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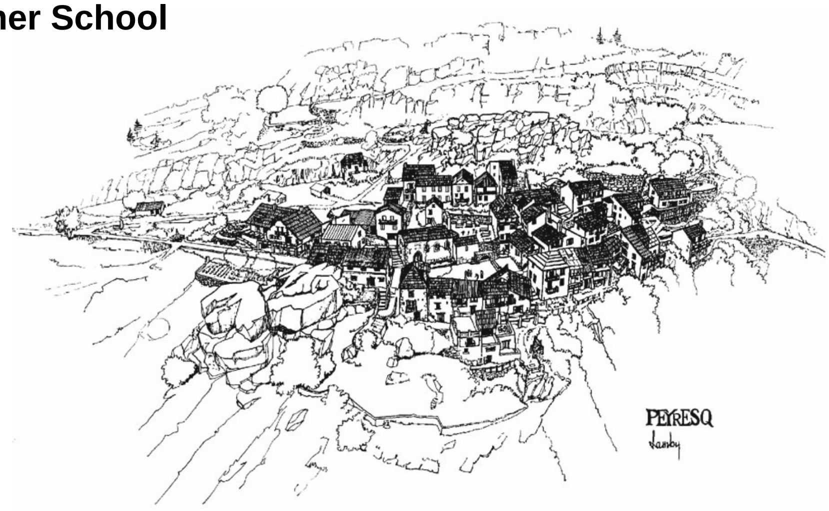

Report

Vulnerability Assessment of Ecosystem Services in the Stockholm-Mälar Region (Sweden)

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Introduction

The perspective of global changes (GC) in atmospheric variables such as precipitation, temperature or carbon dioxide concentrations will substantially impact many ecosystems and the services they provide for society. Such a change in environmental conditions clearly impacts society in different ways and strategies must be found to adapt to these future environmental conditions. Therefore, it is crucial for society to know future trends of how ecosystems might respond to GC and what adaption options are available to minimize the impact of GC on ecosystems.

Over the past decades, scientific studies have investigated the effect of GC on ecosystems. This has included the understanding of how climate and several types of ecosystems interact and the recognition of possible future consequences for society and ecosystems. As the only option, models were applied to prescribe these interactions, thereby accounting for a large spectrum of different natural processes (climatic, hydrological), ecosystems and socio-economic systems. To assess the future impact of the main drivers, such as climate or anthropogenic sectors, these models used data representing the future state of climate, economy and society as boundary conditions. Scenarios can include, at different scales, changes in climate, socio-economics, land-use or population growth.

The simulated responses of different systems to changing drivers is often termed impacts. However, to counterbalance or minimize such future impacts, the assessment of vulnerability and development of adaptation strategies is crucial in maintaining or managing ecosystem services.

Substantial overlapping in vulnerable ecosystems, such as freshwater bodies, agricultural ecosystems and urban areas, was found for the Stockholm-Mälaren region. This region in South-Central Sweden, that represents 6% of the total area of Sweden, surrounds Lake Mälaren (1120 km^2, max 60m deep), which serves as a water supply to several cities.

The Stockholm-Mälaren Region consists of four Swedish administrative counties, with 2.9 million inhabitants. It is the leading business hub in Northern Europe and one of Europe's most dynamic and progressive financial centres around the Baltic Sea shores. The region is growing rapidly, with increases of 1500-2000 inhabitants per year. The shortage of housing facilities led to an increased number of summer cottages; some of them became permanent houses. Over the last 10-20 years, many people moved out of Stockholm into the suburbs. The region is on its way towards creating an ecologically sustainable society, which will serve as an example for other cities and was also rewarded with the first European Sustainable City Award in 1997.

During the last decade, the economy in the Stockholm region was rapidly transformed from an industrial society into a society of information technology (IT), medical industry, biotechnology, consulting, banking, health care, art and culture, management, logistic and engineering disciplines. These international service-companies constitute a dynamic part of today's economy in the region and have strongly contributed to the internationalisation of the economy and to transform it to one of the world's most innovative metropolitan areas. The Region continues to be one of Europe's most popular regions for foreign direct investment and accounts for > 35% of Sweden's total GDP. The transport infrastructure of the region has also been improved over the last few decades.

The central and southern parts of the region are dominated by deciduous forest, and the northern part by forest and low rock islands. The major types of land use are forest (52%), agricultural land (22%), bare rocks (12%) that dominate over natural pits and wetlands (1.5%) or natural grassland (0.05%). Although wetlands and mires are small in extent in this area, they are important freshwater ecosystems, influencing not only biodiversity but also human settlements and activities and providing natural flood control, carbon storage, natural water purification and goods such as fish, shellfish, timber and fibre (UNDP, UNEP, World Bank and WRI 2000).

The Stockholm region experiences a shortage in freshwater supply and, therefore, it is crucial for the development as a whole that water supply can be maintained on the long term. Basic needs such as supply of drinking water and the disposal of sewage water is linked to the Lake Mälaren and the number of drains connected to sewage plants has increased between 1990 and 1999 throughout Sweden. The average water consumption per person in the larger municipalities varies from 400 to 450 l per day per person. Therefore, the maintenance of freshwater supply from surface waters and groundwater reservoirs is crucial. However, these reservoirs are vulnerable to saltwater intrusion, but major concern predominantly arises from anthropogenic pollution from agriculture (pesticides, chlorine, nitrate, phosphorus) or industrial pollution (heavy metals, pathogens, boron, petroleum, etc.) washed into surface waters and groundwater.

