  

D9.2 Case Study 6 Report

Understanding eutrophication processes and restoring good water quality in Lake Ringsjön and Rönne å Catchment in Kattegat, Sweden

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642317.

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Project coordination and editing provided by Ecologic Institute.

Manuscript completed in [09, 2018]

Document title	Report Case Study 6: Understanding eutrophication processes and restoring good water quality in Lake Ringsjön and Rönne å Catchment in Kattegat, Sweden
Work Package	WP9
Document Type	Deliverable
Date	August 2018
Document Status	Final Deliverable

Acknowledgments & Disclaimer

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 642317.

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About AQUACROSS

The project 'Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies' (AQUACROSS) aims to support EU efforts to protect aquatic biodiversity and ensure the provision of aquatic ecosystem services. Funded by Europe's Horizon 2020 research programme, AQUACROSS seeks to advance knowledge and application of ecosystem-based management (EBM) for aquatic ecosystems to support the timely achievement of the EU 2020 Biodiversity Strategy targets.

Aquatic ecosystems are rich in biodiversity

and home to a diverse array of species and habitats, providing numerous economic and societal benefits to Europe. Many of these valuable ecosystems are at risk of being irreversibly damaged by human activities and pressures, including pollution, contamination, invasive species, overfishing and climate change. These pressures threaten the sustainability of these ecosystems, their provision of ecosystem services and ultimately human well-being.

AQUACROSS responds to pressing societal and economic needs, tackling policy challenges from an integrated perspective and adding value to the use of available knowledge. Through advancing science and knowledge; connecting science, policy and business; and supporting the achievement of EU and international biodiversity targets, AQUACROSS aims to improve ecosystem-based management of aquatic ecosystems across Europe.

The project consortium is made up of sixteen partners from across Europe and led by Ecologic Institute in Berlin, Germany.

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1 Introduction and background

The Rönne å case study was selected to serve as an example of the application of resilience thinking in general and the resilience principles in particular for improved governance of aquatic ecosystem services and biodiversity. Complementary to other AQUACROSS case studies, emphasis was put on understanding the social dynamics behind ecosystem services (ESS) management in which decision makers can employ ecosystem-based management (EBM) for improving water quality. More specifically, this involved the collection of qualitative data to characterise social interaction processes and the use of stylised dynamic models to investigate the dynamics of the coupled social-ecological system (SES) emerging from social-ecological interactions enabled and constrained by social and ecological dynamics. We used resilience principles for the case study assessment and thus highlight an agency-centred perspective, the governance structures and long-term dynamics. This case thus follows a slightly different design than in the "standard" AQUACROSS case study with the aim to complement and compare to the ecosystem-based approach but in general adhering to the AQUACROSS Assessment Framework (AF) (Gómez et al. 2017, D3.2). Finally, the case study also served as an example for illustrating the process of stakeholder involvement in scenarios and for developing guidance for other AQUACROSS cases (Martin et al. 2018, D7.2).

Rönne å catchment area is located in Southern Sweden and includes lakes (e.g. Ringsjön) and rivers (Rönne å) leading into the Kattegatt sea (Figure 1). The structure of the Swedish water governance system is complex with multiple actors and frameworks on all scales: local (water councils, municipalities), regional (county administrative boards, water authorities), national (Swedish jurisdiction) and EU (Water Framework Directive (WFD), and more). Enhanced understanding of social-ecological complexity and how it can be accounted for through best-practice water management, multi-level governance and cross-sector collaboration is critical for addressing environmental problems, the provision of ESS and maintenance of biodiversity. In particular, we look at the process of restoring good water quality from the perspective of two water councils (Figure 1) and its implications for the provision of tourism-related ecosystem services along the Rönne å catchment.

1.1 Problem statement

AQUACROSS defines Ecosystem Services (ESS) as "those benefits humans get from ecosystems" (Gómez et al., 2016 but are rather co-produced in intertwined social-ecological systems (Palomo et al. 2016) and influenced by people's co-construction of meaning (Fischer and Eastwood 2016). Co-production highlights how the interaction between social (e.g. stakeholder preferences, objectives, actions, institutions, technology, finances and agency) and ecosystems effects ESS in their social-ecological context (Lele et al. 2013; Spangenberg et al. 2014). Social and natural interactions create trade-offs and affect the quantity, quality, resilience and equity of ESS and ultimately human well-being (Palomo et al. 2016). In line with applying the AQUACROSS Assessment Framework, our approach in the Rönne å catchment deviates from Palomo et al. (2016)'s conceptual model in two ways 1) we investigate ESS interactions (synergies, trade-offs and one-directional changes) not merely trade-offs and, 2) we focus on resilience by examining the meaning of resilience principles for the case.

Figure 1 Rönneå catchment with its municipalities and two subcatchments managed by two different water councils (Rönne River Council and the council for Lake Ringsjön).

Social-ecological processes and the interactions between ESS that emerge from the many ways humans interact with ecosystems are key to understanding how water governance can be improved. The development of scenarios can foster long-term systemic thinking and complement modelling well as it is adaptable and accessible (Bennett et al. 2003). Engaging stakeholders in this process fosters collective action to achieve desired goals and show how stakeholders might respond to future challenges (Bohnet and Smith 2007; Kok et al. 2008). It also provides context specific insights about water governance in the Rönne å catchment area, for example, concerning actors on various institutional levels. Stakeholder engagement is a central principle of EBM (D3.1) The research design has developed organically and balanced research objectives and stakeholder needs. Co-production and ESS interaction (i.e. synergies, trade-offs), dynamics of social-ecological interaction and how one might improve water governance through multi-scale change is interesting from a research perspective, whereas stakeholders want to learn about ESS in general and how they might be integrated into their planning.

Freshwater is the bloodstream of the biosphere and provides ESS that are essential for human-wellbeing (Folke 2003). Mismanagement has previously caused trade-offs in ESS with distinguished winners and losers (Howe et al. 2014), which highlights the importance of a sustainable and holistic governance to ensure the resilience of ESS. Resilience thinking addresses the dynamics of complex SES, i.e. the notion of people and nature as interconnected systems (Folke 2006). Resilience is the capacity of a SES to change and remain within critical thresholds, through adaptability (adjustment to change that enables continuation in the current trajectory), and transformation (the capacity to change trajectory when the current one is unsustainable) (Folke et al. 2010). Seven resilience principles have been identified (diversity and redundancy, connectivity, slow variables and feedbacks, complex adaptive systems thinking, learning, broad participation, polycentric governance) to enhance the resilience of ESS management and governance (Biggs et al. 2012) and are reflected in the AQUACROSS Assessment Framework (D3.2). Shallow lakes, such as Lake Ringsjön in our case, are prone to experience shifts between multiple stable states (Scheffer 1990), which makes it a complex system where non-linear dynamics need to be managed. Eutrophication is the most frequent cause for so called regime shifts between the clear and the turbid state. Increasing turbidity is associated with a decrease in aquatic biodiversity (Jeppesen et al. 2005, Urrutia-Cordero et al. 2017) and fewer ESS. We focus in this case on those ESS linked to water quality and take related biodiversity features into account implicitly.

1.1.1 Research questions

The aim is to understand in our research, from a stakeholder perspective, the following questions:

1. What social-ecological processes and factors are needed to co-create aquatic ESS in Rönne å catchment area?
2. What are the interactions between ESS (trade-offs, synergetic, one-directional) in Rönne å catchment area? Which of those appear only after time lags, are invisible in the landscape or mediated by governing institutions?
3. Exploring the connection to the resilience principles. Collaboration – what do the stakeholders define as collaboration and how does it relate to the resilience of aquatic ESS?
4. How are multiple interests in aquatic ESS supporting or hindering the restoration of the Lake Ringsjön which experienced a regime shift to the turbid state?
5. How can inter-sectoral and institutional conflicts be resolved to develop resilient, regional water governance respecting multiple ESS in the catchment?

1.1.2 Challenges and opportunities

In the Rönne å catchment in general, drinking water supply was the most valued ecosystem service by stakeholders (Löwgren 2005), which has been greatly affected by eutrophication. Lake Ringsjön, which was an important drinking water source used by 25% of the population of Skåne in the beginning of the 1980s, was degraded to a reserve drinking water source in 1987 as a direct result of its poor water quality (Hansson and Bergman 1999).

Lake Ringsjön has also provided services in terms of recreational swimming, boating and fishing, with the National Fisheries Board giving it status as a “nationally interesting lake” due to its high fish production (Ringsjökommittén 1991; Ryding 1983). Swimming was affected by eutrophication in the middle of the 1960s when it was reported that the water in Lake Ringsjön had become too unhygienic for swimming (Hansson and Bergman 1999), although water quality has since increased and no swimming restrictions are currently in place. Recreational fishing was also greatly affected by eutrophication in the lake as the activity dropped markedly during 1973-1989, although the interest increased during the 1990s (Hansson et al. 1999).

Nowadays, municipalities around the lake hope to develop tourism and living areas to attract commuters from nearby cities such as Lund. A clear lake would provide ESS that are particularly relevant for this. Management measures to reduce eutrophication in Lake Ringsjön try to tackle former trade-offs between agriculture and recreational activities, but simultaneously create new trade-offs between commercial fisheries and aims to improve water quality. The biomanipulation (removing a proportion of local fish, cyprinids, from the lake to reduce zooplankton predation) conducted in the lake improves the conditions for zooplankton species (Urrutia-Cordero, Ekvall, and Hansson 2016a; Urrutia-Cordero, Ekvall, and Hansson 2016b) and for large predatory fish (pike-perch, european perch, northern pike) . However recently, a stagnation in numbers of predatory fish was observed instead of expected increase which is likely attributed to ongoing fishing pressure from both commercial and recreational fishery (Nyström and Stenberg 2018).

The management of the river catchment is greatly influenced by the structure of water governance in Sweden, which has recently changed due to the implementation of the WFD and the introduction of water councils in the catchments (see section 2.1.2). However, the legal role/structure of water councils differs between catchments. Whereas in a neighbouring catchment (Kävlinge river catchment), cooperation between the municipalities and councils was settled with a contract, this is lacking for the Rönne å catchment. The water council (the most local institution for the WFD) lacks a legal mandate to foster decisions and restoration activities. Collaboration with municipalities differs a lot in quality and the lack thereof might hinder effective implementation of measures towards WFD goals. Two water councils could potentially merge: Rönne River Council and the council for Lake Ringsjön, which might extend the comparatively strong restoration activities around the lake to the whole catchment where restoration to restore good water quality was less prominent in the past.

1.2 Solutions proposed

The three municipalities around the lake and the public-private partnership for drinking water Sydvatten represented in the water council have a legal mandate and resources for measures in the lake area to improve water quality and shift the lake back into a clear water state. The main anthropogenic drivers linked to eutrophication are nutrient leakage from fertilisers in agriculture, insufficient municipal sewage treatment and insufficient private sewage treatment (Jöborn et al. 2005). In Sweden, nutrient inputs from agriculture and municipal wastewater treatment plants have been regulated since the early 1990’s and decreased nearly to levels that existed before lakes went turbid (Ekologgruppen 2017). A large part of today’s remaining nutrient inputs, 15% of phosphorus loads, result from untreated wastewater inflow from summer houses that lie at coasts and in the watersheds of lakes (Wallin et al. 2013). While regulations have been passed that make modern household sewage treatment mandatory, there is a high cost barrier for investing in this new technology, influencing the effectiveness of the measure (Wallin et al. 2013). A new sewage treatment system costs between 7 000 and 10 000 Euro and there are no government subsidies[1]. This has resulted in the total nutrient emissions from on-site sewage systems being almost as high as urban wastewater treatment plants (ibid.). Therefore, although we acknowledge the role that agricultural activities play in nutrient input, we take into account the regulation to reduce the level of effluent from

[1] https://avloppsguiden.se/faq/vad-kostar-det-att-anlagga-avlopp/

agriculture compared to the lack of reduction of effluent from private sewage treatment, and choose to focus on the regulations surrounding sewage treatment.

