2.3.11</td>
</tr>
</tbody>
</table>

According to Table 6, the only pure abiotic output is the one connected to hydropower production. Lake Storsjön is used as a basin for the hydropower dams located downstream the output of the Lake into the Indalsälven River (Asklund, 2015).
3.2 Identification of the ecosystem services that will be affected by aquaculture expansion

In the following section the findings of the investigation over which ecosystem services will be affected by aquaculture expansion of Lake Storsjön are presented. Table 7 shows the results of the Delphi approach according to the grading scheme reported in Table 1, in Section 2, “Methods”. Below Table 7, each environmental impact and its possible effects on the ecosystem services provided by Lake Storsjön is presented.

Table 7: Matrix of the Delphi Approach Identification of Ecosystem Services of Lake Storsjön that will be affected by Aquaculture Expansion. Note that Table 8 includes only the services that will be affected; the services that have been identified as not perceiving any impact are not reported.

<table>
<thead>
<tr>
<th>Ecosystem Services of Lake Storsjön</th>
<th>Environmental Impacts of Aquaculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nutrient loads</td>
</tr>
<tr>
<td>Wild animals</td>
<td></td>
</tr>
<tr>
<td>Surface water for drinking</td>
<td></td>
</tr>
<tr>
<td>Genetic materials from all biota</td>
<td></td>
</tr>
<tr>
<td>Surface water for non-drinking purposes</td>
<td></td>
</tr>
<tr>
<td>Bio-remediation by micro-organisms, algae, plants and animals</td>
<td></td>
</tr>
<tr>
<td>Filtration/dilution/sequestration/storage/accumulation by ecosystem</td>
<td></td>
</tr>
<tr>
<td>Buffering and attenuation of mass flows</td>
<td></td>
</tr>
<tr>
<td>Maintaining nursery populations and habitats</td>
<td></td>
</tr>
<tr>
<td>Pest control</td>
<td></td>
</tr>
<tr>
<td>Disease control</td>
<td></td>
</tr>
<tr>
<td>Chemical condition of freshwaters</td>
<td></td>
</tr>
<tr>
<td>Experiential use of plants, animals and land/seascapes in different environmental settings</td>
<td></td>
</tr>
<tr>
<td>Physical use of land/seascapes in different environmental settings</td>
<td></td>
</tr>
<tr>
<td>Heritage, cultural intellectual and representative interactions</td>
<td></td>
</tr>
<tr>
<td>Aesthetic intellectual and representative interactions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>No impact</td>
<td>Green</td>
</tr>
<tr>
<td>Low impact</td>
<td>Yellow</td>
</tr>
<tr>
<td>Medium impact</td>
<td>Orange</td>
</tr>
<tr>
<td>High impact</td>
<td>Red</td>
</tr>
</tbody>
</table>
3.2.1 Nutrient load

According to Table 7, nutrients load is the environmental impact that affects the most the ecosystems services of Lake Storsjön. The services of “Wild animals”, “Filtration/dilution/sequestration/storage/accumulation by ecosystem” and “Chemical condition of freshwater” might be affected on a relevant level; furthermore other eight services will be affected on a low level. Since nutrient loading is a direct consequence of the production rates of aquaculture, the effective affection level might change according to the established degree of aquaculture expansion in Lake Storsjön. But on a qualitative level it is already possible to identify some of the possible negative consequences. Issues connected to nutrient loading and water quality or alteration of the phosphorus and nitrogen cycles are well known and might occur (Manahan, 2010). Consequently Storsjön’s capacity of delivering maintenance and regulating services might decrease or be endangered. Harms to the local fauna might be consistent because of changes in the chemical and biological conditions of the lake (leading in the worst case scenario to eutrophication processes), thus a possible reduction of this provisioning service could be expected. Among the most relevant service possibly affected on a small scale, it is important to underline the presence of the provisioning service of “Surface water for drinking”, whose importance has already been highlighted. Some cultural services might be affected too; in fact excessive loads altering the biological and chemical conditions of water can lead to unfavourable consequences. The service of “Experiential use of plants, animals and land/seascapes in different environmental settings” might be endangered since consequences of nutrients load could lead to eutrophication problems (Manahan, 2010). The service “Aesthetic intellectual interactions” might be affected too since the Lake could lose its actual visual appealing status (Smith et al., 1999).

3.2.2 Use of antibiotics, pesticides and chemicals

According to Table 7, the use of antibiotics, pesticides and chemicals is considered to be one of the two most harmful for the ecosystem services of Lake Storsjön. Three services might undergo relevant affections: “Wild animals”, “Bio-remediation by micro-organisms, algae, plants and animals” and “Genetic materials from all biota”. Possible impacts over the “Bio-remediation by micro-organisms, algae, plants and animals” might concur in damaging and depleting a service which is demonstrated to already not function according to the maximum degree possible. Other eight services might undergo small affections, among these ones, the most relevant are the provisioning of “Surface water for drinking”, the regulation of “Chemical condition of freshwater” and the cultural service of “Physical use of land/seascapes in different environmental settings”.

3.2.3 Spread of diseases and parasites

The spread of diseases and parasites might damage on a high level the provisioning service “Wild animals” while the services of “Maintaining nursery populations and habitats” and “Disease control” might be affected on a medium level. Wild animals might face outbreaks of diseases and parasites from direct contact with reared fish (escapees) or from the spread through the water (FAO, 2005). Issues connected to parasites and disease can lead to biodiversity losses and degradation of the ecological conditions of Storsjön. Diseases and parasites originated by reared fish are hardly
transmitted to people (Länsstyrelsen Jämtlands län, 2015). Consequently the affection of the disease control carried out by Storsjön has to be mostly considered without an anthropocentric focus. The ability of the ecosystem of self-regulating and resist to diseases might be endangered by the possible increased pressure caused by frequent diseases outbreaks. Table 7 shows also that other six services might be affected on a low level. The impacts on the biota might in turn cause lower affections to other services such as “Maintenance of nursery populations and habitats” or “Filtration/dilution/sequestration/storage/accumulation by ecosystem”. Cultural services might also be affected on a small scale since the spread of diseases and parasites would change the actual ecological status of Storsjön; consequently the experiential use of plants, animals and land/seascapes in different environmental settings might probably be impoverished.

3.2.4 Spread of invasive species

According to Table 7, the spread of invasive species might have consequences on a relevant level for the provisioning service “Wild animals” and the regulating and maintenance service “Disease control”. Escapees from cages might represent a risk for the local fauna of Storsjön both because might be competing for the same food sources but also in case of predation and alteration of the ecosystem dynamics (FAO, 2005). The previous introduction of species such as Lake Trout in Storsjön has shown how invasive species can easily proliferate and alter the ecosystem balances (Andersson, et al., 2011). The possible impoverishment of the ecosystem of Storsjön might in turn effects on a lower level other services such as “Genetic materials from all biota”, “Maintaining nursery populations and habitats” or “Pest control”. The spread of invasive species might endanger the ability of the ecosystem of controlling diseases. Since genetically variable ecosystems are more resistant to pathogens and diseases, then an impoverished ecosystem could be weaker and more easily attackable (Alahuhta et al., 2013). As discussed for the spread of pests and diseases, changes in the local ecosystem might have consequences on cultural services such as “Experiential use of plants, animals and land/seascapes in different environmental settings” or “Heritage, cultural intellectual and representative interactions”. But the affection might is regarded as low since the direct interactions between people and the Lake’s fauna are likely to occur in a limited range of situations.