The main scientific objective of this study was to assess the impact of climate, land use and socio-economic changes on selected ecosystem services in the Stockholm-Mälaren region.

Methods

One approach to assess the vulnerability of an ecosystem was proposed by Schröter et al. (in press), where vulnerability is a function of exposure, sensitivity and adaptive capacity. We proposed an integrated analysis joining the input from both natural and socio-economic sciences, and a multi-stakeholder approach. Accordingly, the assessment of vulnerability can be divided into several steps: Firstly, define the study area and identify the primary stakeholders. Next, define indicators for the vulnerability of the ecosystem and define how vulnerable the stakeholders are and how they respond to impacts of GC. Then, assess the mitigation options or the adaptive capacity of the stakeholders, to minimize these negative impacts. Finally, the vulnerability is estimated by comparing impacts and the adaptive capacity of the specified indicator of the ecosystems.

To have two contrasting scenarios, we selected the IPCC-scenarios A1 and B2. The first assumes an increasing trend to globalisation and little regulatory measures, the second is based on a more regional development with stricter governmental regulation. We qualitatively downscaled some major drivers for the Mälar region and divided these drivers into 3 categories: (1) Population, (2) Economy and (3) Climate and Environment (see table appendix 5).
Under scenario A1, population and urbanisation increase which is not expected for scenario B2, life expectancy increases in both cases. Economy and consumption increases heavily under both scenarios (more so under A1), while the agricultural sector decreases, but intensifies under A1, involving highly developed technologies. Climatic and environmental change is generally more pronounced under A1, i.e. we experience higher CO_2concentrations, sea level rise, precipitation and ocean temperature. Surface runoff remains unchanged, although this general trend may vary for our specific region for which no precise predictions are available.

Ecosystems goods and services approach

The concept of “ecosystem goods and services” expresses the ability of different levels of the environment (species, genetic, ecosystem) to accomplish services that contribute to human well being. It is, in other words, the concept that express the relationship between human beings and the environment, trying to grasp its different dimensions – material or not.
The main purpose for introducing this idea of functionality of nature is to create an operational tool for answering the question: how to frame the decision on using or not a, environmental component, how to judge on the durability of such an use? Given their multifunctionality, it isn’t relevant to judge the environment benefits directly in terms of natural categories (species, ecosystems), but it is preferable to think in terms of environmental functions (Hueting). The practical meaning of this term is clearly expressed by Paul Ekins (2003): the increasing of human populations and activities makes that all the demands on environment cannot be fulfilled; there is then competition between functions and the continuing over-use of some functions may result in others being lost. That takes away the possibility of beneficing of them in the future. The sustainability definition would hence be the maintenance of important environmental functions, but this raises the question of how stakeholders will continue or not to use them.

The starting point for defining the different dimensions of ecosystems services is the connotation given to the term *human well being*. As Millennium Ecosystem Assessment specifies it: “*Human well-being has multiple constituents, including basic material for good life, freedom and choice, health, good social relations, and security... The constituents of well-being, as experienced and perceived by people, are situation-dependent, reflecting local geography, culture and ecological circumstances*.”

The classification that we use is the so-called 5S’ one:

1. Source (which provides resources for human activities: soil fertility, forestry products, fish, water supply, energy supply, raw materials)
2. Sink (which absorbs, neutralizes and recycles wastes from human activities: stable climate, UV protection, quality air, quality water, quality soils)
3. Life Support (which acts to maintain ecosystems, such as the bio-geo-chemical cycles)
4. Site ("physical place" for human activities)
5. Scenery describes this social determination in terms of values associated with the biodiversity; environmental function in this case translates itself as social benefits: social stability (framework for the social tissue creation/determination/maintenance); system of values maintenance (cultural, ethical, etc.); feeling of security (psychological well-being). It also expresses the cultural determination of values assigned to ecosystems; that what World Resources Institute names "cultural services" and that Global Biodiversity Outlook expresses like this: "*Knowledge of biodiversity at local and regional levels is embedded in cultural practices and languages*."

Definition of driving forces

Usually sustainability challenges are defined[1] in terms of four dimensions under tension, as their objectives can be contradictory: what is *environmentally* right can face what is *economically* desirable, the *economical* growth can face *social* distributional issues, etc.
As the term is dependent on the perspective taken in the analysis, we define here driving forces, as being the structural characteristics of these four systems social, economic, environmental and institutional) and of their interfaces. The stakeholders decide on the solutions to be given to the tension issuing in their relationships.
We present below the logical structure that we follow in the organisation of the thinking about the sustainability issues, which is the tetrahedral framework developed by Martin O'Connor (2000) (see Appendix 2):

Driving forces point on the stakeholders interactions and to the solutions given to the tensions between the dimensions.
Hence, we make the difference between structural indicators (marking changes in the structure of one or the other of the four systems) and indicators that describe driving forces (as features capable to evolve differently in the future and trigger significant changes in their structure and their functioning, depending on the options agreed in the present).

Driving forces:
Economic:
- Economic model (growth-driven? education-driven?)
- Competitiveness and innovation
- Trade (including international)
- Production patterns (industrial vs. high-tech? GMOs?)
- Consumption patterns
- Technological patterns
- Land use patterns issuing from changes in urbanisation, transport infrastructure, evolution of the agriculture and forestry sectors.