As well as targeting the sources of nutrient pollution, Höör municipality has over several years engaged in biomanipulation. Biomanipulation changes the dynamics locally in the lake by reducing the cyprinid (zooplankton-eating fish) population possibly enabling a shift, but the problem with eutrophication is caused on a larger scale (the catchment). This means that this measure will not change the root of the problem.

It is the aim of the water council to improve the water quality in Lake Ringsjön through a democratic and collaborative process. Suggestions to improve this process include strengthening collaboration between water councils so that catchment-wide management becomes better coordinated, and to strengthen cooperation between sectors and levels in the Swedish water governance structure (see section 2.2 and 4.1).

1.2.1 Co-designing research involving stakeholders

The research questions were investigated using a participatory approach in the Rönneå catchment area. In total, three workshops were held, two on municipality level (Höör/Hörby/Eslöv and Ängelholm, Nov 2016), and one on a regional level (Ringsjön and Rönneå water council, Dec 2016). Municipalities were selected by the stage of development of their comprehensive plan (see Annex I section 8.2), which is the main local framework for water management (described in section 2.1 below). Only those were considered who during the projects time were in the process of updating their comprehensive plan to ensure the relevance of workshops to stakeholders. We invited a diversity of stakeholders engaged in 1) drinking water, 2) sewage water, 3) strategic thinking (e.g. environmental planner) and 4) cultural aspects. Both politicians and civil servants were invited to connect with academics, local users, businesses, decision-makers, planners and practitioners providing complementing and broad perspectives. Each workshop (1 full day each) involved up to 12 stakeholders per session. Follow-up interviews with eight participants were conducted to validate insights from the workshops and to explore more in depth the basis of collaboration among multiple institutions related to local freshwater management. The scenarios designed in this collaborative study serve as thought experiments to provoke discussions among scholars as well as stakeholders as to a) how further insights can be generated on the quality and intensity of ESS interactions in SES, and b) how ESS interactions can be integrated into management plans.

2 Establishing objectives

Key Messages

- Agricultural activity and increasing amounts of wastewater from population growth are the primary causes of eutrophication in the Rönne å catchment. Regulations on agricultural activities through EU and national legislation have led to reductions in nutrient input from agriculture – from 1995 to 2000, agriculture was responsible for the largest decrease of 19%. Municipal wastewater treatment has also seen large reductions in nutrient output (10% within the same time period) (de Facto 2003). However, rural household sewage treatment has seen little improvement and low regulation enforcement.

- The policy framework around nutrient regulation consists of top-down policy and legislation that is implemented by government agencies, county administrative boards and municipalities. However, the Ringsjön water council and the lake committee before it have more actively managed the eutrophication problem in Ringsjön, not just putting in measures to reduce nutrients but also performing biomanipulation. Water councils rely on an active collaboration with the municipality and the top-down governance structures to receive funding for this management and therefore the resulting success of water councils in Sweden is heterogeneous.

This chapter explores the current and historical policy objectives for the management of nutrient pollution in the Rönne å catchment. This analysis allows a deeper understanding of the social aspects of our case study, which is of particular importance given our case study's focus on the collaboration between water councils. Additionally, understanding policy objectives for agriculture and wastewater, the key drivers of local nutrient pollution, supports our identification of EBM measures. For the research in our case study, we focus on nutrient pollution as the main threat to aquatic biodiversity. The focus area is the upstream catchment with its main water body Ringsjön, which has been the focus for research and many ecosystem services (particularly linked to tourism), but also consequences for the lower river catchment are considered. The main sources of nutrients – agricultural activity and sewage treatment (in particular, within rural households) – will be the focus of the policy analysis.

2.1 Identifying policy objectives

The two main frameworks – national environmental policy and the EU Water Framework Directive – for tackling agriculture and individual household wastewater discharge are described, with additional policies and legislation summarised in Table 1. We consider both sectoral (agriculture) and environmental policies, as both impact biodiversity (Deliverable 2.1), which in turn effects ecosystem-service provision (Deliverable 5.1).

2.1.1 Environmental legislation in Sweden

The central legislation on biodiversity and environmental issues in Sweden is the Environmental Code which came into force in 1999 (*Miljöbalk* 1998). This includes sectoral legislation developed prior to 1999. The Code is a framework law and so the rules and Ordinances associated with the Code are often made more specific by regulations issued by central government agencies in the environmental sector such as the Swedish Environmental Protection Agency and the National Chemicals Inspectorate (Ministry of Environment and Energy 1999). Therefore there is no central authoritative body implementing the Code, but rather it is used as guidance for all related authorities to follow.

Much of the later EU legislation has also been incorporated into this as amendments and new laws where appropriate. For example, the legal basis for the implementation of the WFD have been incorporated into Chapter 5 of the Code, together with the Ordinance (2004:660) on the government of water quality. The Environmental Code introduced **environmental quality standards**, a legally binding policy instrument which regulates the environmental impact of diffuse emission sources. The standards can be implemented nationwide or in particular geographical areas and are usually based on the requirements of EU Directives. For example, the target for 'good status' within the WFD has been broken down into environmental quality standards for water introduced in 2009 (Hörby kommun 2016).

There is also the Swedish Strategy for Biodiversity and Ecosystem Services (2014), which translates the EU Biodiversity Strategy to 2020 into Swedish milestones. This sets relevant overarching targets to be met by 2020, such as that "ecosystems have recovered, or are on the way to recovery, and their long-term capacity to generate ecosystem services is assured", and that "biodiversity and the natural and cultural environment are conserved, promoted and used sustainably". It additionally includes practical targets to support attainment of these overarching goals, such as increase knowledge of ecosystem services and biodiversity, implement more holistic management, as well as support county administrative boards and municipalities to assess biodiversity, amongst others.

Another important framework for environmental legislation in Sweden is the **Environmental Quality Objectives,** which were approved by the Parliament in 1999. The objectives form the basis of Sweden's environmental policy, which has the goal of handing the next generation a society where all major environmental problems are solved. There are 16 objectives, 7 of which directly target water quality management, the most relevant one being 'Zero Eutrophication'. With respect to nutrient levels in lakes and streams, this Environmental Quality Objective demands that the water bodies meet the requirements for good ecological status defined by the Water Framework Directive (see section 2.1.2) and that total P concentrations do not exceed 25µg/l (Nilsson 2012). The implementation of these filters down from government agencies to county administrative boards, who develop their own frameworks of measures to achieve the objectives (Länsstyrelsen Skåne 2016). The responsibility for each measure is delegated to municipalities, who have overall responsibility for regional and local adjustment of the objectives. Many municipalities have their own environmental goals - for example Höör sets the following local environmental goals in their management plan (Höörs kommun 2008):

- By 2015, the Secchi depth[2] in Ringsjön should be an average of at least 1.5m during the summer months
- By 2008, protected water areas should be based on an ecologically sensitive perspective
- By 2012, the knowledge around migrating trout in Höörsån should increase
- The knowledge about the state of the environment in the municipality's smaller lakes such as Tjörnarpssjön and Vaxsjön should increase

2.1.2 The Water Framework Directive

Implementation in Sweden

Before the WFD, the municipalities (local councils) played a key role in water management in Sweden through their responsibility for land and water resources planning (Lundqvist 2004). The county administrative boards acted as supervisory authorities linked to the national government. To implement the WFD, which requires water management on the scale of

[2] The depth at which a Secchi disc – a white-black disc lowered into the water – ceases to be visible from the surface of the water; a standard measure of water clarity.

hydrological boundaries in large river basin districts (RBDs), a new regional level of water management was introduced – the water authority, which each sit in a river basin district. The water authorities are exclusively responsible for developing River Basin Management Plans (RBMPs) and Programmes of Measures (PoMs). These documents are produced in a six-year cycle and include the analysis of water status and defined environmental quality objectives. The municipalities then develop comprehensive plans, required under the Planning and Building Act, according to these objectives. The municipalities implement the WFD through the environmental quality standards. They also produce local environmental objective programmes, containing an action strategy to meet the Environmental Quality Objectives within the municipality. For example, the action strategy for Hörby includes the development of a VA plan (Vatten och Avlopp – water and sewage) by the city council, and the inspection of individual sewerage systems by the Environmental Committee so that updates to the systems can be imposed if necessary (Hörby kommun 2015). However, due to the creation of water authorities, the municipalities have been granted less responsibility in relation to water management with the implementation of WFD in Sweden (Franzén et al 2015).

The WFD also requires appropriate public information dissemination and consultation processes so that relevant stakeholders are actively involved in water planning and management (Directive, 2000/60/EC). This has led to the establishment of water councils at the local catchment level by the water authority in the case study area (Västerhavet vattendistrikt) (Swedish Water Authorities 2007). The water councils' role is to provide a transdisciplinary platform for integrated water management to facilitate common understanding and help identify water quality problems and solutions (Swedish Water Authorities 2007). The water councils represent local stakeholders and therefore overlap with the traditional water associations that were present in the case study catchment, but their role represents a shift from monitoring water quality only to a more active role in water management under WFD (Franzén et al 2015). The water councils do not have a legal role in water management but are consulted for input into the RBMPs and PoMs in relation to their catchment area (ibid.).

2.1.3 Other policies regulating nutrient input

Table 1 Summary of other policies regulating nutrient input from agriculture and private sewage in Sweden.

Policy	Aim	Implementation	Outcomes
EU Common Agricultural Policy (1995)	The aims of the CAP are to increase agricultural productivity, ensure reasonable standard of living for farmers, stabilise agricultural markets and to ensure supply of agricultural produce at reasonable prices for consumers.	In the period from 2014-2020, €4.9 billion is allocated to Sweden's direct payment scheme under CAP, where 30% of this allocation is linked to environmentally friendly farming practices: crop diversification, maintaining permanent grassland and dedicating 5% of arable land to environmentally friendly measures (European Commission 2017).	• The majority of CAP budgets have gone to direct payments which cannot be linked in the past to targets and therefore have lower environmental effectiveness. • Low profitability and policy reforms have led to a decrease in farmland area in Sweden which has lowered the environmental load from fertiliser use. • The CAP is seen to have had both positive and negative effects on the environment, positive through the encouragement of environmentally sensitive farming practices, and negatively through the inability of policy to maintain any positive environmental effects (essentially the absence of necessary policy) (Naturvårdsverket 2011).
EU Nitrates Directive (1996)	The Nitrates Directive aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices.	• The Nitrates Directive is implemented through an action programme for a reduction of nutrient losses from agriculture. The action programme is implemented through the Swedish Environmental Code, voluntary schemes such as 'Focus on nutrients' and the Rural Development Programme. • It is also incorporated into Chapter 12 of the Environmental Code and the subordinate Ordinance (1998:915).	As a result of this Directive, the use of fertilisers in agriculture has been more strictly regulated and 70% of arable lands in Sweden were designated as vulnerable in 2011 (Nilsson 2012), with new areas identified or taken off the list each time there is a review (Jordbruksverket 2014).
"Focus on Nutrients" Programme (2001)	Gives farmers advice on how to reduce nutrient surplus and protect water quality.	"Focus on Nutrients" provided a new type of free advisory service to Swedish farmers, including follow-up services, a systematic approach, training the advisors, a holistic view, compiling results and reporting, communication and climate advice (Greppa Näringen 2011).	• Participation was highest in the case study county Skåne, where 50% of the area was included in the program (Prestvik et al 2013). • The majority of farmers who were involved adjusted their activity to reduce nutrient inputs into the waterways (Greppa Näringen 2011)