3.2.5 Physical use of the landscape

As can be seen from Table 7, the physical use of the landscape impact might have consequences only on cultural services. The service “Physical use of land/seascapes in different environmental settings” might be affected on a relevant level while the services “Experiential use of plants, animals and land/seascapes in different environmental settings”, “Heritage, cultural intellectual and representative interactions” and “Aesthetic intellectual and representative interactions” could be affected on a small scale. The introduction of cage systems might clash with opposing interests connected to the summer recreational values or activities provided by the Lake and with the intellectual interactions provided by the ecosystem (Alanära & Andersson, 2000; Cati, 2015i). Issues connected to opposing interests could cause losses on a societal and economic level since the coexistence of aquaculture and leisure activities such as water sports and swimming might be problematic if not carefully managed (Naturvårdsverket, 1993). But the degree of affection is ranked as low and this might suggests that this issue could not occur often because of the extensive water surface of Storsjön and because of a perceived trust in good planning for aquaculture development.
For what concerns the possible negative consequences on the intellectual interactions provided by Storsjön, then the degree of affection might have been ranked as low since the perception of this impact is dramatically variable and it strongly relies on the personal opinion of people. If aquaculture is perceived positively, then the interactions might not be affected while if aquaculture is perceived negatively then a negative affection is likely to occur (Cati, 2015i).

3.3 Identification of the ecosystem services possibly required by aquaculture expansion

The results of the identification of the ecosystem services possibly required by aquaculture expansion in Lake Storsjön are reported in Table 8. The degree of dependence on each service is graded according to Table 2, available in Section 2, “Methods”. The services are presented in the following sections according to the degree of dependence of aquaculture.

Table 8: Matrix of the Ecosystem Services Required by Aquaculture Expansion in Lake Storsjön and of the Respective degree of dependence. Note that Table 8 includes only the services that will be necessary to aquaculture; the services for which aquaculture has a null degree of dependence are not reported.

<table>
<thead>
<tr>
<th>Ecosystem Services of Lake Storsjön</th>
<th>Degree of dependence of aquaculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water for non-drinking purposes</td>
<td>Total</td>
</tr>
<tr>
<td>Filtration/dilution/sequestration/storage/accumulation by ecosystem</td>
<td>Total</td>
</tr>
<tr>
<td>Buffering and attenuation of mass flows</td>
<td>Partial</td>
</tr>
<tr>
<td>Pest control</td>
<td>Total</td>
</tr>
<tr>
<td>Disease control</td>
<td>Partial</td>
</tr>
<tr>
<td>Chemical condition of freshwaters</td>
<td>Total</td>
</tr>
<tr>
<td>Renewable abiotic energy sources</td>
<td>Total</td>
</tr>
</tbody>
</table>

3.3.1 Total dependence

As can be seen in Table 8, aquaculture expansion might be totally dependent on three services: “Surface water for non-drinking purposes”, “Filtration/dilution/sequestration/storage/accumulation by ecosystem” and “Chemical condition of freshwaters”.

Aquaculture totally relies on the availability of the service “Surface water for non-drinking purposes”. The volume of water provided by Lake Storsjön is the most fundamental condition for the establishment of aquaculture; it is clear that without any adequate volume of water then any expansion is not possible.

The service of “Filtration/dilution/sequestration/storage/accumulation by ecosystem” is considered to be fundamental since it ensures critical conditions for aquaculture with regards to water quality,
animal welfare and health issues. The actions of carried out by the Storsjön ecosystem concern different categories of substances such as nutrients, organic matter, metals and hazardous agents. Considering nutrients and organic matter, this service is fundamental in dispersing and sequestrating phosphorus, nitrogen and carbon compounds released into the Lake so that background levels are kept at acceptable level for aquaculture development. High concentration of metals can negatively affect the health of the reared fishes leading to the development of diseases and to death. Thus this service guarantee proper conditions for aquaculture expansion. The effect of this service on hazardous compounds detected in Lake Storsjön avoids also possible negative consequences in terms of excessive uptakes in the farmed species (Alanära & Andersson, 2000). The dependence of aquaculture is total since it affects a wide amount of conditions that are necessary for a successful development of aquaculture. If this service is lost or depleted then it might not be possible to implement aquaculture in Lake Storsjön.

The regulating & maintenance service “Chemical condition of freshwater” allows the maintenance of certain parameters necessary to the establishment of aquaculture. In particular the average pH value ensured by Storsjön allows the development of aquaculture projects (values below 5.5 are demonstrated to be dangerous for the fishes) (Alanära & Andersson, 2000; Indalsälvens Vattenvårdsförbund, u.d.). The average alkalinity is also important in ensuring an appropriate water environment for the reared fishes. The average dissolved oxygen content is furthermore necessary for the growth and metabolic processes of the species farmed (Indalsälvens Vattenvårdsförbund, u.d.). Whenever these conditions would be altered or deteriorated then the possibilities for aquaculture development are dramatically lowered.

3.3.2 Partial dependence

Table 8 shows that aquaculture expansion in Lake Storsjön might be partially dependent on four services: “Pest control”, “Disease control”, “Renewable abiotic energy sources” and “Buffering and attenuation of mass flows”.

The service of “Pest control” might be needed because of two different reasons. First this service might avoid the direct negative effects of pest on the farmed fish. Second it might avoid negative implications for the Storsjön ecosystem that in turn could then lead to harms to the farmed fish. For what concerns the first effect, it is considered that only small pest species such as insects or microorganisms would be able to interact with the species in the cages; larger pest species such as fishes do not have to be included in this reasoning since they can’t affect the farmed species. Pest fishes do not compete for the same food sources as reared fishes and they can’t attack them because of the physical obstruction caused by the cage system. On the other hand small pest species could might prosper in the proximity of the cage environment causing diseases among the fishes. The control of these small pests carried out by the Storsjön ecosystem thanks to its biota might prevent direct negative consequences on the farmed. For what concerns the second effect, it is considered that the spread of weeds or algae might alter water quality parameters (pH level, oxygen content) and in addition lead to problems connected to eutrophication processes thus reducing the production potential of the waterbody (Havs och Vatten Myndigheten, 2015; Sheppard et al., 2006). But the oligotrophic status of Lake Storsjön and its large volume of water shall avoid issues connected to the spread of pest vegetation thus guaranteeing proper condition for aquaculture. In conclusion the
presence of pest species in Lake Storsjön is not assessed at the moment thus aquaculture is considered to be only partially dependent on this service in case of possible alterations in the ecosystem balance.

The service “Disease control” might be required by aquaculture since it has the potential of avoiding stress conditions that can lead to the development of diseases among the farmed fishes. Storsjön mostly supply this service in terms of maintaining suitable chemical conditions of freshwater and supplying an adequate amount of freshwater to the cage systems. These actions have the positive outcomes of avoiding inappropriate living conditions for the reared fishes and dispersing high concentrations of dangerous agents that could consequently lead to the development of diseases (Kautsky et al., 2000). Aquaculture is considered to be partially dependent on this service because Storsjön does not host any recognized diseases possibly affecting farmed species.