Institutional:
- Institutional relationships between the four counties
- Political model (centralised vs. decentralized)

Social and demographic:
- Growing population, accompanied by the urbanisation pressure
- [Perceptions of] consumption and maintenance of Swedish life style (actually: consumer-driven life-style)

[1] *Other definitions:*
The exposure is defined as pressures (physical, chemical) acting on the environmental service considered (freshwater supply).
The sensitivity is defined as structural features and functions of the "object" we are looking at (the environmental service). In our analysis is evaluated in two different scenarios (A1 and B2).
The adaptive capacity is defined as intrinsic property that can be identified in the present state of a system that gives that one the possibility to answer to the sensitive situations.

Stakeholder involvement

The methodology for the identification of stakeholders is in accord with our focus on ecosystems goods and services: the unsustainability in the management of these ones comes from the concurrent use by several actors. Following the identification of pressures on freshwater (climate change, water abstraction, chemicals and peat extraction), we've chosen several main uses as being representative for this region (see appendix): freshwater is used as "sink" for pollution (by industry, agriculture, urban settlements) and as source of water for drinking and agriculture. Ideally, our analysis should lead to a set of indicators (of vulnerability) to be submitted to stakeholders validation and to be monitored and adapted (as the degree of vulnerability changes) through the time at regional level.

Stakeholders: a typology

1. Productive sectors: agriculture, forestry and industry
2. Water and Waste Services/Companies
3. Transport Services
4. Consumers (through their representatives, such as consumer protection NGOs)
5. Institutions
   at different scales: local municipalities and also higher-levels of territorial administrations (up to national: EPA, ministries, etc. and EU scales) coordinating different (economic) sectors
6. NGO's that represent diverse environmental concerns.

Results: Vulnerability Assessment

Institutional

Structural indicators:

- Decision processes
- Institutional coherence (efficiency of regulations, transparency, right to know, legitimacy)
- Environmental governance: (exiting regulation, taxes, "sharing the burden", Access to private information)

Exposures. Sweden is characterised by centralisation in administrative structures: traditional state-based functions such as the institutions of a national and international centre for commerce, finance, political and diplomatic contacts, international fairs and conferences are located in Stockholm. Political administration is organised on self-governing municipalities and County Administrative Boards.

Sensitivity. The switch from the industrialised type of economy to the high-tech one has the potential to create even more disparities between regions (highly educated and richer ones versus poorer ones, receiving less political attention), that can also affect the integrated management of freshwater at the level of the hydrological basin.

Vulnerability: According to current Swedish legislation, municipalities are autonomous and self-governing, a situation which could lead to tension in the region. Such difficulties may well include the development and implementation of long-term visions and strategies. In general one can say that the autonomous and self-governing municipality is primarily functioning in its own interests. Even if the process of co-operation across the region is currently working well, the risk remains that single municipalities may simply stop projects, which would otherwise benefit the region as a whole, for their own reasons – be they fiscal or political.

Economic

Structural indicators:

- level of education of the working force
- Regional GDP
- Innovation

Exposures. The main characteristics of production are mostly labour intensive and public services (tertiary sector). There are times of transition, when industrial society is rapidly transforming into the knowledge society (the region is the preferred location for advanced service companies and high-tech industry). Uppsala, located at about 70 kilometres to the north of Stockholm is the religious and scientific centre though perhaps of more importance today is its human and institutional investment and expertise in the biotechnology industry.

Sensitivity and adaptive capacity. In both scenarios, the GDP evolves positively and represents one of the aspects of the adaptive capacity of the socio-economic system (see appendix)

Vulnerability. The vulnerability of the economic sector is low, giving the very well positioning in Europe of this region and the availability of the adequate workforce and investment resources, but the vulnerability of certain economic actors can be important (following, for example, rise in drinking water or waste treatment prices).

Social

Structural indicators:

- Employment
- Social cohesion
- Distribution of welfare among social groups
- Equity of opportunity (gender, races, integration, etc.)

Exposures. The Mälar region is a divided region from the socio-economic point of view: The socio-economic relationship between the eastern part and the western part of the region may however pose a significant restraint on future development. The eastern part is traditionally dominated by jobs in the service sector, education and research while industry dominates in the western part. The employment is divided among three sectors: Industry/Building (17,0 %), Private services (50,0 %), Public services 28,0 %.

Sensitivity and adaptive capacity. In order to address this discrepancy, a policy focused on education in the western par can transform this sensitivity into adaptive potential.
From the spatial distribution point of view, there is a dominance of the centre. Stockholm is the only city of metropolitan size in the country, and it thus naturally dominates the region with little competition. Compared to other towns and settlements in the region it is significantly larger, and 2/3 of the population of the region reside there. Stockholm attracts, due to its size and character, the majority of inward investment to the region. The over development of Stockholm city could however entail significant additional social costs, which may then have a knock-on effect in terms of emigration and a decline in the region’s tax base. Developments such as this would only serve however to increase the already outstanding imbalance between the eastern and western parts of the region.
The expectancies in terms of life style are changing the land use in the region: the Swedish prefer more and more live on the country side, and for this reason they are leaving the city for its surroundings. There is hence a potential of land use change towards more build-up areas.
Also, the forests around the living space are more used than before, when people preferred to practice long distance tourism (the number of people using forests in the area of 2 km around the living space has increased, while the number of those going far away than 20 km has decreased).
The cultural definition of the aesthetic value of nature relates more to open landscapes, hence grasslands have priority on conservation (furthermore, European subsidies can support this trend) and can take advantage on forests in landscape management options.