EU Rural Development Programme (2007)	The RDP is a tool for developing Sweden's rural areas. It includes payments for environmentally friendly farming methods.	• Measures supported along this line are: cover/catch crops, spring tillage, riparian buffer zones, wetlands, extensive ley cultivation, controlled damage, buffer zones on erosion sensitive lands, and small wetlands as phosphorus traps (Collentine 2016). • The RDP for 2014-2020 focuses on restoring, preserving and enhancing ecosystems related to agriculture and forestry: >28% of agricultural land will come under contracts for biodiversity and 33% for better water management (European Commission 2018) with a total of 61% of the budget allocated to environmental measures (Ministry of Enterprise and Innovation 2015).	During the 2007-2013 RDP, there was variable success in meeting targets from environmental investments. For example, the target achievement for the ha of wetlands was 86% whereas less than 10% of the target for phosphorus traps was met (Jordbruksverket 2016).
EU Urban Wastewater Directive (1996)	*The aim of the Urban Wastewater Directive is to protect the environment from the adverse effects of urban waste water discharges and discharges from certain industrial sectors. The Directive has been incorporated into the Swedish Environmental Code and Swedish Environmental Protection Agency regulation.*		
Private sewage treatment (Swedish Environmental Code)	The Environmental code gives the following regulations with regards to private sewage treatment: • Prohibits emitting untreated wastewater from water closets into water areas • Permits are required to install an on-site toilet wastewater treatment facility or connect a water closet to such a facility • Other kinds of sewerage facilities require notification to the enforcement authority	Legislation only states very general and basic treatment demands, that all private sewerages must have further treatment facilities other than sludge removal. The basic standard is that they must ensure at least 70% treatment for phosphorus compounds but in areas of high protection, phosphorus treatment must be 90% and nitrogen treatment 50% (Nilsson 2012). The municipal board generally acts as the permit and enforcement authority.	An estimated 750,000 properties in Sweden are not connected to the municipal wastewater treatment plants, and only around 60% of these are thought to have installations that meet the requirement of the Environmental Code. The amount of phosphorus released from this type of wastewater disposal is more than half the total amount discharged from the municipal wastewater treatment plants (Swedish Environmental Protection Agency 2009).

2.1.4 Progress and gaps

The CAP is seen to have both positive and negative effects on nutrient levels. Its overarching aim is to increase agricultural productivity. However there are strong indications that implemented environmental protection measures have achieved a reduction in nutrient leaching from agricultural activities (Fölster et al 2012). Changes in the use of agricultural land and more efficient use of nutrients resulted in an annual reduction of nutrient leaching from arable land of 12% nitrogen and 7% phosphorus (Prestvik et al 2013). In the south west of Sweden where the case study is based this is particularly evident, where the increase in grasslands and catch/cover crops, and the increase in spring cultivation could explain the reductions of nutrients in the water (Prestvik et al 2013). However, agriculture remains the biggest contributor to nutrient input.

Wastewater treatment from municipal water treatment plants and industries has improved considerably. However, discharges from properties with private wastewater disposal have shown no improvement (Swedish Environmental Protection Agency 2009). As the regulations detailed in the Environmental Code are not subject to any periodic reporting duties, authorities must search information about individual sewerage systems under their own initiative. This, in combination with the historical sewage systems in holiday houses built before the regulations came into place, make them difficult to enforce.

The county administrative board estimates that it is not possible to reach the Zero Eutrophication Environmental Quality Objective by 2020 with existing measures alone (Naturvårdsverket 2016).

2.2 Co-designing policies involving stakeholders

The mitigation of eutrophication in Sweden has mainly been carried out through the regulatory processes described in the previous section. However, the high costs of monitoring and enforcement have meant that the management of Rönne has historically been undertaken in a bottom-up manner, through the contribution of local stakeholders within traditional water associations (Jonsson 2005). The Rönne River committee, formed in 1978, represented a variety of stakeholders from municipalities to water users (see Annex I section 8.1). It now exists alongside the Rönne water council which has a wider remit under WFD. The Ringsjön Lake committee was established separately in 1980, covering the subcatchment of the Ringsjön lakes. The committee's research laid the foundation for "Lex Ringsjön" in 1985, now included in the Environmental Code. This meant that Ringsjön could be classified as an "especially pollution sensitive area", leading to regulations for fertiliser use and storage as well as for individual sewers. These reduced the supply of phosphorus to the lake from >30t/yr to 10t/yr, although there were no visible effects on water quality.

The Ringsjön Lake and Rönne River committees have worked as two separate water associations, with the Lake committee being replaced by the Lake water council in 2007

(Franzén et al 2015). The two councils conduct a yearly water monitoring programme through a consultancy Ekologgruppen (Ekologgruppen 2017).

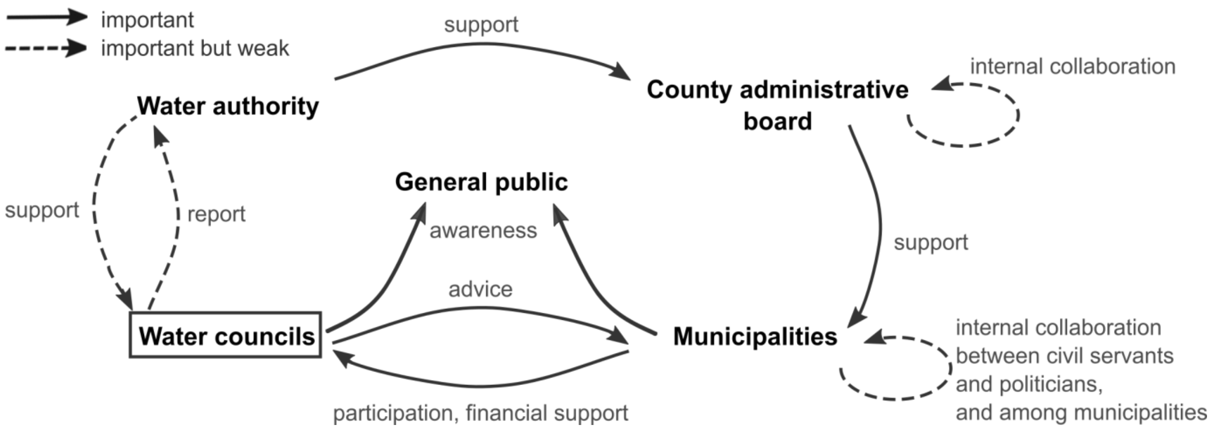

Figure 2 Collaboration between local and regional institutions for managing freshwaters in the Rönne å catchment.

Current water management collaboration

Through the series of workshops and selected follow-up interviews carried out in winter 2016/2017, we clarified how collaboration among decision makers in water management works today. This also demonstrates how the implementation of policy targets is decided upon on the local level. Figure 2 shows the main decision making institutions besides the water council. The water authorities represent the intermediate level between the national government and the local water councils. They are responsible for reporting progress on the implementation of the Water Framework Directive. However, while doing this their support for water councils to not only monitor the freshwater bodies but also implement measures for their improvement is somewhat limited or at least very heterogeneous. Water authorities mainly act through their support of county administrative boards which provide funding and legislation support for municipalities. The water councils are very much dependent on the active collaboration by municipality representatives. Since water councils do not have legislative power or even the budget to fund a single position for their own administration, their activities depend on legislative and funding support from municipalities.

Stakeholders' perceptions of weaknesses in current collaboration

The collaboration between the water councils and the water authority is perceived as weak, described as one-way email communication and reporting. One reason for this may be the ambiguities in the division of responsibilities (Eckerberg et al 2012), or because the water authorities assume the county administration boards should be responsible for local cooperation (Broman and Hansen 2013). However, the water authorities are aiming to increase their support and communication towards the water councils. The water authorities are including everyone with concerns about water issues to be involved in the earlier phase of creating the 'water measures program'. Within the county administrative board, there is a lack of internal collaboration as it is very sector-driven. In a study by Hedelin et al (2008), it appears that the planners responsible for implementing the WFD on the county boards were not skilled in developing participation and collaboration. Although there was appreciation for the local knowledge of stakeholders, the planners had a simplified view of the benefits of consensus decisions and conflicts of value.

These weaknesses and insights were used to develop scenarios in section 4.2 to highlight some of the challenges for strengthening management of biodiversity and ESS.

3 Assessing the current state of the social-ecological system

Key Messages

- The main drivers of eutrophication in the Rönne å catchment and Lake Ringsjön are urban development and agricultural production, which results in nutrient runoff pressure from agricultural activity (accumulated over decades and present as internal loading today) and an increasing amount of wastewater from population growth.The state of Lake Ringsjön and its biodiversity has improved since the 1960s-1970s with decreasing nutrient levels and increasing Secchi depths (see Figure 9 in Annex I). However there is still some way to go for stakeholders to be satisfied with the ecosystem services that can be gained from the lake.
- A clear Lake Ringsjön is a primary objective for the municipality as toxic algae blooms reduce ESS for local residents and tourists. Restoring a lake that shifted into a turbid state is challenging because of multiple social, social-ecological and ecological interactions at different temporal and spatial scales that affect restoration outcomes. It is demanding because effective management needs to attend to ecological and social processes at different time scales in order to reverse ecological dynamics towards a clear water state. This requires collaboration of different actors with different interests from local to regional scale. Stakeholders identified the need for enhanced collaboration to manage water quality in the lake and the catchment and the ESS provided by a good quality (recreation, swimming, fishing, etc.).
- Social-ecological action-situations are an approach that complements the AF by putting particular emphasis on the diverse types of material and non-material social-ecological interactions and their links to social and ecological processes that jointly determine emerging dynamics of SES. The approach was particularly helpful to analyse the governance processes that need to be enhanced to ensure that EBM measures are effective. On the social side, ecological monitoring, restoration measures, and regulation of human activities causing pollution were identified as important to address eutrophication and help restoring the clear water state.
- Ecosystem services as they are enjoyed by humans are co-produced in social-ecological systems. Changing preferences around the lake, not environmental conditions, have changed the previously agriculture dominated society and landscape to enable more diverse ecosystem services and beneficiaries today.

- Ecosystem services interact spatially in multiple ways. Costly restoration to improve upstream water quality enables free-riding on those improvements in the downstream area. Areas with focus on single provisioning services (nutrient rich agriculture) may benefit from shifting the management focus to underlying regulating services (soil quality) and embracing the view on multi-functional landscapes (e.g. by addition of wetlands to compensate for eutrophic river segments before entering the lake).
- Ecosystem services interact through more than just geographic space or ecological food webs but also through time and institutions. Water councils in Sweden seem to be well equipped to identify and steward interactions in aquatic services which strongly link to water quality (e.g. drinking water, fishing) but for whose management institutional barriers, political short-termism, and sectoral divides need to be overcome.

