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Research, part of a Special Feature on Ecosystem Services, Governance and Stakeholder Participation

Ecosystem Services Linking Social and Ecological Systems: River Brownification and the Response of Downstream Stakeholders

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ABSTRACT. The theoretical framework of ecosystem services and that of resilience thinking are combined in an empirical case study of a social-ecological system. In the River Helge å catchment in southern Sweden, a slow increase in dissolved organic carbon (DOC) results in brownification of the water with consequences on ecosystem services in the lower part of the catchment of concern by local resource managers. An assessment of ecosystem service delivery was conducted to (1) identify plausible drivers of brownification in the study site and assess future ecosystem service delivery for stakeholders in downstream areas. An analysis of the perspective of beneficiaries, using qualitative methods, was pursued to (2) evaluate the impacts of brownification on downstream stakeholders.

Our analyses of drivers of brownification in combination with climate change projections suggests that Kristianstads Vattenrike Biosphere Reserve will experience extreme water flows much more frequently than the system is accustomed to today, and that these water flows will be highly affected by brownification. The combination of severe summer flooding and high water color constituted a new disturbance regime and thus requires new adaptive strategies by local stakeholders. A range of coping and adaptation strategies were displayed by the farmers but also a possible transformation strategy, i.e., abandonment of the seasonally flooded meadows. Because hay making and grazing are central components in the active management of the Kristianstads Vattenrike Biosphere Reserve, to discontinue this practice would have system-wide ramifications for the Biosphere Reserve. The vulnerability of fishing in the culturally significant ”Eel Coast,” part of the downstream area, was also exposed.

We argue that for environmental monitoring of slow changing variables to make sense to local stakeholders, clear links to ecosystem service benefits are required. The responsibility for this and thus for matching of social and ecological scales falls heavily on regional managers. We further argue that resilience of a social-ecological system can be estimated by observing and analyzing how local stakeholders respond to disturbances, i.e., by analyzing their response strategies.

Key Words: *adaptation; brownification; coping; ecosystem service; governance; resilience; response strategies; social-ecological system; transformation*

INTRODUCTION

To assess how a change in ecosystem service delivery affects resource users we combine the theoretical framework of ecosystem services and that of resilience thinking. The concept of ecosystem services was used by the Millennium Ecosystem Assessment to link ecological processes with human well-being. This concept has yet to penetrate and influence regional/local management (Cowling et al. 2008). To quantify and value ecosystem services, The Economics of Ecosystems and Biodiversity (TEEB) has suggested a hierarchical typology by separating ecological processes from the actual benefits dependent upon these processes (Balmford et al. 2008). In alignment with the TEEB definition we use “ecosystem service benefits” to mean the end products that are directly used by humans and hence are also desired by humans, e.g., crops, fish, drinking water, biofuel, and space for recreation/tourism.

The flow of a specific ecosystem service has a specific direction, meaning that ecosystem service benefits are often dependent on ecological processes generated at a different location or at another time (Fisher et al. 2009). Different distribution of supply and demand sometimes creates what is known as upstream-downstream conflicts. Populations living upstream in a catchment may affect the hydrological properties in such a way as to infringe on the livelihood of those living downstream (Mostert 2009). In the literal sense this has been explored in water management and arguments have been made to adapt a catchment-based approach for management (Falkenmark 2003), and as a metaphor it is equally true for other ecosystem services such as pollination and pest control, where distribution of supply and demand may differ.

Ecosystem services are likely to be valued differently by different stakeholders and a management strategy based on a single set of stakeholders may therefore be unacceptable for others (Hein et al. 2006). This is a challenge especially when ecosystem management is expressed as adaptive comanagement and then dependent on active engagement and participation of local stakeholders. Furthermore a key for successful adaptive comanagement is to create a positive feedback loop, i.e., a mechanism for progressively improving