Vulnerability. The social category vulnerable to the switch in economic patterns is the one of less qualified people (for example, among immigrants). More, immigrants have the tendency to stay together, hence to form enclaves difficult of integrate in regional dynamics. The Swedish social system is a well-organised one, nevertheless it is important (as an adaptive measure) to think about qualifications and long-term education programmes.

Drinking water consumption

The sources of drinking water in this region are the Lake Mälaren (big cities), rivers, groundwater and smaller lakes (small cities, villages, households).

Exposures. Large-scale factors include increases in temperature at summer (increased evapotranspiration), change of precipitation peaks in the winter period, higher frequency of extreme events (such as storms). Extreme events are mostly connected to risks of seawater intrusion into the lake Mälar. Local factors include agricultural pollution (mainly N, P and chemicals), pollution from transport (roads and airports) and industry (heavy metals, acidity), cities and small households in the catchment areas of rivers and lakes. Eutrophication effects in interaction with prolongation of seasonal cycles and higher summer temperature will lead to increased growing activity of cyanic algae (water blooming) and decomposition of organic matter, causing O_2 deficiency at the end of summer and strong decrease in water quality. Around the lakes, there are several huge industrial complexes, developing medical industry and biotechnology, which use water resources and act as potential pollution sources. An increasing threat to water resources is increasing trend of tourism activities around the lakes and holiday housing in the 100m distance of lake coasts. Tourists act as new sources of water pollutants and ground water users.

Sensitivity. Intermediate - Drinking water resources are sensitive to global changes of climate and extreme events, population growth (A1) and to local pollutions. The main cause of sensitivity is the small catchment area, which leads to high dependency on local precipitations. Local pollution can have remarkable effects. The increasing abstraction of groundwater can lead to salt water intrusion in coastal areas. Another future danger is the increase in sea level in the Baltic sea. The difference in height between the Baltic Sea level and the Lake Mälaren water level is low (yearly average 60-70 cm), and sometimes, the brackish water from the Baltic Sea runs into the lake, causing an increase in the content of chloride in the water. During the next 50 years, the sea level rise is expected to be between 25-50 cm taking into account the land uplift (A1 and B2, Persson et al. 2004), increasing the frequency of salt water intrusions.

Adaptive capacity.
Awareness of the population: High – The region has a highly developed social system and a high awareness of politicians and citizens.
Adaptive ability: High – The economy in the region has a high technological level, the sustainability of political systems and the interest of people is high. However, there is still missing technology to clean out heavy metals and drugs. Nature protection agencies have strong power in the society and people are able to respond to increasing prices of water supply. The probability of salt water intrusion effects at high sea level are avoided through the coinciding increase of higher flows during autumn and winter (Persson et al. 2004).
Action ability: Intermediate to high – The Stockholm-Mälar region is an economically strong region with high sustainability standards. The IT sector increases and will decrease the dangers by industry. There are problems with transport and household pollution, which need regional and national-state level regulations. However, the readiness of people to decrease the standards for welfare is low.

Vulnerability. Low (B2) to intermediate (A1) - The economical adaptive capacity of the region and society is high, but the region is very sensitive to changes in precipitation and temperature, and to sea level rise. The adaptive capacity of people/society is intermediate to low, they are not ready to change standards in living. People are used to high social and provisional standards, but at the same time flexible regarding rises in water prices.
Thanks to the high economical and technical level of region, alternative water resources could be created, but it would take some time (water pipes from other regions, sea water cleaning).

Forest

Forests in the Stockholm-Mälar region currently cover 52% of the surface area, with an increasing trend in the past 30 years. At the same time, forest exploitation in the area is high: mainly spruce (*Picea abies*) is harvested and replanted. There are both mixed deciduous and coniferous forests, the former concentrated to the northern parts of the region. The forest stands are often interrupted by arable land, settlements and traffic, and hence highly fragmented.

Exposures. Forests are directly exposed to all climatic changes but also indirectly to changes in population (e.g. tourism, recreation and urbanisation) and economy (e.g. enhanced wood exploitation).

Sensitivity. Forests in the Stockholm-Mälar region are anticipated to be more sensitive to socio-economic than climatic pressures. It is now known that the future CO_2-concentration (ca. 550ppm for 2050) will probably not have very pronounced effects on tree growth (Körner et al. 2005), even less so on coniferous trees. Indirect CO_2-effects on water relations and extreme events on the other hand are more probable. Sensitivity to rising temperatures is minor. Sensitivity to eutrophication and salinisation of soils due to a rising sea level is more relevant. Sensitivity to socio-economic pressures (recreation and forestry) is low since there is high environmental awareness and sound forestry in this mainly urban area. In contrast, the growing urbanisation can become a pressure. These sensitivities are similar for both scenarios.

Adaptive capacity. Adaptive capacity of temperate forests to altered water relations (higher soil moisture) and extreme events (droughts) is rather high (Leuzinger et al. 2005). Adaptation to rising temperatures will probably evoke a shift of the border between deciduous and coniferous forests to the north, without further implications. The capacity to adapt to eutrophication, acidification (through nitrogen deposition) and possible salinisation are limited and there is a large literature body showing that these factors can have very adverse effects on forests.

Vulnerability. The vulnerability of the forests in the Stockholm-Mälar region is intermediate, and mainly originating from changed soil properties. It is higher under the A1 scenario, where increased nitrogen deposition and salinisation through rising sea level pose the greatest risk, especially because human counter actions to alleviate these problems are often taken too late for slow growing forests.