The service “Renewable abiotic energy sources” (hydroelectric production in the Indalsälven River) affects the waters of Lake Storsjön because of the established regulation levels. This affection has two consequences for aquaculture: a quantitative one and a qualitative one. The quantitative consequence is that the water volume of Lake Storsjön is altered thus aquaculture might be affected by this amplitude. But the level of dependence on this service is ranked as partial because the oscillation levels are regulated in order to not be high and they can be based also on the volume requirements established by aquaculture production. In case of extreme events requiring high oscillation levels then the degree of dependence could rise. The qualitative consequence is the runoff of nutrients and the degradations of the benthic conditions close to the shores cause by outflow of water and by the oscillation levels. This consequence enhances larger production of aquaculture in Lake Storsjön because the nutrient load capacity is incremented (Hedlund, et al., 2014). But the dependence on this side of this service is ranked as partial since aquaculture development could take place also without this specific consequence.

Aquaculture development requires certain background levels of nutrients and organic matter in the sediments (Alanära & Andersson, 2000). These background levels are originated by natural and anthropogenic sources. The service of “Buffering and attenuation of mass flows” is thus necessary in order to maintain adequate nutrient and organic loads in the sediments of Storsjön. The dependence on the service is categorized as partial since an eventual loss of this service could partially affect the nutrient load capacity of the Lake.
4. Discussion

4.1 Ecosystem services provided by Lake Storsjön

According to this thesis thirty-nine services of the CICES classification are currently provided by Lake Storsjön. These ecosystem services affect a wide number of sectors of society and they provide important economic, social and environmental values to the Municipalities of Berg, Krokom, Åre and Östersund.

The service of “Surface water for drinking” is particularly interesting since it provides to a large amount of population a fundamental resource that has only to be partially treated. Thus, among the provisioning services, this service can be considered to be essential and hardly replaceable. The provisioning of “Wild animals” does not play a really crucial role on an economic and societal level since the consumption of wild fish from Lake Storsjön is not considered to be fundamental for the food industry. The service “Animals from in-situ aquaculture” seems to represent a more reliable and manageable food source instead.

Despite being probably the less visible and detachable of the ecosystem services of Lake Storsjön, the regulating & maintenance services seem to be the most valuable ones in ensuring the current living conditions for the Municipalities surrounding Lake Storsjön. Most of the regulating & maintenance services might be almost impossible to replace or they might imply extremely high societal, economic and environmental losses in case of possible disruptions. They appear to be fundamental in balancing and maintain the current environmental conditions for the area of Lake Storsjön ensuring a welcoming and healthy environment.

The cultural services are deeply interconnected to many sectors of society and they play a relevant mostly on a social and economic level both on a local, regional and national scale. Since the development of Jämtland aims for sustainable growth, including tourism and attractiveness, then these services seem to be crucial in ensuring a high degree of welfare to the surrounding municipalities. The cultural services provide many employment opportunities in different fields such as tourism, scientific research, education, outdoor recreation and culture. At the same time these services provide a wide number of cultural heritage and environmental settings sites enhancing the attractiveness and health of the Storsjön ecosystem. These services are deeply integrated in society and they can be considered to be hardly substitutable.

The abiotic output “Renewable abiotic energy sources” is particularly relevant on a societal and economic level and it might be hard to substitute in a short term perspective.

Some of the services might be impossible or hard to substitute. Other services can be considered to be quite unique. The degradation or loss of other services might imply relevant consequences in a social, economic and environmental perspective.
4.2 Identification of the ecosystem services that will be affected by aquaculture expansion

This thesis showcases that aquaculture expansion will impact or lead to trade-offs with fifteen of the ecosystem services provided by Lake Storsjön. This because operations of ecosystem management required by aquaculture have the potential to cause environmental impacts which can affect the others services provided by the Lake. Most of the possible environmental impacts connected to ecosystem management operations might have a low or medium impact over the other services and only one service might face a high degree of affection caused by a possible impact of aquaculture. The services that might perceive most of the relevant affections are: “Wild animals”, “Genetic materials from all biota”, “Bio-remediation by micro-organisms, algae, plants and animals”, “Disease control” and “Maintaining nursery populations and habitats”.

The environmental impacts that might cause more consequences are the nutrient loads together with the use of antibiotics, pesticides and chemicals. These impacts are followed by the spread of diseases and parasites, then the spread of invasive species and last the physical use of the landscape. The nutrient load might cause the possible impairments of services of “Filtration/dilution/sequestration/storage/accumulation by ecosystem” and “Chemical condition of freshwater”; they both could be hard to manage and they could imply social, economic and environmental losses. A damage on the service “Wild animals” is considered to possibly cause negative consequences on an environmental level more than a societal and economic one (note that the provisioning of wild fish implies the consideration of fishing as an activity to provide food and not as a leisure one). The use of antibiotics, pesticides and chemicals causing the affection of “Wild animals” might be concerning in an environmental perspective while the possible negative consequences on “Genetic materials from all biota” might be hard to fully assess and comprehend until accidents occur. The spread of diseases and parasites might not have heavy consequences on a social and economic level since the role of wild fishes in the local food supply chain is not believed to be crucial. But this issue shall be furthermore analysed. The spread of invasive species might have impacts mainly on an environmental level or possibly affecting services connected to fishing activities. The physical use of the landscape might affect only cultural services and it strongly relies on the personal perception of aquaculture thus it is considered to be the least impacting element.

It might be impossible to plan aquaculture expansion in order to totally avoid any consequence on the ecosystem services provided.

4.3 Identification of the ecosystem services possibly required by aquaculture expansion

Aquaculture expansion in Lake Storsjön might depend on seven of the ecosystem services provided. According to this thesis, especially without the availability of the provisioning service “Surface water for non-drinking purposes” or the regulating & maintenance services “Filtration/dilution/sequestration/storage/accumulation by ecosystem” and “Chemical conditions of freshwater” aquaculture expansion in Lake Storsjön would not be possible. These services are in fact fundamental in order to provide the conditions necessary for this sector. Also the services o
“Buffering and attenuation of mass flows”, “Pest control”, “Disease control” and “Renewable abiotic energy sources” are defined as partially necessary in order to support aquaculture expansion. It is clear that aquaculture requires in particular regulating & maintenance services in order to be expanded. These services supply some functions that would be hardly substituted by operations of ecosystem management.

4.4 How to steer a conscious aquaculture expansion in Lake Storsjön?

If aquaculture is perceived as a necessary factor to growth and development the needs of this sector (with regards to ecosystem services) and the consequences of ecosystem management operations on other ecosystem services should preferably be included into decision making processes.

The key in achieving a conscious aquaculture expansion in terms of ecosystem services relies then on the degree of implementation of ecosystem management operations, on the recognition of its trade-offs and on the preservation of vital ecosystem services both for aquaculture expansion and for society.

A practical implication of this reasoning might include the selection of native species to breed. Avoiding the use of alien species would reduce risks associated with escapees and consequent alteration of the ecosystem. Using native species might also reduce the risk of introducing external pests, pathogens and diseases in the Storsjön ecosystem. Then it might be optimal to avoid the use of hazardous agents and whenever not possible choose the most conscious alternative. The use of antibiotics, pesticides and hazardous chemicals shall be avoided to the maximum extent possible. Whenever not possible, the most environmentally conscious alternative available on the market shall be used.