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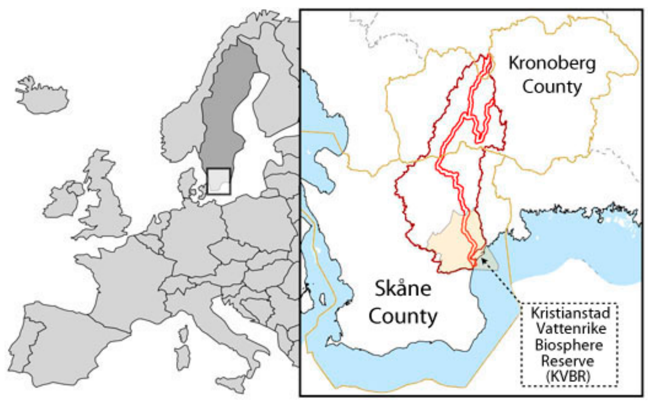
the situation where it is key to "...ensuring that the local people reap the benefit of their own management actions so that conservation actions are maintained" (Berkes 2007:15191). This may not be easy if the production area for an ecosystem service and the benefit area are widely spatial and/or temporally separated.

The spatial, and temporal, dimension of how ecosystem services are generated and where corresponding well-being is appreciated, makes the ecosystem service approach a potentially useful framework for identifying and connecting stakeholders in the landscape. Engagement in appropriate processes, e.g., deliberation of various sorts, by stakeholders is paramount to effectively manage the sustainable generation of ecosystem services (Dietz et al. 2003). It is likely that the distribution of ecosystem services in the landscape, what benefits that are derived from them, and who the beneficiaries are, in many cases are unknown, at least until severe problems in delivery of services occur. The ecosystem service approach can make such links more visible and support problem solving and proactive management.

We apply and explore these ideas in the context of recent and growing concern about freshwater ecosystem services. In many areas in the northern hemisphere, freshwater systems, and particularly rivers, are deteriorating because of increased levels of dissolved organic carbon (DOC). Increasing levels of DOC have been observed in North America, Europe, including UK, Norway, Finland, Germany (Evans et al. 2005), and in Sweden, e.g., in the River Helge å in southern Sweden (Pirzadeh and Collvin 2008). There are several consequences associated with increasing levels of DOC. Primary production can be directly affected following obstruction of sunlight with possible cascading effects. There is evidence for DOC imposing oxidative stress, slowing down photosynthesis, and reducing the growth rate of aquatic macrophytes (Kamara and Pflugmacher 2007). Also, dissolved organic carbon mobilizes certain heavy metals and pollutants (Kalbitz and Wennrich 1998). Water treatment plants must invest in technologies to remove DOC, which directly increase costs for the municipalities affected, or in severe cases change water supply for drinking water (Murrey et al. 2007; Karlskrona Waterplant, *personal communication*). The aesthetic appeal of lakes and streams for recreation can be negatively affected and a significant increase in the release of DOC could have an impact on coastal marine ecosystems and even affect the global carbon balance (Freeman et al. 2004).

The watershed of River Helge å stretches from southern boreal forest in the province of Småland in southern Sweden down to a highly cultivated agricultural floodplain in the province of Skåne. It flows through 14 municipalities before the river meets the Baltic Sea (Fig. 1). The Kristianstads Vattenrike Biosphere Reserve (KVBR) is located in the lower reaches of River Helge å, covering the floodplain and a connected marine area including the urban region of the municipality of Kristianstad. The core of the Biosphere Reserve is the largest area of seasonally flooded meadows in Sweden. The creation of the reserve was a reaction to the lack of fit between problems observed in the landscape and the institutions, structures, and processes for dealing with them (Olsson et al. 2007). The current management structure of the Biosphere Reserve has been described as a successful example of adaptive comanagement (Fabricius et al. 2007, Schultz et al. 2010).