As indicated above, we focus particularly on understanding governance, particularly policy making processes and human behavioural responses that affect the development and implementation of EBM policies for improved water quality and associated ESS. We have applied a mix of qualitative and quantitative methods to assess 1) key social, social-ecological and ecological processes that together determine successful lake restoration as a management activity to enhance the provision of water-related ESS, 2) the perceptions about ESS interactions among different stakeholders as well as shortcomings in the current governance structure that prevent the development of more effective ESS policies and management strategies, 3) the consequences of delays in policy response or implementation for the restoration of good water quality resulting from the interplay between social processes and non-linear ecological dynamics (social-ecological modelling). Our assessment builds on the holistic, integrated systems approach of the AQUACROSS Assessment Framework (AF). It focusses on policy processes, governance structures and citizen behaviours ('social functioning' as complementary to ecosystem functioning) and the temporal dynamics of change processes (e.g. the introduction of a new policy) as these were main concerns voiced by stakeholders in the case. In order to address the social and temporal dimensions, we incorporate into our application of the AF insights from resilience thinking (Folke et al. 2016), particularly its focus on dynamics of change and the intertwined nature of social-ecological systems, and the resilience principles (Biggs et al. 2012), particularly the governance-related principles. We thus operationalized the AF for our case through the use of the resilience principles and the SE-AS approach (Schlüter et. al under review) and social-ecological modelling (Martin & Schlüter 2015). The former is a way to assess the social and ecological sources of resilience of ESS in a social-ecological system. It complements the DPISR approach by its focus on structures and processes (i.e. the state) of a SES that provide resilience to pressures. The SE-AS approach is a tool to map key social- ecological interactions that are affecting ESS and linking them to social interactions and ecological processes that jointly produce the ESS. This combination of approaches within the framework of the AF allowed us to:

1. take an agency-centred perspective, i.e. studying key human actors and ecosystem components that through their interactions co-produce ecosystem services, rather than a variable-centred approach that focusses on indicators as aggregated information on certain phenomena. This more disaggregated view allows us to study

how pressures, policies or ecosystem responses emerge from these interactions, taking heterogeneity of actor preferences and consequences of adaptive or non-adaptive behaviours of individuals into account. Rather than describing adaptation of the social and ecological systems directly at the aggregate levels we are thus interested in the emergence of system level adaptation from individual level adaptations (or lack thereof).

2. focus on governance structures and social processes that enable or prevent the development and implementation of effective ecosystem management strategies.
3. focus on temporal and dynamic aspects, particularly the consequences of a mismatch of social and ecological time scales, e.g. when policies are delayed while ecological processes continue to develop. Managing slow variables and feedbacks is an important resilience principle, and it is of high relevance for the issue of lake restoration in our case where different short and long-term goals and actions of different stakeholder groups shape social responses that interact with non-linear dynamics of the lake. These range from several direct and distant activities causing eutrophication (agriculture, municipal and private sewage treatment) but also recreational activities (swimming, angling), monitoring and restoration (biomanipulation) at the lake to differences in long term goals and values e.g. whether the landscape should remain an agricultural landscape or a landscape for tourism (which leads to different valuations of water quality).

The added value of our specification of the AF using resilience thinking is that it i) allowed us to attend to stakeholder interests by being more explicit about social interactions and dynamics that affect ESS management, ii) focus on the temporal dynamics of ESS restoration, particularly the interplay between social change (i.e. the implementation of a management measure) and ecological dynamics (i.e. ecological feedbacks), iii) assess structural changes need to improve the feedbacks between ecological change such as loss of ESS or biodiversity, management responses and subsequent effects on ESS, thus going through the entire cycle of the AQUACROSS concept.

3.1 Assessment of current human actions and ecosystem processes influencing the lake state

Threats – pressures – state and their trend through time

The county of Skåne (our study site) is a region dominated by intense farming and a relatively large population – 2016 saw a record population growth rate of 1.6% with 1,324,565 inhabitants in Skåne at the turn of that year (Regionfakta 2018). One quarter of the national agricultural production is produced in Skåne (Johansson et al. 2014) with the highest amount of mineral fertiliser used here – 132 kg of nitrogen was sold per ha of utilised arable land during 2016-2017 (Regionfakta 2018) compared to a Swedish average of 83kg.

Eutrophication is caused by pollution primarily from three sources: diffuse nutrient leakage driven by agricultural practices and discharge of effluents of insufficiently treated water from municipal sewage treatment plants and decentralised sanitation facilities in private households, driven by urban development (see Figure 10 Annex I).

The lakes of Ringsjön had an unsatisfactory ecological status in the 2010-2016 assessment, although the measured Secchi depth during that period has been gradually increasing indicating an improvement in water quality (Ekologgruppen 2017). The surface samples of total phosphorus have decreased from highs of around 350 µg/l in the 1970s to below 50 µg/l in 2017. Nitrogen decreased from highs of 3,500 µg/l to below 1,000 µg/l in the same time period. Looking at the entire Kattegatt basin (see Table 8 and 9 in Annex I), an overall decrease in the nutrient input can be observed, with reduction in both municipal wastewater treatment and agriculture, but not individual drainage loads.

This is attributed to the large number of measures that have been introduced to regulate agricultural nutrient input (see section 2.1). An assessment in 2003 found that between 1995 and 2000, agriculture accounted for the largest decrease in the emission of phosphorus compounds, with a reduction of 19% (de Facto 2003). On the other hand, nutrients from single household sewage systems are still significant and have not been reduced following regulation, justifying the dual focus of the policy review in section 2.1.

Key actors, ecosystem components and their interactions

Here, we describe the lake SES in terms of those social, social-ecological and ecological interactions that jointly co-produce the water-related ESS desired by society. Ringsjön, the largest lake in the Rönne å catchment, is a shallow lake that has shifted from a clear water to a turbid lake in the 1960s, caused by a slow accumulation of nutrients in the lake sediments. Turbid, highly eutrophic lakes pose a challenge for communities and lake managers who aim to restore the clear state of the lake to support lake-related ecosystem services such as recreational activities and drinking water supply. In the case of Ringsjön there have been several attempts to restore the lake by shifting it back into a clear water state, most recently with the help of bio-manipulation. Lake restoration activities have been under way since 1998, including regulation of sewage treatment and bio-manipulation, however with varying success.

We have applied the SE-AS framework to address and deepen those aspects of the AF that relate to the feedbacks between ecological change and social responses and the social processes that shape these feedbacks. Specifically, we mapped the different types of social-ecological and social interactions relevant for successful restoration of Ringsjön (Schlüter et al., n.d.). The framework combines insights from institutional analysis of common pool resource dilemmas (Ostrom 1990) with a complex adaptive systems (Levin et al. 2013) and a resilience thinking approach (Folke et al. 2010). Key actors for lake restoration are the municipality, the water council, regional authorities, households and tourists. Key ecosystem components are nutrients, algae, macrophytes, whitefish (bream and roach) and pike.

The actors and ecosystem components interact in various social-ecological, social and ecological contexts. Interactions between different actors and different aspects of the lake jointly influence the success of restoration (Figure 3). First, there is the social-ecological action situation (AS) of nutrient pollution by private house owners in the catchment (Pollution AS) that among sources from agriculture and municipal wastewater treatment causes harmful algae blooms and changes the food web towards a dominance of fish species such as bream and roach that are less valued by recreational fishers. Once an awareness of the problem reached policy making (1970's), algae abundance was monitored (Monitoring AS) and the municipalities and the water council together agreed on policies for nutrient regulation (Policy making AS). The implementation of the regulation was successful for reducing nutrients from agriculture and municipal wastewater treatment (not included in this analysis).

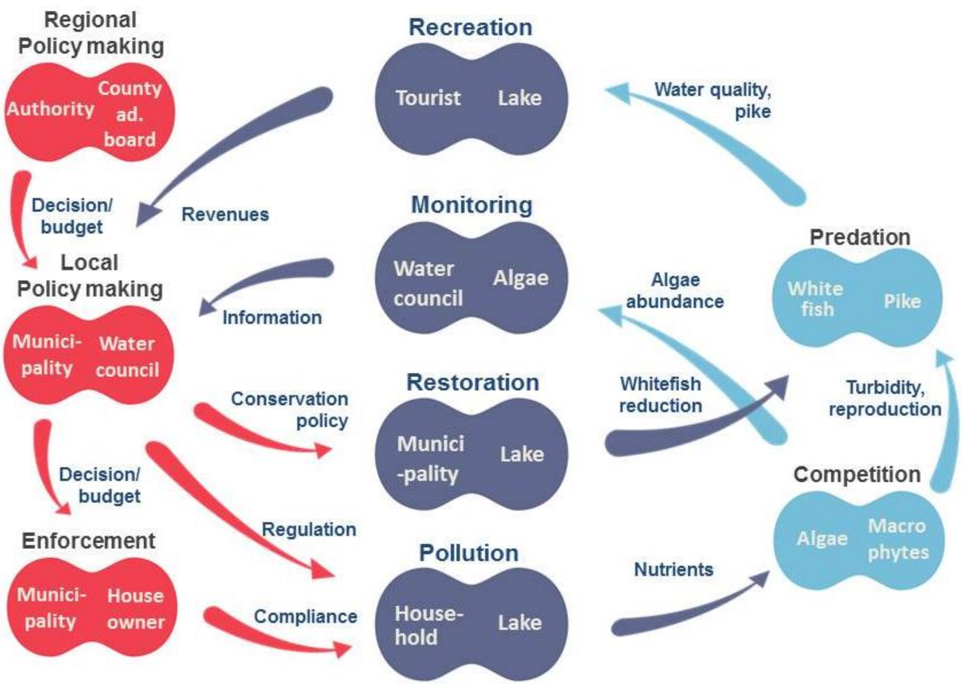

Figure 3 The main social (red), social-ecological (dark blue) and ecological (light blue) action situations that in concert determine the dynamics of multiple ecosystem services linked to water quality in a shallow lake.

The installation of new private sewage treatment technology, which is a high cost investment, however, depends on enforcement measures and how individual house owners were involved in the regulation process (Enforcement AS). In this case enforcement was carried out through municipal inspectors who checked on private sewage installations (Wallin et al. 2013). As the lake was already in a turbid state, the municipality engaged in bio-manipulation, i.e. a direct manipulation of the food web through the removal of white fish which is expected to decrease algae blooms and favour commercially higher valued fish (Restoration AS). Regular monitoring supports this activity by showing progress towards the clear state by indicators from phyto-, zooplankton and macrophyte diversity. These indicators also serve as targets until which restoration is continued. Both enforcement and bio-manipulation are costly thus requiring repeated interactions within the policy making AS to allocate the required budgets. One future vision and motivation for the restoration of shallow lakes is that investments to restore a clear state facilitate more touristic lake use which will eventually provide revenues for municipalities (Recreation AS).

The AS configuration exemplifies that the overall success of lake restoration depends on three major processes to happen simultaneously. First, governing institutions need to deal with the legacy of past activities that affect the state of the lake today, for example through high nutrient levels in sediments, as well as ongoing pollution. They require measures to actively shift the lake back (bio-manipulation) as well as regulation and enforcement measures to reduce new inflow. Second, municipalities need to employ experts to conduct the practical restoration after evaluating carefully which methods are suitable in the local case. And third, the lake use through tourism (recreation) is both dependent on the success of the first two activities while at the same time reinforcing their implementation. It may possibly accelerate the whole restoration process to include potential beneficiaries of the improved lake ecosystem from the beginning.

In summary, applying the SE-AS framework highlights how lake management needs to deal with three challenges at once: past practices which caused the nutrient pollution in the catchment, present ecosystem manipulation and pollution while linking potential future income through touristic or other beneficiary activities to restoration investments. This challenge requires a sufficient investment in collaboration between different actors while it is uncertain when and how much of this investment will pay off. As a first step, we investigate interacting time lags resulting from a subset of these linked action situations using a hybrid system-dynamics and agent-based model (Martin and Schlüter 2015, and section 4.2.2).