Aquaculture might be perceived as a more relevant service than others by society (since its outcomes are more evident) and the arising trade-offs should preferably be recognized on a social, economic and environmental level. If this possibility is implemented in a democratic and legal way then this scenario will represent the need of the majority of society and shall be accepted. But it is fundamental to not forget that even in case of similar strategic choices, then the possibility for future generations to access ecosystem services of Lake Storsjön shall be maintained. Trade-offs among ecosystem services should only ever be accepted within their resilience capacity. Practically, this means that ecosystem management operations connected to aquaculture shall be considered sustainable and acceptable until they do not preclude the possibility of accessing certain ecosystem services in the future. This reasoning implies a more elastic view of ecosystem services in a resilience thinking perspective. Assuming this perspective lead to the consideration of ecosystem services as a system which is able to absorb disturbance and reorganize while undergoing a change and possibly maintain its ability of delivering benefits in a later stage (Tuven, 2012). In a nutshell the regeneration capacity of ecosystem services shall not be overshoot.

The ecosystem services that are demonstrated to be vital for aquaculture expansion shall be protected from environmental deterioration and other trade-offs. In addition they shall be protected from the possibility that an uncontrolled aquaculture expansion would directly affect them causing a collapse.
of the sector. At the same time the ecosystem services that are demonstrated to be hard to be substituted or vital for the society have to be maintained at the cost of a lower aquaculture expansion. For instance the importance of the provisioning service “Surface water for drinking” is clear and the results of this thesis assess that disturbances to this service might occur because of environmental issues connected to aquaculture. Although the possible degree of affection is ranked as low, it is not reasonable to endanger this service at any level. Aquaculture systems shall not be located close to uptake points from drinking water and furthermore they should not be placed in proximity to currents which usually transport water to these locations.

Accepting or establishing limits for eventual trade-offs in ecosystem services connected to aquaculture development as well as protecting the most relevant ecosystem services (both for society and aquaculture) and promoting a sustainable degree of implementation in ecosystem management operations is a responsibility left to the stakeholders involved in the management and administration of Lake Storsjön. The upcoming project “Vattenanvändningsplan för Storsjöns vattensystem” can be seen as the required common planning strategy that will include the stakeholders’ decisions concerning these issues.
5. Conclusion

According to this study Lake Storsjön delivers thirty-nine of the fifty-nine ecosystem services described by the Common International Classification of Ecosystem Services (six provisioning, sixteen regulating & maintenance, eleven cultural and six abiotic outputs).

Of these thirty-nine ecosystem services delivered, five have been identified to be specifically prone to be negatively impacted by aquaculture expansion in Lake Storsjön; these are: “Wild animals”, “Genetic materials from all biota”, “Disease control”, “Maintaining nursery populations and habitats” and “Filtration/dilution/sequestration/storage/accumulation by ecosystem”. For the other services the degree of affection is considered to be in between low and medium, not representing direct harm for the majority of the actual services delivered.

Three ecosystem services have been identified as vital for the expansion of aquaculture in Lake Storsjön; these are: “Surface water for non-drinking purposes”, “Filtration/dilution/sequestration/storage/accumulation by ecosystem” and “Chemical condition of freshwater”. These services have to be safeguarded and maintained in order to guarantee adequate conditions for an expansion of this sector.

An economic evaluation of the ecosystem services provided by Lake Storsjön and a comparison to the economic benefits guaranteed by aquaculture expansion could be a useful task in order to clearly define gains and losses as well as to deepen the trade-offs knowledge. Such an economic evaluation is not included in this thesis and it is only recommended as a possible future continuation of this work.

In addition to the economic perspective, it seems that the most relevant factor when discussing planning and development processes towards ecosystem services is the importance of not overshooting the resilience ability of the ecosystem in order to ensure the accessibility of the services to future generations. This belief is recommended to be applied to Lake Storsjön in order to guarantee a conscious expansion of the aquaculture sector on a social, economic and environmental level.
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# Appendix

## 1. Contacts

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Competence</th>
<th>Communication type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asklund, Ragnar</td>
<td>Jämtkraft AB, Kyrkgatan 21, 831 31 Östersund, Sweden.</td>
<td>Electric production management</td>
<td>E-mail</td>
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<tr>
<td>Cati, Massimo</td>
<td>Länsstyrelsen Jämtlands län, Residensgränd 7, 831 36 Östersund, Sweden.</td>
<td>Societal management</td>
<td>E-mail, meetings, phone calls</td>
</tr>
<tr>
<td>Hagström, Anders</td>
<td>Länsstyrelsen Jämtlands län, Residensgränd 7, 831 36 Östersund, Sweden.</td>
<td>Environmental protection management</td>
<td>E-mail, personal meeting</td>
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<tr>
<td>Johnsson, Kurt</td>
<td>Storsjödjurscenter, Svenstavik, Sweden.</td>
<td>n.a.</td>
<td>E-mail</td>
</tr>
<tr>
<td>Löfvenberg, Ulf</td>
<td>Östersund Kommun, Rådhusgatan 21-23, 831 35, Östersund, Sweden.</td>
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<td>E-mail</td>
</tr>
<tr>
<td>Näslund, Ingemar</td>
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<td>Water management</td>
<td>E-mail</td>
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<tr>
<td>Olofsson, Erik</td>
<td>Torsta AB, Ösaväge 20, 836 94 Ås, Sweden.</td>
<td>Aquaculture projects management</td>
<td>E-mail, phone call</td>
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<tr>
<td>Tajani, Kristina</td>
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<td>Ecology department</td>
<td>E-mail</td>
</tr>
</tbody>
</table>
2. Description of the ecosystem services delivered by Lake Storsjön

2.1 Provisioning services

2.1.2 Wild animals and their outputs

Lake Storsjön is the natural habitat of different species of birds, fishes, freshwater crustaceans and reptiles. The consumption of birds and reptiles is not widespread and culturally not popular in Sweden; while fishing freshwater crustaceans is strictly regulated and occurs only in sporadic cases due to the limited population currently living in the Lake (Sveriges Riksdag, u.d.). Because of these reasons only fish species are considered within this ecosystem services class. Sixteen different species of fish have been detected in the waters of Lake Storsjön. The most occurring species are: European Whitefish, European Perch, Char, European Smelt, Grayling, Burbot, Roach, Common Minnow and Alpine Bullhead. Other species reported in the Lake but whose occurrence is not documented are: Lake Trout, Arctic Char, Northern Pike, Crucian Carp, Ninespine Stickleback, Three-spined Stickleback and Brook Trout (Andersson, et al., 2011). It is estimated that Storsjön provides around 50 tons of fish per year with a distribution rate of around 5-7 Kg/ha (Cati, 2015c).

2.1.2 Animals from in-situ aquaculture

Two aquaculture farms are currently being run in the waters of Storsjön. The first farm is located in the Municipality of Östersund (Frösön), it produces 20 tons/year of Char and Rainbow Trout. The second farm is located in the Municipality of Berg (Vattenviken) and it produces 40 tons/year of Rainbow Trout only (Cati, 2015b).