Agriculture

Agriculture will constitute of 10-15% for A1 and 15-20% for B2 of the total future land use, especially used for crop production.

Exposures. The predicted shortage in water supply will cause limitations in agricultural irrigation use and increases in temperature and evapotranspiration. This may reduce soil moisture and therefore lead to a shortage in soil water availability for plant growth. Increases in population and industry may lead to elevated drinking water demand and industrial water use.

Sensitivity. Soil moisture may decline and limit the growth of plants and crops. This amplifies the shortage of water availability for irrigation and industrial use substantially. More positively, the likelihood of agricultural losses of nutrients and other pollutants to surface waters may decline with future.

Adaptive capacity. Farmers may adapt to the amplified water-shortage by using new and more sophisticated techniques for irrigation or to replace the conventional crops by more water-use efficient crops or even genetically modified crops. Alternatively, soil moisture conserving tillage methods may be applied. However, studies showed that elevated temperatures allow sowing crops earlier (in spring) thereby leading to higher annual yields. From a strategic point of view, some farmers may also switch from conventional crop farming to biological production. This might have the advantage that these farmers can limit their crop production for the benefit of sustainable and locally produced crops.

Vulnerability. Agriculture will strongest suffer from reduced soil moisture conditions needed for crop growth and other resources for water supply will become rare. Therefore, ist vulnerability is judged as high under A1 and intermediate under B2. The vulnerability for irrigation systems is low as only a small fraction of cropland is irrigated and adaptation options are available.

Wetlands, rivers and lakes

Exposures. The actual pressures on wetlands and lakes are manifest at different scales:
Global: climate change (temperature and CO_2% rise, changes in precipitations regime and distribution amongst seasons, extreme events)
Regional: eutrophication (coming from agriculture and urbanisation), pollution (domestic wastes, from transport, industrial or even from unknown sources – such as the mercury pollution), water use and peat mining.

Sensitivity. Increases in precipitation and extreme events will cause changes in timing and amount of run-off and flooding of rivers. Water quality of rivers will adversely be affected by pollution (mainly from urbanisation and agriculture). Lakes and wetlands (peat bogs or mires) will show

hydrological changes in response to climate change (changes in evaporation and precipitation) and water abstraction, and will be negatively affected by pollution and eutrophication. The water level of lakes can decline in response to higher evaporation. However, due to the increase in precipitation, this effect can be mitigated. A decline in water level would affect inshore vegetation and aquatic biota in a negative way and would increase eutrophication effects (higher nutrient loading per unit area/volume). Eutrophication of lakes and wetlands results in a higher primary productivity which in turn leads to oxygen deficits, decreasing water quality and loss of species diversity.
The effects on the productivity of aquatic and grassland vegetation is not clear, given the multiplicity of factors involved: increase of CO_2 concentrations and nutrient levels (N), rising temperatures but also modifications in precipitations regime between summer and winter. However, hydrological changes and increasing temperatures will result in changes in distribution of the species and will alter community structure. Peat formation will be reduced in response to higher temperatures (up to 25% per 1-2°C (Watson et al., 1998)). Increasing water demand and aforestation are important threats to the integrity of wetlands. The negative effects of acidification of species and trophic level diversity will be less important.

Adaptive capacity. The adaptive capacity of lakes, rivers and wetlands to above mentioned changes is probably intermediate. Rivers have a higher adaptive capacity than wetlands and lakes due to their relatively fast turn over. Measures can be taken to cope with the expected changes and these include protection, management, restoration and creation of habitats, reduction of pollution and land use stress and the reintroduction of species. Depending on the rate of migration of warm water species, and the concomitant replacement of cold water species, biodiversity could eventually even increase.

Vulnerability. Taken into account their sensitivity and intermediate adaptive capacity, the vulnerability of freshwater ecosystems in the Stockholm-Mälar region to global changes will be intermediate to high and slightly higher under the A1 scenario.

Tourism

Stockholm City is the primary attraction, but also in the other districts tourism is increasing. The profile of Stockholm is that of a city on water with a large variety of tourist attractions, mostly based on specific events, particularly in the realms of culture and leisure time activities. Tourism in Uppsala is growing and it is primarily the historic dimensions of the city that attracts visitors.
There are four main touristic districts in the Stockholm-Mälar region:
• Stockholm’s metropolitan area including its surrounding population centres.
• The coastal area and the archipelagos.
• The land of Mälaren with its inner archipelago.
• The surrounding countryside with many historical reminders of the iron industry.
In the rest of the region tourism has developed primarily around two themes, nature and history. The landscape around Lake Mälaren, with its accessible historical and cultural attractions as well as the beauty of its natural surroundings makes it an area ripe for tourist development.
(Legeby & Engström 2002, p. 128 ff.).

Exposure. Winter tourism is mainly affected by increasing temperatures causing a decline in snow cover. Summer tourism is affected positively by land use change but negatively by the pollution of rivers and lakes as well as by the expansion of built-up areas into the surroundings.

Sensitivity. Above all the land of Mälaren and the coastal area where nature tourism takes place are sensitive to GC. One has to distinguish between summer tourism and winter tourism.
Summer activities in this region are hiking, fishing, canoeing, horse riding, golf and cycling. Due to rising temperatures in both scenarios and no increase of precipitation in summer the summer tourism will in fact profit from CC. Also a decrease of agricultural area connected with an increase in natural areas support summer tourism in the region. Factors affecting summer tourism negatively are the pollution of rivers and lakes and also built-up areas in the countryside. Winter activities in the region are long-distance ice-skating and cross-country skiing. Both are negatively affected by CC: due to an increase in winter temperature the lakes and rivers will freeze only for a limited time period; even in recent years only in very cold winters ice skating can be practiced. Cross-country skiing is also affected by increasing temperatures: precipitation will fall as rain rather than as snow.