3.2 Assessment of current functioning of ESS management

This section links our assessment of the co-production of ecosystem services to the assessment of stakeholder perceptions and the current governance structure. The latter assessment was carried out through stakeholder workshops and interviews and enables identification of measures for improving ESS and biodiversity governance. When seeing ecosystem services as an outcome from particular decisions and processes in a social-ecological system, one can differentiate two dimensions along which social-ecological, micro-level factors matter and explain the macro-level outcome of ESS benefits or failure:

1. **Which aspects determine when and how ESS matter for human well-being?**

To understand what makes a service to human well-being, one needs to consider the aspects that accompany the production chain before a service is enjoyed or consumed, such as social processes on norms, preferences or power relations (Spangenberg et al. 2014). Löwgren (2005) investigated the preferences of different stakeholders within the Rönneå catchment and found that although the most valued ESS was drinking water, farmers and industrialists put more emphasis on water as a means of production (irrigation, industrial production, hydropower generation etc.). A social-ecological perspective supports the identification of more indirect, planned or less tangible social inputs (e.g. access rules, markets, institutions) to understand better when, where and under which conditions ESS are perceived (Sarkki 2017; Palomo et al. 2016). Palomo et al. (2016) highlight the co-production of ecosystem services as a mixture of natural capital and various forms of social capital (e.g. financial, technological, etc). Respecting the societal inputs and conditional aspects allows a more balanced representation of ecological and social systems, accounts for feedbacks, slow and fast processes, and integrates relevant context for conditions under which ES producers and users manage their environment and govern their system (Biggs et al. 2012).

For example, consider drinking water: The same service can be enjoyed with different degrees of human input. Why does it matter? The purification costs differ strongly between clear and turbid water. An agricultural dominated society might accept turbid water at the cost of more expensive purification technologies. However, a society interested in a multi-functional landscape might be able to regulate pollution activities at a low cost and may therefore enjoy cleaner water with less expensive purification. In our case, the drinking water company Sydvatten contributes with 10% to the annual costs of the water council measures around Ringsjön to ensure a long-term cost reduction of purification in case the lake is used as drinking water.

2. **How do co-produced ESS interact and what are implications for management?**

As societal inputs are usually distributed over many services, decisions need to be taken on where and how much to manage. Co-production affects ecosystem services in multiple ways, through changing quality, trade-offs between single ESS, and emerging bundles. For example, policies that act to increase agricultural intensification will reduce other ESS (e.g. pollination, water quality etc.). The interaction can be of many natures: synergistic, inhibiting, one-directional or bi-directional, complete or in degrees. One way to analyse spatially **interdependent ecosystem services** is by ecosystem service bundles (Queiroz et al. 2015; Renard et al. 2015). When acknowledging the co-production nature, the reasons for interaction can be found not only in the ecological/biophysical system (Bennett 2009) but also in the social system. In short, reasons for ESS interaction can be spatial, social or temporal (Tomscha and Gergel 2016). There exist a few frameworks which account for some of the above mentioned dimensions so far, but none of them integrates them all.

Knowing about interacting ESS matters for strategic local governance, because decisions about how single ESS yield value for human well-being should become more explicit (Reyers et al. 2013) and priorities accounting for ESS interactions can be designed instead of unintendedly happening. The workshops undertaken by Löwgren in the Rönne å catchment show how stakeholders have differing preferences as to what ESS are important, but also show some consensus on how the water should be managed (Löwgren 2005). Multiple added values for several provisioning services can be achieved, for example, by managing regulating services rather than by managing provisioning services alone (Bennett et al. 2009).

For example, consider recreation: By managing water quality in Lake Ringsjön in our case, the municipalities support multiple related provisioning (fishing, drinking water) and cultural ecosystem services (swimming, bird watching, hiking and others), including biodiversity. The lake serves prominently as a commonly shared resource through which the effects from multiple activities in the catchment are connected. While the municipalities at Ringsjön have a long history of agriculture dominated landscape, their current comprehensive plans emphasise multi-functionality and recreational values for local residents and tourists (e.g. Hörby Kommun 2016). The interconnectedness of services linked to water quality is less visible in the lower Rönne river catchment. The economic activities are more segregated and less dependent on water quality at a particular place. As an exception, the coastal municipality Ängelholm voiced an increasing importance of recreational activities both at coastal and inland waters (Workshop Nov 2016).

3.3 Co-designing understanding of ecosystem services involving stakeholders

We focused in our research on ESS which are directly linked to water quality because they are a key concern in the case study, both for Lake Ringsjön but also for the entire catchment. We conducted several stakeholder workshops to assess priorities, understanding of the perception of ESS trade-offs and possibilities for ESS management. Here, we report on workshop results on aspects for co-production of ESS which are directly linked to our main, first two research questions:

1) What social-ecological processes and factors are needed to co-create desired aquatic ESS in Rönne å catchment area?

2) What are direct interactions between ESS and indirect (social-ecological) interactions with individual aquatic ESS in Rönne å catchment area?

In our three workshops, we asked the participants: Which procedural steps, aspects and actors characterise the co-production of aquatic ESS? (see Annex II)

Table 2 Processes and factors for particular aquatic ecosystem services named by workshop participants in the CS area, Nov and Dec 2016.

ES	Social	Ecological
Drinking water	– regulations (drinking water directive) – stable distribution network – private wells: great responsibility	– precipitation (volume) – clean inflows (quality) – vicinity to forest and wetlands – surface water
Water purification (nutrient retention and sewage treatment)	– citizen dialogue, inform farmers to not overfertilise – recycling infrastructure – money – regulations, some should be more visionary and prohibit plastic bags – local responsibility for handling of precipitation water – suitable dams	– biodiversity – water
Outdoor recreation	– access, signs, information, cleaning and maintenance of rest places – education, understanding and support measures to improve sites – dialogue with land owners – cross-boundary collaboration – discussion and decision on tolerable use intensity – zones along the river which are not cultivated	– animals, people, wetlands

Voices in those discussions raised for example:

- "We need more precautionary measures to keep the quality of ES high"
- "It requires a more adaptive way to take decisions, and a way to measure and follow up to govern ES better."
- "It might be counter-intuitive but for people to enjoy the recreational values of nature, we might have to interfere with it by creating houses, roads, and hiking paths."

- "People seem to be afraid of being in nature. We need something to stick in their hands: folders, information and such. When they are in nature they need signs."

We followed up asking "Which interactions among ES and land uses are perceived?" From the resulting ES flower figures (see Annex II), the following views were collected:

- Provisioning and cultural ES often relate in trade-offs to each other.
- Good water quality increases the beauty of nature. Synergy between running water quality and natures beauty.
- Increased agriculture decreases recreational value of water as accessibility decreases (competition for space).
- Poor water quality hinders drinking water production and recreational fishing.
- There is a conflict between fishers and bird watchers. No conflict between recreational fishing and other recreational values (e.g. swimming).

Taking the results from eight different focus groups doing this exercise, recreation was the single most popular service discussed. Therein, the access to recreational areas was discussed since those can be locked by other land uses (agriculture, private residential areas) or need to more easily accessible via signs and information. Among the provisioning services, many are still prominent, crop production was most salient. The exercise on interactions among ESS revealed that, at least hypothetically, many interactions exist that are rarely mentioned explicitly by decision makers. Beyond the classical trade-off among provisioning and recreational services, stakeholders identified also an effect of agricultural and forest production on drinking water. We explore interactions among water quality, fishing, and recreational services under the different scenarios developed in the following chapter.

4 The baseline and future scenarios

Key messages

- For the baseline scenario, consequences from ongoing biomanipulation on lake and lower river water quality are projected together with expected ecosystem services linked to water quality. In particular, we simulate and evaluate emerging time lags in lake restoration. As a general driver for this scenario, we consider the local policies to improve recreational services for residents and tourists. However, recent progress in this direction is likely hampered by diverging interests and interacting ecosystem services in the area.
- As a result from stakeholder workshops and interviews, we identified two dimensions along which decision making in water governance could strongly differ in the future: a) by the time horizon considered for expected effects taking place, and b) by the geographical space and institutions involved in the collaboration on implementing measures.
- In alternative 1, we explore the time lags in lake restoration emerging from biomanipulation combined with fishing quota for pike and different time horizons under which water related services are expected to improve.

- In alternative 2, we explore an improved way of collaboration on the catchment scale with restoration benefits considered beyond the lake.

Our goal is to better understand the decision-making process by local and regional actors on measures to improve water quality and ESS. The characterisation of the current complex socio-ecological system (section 3) identified that addressing eutrophication as a pressing local objective that will support human well-being. To understand the impact of different EBM measures and policy instruments, we co-developed scenarios with stakeholders.

Scenario building process: Scenarios in the form of narratives are constructed to describe alternative pathways for local and regional actors to collaborate in different degrees to reach common or distinct goals. The function for stakeholders in these scenario processes is to a) co-develop knowledge with people from different sectors and levels, b) so that networking becomes a resulting benefit as, c) learning about the concept of ESS and its use in practice.

Expected outcome: The output narratives explore the implementation of WFD related policies (to improve water quality), different planning horizons and different ways of increased collaboration. Our focus on collaboration links to resilience thinking mainly through the principle of "broadening participation". The scenarios link further to model-based analyses.

4.1 Identifying gaps between baseline outcomes and objectives

4.1.1 Current status of policy implementation

As covered in more detail in section 2.1, at the national level, the most relevant policy objectives governing water quality in Rönneå stem from the Swedish Environmental Quality Objectives (Swedish Environmental Protection Agency 2016). These include objectives for a Non-Toxic Environment, Zero Eutrophication, Flourishing Lakes and Streams, A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos, and A Good Built Environment. EU Directives such as WFD, and other environmental protection directives have been incorporated into the requirements for these Environmental Quality Objectives. The policy objective to achieve Good Ecological Status by 2015 through the WFD was postponed until 2021.

At the local level, municipalities have developed comprehensive plans and local environmental objective programmes containing action strategies to meet the Environmental Quality Objectives (e.g. see section 2.1.1 – Höör's local environmental goals).

The enforcement of the upgrades to private sewage treatment systems that is required from the Environmental Code is heterogeneous among municipalities.

4.1.2 Gaps between how indicators develop in the baseline and target objectives

The Zero Eutrophication Environmental Quality Objective aims to keep nutrient levels in the soil and water such that they do not have an adverse effect on human health or biological diversity (Swedish Environmental Protection Agency 2016). Within this aim, the WFD target of good ecological status is integrated into its assessment criteria. However, Skåne's waters are not on track to achieve good ecological status according to the recent analysis by the county administrative board (Naturvårdsverket 2016). Although Lake Ringsjön received an unsatisfactory ecological status in the 2010-2016 assessment, there are positive signs of water quality improvement. Some indicators meet the prescribed targets, for example, the Höör municipality environmental target of 1.5m Secchi depth was met in Östra Ringsjön and Västra Ringsjön in 2017 (Ekologgruppen 2017).

There is a clear gap between the objectives detailed in the Environmental Code (detailed in Table 1 and discussed in section 2.1.4) to regulate private sewage treatment and the progress achieved in this regulation. Discharges from these properties have shown no improvement in treatment, with an estimated 60% of such properties meeting the requirements of the Environmental Code (Swedish Environmental Protection Agency 2009).

Within the structure of the national and local institutions that govern and manage water quality, there is a gap in the ability to make ecosystem service improvements benefit a larger catchment society, such as those stakeholders downstream. This is likely due to the separation of the two water councils – Lake Ringsjön, which undertakes more activity around water management such as the biomanipulation projects, and the Rönneå water council. There is also a gap in the ability to foresee time lags or delays in the effects of the implemented projects, for example, the variable outcomes of the initial trial of biomanipulation in Ringsjön (Hansson and Bergman 1999). There is a potential to make benefits from improved water quality available earlier and to a broader set of interest groups.