2.1.3 Surface water for drinking

Six uptake stations provide surface water for drinking from Lake Storsjön. Four of them are located in the Municipality of Åre (Gärsta, Hallen, Vällviken, Arvesund), one is located in the Municipality of Östersund (Minnesgärdet) and one is located in the Municipality of Berg (Side). The total amount of extracted drinking water is 16,835 m³/day (Cati, 2015d). The uptake station of Minnesgärdet, located in the central part of Lake Storsjön, provides drinking water to the circa 60,000 inhabitants of the city of Östersund and it also provides drinking water to other farmland and villages around the Lake; it is considered to be the main uptake station because of these reasons (Jonsson & Agerberg, 2014). An unknown number of private users also extracts water from Storsjön for private water supplies.

2.1.4 Ground water for drinking

Ground water for drinking purposes is extracted within the Storsjön water system. The most important uptake station is located in Uddero (Krokom Municipality) where the current abstraction rate is of about 1,700 m³/day (Cati, 2015d).
2.1.5 Genetic materials from all biota

Both fish and plant genetic materials are expected to be provided by Lake Storsjön since this service is usually provided by similar lakes in Scandinavia (Alahuhta, et al., 2013). Despite the acknowledgment of the existence of this service still key gaps in knowledge are evident and they do not allow a deep understanding and identification (Harrison, et al., 2010).

2.1.6 Surface water for non-drinking purposes

In the Municipality of Östersund, water is extracted for artificial snow making needed for the ski slopes of Frösön. The maximum extraction rate is of 21,600 m³ per year. In addition, the CHP plant located in the Municipality of Östersund has the right to extract around 350,000 m³ of water per year for cooling use; the water, after the usage is returned to the Lake (Tajani, 2015). There is the suspect that water is abstracted for other purposes such as irrigation but there are no official data available.

2.2 Regulating and Maintenance Services

2.2.1 Bio-remediation by micro-organisms, algae, plants and animals

As in other freshwater ecosystems, bio-remediation processes might occur in Lake Storsjön and these are carried out by micro-organisms, algae, plants and animals which guarantee the accumulation or destruction of hazardous wastes and nutrients (Alahuhta et al., 2013; Bernes, 2001; Mananhan, 2010). There is a lack of studies conducted on Lake Storsjön for what concerns this issue thus it is impossible to refer to specific investigations when describing this service.

Bio-remediation processes in lakes such as Lake Storsjön, seem to be mostly effective for nutrients because of the cold temperatures of the water (Fröling, 2015). In this case, the role of aquatic vegetation could be considered particularly relevant because of actions of phytoaccumulation, phytodegradation, phytostabilisation, rhizodegradation and rhizofiltration carried out with regards to nitrogen and phosphorus (Alahuhta et al., 2013).

2.2.2 Filtration/sequestration/storage/accumulation/dilution by micro-organism, algae, plants, and by ecosystem

This service refers to the combined biophysical interactions of the biota (micro-organism, algae, plants and animals) and of the abiotic components of ecosystem itself (air, water, sediments) in carrying out a series of action needed in order to filtrate, sequestrate, store and dilute some substances that are released into freshwater ecosystems (Haines-Young & Potschin, 2013). There is a lack of specific studies concerning this ecosystem service and Lake Storsjön but the occurrence of the service in lakes with similar characteristics is proved (Alahuhta et al., 2013).

The main substances that are supposed to undergo these processes are those that can be found in Lake Storsjön: chlorinated pesticides, dioxins, industrial pollutants, flame retardants, heavy metals, nutrients, organobromide compounds, organotin compounds, perfluorinated substances, polyaromatic hydrocarbons and tributyltin compounds (Vatteninformationssystem Sverige, u.d.). These substances are spread both through long-range air transport and from local point sources (Länsstyrelsen Jämtlands län, 2014a). These local point sources are agriculture, forestry, storm water runoffs,
industry and domestic waste water activities (Alahuhta et al., 2013; Bernes, 2001; Länsstyrelsen Jämtlands län, 2014a).

The concentrations of most of these substances are generally very low in relation to the maximum values recommended by current environmental quality standards (Länsstyrelsen Jämtlands län, 2014a). But the concentration of TBT is above the current limit value. Furthermore the concentrations of PAHs, anthracene and TBT in sediments have to be considered high (Vatteninformationssystem Sverige, u.d.).

Other substances have started to be bio-accumulated at higher trophic levels. This shows that the loads of these substances are too high and that the ecosystem does not managed to carry out this service at its full potential. The results of the analysis of substances accumulated in European Perch muscles showed the presence of hexabromocyclododecane, perfluorooctanesulfonic acid, dioxins and polychlorinated biphenyl, but at levels below the current environmental quality standards (Länsstyrelsen Jämtlands län, 2014a).

Some heavy metals such as mercury, quicksilver are bio-accumulated and the concentrations of these substances in freshwater fishes of Storsjön do not comply with the EC Water Framework Directive (2008/105/EC and 2013/39 /EU) (Vatteninformationssystem Sverige, u.d.).

For what concern nutrients, Lake Storsjön absorbs and retains different phosphoric and nitrogen compounds but the Lake has not been regarded as subject to nutrient or organic enrichment. (Vatteninformationssystem Sverige, u.d.).

2.2.3 Mass stabilization and control of erosion rates

Since high hydrological flows can create floods that stimulate erosion, Storsjön can indirectly support the control of erosions rates in the southern Indalsälven catchment area thanks to its holding capacity in case of heavy rains or floods (Alahuhta et al., 2013). This service is not totally carried out on a natural base because of the controlled water volumes of the Lake required by hydropower plants located in the Indalsälven River (See 4.1). There could be the possibility that in order to increase the production on the Indalsälven River, then major outflows from the Lake could be allowed thus endangering the delivery of this service.

2.2.4 Buffering and attenuation of mass flows

Retention of soils and sediments is generally carried out by lakes in the Scandinavian region. Lake Storsjön is supposed to retain terrestrial inputs and to let them sediment or decompose within its water. These processes involve all of the matter that is drained into the basin of Storsjön from the catchment area of the lake and from the Indalsälven River as well as indigenous organic matter. In particular carbon, phosphorus and nitrogen are expected to undergo these processes. Buffering and attenuation of mass flows carried out by Storsjön partially avoids the uncontrolled run off of these materials in case of severe rain or floods events. It is relevant to observe that this service, if carried out at unsustainable rates, could in turn lead to negative consequences for the Lake such as the formation of a shallower bottom or alterations in the chemical and ecological status of the waters (Alahuhta et al., 2013).
2.2.5 Hydrological cycle and water flow maintenance

Lake Storsjön plays a relevant role within the Indalsälven catchment area and it supports the region in maintaining its hydrogeological cycles and water flows. Storsjön is used as a basin for hydropower production in the Indalsälven River thus the regulation of hydrological cycles and water flows is controlled (Asklund, 2015). The average water volume is of 8.88 Km³ (SMHI, 2015). The volume of water retained fluctuates according to the season and to the level established according to hydropower production (Asklund, 2015). The basin is filled during the spring meltdown and summer (when electricity usage is lower) while it is emptied during the autumn and winter season (when electricity demand is higher). Furthermore the Lake undergoes partial or total freezes of its surface during the winter and early spring seasons and it accumulates snow over it; at the meltdown the ice and snow are released into its waters. During the late spring Storsjön receives additional waters from the meltdown of the snow and from runoff from the nearby mountain region. Summer and autumn rain precipitation represent other inputs; the average precipitation rate is of 900 mm per year while the evaporation rate is of 250 mm per year (SMHI, 2005). The delta between the full and empty basin is of 1.25 Km³, this means a yearly oscillation of 2.75 m (Cati, 2015e; SMHI, 2005). In 2013 the average controlled inflow has been of around 125 m³/sec and the outflow has been of 278 m³/sec (SHMI, u.d.). The turnover time of Storsjön is approximately 1.2 year (Länsstyrelsen Jämtlands län, 2014a).