Adaptive capacity. Nature's adaptive capacity to GC is very low regarding the features important for tourism. Being an important economic sector the tourism economy is capable to deal with smaller changes in climate, for example through providing travel services for skiers from one snow region to another.

Vulnerability. Summer tourism will primarily benefit from CC, hence his vulnerability is low in both scenarios A1 and B2. Winter tourism is heavily affected by raising temperatures generating a decline in snow cover and a shortening of the ice skating season. Given only a medium Adaptive Capacity the vulnerability of winter tourism is intermediate in the B2 scenario but high in the A1 scenario (because of greater impacts).

Conclusions

Generally, the vulnerability of the Stockholm-Mälar region in Sweden is only moderate, particularly in the European or even worldwide context. Especially lakes, wetlands and soil water availability are most vulnerable. The already existing water-shortage and the decline in soil water availability will substantially limit crop production in this area. Winter tourism is affected mainly by rising temperatures, a decline of snow cover and the shortening of the ice skating season.

The vulnerability of the socio-economic system is as dynamic as the relationships between stakeholders are evolving. This is the reason for thinking to create a set of indicators relevant for the actual state of the system and for the forces having a potential to change it. Actually, the analysis highlights several factors of vulnerability: the relationships between different management and political institutions at county level, the inequalities between social groups and the distribution of the welfare amongst them, the correlation between the speed of the innovation and of apparition of pressures in the new type of economy and the one of the institutional system to the new threats. The high value of the environment in the Swedish style of life is a very important component of the adaptive capacity.

An eventual rise in prices of drinking water or waste water treatment services, following the perturbation of water resources can also render some categories of users which are actually sensitive (especially those characterised by low revenues), vulnerable and create, in absence of adequate regulatory measures or taxes, inequalities amongst the users of the services (some actors obtaining a profit by creating pressures and some others paying the price).

Scenario A1 generally means stronger environmental impacts (exposure combined with sensitivity). However, adaptive capacity is high for both scenarios due to high standards of knowledge and public awareness. High economic growth (availability of financial means) and sophisticated technologies might even lead to higher adaptive capacity under A1 compared to B2. The emerging vulnerability (impact combined with adaptive capacity) is still estimated to be higher under A1 as the most crucial pressures (elevated CO_2, temperature increase) are more pronounced under A1.