4.2 Scenario development

4.2.1 Procedure for integrating stakeholder preferences into the scenarios

Social-ecological processes and ESS interactions are key to understand how water governance can be improved. The aim is to understand, from a stakeholder perspective, the following questions:

1. What are the goals from decision makers linked to water governance and co-production of ESS in the Rönne å catchment area?
2. What are relevant processes of change for improving water governance?
3. With regards to resilience principles – what are challenges and opportunities to improve collaboration among stakeholders and how does it relate to the resilience of aquatic ESS?

The focus on ESS co-production, synergies and trade-offs framed our stakeholder workshops as well as model simulation design (Figure 4). From the workshops, we identified key social-ecological interactions (described in section 3.1), which informed both model and scenario design.

With regard to the later scenario evaluation (section 5), we identified focus questions for the baseline and alternative policy scenarios. The questions were motivated by interests expressed by stakeholders and formulated such that they could be evaluated with model simulations:

- Baseline: **How fast is lake restoration happening by reducing the lakes' nutrient inflow together with biomanipulation?** This question can be answered by model simulations (semi-quantitative) and mainly addresses the efficiency of restoration measures.
- Alternative 1: **How much faster can multiple interests in ESS dependent on the clear water state be fulfilled?** Measures to explore are a reduction in pike fishing and different planning horizons, which means different scopes for expected ecosystem services. The approach is the same as under the baseline. This question mainly addresses the equity of restoration measures, but also informs on efficiency.
- Alternative 2: **What is the larger added value for municipalities from lake restoration in the catchment?** This addresses both the equity and effectiveness of restoration measures and will be explored in a qualitative way through interviews.

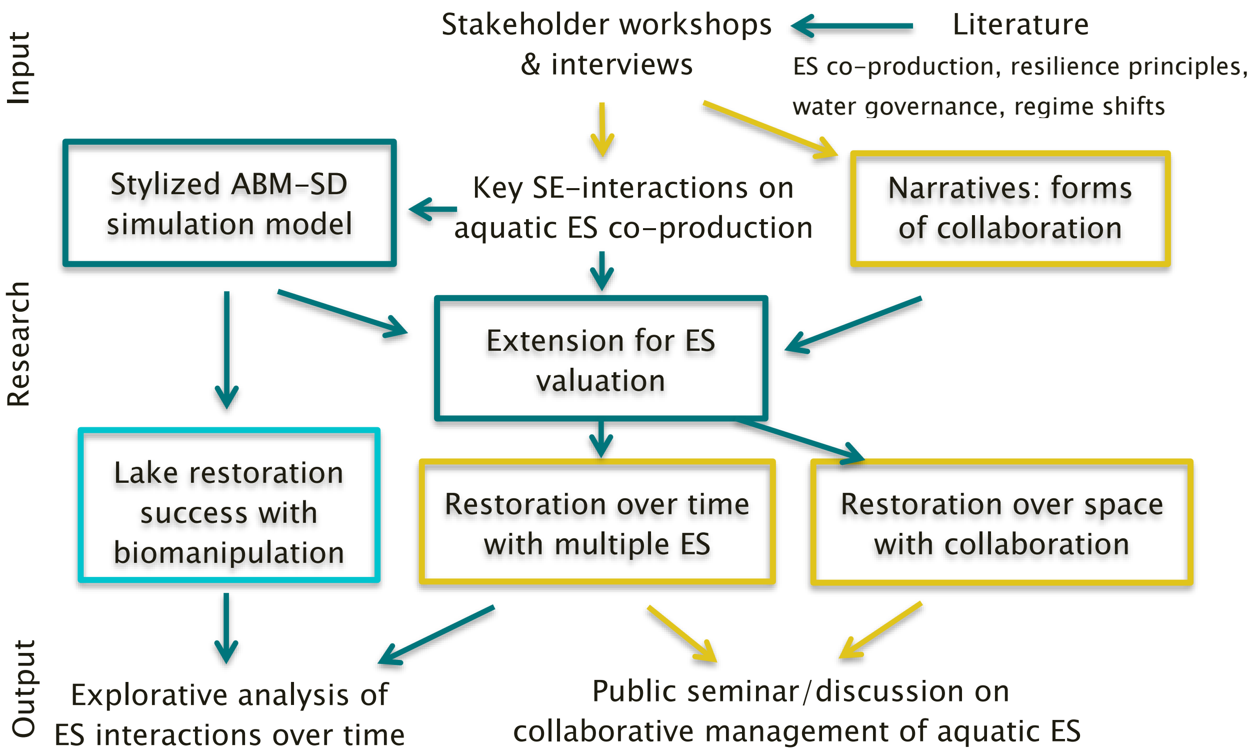

Figure 4 Workflow of how participatory scenario development and model analysis (agent-based and system dynamics) interacted in CS 6. The purpose was to learn how time lags in a SES affect aquatic ESS co-production, their interactions and lake restoration.

Process and methods

To develop scenario narratives, we followed a step-wise procedure. First, for understanding the baseline, we collected socioeconomic, institutional and policy data to include several municipalities with similar conditions in our study. We only included municipalities that are currently updating their comprehensive (also called master) plan that states their visions and goals, as they are thinking holistically and long-term. Second, we prepared three stakeholder workshops and follow-up interviews (see more details in Annex II) conducted in late 2016/early 2017. Third, while conducting the workshops, we ran exercises with focus groups and documented the discussions. Exercises were designed to incrementally build an understanding of underlying conditions for aquatic ESS in place, their interrelations and the future prospect of how they are affected by policy measures. Finally, the results were analysed according to our research questions and for drafting narratives as a basis for our scenarios.

Scenario narratives

Our scenario narratives depict stakeholder understanding of how to enhance the provision and management of ESS, and how measures could affect ESS interaction. Those narratives are also expected to stimulate further discussions among stakeholders.

- *Narrative 1 Baseline – status quo*

  No major changes in water governance in Rönne å catchment area occur. The collaboration between the municipalities surrounding lake Ringsjön continues and so does the biomanipulation project which reduces white fish. This has a positive effect on water quality and many recreational ESS. However, biomanipulation measures are costly and change trophic cascades rather than underlying problems (e.g. agricultural runoff), which hinders a regime shift. Collaboration with municipalities up north is still limited which creates problems in reaching "good water status". These northern municipalities in Rönne å catchment area are struggling as environmental documents are considered to be "nice guidelines" but "nothing will ever change" (workshop participant) and environmental problems are handled in an ad-hoc way rather than in a planned and structured manner.

- *Narrative 2 – New visions for more distant futures*

  The three water councils (Rönneå, Ringsjön and Kattegatt coastal water council) improve collaboration and develop comprehensive management plans together. The planning horizon has increased from roughly five to 10 to 20 years. This enables long term benefits from water restoration measures to be taken into account. Particular measures are biomanipulation together with the implementation of temporary fishing quotas for pike. While short-term measures have had little effect on the lake's state so far, the benefits where visible to fewer people. But as the conditions at the lake improve, fewer algae blooms occur. Local residents begin to see their benefits for recreation (swimming, hiking) and support comprehensive plans which aim for a stabilised clear, fishing lake.

- *Narrative 3 – Broader collaborations in the catchment*

  The three water councils (Rönneå, Ringsjön and Kattegatt coastal water council) have merged and become one regional council including all 14 municipalities within Rönneå catchment area. Beyond that, the water councils have regular exchanges with other councils to learn from each other's experiences. Collaboration now crosses institutional borders in municipalities (e.g. drinking water, storm water and urban development) and sectors (both politicians and civil servants are included) but also between municipalities. They plan and govern their water in a more holistic way as they have strengthened the resilience principle of broadening participation, and created a better fit between institutional and natural boundaries. Factors that have improved water governance are 1) common understanding of contributions and distribution of financial capital, 2) a continuous rotation of which municipality is chair and, 3) improved personal relations and trust. Nutrient content in freshwaters is stabilizing, and migratory barriers are slowly decreasing (and biodiversity is slowly increasing) without major conflict. Creating the new water council was time-consuming for everybody involved, but building relations over years was key. Measures that have been implemented are 1) merging of water councils to improve regional water governance, 2) continued biomanipulation, 3) emergency plans if unforeseen events occur, 4) areas with high biodiversity have been protected and 5) cleaning storm water. There are social consequences for some individuals as less crops and less local electricity (hydro power) is being produced. However, reaching good water status and thus good water quality has had a positive effect on many recreational ESS (e.g. swimming and fishing). Regional tourism in the area is booming, as the recreational fishing has improved substantially, thus creating new jobs.

4.2.2 Method for analysing scenarios with stylised models

The results from the stakeholder-based scenario development process informed the development of a stylised, social-ecological model (a hybrid model combining agent-based and system dynamics modelling) (Martin and Schlüter 2015, Annex III). The model is used to simulate and analyse emerging time lags in lake restoration. The system dynamics part of the model implements the shallow lake model from Scheffer (1989) which shows bistability represented by a hysteresis curve (Figure 5). The agent-based model consists of one regulating municipality agent and a number of private house owner agents. The purpose of the coupled model is to enhance understanding of how micro-level interactions (here decisions of individual agents in response to a new policy) affect macro-level behaviour of the social-ecological system, particularly the time lag between the development of a restoration policy and the attainment of a desired ecological state. The model is implemented in NetLogo and can be accessed at OpenABM.org (Martin 2017).

Time lags in lake restoration from the model are evaluated against the stable states that the lake is moving in between (Figure 5, Martin and Schlüter, in prep). The ecological dynamics are deterministically simulated and are driven by the nutrient concentration. The scenarios allow variation of multiple social mechanisms which dynamically affect the nutrient concentration. As a result, time lags for reaching the clear lake state can be projected as emerging outcome from social responses to eutrophication.

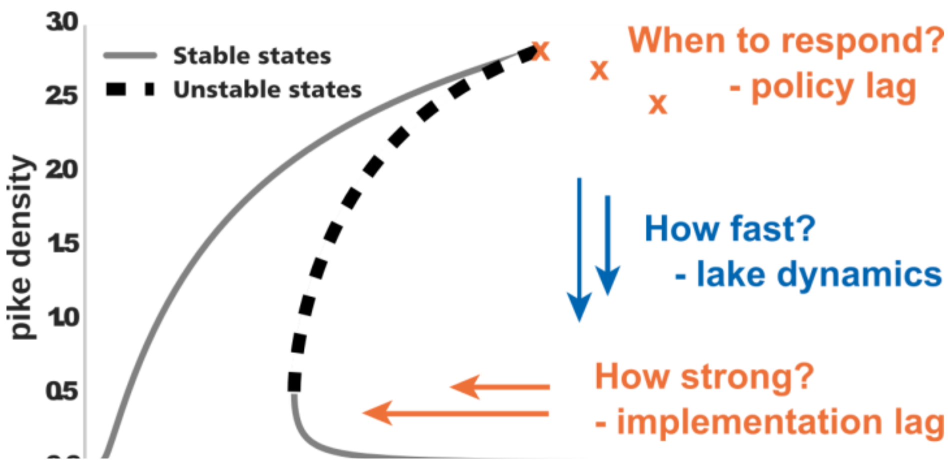

Figure 5 The hysteresis curve for the ecological model shows the stable and unstable equilibrium states between the driving nutrient concentration and the responding pike population (Scheffer 1989). Two social parameters of the coupled model determine when the restoration starts (policy lag) and how strongly it is implemented (implementation lag, both orange). The momentum of how quickly the lake shifts from the clear to the turbid state during the transition phase results from the non-linear lake dynamics (blue).