2.2.6 Flood protection

As many other Scandinavian lakes, Storsjön plays an important role in flood control as it can store additional water (Alahuhta, et al., 2013). The volume of Storsjön is of 8.88 Km³; this volume is partially controlled thanks to the damn system required by hydropower production in the River Indalsälven. Different scenarios have been assessed in order to determine the flooding levels possibly occurring; Storsjön is assumed to stand the 100-years flood without causing any risk for the human activities and settlements in the basin. Investigations are currently undergoing to assess the 500-years flood levels in the Municipalities of Åre and Östersund since this time frame would provide relevant information in case of more extreme floods connected to the forecasted climate changes in the region of Jämtland. Negative consequences have been assessed for the worst case scenario (break down of the Indalsälven damn system), in this case Lake Storsjön would not be able to withstand the flood and relevant areas (including settlements and infrastructures) are considered to be endangered (Cati, 2015f).

2.2.7 Ventilation and transportation

Storsjön regulates air flows thanks through difference of air pressure compared to terrestrial land (Alahuhta, et al., 2013). The average wind speed for the Storsjön area is between 5.5 m/s and 6.5 m/s (considering water as open land). Average wind speeds are higher than outer parts of Jämtland but the proximity of the Lake to the mountainous part of the region could be a reason behind this fact (SMHI, 2014). There is a lack of data concerning how and with what magnitude exactly Storsjön affects the local climate in terms of ventilation.

2.2.8 Pollination and seed dispersal
Despite the presence of pollination and seed dispersal is usually assessed for freshwater ecosystems and consequently for Storsjön too, still the magnitude and relevance of this service requires further investigation (Harrison et al., 2010). In particular freshwater plants are considered to be relevant for this service but ecological knowledge of dispersal of different biological groups is not well developed due to their different dispersal characteristics (Alahuhta et al., 2013).

2.2.9 Maintaining nursery populations and habitats

Storsjön is considered to provide habitat refuges for populations that usually habits oligotrophic and cold water bodies (Alahuhta et al., 2013). The morphological and ecological status of the Lake are classified as moderate. This classification shows that the Lake is supposed to hold the capacity of maintaining nursery population and habitat despite of changes in the flow, continuity and morphological conditions of its waters (Vatteninformationssystem Sverige, u.d.). Despite the provisioning of this service, Lake Storsjön is not stably maintaining nursery population and habitats of endangered species. All of the fish species reported to inhabit Storsjön are classified with a “Least concern” status in the “IUCN Red List of Threatened Species” (Andersson et al., 2011; IUCN, 2013). Due to the low or null occurrence of Swedish freshwater molluscs species and vascular plants species threatened at a European level, it is considered that Storsjön is not maintaining any of these Red Listed species (IUCN, 2013). Storsjön has been proven to provide valuable habitat to otters that are occasionally reported to inhabit the ecosystem; otters are protected since 1969 and in Sweden, the species is red listed with a vulnerable status. No occurrences of European crayfish are verified within Lake Storsjön. Anecdotal evidence suggests that crayfish has occurred. This stock disappeared probably in the late 1990s. Few scattered populations of signal crayfish can be found in Storsjön. The northern crested newt and the smooth newt (both protected by Swedish law) have been reported to inhabit some of the small ponds located in proximity of Storsjön (Länsstyrelsen Jämtlands län, 2015).

2.2.10 Pest control

Freshwater ecosystems such as Lake Storsjön can have a valuable role in biological invasion resistance and pest control. In particular fish species and waterfowls can regulate the widespread of insects (Alahuhta et al., 2013). But this service can be dramatically altered by human direct or indirect actions. For instance directly introduced species create a threat to freshwater biodiversity and climate change can further increase invasion of exotic species (Heino et al., 2009). Native species could not be able to stand these phenomena and thus this service could be endangered. The direct impacts from the introduction of new species might stem from predation, competition, and spread of parasites and diseases to which species native to boreal freshwater ecosystems are not adapted (Wrona et al., 2006).

2.2.11 Disease control

Lake Storsjön has been demonstrated to act as a disease control system thanks to the sedimentation and dilution of the concentration of fecal pollution which is in general known to spread a range of pathogens, such as virus, bacteria and parasitic protozoa. Specific outbreaks of Cryptosporidium hominis parasites in Östersund drinking water supplies, with consequent booms of gastroenteritis cases in the population, have underlined the crucial role of the Lake in controlling diseases (Jonsson & Agerberg, 2014). Whenever unfavourable specific conditions undermine Storsjön and its function to deliver this service then the risk of diseases increase. The service of disease control can be seen as
a direct consequence of pest control too. If species such as fishes manage to regulate the populations of insects (both native and invasive) then the possibilities of limiting the spread of diseases are increased (Alahuhta, et al., 2013).

### 2.2.12 Chemical condition of freshwaters

Lake Storsjön maintains and regulates the conditions of its freshwater. The overall chemical status of the Lake is considered not to be good because of certain concentration of pollutants that are considered to be too high according to the EC Water Framework Directive (Vatteninformationssystem Sverige, u.d.). But for other parameters Storsjön manages to regulate and maintain good chemical conditions of freshwaters. This service is assessed with the provisioning of data concerning chemical factors of the fresh water of Storsjön such as pH, COD, turbidity, alkalinity, conductivity and oxygen content. The values reported are averages of the data measured in 3 stations (Ytterån, Brunfloviken, Svenstavik) and refer to year 2014 for the pelagic area of the Lake. The average pH value is 7.6, the average COD is 6.2 mg/l, the average turbidity is 0.31 FNU, the average alkalinity is 0.36 mEq/L, the average conductivity is 6 mS/m and the average oxygen content is 11.2 mg/l (Indalsälvens Vattenvårdsförbund, u.d.). Lake Storsjön is not undergoing nutrient or organic enrichment and acidification processes; at the same time its waters are used as drinking water supplies (Vatteninformationssystem Sverige, u.d.). Consequently the service of regulating and maintenance of chemical condition of freshwater is successfully supplied by Lake Storsjön but some issues if not furthermore investigated and tackled could threat this service in the future.