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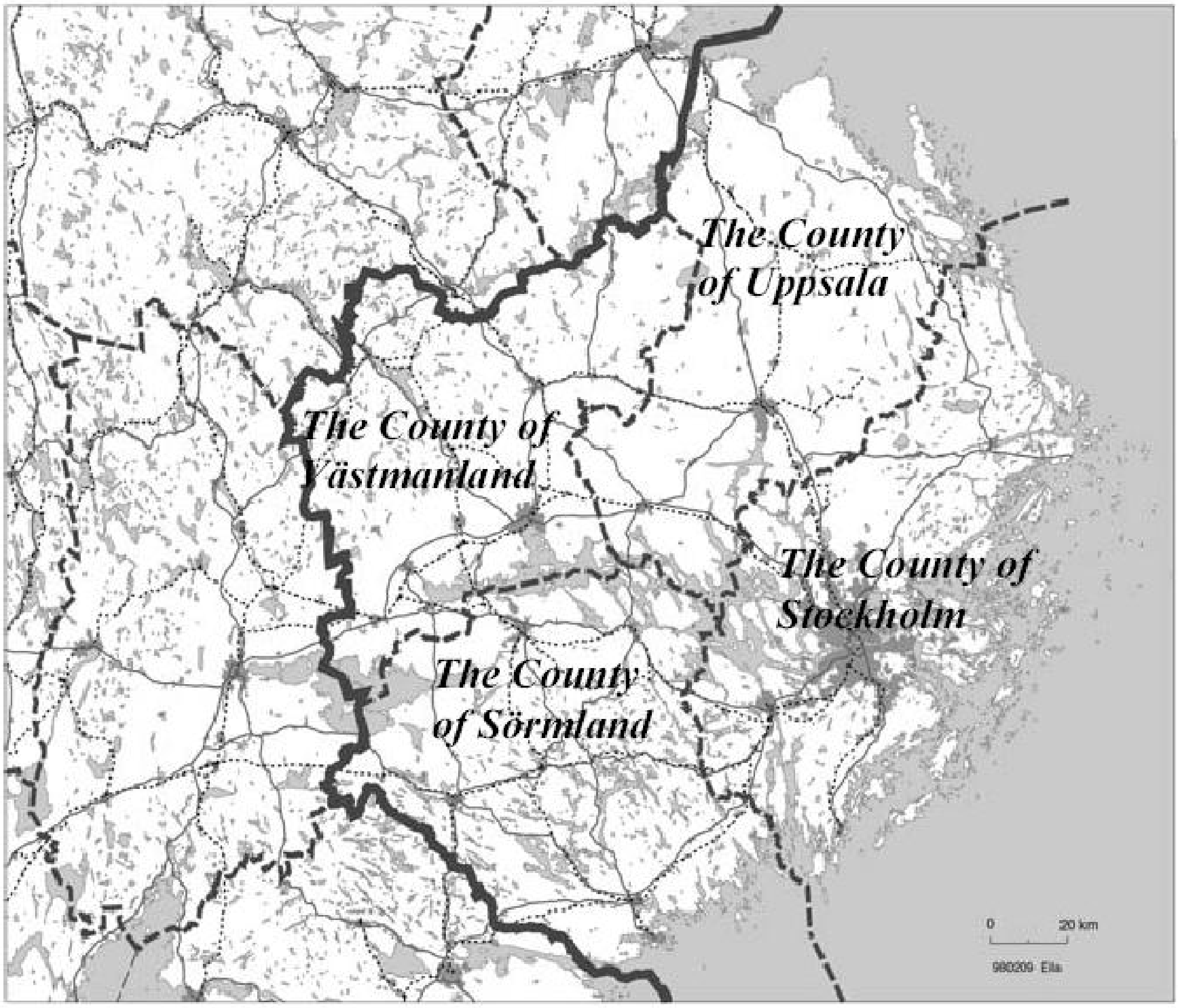
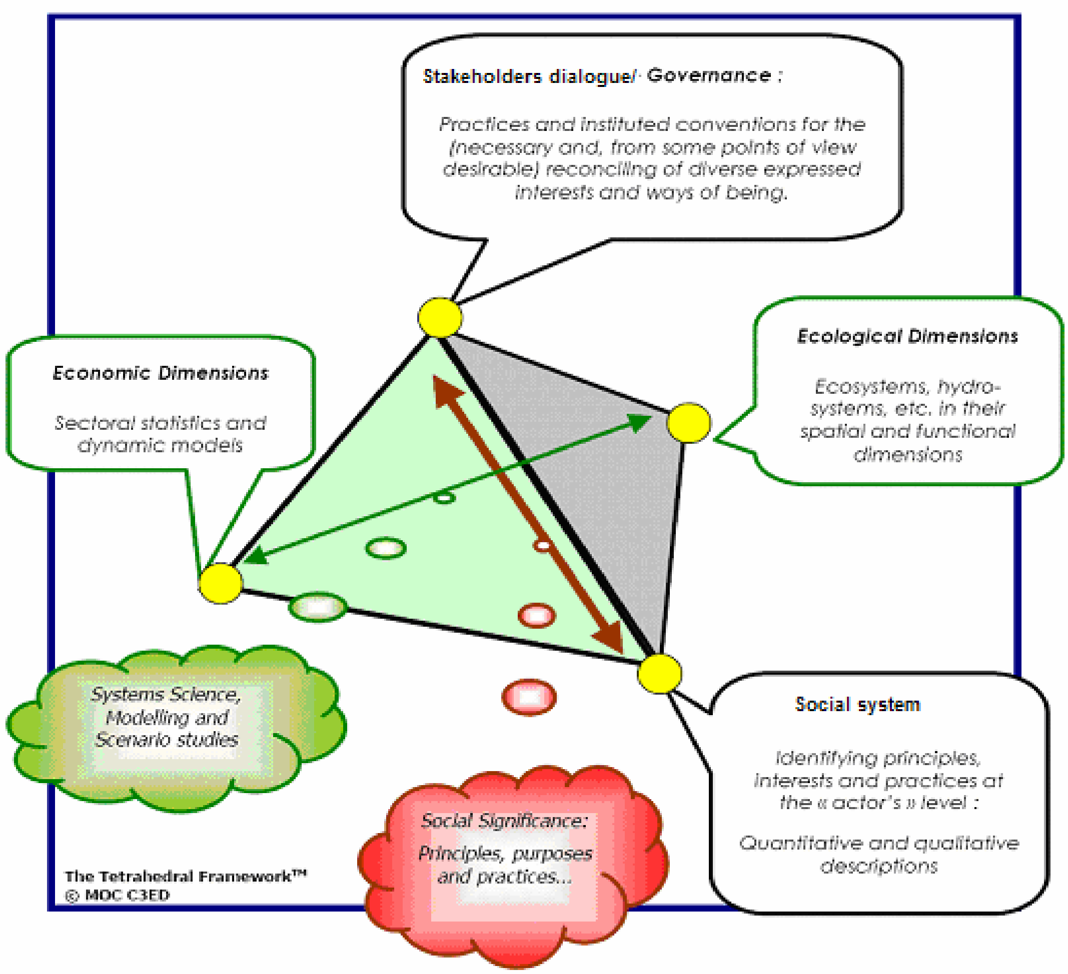
Appendix 1

Map of the Stockholm-Mälar region



Appendix 2

The tetrahedral framework



Appendix 3

Scenario downscaling results for the Stockholm-Mälar region

What pressures exist? EXPOSURE	How will pressures develop in the future? SCENARIOS		Who/What generates pressures? STAKEHOLDERS
	A1	B2	
Climate Change			
Summer temperature	++	+	
Winter temperature	++	+	
Precipitation	+	+	
Sea level rise	++	+	
(CO_2)	++	+	
Extreme events	++	+	
Land use			
agricultural area	--	-	
(semi-)natural area	++	++	
urban/rural area	++	+	
Chemicals			
Eutrophication	+	0	agriculture, urbanization
Pollution	++	+	industry, agriculture (pesticides, nutrients), transport/traffic (20%)
Acidic deposition	-	0	agriculture, industry
Heavy metals			agriculture (metals from sewage sludge), Mercury
Water use	++	+	industry, agriculture, urbanization (drinking water, dillution of sewage water)
industrial	0	0	
agricultural	-	-	
drinking water	++	+	
Peat Mining	-	-	