4.2.3 Design of scenario analyses on consequences from EBM measures

While our simulation model LimnoSES provides quantitative projections of the dynamics in nutrient concentration and pike density, those numbers serve as a qualitative response pattern to compare the effects from different social and social-ecological processes (e.g. policy and implementation lag). To collect further model-supported evidence on how the earlier introduced scenarios determine the long-term dynamics at the lake and thereby the enjoyed ESS, amendments to the current version of LimnoSES are planned. So far, we collected qualitative hypotheses on scenario effects which are required to design suitable simulation experiments (Table 3).

Table 3 Planned experiments to support model-based scenario analysis.

Scenario	Model extension	Hypotheses
Baseline: How fast is lake restoration happening by reducing the lakes' nutrient inflow together with biomanipulation?	+ whitefish reduction (biomanipulation) + independent sewage system upgrade	Biomanipulation with a minimum intensity results in a faster lake restoration than by nutrient reduction alone. However, without nutrient reduction, biomanipulation effects are reversed.
Alternative 1: How much faster can multiple interests in ESS dependent on the clear water state be fulfilled?	+ regulation of fishing + valuation of drinking water, swimming and fishing in relation to the lake state in two planning horizons (< 5 years vs. > 10 years)	With short planning horizons, only few clear water dependent ESS can be restored and it is risked that those improvements are lost after short time. Longer planning horizons enable stronger reinforcing feedbacks of restoration, resulting in non-linearly larger improvements.
Alternative 2: What is the larger added value from lake restoration in the catchment?	+ estimation of time lag and magnitude of lake water quality on lower catchment services (fishing, swimming) + social process of supporting or withdrawing restoration investments	With increased geographical and institutional scale, lake restoration and its ESS can experience either reinforcement or weakening depending on the alignment of ESS demands.

5 Evaluation

Key messages

- Within the AF, resilience principles complement the understanding of how to manage ESS and biodiversity in SES beyond EBM by emphasizing social feedback processes and social-ecological interactions determining long-term dynamics.

- The baseline on lake management seems “good enough” for reaching local environmental goals by taking into account the most relevant ecological feedbacks, but for ESS and biodiversity improvements on the catchment level it is less clear. ESS trade-offs considered in the alternative scenarios can improve fairness over space (catchment vs. subcatchment), over sectors (producing vs. regulating services) and over time (among generations, considering different planning horizons). Current policies and governance structures do not address those ESS trade-offs yet.
- No single solutions but continuous learning among stakeholders help identify suitable measures for improving ecosystem state and human well-being simultaneously. Careful consideration of trade-offs among ESS will help to form alliances in support of currently undervalued regulating ESS, which other services depend on in the long term.

5.1 Suggestions for developing an EBM plan

As discussed in section 3 and 4, changes in water governance are the key aspect for improving the management of ESS and biodiversity in our case study. In particular, we emphasise long-term planning and cross-administrative collaboration in the policy scenarios. We suggest governance changes described in alternative scenarios as narratives in section 4. These alternative options would better support selection and implementation of EBM measures and policy instruments. While these technical measures are beyond the scope of our report, potential technical measures/instruments include

- Wetland extension in the vicinity of the lake and the main nutrient inflows
- Modernization of sewage treatment systems in summer houses that are not connected to the central sewage system: improved monitoring of individual sewages and if it does not meet the standards the system needs upgrading.
- Dividing the costs between the polluter (e.g. farmers) and water council for monitoring of nutrients according to an agreed key.
- Improved sharing of information and knowledge to the public & between members in the water council.
- Temporary reduction of fishing rights at the lake.

There are several social and economic aspects to consider regarding the above measures:

- Biomanipulation is feasible but costly. The intention is to shift the lake to the clear state which then should reinforce itself without further inputs or disturbances through human interaction. However, it is unclear how many years the measure has to be carried out before the lake is in the other stable state. There is a high risk that ending it at the wrong moment and without a plan for future fishing strategies, the currently observed positive effects will abate and the lake system will go back into an eutrophic state as has happened with a previous attempt with biomanipulation (1989-1990).
- Private house owners are reluctant to install adequate private sewage treatment facilities as they are costly (Wallin, Zannakis & Molander 2013). House owners are required by law to invest in the private sewage system if it is not possible for them to

be connected to the municipal systems. This measure will decrease eutrophication in the catchment but it is dependent on costly investments by individual households.

- The costs for monitoring are shared among the responsible participants in the water council. Although it is costly for individuals, such as farmers, the program is designed to be cheaper for all members compared to individual monitoring controls.

Designing and implementing a suitable set of measures to improve EBM and the overall governance of ESS trade-offs in the catchment area lies in the responsibility of local municipalities and water councils. However, some consequences from regulation and lake restoration can be explored further through our model-based scenario analysis.

5.2 Qualitative evaluation

Many shallow lakes experienced eutrophication and regime shifts in the past which pose a significant challenge to managing institutions (Jeppesen et al. 2007) because of their non-linear dynamics and the need for continuous learning to address emerging policy outcomes (Janssen and Carpenter 1999). We have analysed the problem of freshwater restoration in the catchment by focusing on the potential trade-offs and synergies among ESS connected to the clear water state of the lake. The connectivity between ESS can point towards those social-ecological and social interactions which may be critical for enabling successful restoration. These include the need for regional cooperation or the extension of wetlands. In the following section, we demonstrate how currently implemented and discussed measures in our case may contribute to successful restoration and improve resilience of the lake-related SES (Section 5.2.1). Further, emerging from our stakeholder process, collaboration among decision makers and interest groups was identified as most critical to manage aquatic ESS (Section 2.2). Taking a resilience perspective allows us to holistically and in a dynamic way evaluate the proposed measures and the underlying social processes related to collaboration in a qualitative scenario analysis (Section 5.2.2). The analysis is supported by our stylised simulation model focussing on the unfolding of social and ecological processes through their interactions, particularly how time delays in the social system can slow down lake restoration in a non-linear way. Our stylised model analysis complements empirical studies on lake management since the dynamics resulting from interactions between actors and between actors and the lake cannot be studied empirically due to limited data availability (particularly of social and human behavioural data and time series).

5.2.1 Resilience principles serving as evaluation criteria

Managing a lake that has previously experienced a regime shift requires a careful evaluation of the major driving and feedback dynamics. To enhance the resilience of the clear state, multiple measures were examined empirically as to their long term effects (Søndergaard et al. 2007). Here, we summarise the implemented and proposed measures for Lake Ringsjön and how they are expected to enhance the resilience of the clear state (Table 4).

Table 4 Measures evaluated by their contribution to resilience of ESS in the lake-related SES.

Scenario	Measure	Resilience principle targeted	Related evidence
Baseline	Biomanipulation	Principle 3: Manage slow variables and feedbacks Biomanipulation intends to shift ecological feedbacks by changing the abundance of certain species so that feedbacks of the clear water state become dominant and clear water species diversity re-establishes.	From Ringsjön (Ekvall, Urrutia-Cordero, and Hansson 2014, Nyström and Stenberg 2018)
	Enforce private sewage system upgrades	Principle 3: Manage slow variables and feedbacks Sewage system upgrades reduce the main slow variables (nutrients) that drives lake eutrophication	For Southern Sweden (Wallin, Zannakis, and Molander 2013)
Alternatives	Temporary reduction of commercial fishing rights	Principle 3: Manage slow variables and feedbacks Reduced fishing reinforces ecological feedbacks that are critical for the clear state recovery	For European temperate lakes (Mehner et al. 2004)
	Extend wetlands at eutrophic inflows	Principle 3: Manage slow variables and feedbacks Wetlands reduce the main slow variable (nutrients) that drives lake eutrophication, Principle 1: Maintain diversity and redundancy Wetlands enhance ecological diversity and redundancy which increase the capacity of the ecosystem to respond to changes	From a neighbouring catchment (Lindahl and Söderqvist 2004)

The measures mainly reinforce the feedbacks of the clear state (reduce planktivorous fish, increase zooplankton and macrophytes abundance) and reduce the slow drivers of the turbid state (nutrients). Diversity of zooplankton and macrophyte species are increased to enable redundancy in the freshwaters ability to balance climate variability while stabilizing the clear water state.

Based on our analysis of relevant social-ecological interactions for lake restoration (Section 3.1), we identified several social processes that influence the effectiveness of the proposed measures and may be critical for their successful implementation, for the development of additional measures, and for enhancing the resilience of the SES in general. Therefore, we integrate those additionally to the above measures into the following scenario assessment.

5.2.2 Preliminary scenario assessment results

We assess our scenarios for managing lake restoration using the resilience principles and results of our preliminary model analysis. One example for scenario analyses in our agent-based model is the variation in upgrade probability (implementation time lag) of private sewage systems. We simulate different enforcement mechanisms which increase the upgrade probability over time and result in a reduction of the nutrient flow into the lake. Simulations show that under some conditions a 'social pressure' mechanism would allow a faster upgrade and therewith a quicker nutrient reduction (Fig 6).

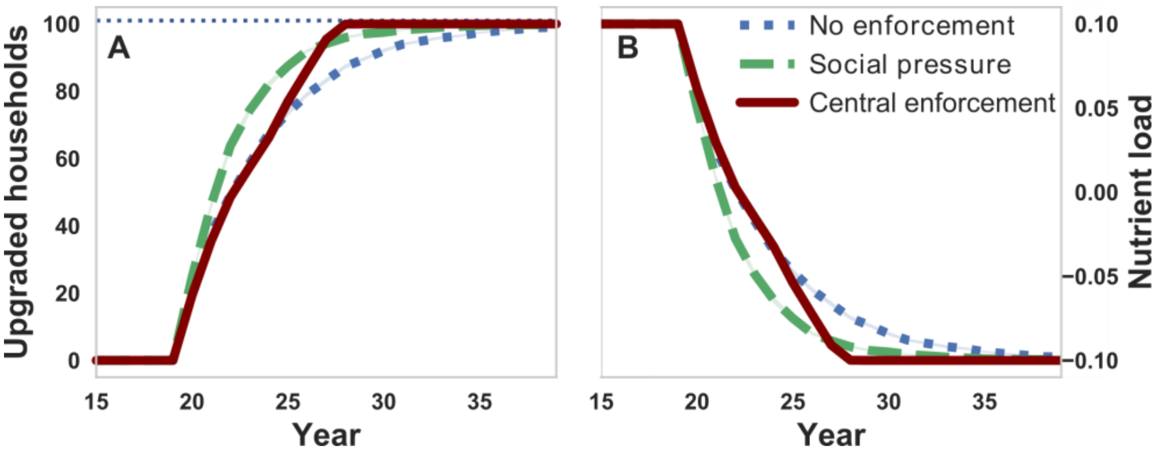

Figure 6 Alternative simulations of sewage system upgrades resulting in decreasing nutrient loads to the lake.

Single simulations from our model provide time series for nutrient and pike concentration which later can be used to evaluate the lake state over time and emerging implementation time lags. Figure 7 shows example runs for different policy time lags (pro-active, intermediate and late) where linear increases in the policy time lag result in non-linear increases of the lake restoration, here shown by the response of the pike population indicating the clear water state. Causes for the non-linear prolongation are a) socially mediated delays in policy implementation and b) ecological reinforcement feedbacks of the turbid state. Simulation analyses suggest windows of opportunity where measures for lake restoration are more effective and thus support long-term planning.