### 2.2.13 Global climate regulation by reduction of greenhouse gas concentrations

Inland waters play a relevant role in the global carbon cycle and thus potentially affecting climate too (Tranvik et al., 2009). Lakes have to be considered both sinks and sources for carbon (Alahuhta et al., 2013). Most boreal lakes are consumers of organic carbon and sources of carbon dioxide to the atmosphere; lakes transfer terrestrially fixed carbon to the atmosphere. At the same time, lakes are carbon sinks, as they bury carbon in their sediments and thereby generate large pools of organic carbon in the boreal landscape; furthermore direct uptake of atmospheric carbon takes. It is assumed that Storsjön has the same behaviour of other boreal lakes thus functioning both as a source and as a sink in the carbon cycle. But the global climate regulation provided by Storsjön has to be mainly allocated to the direct uptake of atmospheric carbon and to the consequent carbon storage in the sediments. It has been calculated that the range of atmospheric deposition of dissolved organic carbon with precipitation over Swedish/Finnish lakes has to be assessed between 1 and 1.4 g of Carbon for square meter per year (Sobek et al., 2006). The direct uptake is carried out thanks to aquatic plants, algae and micro-organisms that in turn directly decreases the CO2 flux (Alahuhta et al., 2013; Tranvik et al., 2009). The uptake of CO2 then undergoes different cycles within the Lake, entering the pelagic carbon pool, and from there it can become part of the sediments or it can be transported out from the Lake with outflows. It has been demonstrated that boreal lakes in Sweden can store within their sediments as much as 19% of the carbon inputs in the system, while the downstream exports are considered to be 39% of the inputs (these refers to both dissolved inorganic carbon and total organic carbon) (Tranvik et al., 2009).

### 2.2.14 Micro and regional climate regulation
Despite the lack of specific information and studies concerning the specific effects of Storsjön on the micro and regional climate regulation it is possible to assess this service referring to the behavior of boreal lakes. Lake Storsjön, as other Scandinavian lakes, regulates the micro and regional climate thanks to a series of different actions carried out contemporarily. These actions are: balancing extreme climate conditions, influencing regional and local precipitation patterns and rates, reflecting sun radiations from water columns and absorbing heat (Alahuhta et al., 2013). A direct implication of these actions is a local or regional humidification of the atmosphere specifically during the summer. It is relevant to note that when boreal lakes are frozen, then their impact on the climate is generally reported to be weak (Krinner, 2003).

### 2.3 Cultural Services

#### 2.3.1 Experiential use of plants, animals and land/seascapes in different environmental settings

This service describes the experiential physical and intellectual interactions that can be established between nature and human beings. These interactions can be theoretically experienced in every part of Lake Storsjön since its entire surface could carry out this service. Nevertheless in order to facilitate the identification it is established that Lake Storsjön delivers this service specifically trough different type of areas such as Natura 2000 sites, natural reserves or former landscape protected areas. Even though these sites are partially located on land, the proximity of the Lake and its interaction with the terrestrial components is necessary in order to deliver the actual experiential value perceived. Within Berg Municipality there are two relevant sites: “Hoverberget” (Natura 2000 and natural reserve) and “Hackåsbygden” (former landscape protected areas). There are three relevant sites in Krokom Municipality: ”Aspbacken-Trång” (Natura 2000), ”Acksjön Rödön” (Natura 2000) and ”Väster Rödösundet – Krokomsviken-Åssjön” (former landscape protected area).

There are six sites located in Östersund Municipality: ”Odensalakärret” (Natura 2000-natural reserve), ”Grytan” (Natura 2000), ”Skansholmen” (Natura 2000), ”Andersön” (natural reserve), ”Söder om Vallsundet - gränsen Marieby socken” (former landscape protected areas). Within Åre Municipality there are around twenty sites on the western side of Storsjön which are former landscape protected areas (European Environment Agency, u.d.; Naturvårdsverket, u.d.). In total Lake Storsjön provides this service thanks to 178.9 ha of Natura 2000 sites, 1138 ha of Natural reserves and at least 186.6 ha of former landscape protected areas.

#### 2.3.2 Physical use of land/seascapes in different environmental settings

The physical use of Lake Storsjön takes place either during the summer and the winter season, when the Lake surface is frozen. A large number of activities is organized within the borders of Östersund Municipality while other activities relying on the individual willingness and interest are freely carried out in all the parts Storsjön. During the winter season, Östersund Municipality arranges the so called “Vinter Parken” on the shores and frozen waters of Storsjön. The winter park is the starting point for ice-skating and cross country skiing tracks, walking paths, horse-sledding and kite skiing; furthermore there is a wellness area provided with hot tubes connected to a bathing site, a hockey field and a playground for kids (Visit Östersund, 2014). Activities such as cross country skiing, ice skating, snow mobiling and walking over the frozen Lake are freely and independently carried out all over Storsjön and because of this reason it is impossible to measure the actual number people involved. During the
summer season a wide number of water sports and activities is carried out on Storsjön. Sailing and motor boating are privately practiced and a wide number of boats is harboured in Östersund and Frösön thanks to the Östersund Frösö Båt och Hamnföreningen which accounted 123 members in 2014 (Östersund Frösö Båt och Hamnförening, 2014). Kitesurfing, windsurfing and kayaking are practiced in the Lake on a private base thus is not possible to measure the number of users. Wakeboarding is practiced both with private motorboats and at Surfbukten, a cable park located in Östersund; Surfbukten received 9000 visitors during summer 2013 (Visit Östersund, 2013). Bathing is common during the summer season, there is a wide number of spots easily accessible and provided with facilities such as piers, gangways and picnic areas; some of the most popular spots in the Municipality of Östersund are: “Orrvikens Bad”, “Hara Byggä”, “Andersön”, “Frösö Strand”, “Minnesgärdet”, “Mårtensväken” and “Göviken” (Östersund Kommun, 2014). Fishing in Lake Storsjön is a popular activity, both during the summer and winter season (ice-fishing). The activity is generally free; but for trolling, use of fishing bait or nets within the territory of the four established fishing reserves (Berg, Krokom, Östersund and Åre) a fishing license is required. For the four fishing reserves, 371 licenses have been sold during 2014 (Cati, 2015g). It is estimated that around 5000 people fish every year in Lake Storsjön (Cati, 2015c).

2.3.3 Scientific intellectual and representative interactions

Lake Storsjön provides scientific intellectual and representative interactions. These interactions can be expressed in terms of scientific projects, articles and studies based on the Lake. Because of the wide borders of this class only some of the interactions are assessed. For what concerns articles and studies, the service is assessed in terms of scientific articles and studies available on four scientific databases such as: Science Direct, Springer Link, Web of Science and Diva. The results reported below are obtained using only the keyword “Storsjön” in the search engines and selecting articles that broadly discuss issues concerning Storsjön. Eight academic articles strictly concerning Lake Storsjön are detected; these articles belong to interdisciplinary fields such as geology, water chemistry and human geography. Some of the scientific projects connected to Storsjön are for instance “Indalsälvens Vattenvårdsförbund” or ”Vattenanvändningsplan för Storsjöns Vattensystem” and are carried out by different agencies or institutions (Indalsälvens Vattenvårdsförbund, u.d. ; Länsstyrelsen Jämtlands län, 2015).

2.3.4 Educational intellectual and representative interactions

Educational interactions are provided by Lake Storsjön but these interactions are already incorporated in other services such as “Cultural and heritage interactions” and “Experiential use of plants, animals and land/seascapes in different environmental settings”. These services seem to provide intellectual and representative interactions on their own and it is hard to assess this service as a standing alone service.