Appendix 4

Vulnerability Assessment results for the Stockholm-Mälar region (Ecosystem Service "Freshwater supply")

Stakeholders who are affected	Who benefits of Freshwater supply?	Sensitivity		Adaptive capacity	Vulnerability	
	SCENARIOS	A1	B2		A1	B2
	agriculture					
farmers and farmers' union	irrigation	intermediate	low	high	intermediate	low
farmers and farmers' union	soil water availability	intermediate	low	low	high	medium
Stockholm city, small cities, small household holiday pop.	**consumers of drinking water**	Low-intermediate	low	high	intermediate	low
	ecosystems					
forest industry	forest	medium	low	low	intermediate	low
Environment Ministry, fishing sector, EPA, NGO, tourist organization	lakes	high	intermediate	intermediate	high	intermediate
Environment Ministry, fishing sector, EPA, NGO, tourist organization	rivers	intermediate	low	intermediate	intermediate	low
Environment Ministry, EPA, NGO, tourist managers	wetlands	high	intermediate	intermediate	high	intermediate
EPA, tourist managers	**tourism**					
	winter tourism	intermediate (-)	intermediate (-)	low	high	intermediate
	summer tourism	intermediate (+)	intermediate (+)	high	low	low

Appendix 5

Scenario Data for the SRES scenarios A1 and B2

Scenario		**A1**	**B2**
Time scale	2000	2050	2050
Population			
Population	8.8 Mio	9.5 Mio.	8.7 Mio.
Life expectancy	78	88	88
urbanisation (relative)	0,78	0,86	0,78
Economy			
private consumption per capita (1000$)	14	60	35
total GDP (relative)	1	10	4
GDP agri%	0,034	0,016	0,02
% increase in grain production	1	1,063	0,94
Climate Change / Environment			
CO2 concentration (ppm)	370	600	500
T increase	0	3	2
yearly mean T	3-6	6-9	6-9
Ocean T change	0	3	1,75
sea level rise	0	45	35
yearly precipitation	500-600	600	600
yearly runoff (relative)	1	1	1
Surface Runoff Quantity		0	0
Surface Runoff Quality		0	+
Surface Lake Quantity		0-	0-
Groundwater Quant		0	0
Groundwater Quality		0	0

Appendix 6

Table structuring the Ecosystem Goods and Services approach for the study area, example: rivers and lakes

<table>
<tr><td colspan="14">Surface freshwater aquatic ecosystem (rivers)</td></tr>
<tr><td>Environmental good & service</td><td colspan="4">Resource of freshwater</td><td></td><td colspan="2">Regulation of the hydrologic cycle</td><td colspan="2">Space for aquatic transport infrastructure [1]</td><td colspan="4">Recreational value of the rivers</td></tr>
<tr><td>Adaptive capacity</td><td colspan="4"></td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="4">The high appreciation of the environment in inhabitants apprehension (culture and life styles)</td></tr>
<tr><td>Sensitivity</td><td colspan="2">Agriculture</td><td colspan="2">Drinking water</td><td></td><td>Flooding events</td><td>Spatial development of the cities</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Pressure (exposure)</td><td colspan="4">Land use change [1]</td><td></td><td colspan="2">Climate change

(sea level rise, precipitation patterns, evaporation rates, intrusion of salt water, land uplift => the total amount of freshwater flowing into the sea & the distribution of these flows) [3]</td><td colspan="2">Land transportation (train, road) [1]</td><td colspan="4">Expansion of the build-up area [1]</td></tr>
<tr><td>Driving force</td><td>New businesses</td><td>Growing population</td><td>Growing economy</td><td>Consumer-driven life-style</td><td></td><td colspan="2">Global</td><td>Industrialisation</td><td>Need for road inter-regional accessibility</td><td>Growing population</td><td>Growing economy</td><td>Development of new businesses</td><td>Consumer-driven life-style</td></tr>
<tr><td>Pressure (exposure)</td><td colspan="4">Climate change

(sea level rise, precipitation patterns, evaporation rates, intrusion of salt water, land uplift => the total amount of freshwater flowing into the sea & the distribution of these flows) [3]</td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Driving force</td><td colspan="4">Global</td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="4"></td></tr>
</table>

Surface freshwater aquatic ecosystem (lakes)									
Environmental good & service	Fish supply (Lake Mälaren) [3]		Dilution of wastes (Lake Mälaren) [3]	Regulation of hydrologic flows	Space for aquatic transport infrastructure	Recreational value of the lakes			
Adaptive capacity						The high appreciation of the environment in inhabitants apprehension (culture and life styles)			
Sensitivity				Flooding events (the outflow of water from the Lake Mälaren to the Baltic Sea) [3]		Tourism (hiking, golf, canoeing, cycling, fishing)		Local population	
Pressure (exposure) per sector	Disposal of sewage water [3]	Extraction of water for drinking [3]	Disposal of sewage water [3]	Climate change (sea level rise, precipitation patterns, evaporation rates, intrusion of salt water, land uplift => the total amount of freshwater flowing into the sea & the distribution of these flows) [3]		Expansion of the build-up areas [1]			
Drivers	Growing population		Growing population			Growing population	Growing economy	Development of new businesses	Consumer-driven life-style