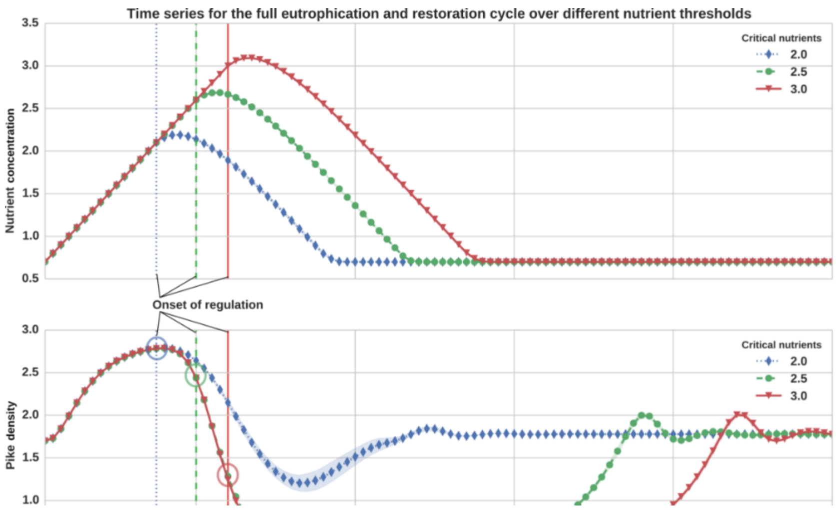

Figure 7 Simulation results for three different policy lags in lake restoration – proactive, intermediate and late.

For our qualitative baseline assessment including EBM and technical measures proposed in the case we account for social processes related to the need for collective action for managing freshwater systems (Table 5). Our policy scenario assessments focus particularly on the social-ecological interactions relevant for improving decision making and action for enhanced ESS, biodiversity and human well-being where local goal setting is equally important as national or EU policies. This study complements other applications of the AF and scenario analysis by focusing on the interplay between social processes and ecological dynamics that jointly determine the success of management measures.

For the Swedish case, restoration activities should be seen on a broader scale, both in terms of long-term goals for the adjacent municipality (which they already do now) but also broader in interests (across sectors, as the water council is set up for but has little legitimacy on decisions) and in the catchment (in terms of added benefits for lower stream water quality improvement).

The main difference between the baseline scenario and the alternative policy scenarios is the way how collaboration enables additional measures while considering ESS trade-offs over time (Alternative 1: ESS valuation over different planning horizons, regulating fishing) and across sectors and space (Alternative 2: Restoration investments based on broader interest groups). The alternative scenarios are not mutually exclusive but highlight different dimensions over which a combination of measures can improve the resilience of aquatic ESS in the Rönne catchment.

Next to the technical and EBM measures such as bio-manipulation and wetland restoration, the resilience of ESS and biodiversity can also be enhanced through strengthening and building capacities within the governance system and society. These social interactions can enable or accelerate the implementation of measures, improve the development of measures by integrating diverse knowledge and understanding, increasing willingness to contribute to the financing and implementation of measures, etc. (Table 5).

The fundamental governance challenge for enhancing ESS and biodiversity lies in the need for mobilizing collective action between policy actors, stakeholders and citizens in developing and implementing policies based on the best available knowledge. Social interactions are thus fundamentally important and need to be taken into account when developing policies and measures. Cost-benefit analysis are an important tool for prioritizing EBM measures, but choices ultimately will be determined by political processes involving power issues, conflicting interests and unforeseeable path-dependencies (Robards et al. 2011). In the Rönne catchment the importance of social processes has been highlighted by the fact that collaboration has emerged as a central theme in our stakeholder engagement process.

Table 5 Evaluation of the contribution from enhanced and novel social interactions for achieving resilience of ESS in the lake-related SES.

	Interactions	Description	General effect on resilience of SES	Effect on EBM measures
Baseline	Local policy making	Little interactions between sectors leading to sector-based regulation with little coordination	Resilience my decrease because trade-offs between ESS are not considered (Principle 2: Connectivity) Limited knowledge available to tackle novel problems (Principle 1: Diversity)	Limited ability to develop and implement policies that involve several sectors such as wetland restoration
	Regional policy making	Little coordination on boundary crossing issues	Lack of fit between ecological and management scales can lead to reduced resilience (Principle 2: Connectivity)	Limited ability to develop and implement policies that address catchment-level issues or cross-boundary effects
	Rule enforcement	Heterogeneous implementation	---	Reduction of nutrient inflows is only partial
	Financial support	With low vertical coordination, funding remains uncertain	Resilience may decrease when funding for measures varies irrespective of implementation success (Principle 7: Polycentric governance)	Limited capacity to carry out bio-manipulation for the duration needed
Alternative 1	Local policy making	Comprehensive plans consider socio-ecological dynamics	Resilience is improved when long-term dynamics are not only understood but also acted upon through collaboration and planning beyond legislation periods. (Principle 3: Slow variables and feedbacks, Principle 7: Polycentric governance)	Taking non-linear dynamics into account would enable a greater priority to politically uncomfortable measures, as for example temporary reduction in fishing.
	Subsidizing OSS upgrades and rule enforcement	Reinforce private motivation and capability to perform upgrades	Social reinforcing feedbacks increase the overall resilience when it is well coordinated, e.g. by securing necessary funding (Principle 3, Principle 6: Learning, Principle 7)	More effective reduction of nutrient inflows.
Alternative 2	Regional policy making	Improved support, enabling e.g. wetland restoration at strategically valuable spots	A suitable fit between management and ecological scales improves resilience (Principle 1: Diversity and redundancy, Principle 7)	As part of an integrated management strategy, measures get implemented that require transboundary collaboration, such as wetland creation.
	Financial support	Improving vertical coordination among water ministries, county ad. Boards and water councils	(Principle 7)	

5.3 Pre-conditions for successful implementation of EBM solutions

Our investigation on collaboration in water governance in Sweden revealed a few entry points that could improve the management and resilience of ESS, biodiversity and their interactions and making the related regulations more just. Together these will support the selection and implementation of EBM measures.

- We identified weaknesses in cross-sectoral and cross-boundary collaboration on the local and regional level hampering the implementation of EBM measures. For example, measures that account for connectivity of the ecosystem and ESS cannot well be taken care of and there are little opportunities to engage downstream actors in supporting upstream actions.
- Water councils represent a broad range of interests and can overcome sectoral divides in municipalities when it comes to regulation of access and interaction with freshwater and wastewater actors. The collaboration among municipalities and water councils is crucial to link broad knowledge and interests to legislation and funding resources. Further, water councils have the potential to build up comprehensive understanding on the social-ecological system and to integrate a long-term perspective on the main dynamics from human-nature interactions.

6 Discussion

6.1 SES assessment using resilience to support EBM

Our case study has the role to integrate resilience thinking for improved governance of aquatic ecosystem services and biodiversity. Here, we report back on insights from our CS regarding how resilience principles support ecosystem-management of the social-ecological system (Annex III 3).

What can we learn from resilience principles for EBM management of ESS/biodiversity?

Resilience principles guide the management of ESS and biodiversity in a generic way, particularly by focussing on structures and processes of the SES and its governance system. There are risks and opportunities here: recommendations based on the state of the SES with respect to particular resilience principles in our case of lake restoration can be difficult to specify and link to concrete measures. There needs to be another step in between that operationalises those principles considered most relevant in the case by assigning concrete measures and indicators (see our attempt doing this for our case in Table 4). However, the generic nature of how the SES is assessed enables well-founded motivations for further research and learning processes among stakeholders. Additionally, the resilience principles are useful for identifying important social or political dynamics, such as conflicts between multiple users, conflicting interests or values, or misfit of institutional arrangements that may critically influence the design and effectiveness of EBM measures. An inspection of resilience principles is an especially suitable entry point when goals are vague or disputed, or the understanding of processes is linked to multiple risks and uncertainty. Thus, resilience principles help to avoid single analyses of ESS or biodiversity traits that are too narrow to estimate their overall resilience within the SES. Our case study shows that, often, more interactions on land-use change and further human-environment interactions need to be inspected for a proper assessment.

7 Conclusions

We investigated water and ESS governance in the Rönne catchment in Southern Sweden with a particular emphasis on how resilience thinking support the development of strategies and measures to enhance ESS and biodiversity. We followed the AQUACROSS AF focussing on the social dimension to answer five research questions:

1. *What social-ecological processes and factors are critical for co-creating aquatic ESS in Rönne catchment area? (Section 3.2 and 3.3)*

Changing preferences around the lake, not environmental conditions, have changed the previously agriculture dominated society and landscape towards a landscape with more diverse ecosystem services today. There is a focus on recreational values at lake Ringsjön and the lower catchment shorelines which rely on access and guidance for occasional visitors as well as local residents.

2. *What are the interactions between ESS in Rönne catchment area? Which of those appear only after time lags, are invisible in the landscape or mediated by governing institutions? (Section 3.2 and 3.3)*

Ecosystem services interact spatially, over time and through institutions. Costly restoration to improve upstream water quality enables free-riding on those improvements in the downstream area. Areas with focus on single provisioning services (nutrient rich agriculture) may benefit from shifting the management focus to underlying regulating services (soil quality) and embracing the view on multi-functional landscapes (e.g. by addition of wetlands to compensate for eutrophic river segments before entering the lake). Non-linear dynamics in lake water quality require a long-term perspective for managing the drivers while the benefits may not be apparent yet. Water councils in Sweden seem to be well equipped to identify and steward interactions in aquatic services which strongly link to water quality (e.g. drinking water, fishing) but for whose management institutional barriers, political short-termism, and sectoral divides need to be overcome.

3. *Broaden participation and promote polycentric governance (Principles 6 & 7) – How do stakeholders define collaboration and how does it relate to the resilience of aquatic ESS? (Section 2.2, 4.2, and 5.1)*

Water councils rely on an active collaboration with the participating municipalities and the top-down governance structures to receive funding for management measures which leads to very heterogeneous functioning of water councils in Sweden. Stakeholders identified the need for enhanced collaboration across sectors in local administration and across administrative boundaries to manage water quality more effectively.

4. *How are multiple interests in aquatic ESS supporting or hindering the restoration of the Lake Ringsjön? (Section 3.2, 4.2)*

Several recreational ESS are linked to good water quality and therefore enable collaboration among multiple interest groups to engage in restoration. The restoration is slowed down by time lags in policy making and implementation but intensive measures show first effects.

5. *How can inter-sectoral and institutional conflicts be resolved to develop resilient, regional water governance respecting multiple ESS in the catchment? (Section 4.2, 5)*

We suggest to consider more explicitly ESS trade-offs in scenarios which enable a fair share of benefits over space (catchment vs. subcatchment), over sectors (producing vs. regulating services) and over time (among generations, considering different planning horizons). No single solutions but continuous learning among stakeholders is expected to help identifying suitable measures for improving ecosystem state and human well-being simultaneously. Careful consideration of trade-offs among ESS will help to form alliances in support of currently undervalued regulating ESS, which other services depend on in the long term.

This report is largely based on results from social data collections (interview, questionnaire, focus group discussions), an extensive stakeholder process, expert consultations as well as qualitative, dynamic model-based scenarios. The model-based analyses will be expanded to include the different policy measures proposed in the baseline and policy scenarios.

In summary, we come to the following conclusions for improving management and governance of biodiversity and ecosystem services in freshwater systems:

- Resilience thinking helps to identify feedback processes and social-ecological interactions which determine long term outcomes from restoration measures. Delayed regulation and implementation results in extended delays of water quality improvements. Collaborative restoration around Ringsjön proved to be effective but catchment collaboration remains weak.
- ESS trade-offs considered in policy scenarios can improve fairness of restoration measures over space (catchment vs. subcatchment), over sectors (producing vs. regulating services) and over time (among generations, considering different planning horizons). Current policies do not yet address these ESS trade-offs.
- No single solutions but multiple solutions and continuous learning among stakeholders help identify suitable measures for improving ecosystem state and human well-being simultaneously. Water councils are well prepared to consider trade-offs among ESS and to form new alliances in support of currently undervalued regulating ESS, which other services depend on in the long term.

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Annex

All annexes are available on the AQUACROSS website Case Study 6 page.

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