2.3.5 Cultural and heritage intellectual and representative interactions

Different sites in the proximity of Storsjön are reported to provide cultural and heritage intellectual and representative interactions. Despite the lack of particularly protected areas in these terms, a series of locations can be listed. Nearby the island of Andersön (Östersund) it is possible to visit the ruins of the church of Sunne which are close to the shores of the Lake (Länsstyrelsen Jämtlands Län,
“Skansholmen” is a site located on the island of Andersön (Östersund) that hosts the ruins of a 17th century fortress (Cati, 2015h). The entire island of Andersön itself is regarded as a cultural site because of the important traces that attest the agricultural development in the region as well as being the location of different battles during the Middle Ages (Länsstyrelsen Jämtlands Lan, u.d.). Traces of iron-making sites can be found in the “Myssjö-Oviken” area and around “Åsviken”. Iron-making took place at the lakeshore, where today can find furnaces and slags (Cati, 2015h). A few registered Stone Age settlements can be found around Storsjön. The settlements were discovered in sheltered bays on the island of Andersön and in the locations of “Myssjönäset” and “Åviken” (Cati, 2015h). Other cultural and heritage interactions are provided by the Jamtli Museum in Östersund whose outdoor section directly faces Lake Storsjön and aims to provide a reconstruction of life conditions in Jämtland during different historical periods. The link between Jamtli Museum and Storsjön is reinforced by different exposition that document the influence of the Lake in the local culture and history; during 2013, Jamtli received around 200,000 visits (Visit Östersund, 2013).

2.3.6 Entertainment intellectual and representative interactions

Different entertainment events and activities are partially dependent on Lake Storsjön in order to deliver their final value. This dependence is expressed by the intellectual and representative interactions established by the end users and the Lake. For instance, the music festival “Storsjöyran” organized in Östersund a part from the direct connection established with the Lake by the name of the festival provides entertainment interactions since the stage is located close by the water of Storsjön. Storsjöyran attracted 38700 visitors in 2012 (Visit Östersund, 2013).

2.3.7 Aesthetic intellectual and representative interactions

The presence of Lake Storsjön provides aesthetic intellectual and representative interactions. Its large extension and proximity to the nearby agricultural, forest and mountainous landscapes characterize a noticeable section of the Jämtland region as well as providing valuable views to the Municipalities that surrounds it. The aesthetic value of Lake Storsjön it is considered to be perceived by a large amount of people; its perception might take place during a wide number of moments, the performance of specific activities or and by specific sites. Some of the aesthetic interactions are already incorporated in other services such as the “entertainment interactions” or “physical use of land/seascapes in different environmental settings” thus this specific service is difficult to singularly assess. But some activities can be regarded as highly relying on aesthetic intellectual and representative interactions established with Storsjön in order to deliver their final value. For instance, during the winter season, the ski slopes of Gustavsbergbacken and Ladängen, located in Frösön (Östersund), offer a panoramic view over the city and Lake Storsjön and attracted 6915 visitors during winter 2013-2014 (Löfvenberg, 2015). Golf is played in different courses which offer a scenic view over Storsjön, such as Östersund-Frösö Golfklubb, Norderöns Golfklubb IF Njord and Sandnäset Golfklubb in the Municipalities of Östersund and Krokom. Other aesthetic interactions are provided by activities such as the bar Frösötornet or Arctura Skybar & Restaurant in Östersund that offer to their customers a privileged view over Storsjön. Frösötornet hosted 7150 visitors during 2012 being a famous tourist attraction in Östersund (Visit Östersund, 2013). Last but not least, it is relevant to consider this service in terms of scenic views provided to houses and specific sites such as the park “Badhusparken” in Östersund.
2.3.8 Symbolic interactions with biota, ecosystems, and land/seascapes

The strongest symbolic interactions provided by Storsjön is represented by the myth of the “Storsjödjuret” or the Lake Monster that according to the local tradition is believed to live in the waters of Storsjön since the middle Ages (Länsstyrelsen Jämtlands Län, 2014c). The myth of Storsjödjuret has led to the organization of several initiatives connected to it, especially for what concerns the tourism industry and kids entertainment. A centre (Storsjöodjurscenter) entirely focused on the Lake monster has been opened in Svenstavik in the Berg Municipality and in 2014 it received around 1000 visitors (Johnsson, 2015). Östersund’s Municipality has developed a mascot called “Birke” who is a friendly caricature of the Storsjöodjur and appears in official occasion to entertain the population. A series “Birke”-based gadgets, toys and books has been developed and it is currently sold online and in different shops of the region (Nestorville, 2014). The monster of Lake Storsjön has a relevant occurrence in artworks from the region too, from the oldest example of the ancient Frösön runestone, until contemporary local artists (Länsstyrelsen Jämtlands Län, 2014c).

2.3.9 Spiritual interactions with biota, ecosystems, and land/seascapes (environmental settings)

Seven different sites can be catalogued as providers of spiritual interactions with the biota, the ecosystem and the landscape of Storsjön. These sites are selected because of the presence of spiritual sites, such as churches and because of their proximity or view over Lake Storsjön. The mix of these two elements provides valuable spiritual interactions. In the Municipality of Östersund there are the Sunne kyrka, Frösön kyrka and Stora Kyrka; Frösön kyrka received during the year 2013 a total amount of 40000 visitors being the 5th most frequented attraction of the Municipality of Östersund (Visit Östersund, 2013). Other sites can be found in the Municipality of Berg: Hackås kyrka, Berg kyrka, and Myssjö kyrka. Finally Marby kyrka is located in the Municipality of Åre (Cati, 2015h).

2.3.10 Existence cultural outputs

Storsjön is considered to provide existence cultural outputs; these outputs are defined by the enjoyment of the idea that the Lake is existing. This service refers to the intrinsic value of Lake Storsjön and so to its existence per se. The service is surely provided but its magnitude has to be assessed; since Storsjön it’s the fifth biggest Swedish Lake, it is supposed that the existence service is delivered to a large fraction of the Swedish population more than the Jämtland one only.

2.3.11 Bequest cultural output

Lake Storsjön provides a bequest cultural output. This output can be summarized as the willingness to preserve Storsjön’s plants, animals, ecosystems, landscapes for the experience and use of future generations. This service implies moral/ethical perspective or belief within the current generations and it expresses the value that people place on knowing that future generations will have to enjoy Lake Storsjön. This output shall be considered particularly relevant for the local population since it is reasonable that it would perceive this service in a stronger way than people with weak connections to Storsjön. This service can be expressed in terms of value created (and distributed to the local population) by the knowledge of having the chance of leaving a valuable legacy (in terms of ecosystem services) to the next generations.
2.4 Storsjön’s CICES accompanying classification of abiotic outputs from natural systems

2.4.1 Renewable abiotic energy sources

Lake Storsjön belongs to the Indalsälven catchment area; the river is the only inlet and outlet of the Lake. Storsjön plays a relevant role in regulating and contributing to the electric production of 14 hydropower stations located downstream on the Indalsälven course (Asklund, 2015). Lake Storsjön is used as a water reservoir holding 8,88 cubic Km of water (Cati, 2015e); but because of its crucial role in balancing the Indalsälven catchment area it is considered that the hydropower generation of the river has to be attributed to Storsjön too. The overall installed capacity of the downstream plants is of about 1350 MW. In particular the hydropower station of Hissmofors, located at the confluence of Lake Storsjön into the Indalsälven River, directly produce electricity from the use of Storsjön waters. It is relevant to mention that there are also some big reservoirs upstream Storsjön that also regulate the water of the Lake on a yearly basis (Asklund, 2015).