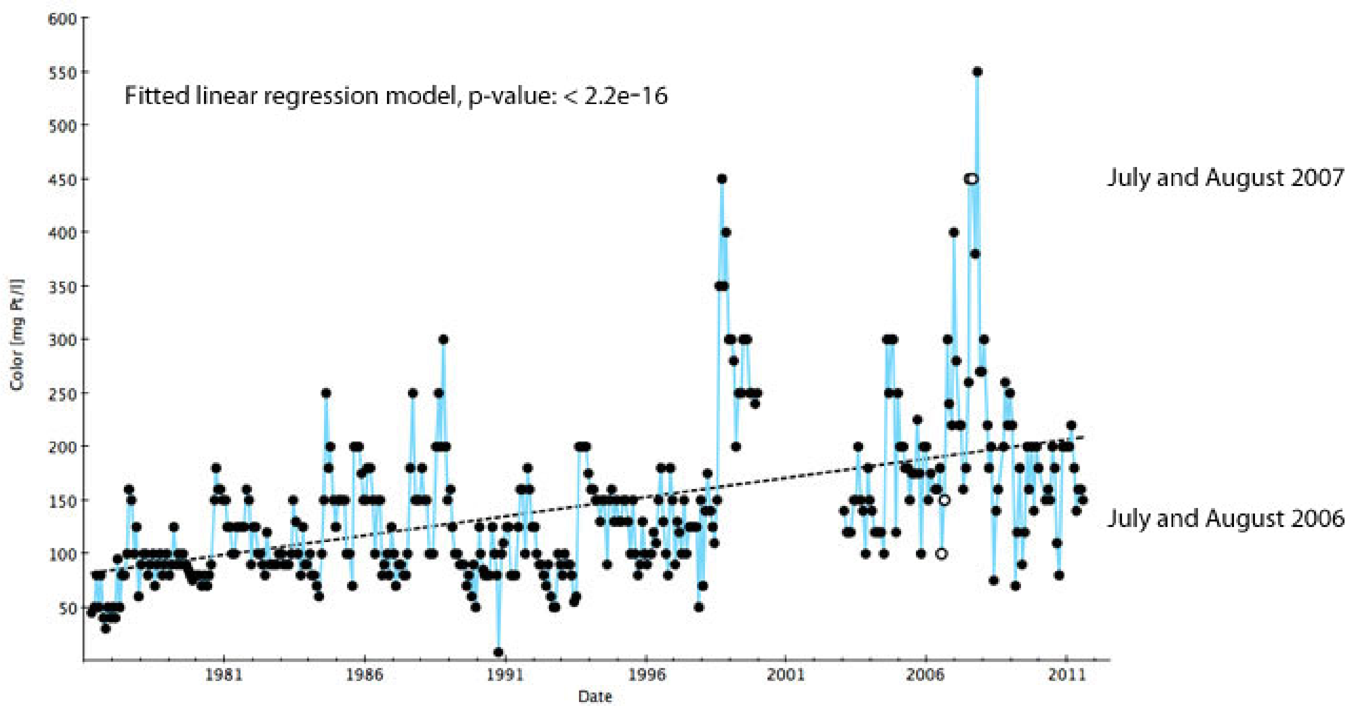
Fig. 1. Map of River Helge å catchment in southern Sweden, including buffer zone extending from the main flow of the river, Skåne County, Kronoberg County, and the Kristianstads Vattenrike Biosphere Reserve.



In July 2007 the River Helge å had extremely high water tables, the highest during the summer season since measuring began in 1905. This coincided with a peak in coloration of surface water (Fig. 2). The brownish water was featured in the local press as a new phenomenon and the issue of brownification became known to the general public. These factors in combination resulted in deposition on grass, shores, and beaches. Brownification became a concern for the biosphere managers (managers of KVBR, *personal communication*) and there was uncertainty regarding what it could mean for the identity and future of the Biosphere Reserve. Local managers suspected that the ability of the Biosphere Reserve to address this issue on a relevant scale and to incorporate both relevant drivers and stakeholders was limited.

The origin of DOC in rivers and streams is mostly terrestrial humus substances from the catchment (Sachse et al. 2005). The visible syndrome of increasing levels of DOC is brownification or browning of water color. The difference in color for different water bodies is assumed to be because of differences in vegetation, soils, and the strength of processes such as decomposition and sedimentation. The relative importance of different drivers and the causality behind brownification is contested and conclusive evidence still lacking. Four prominent hypotheses discussed in the literature

Fig. 2. Color of surface water in River Helge å as measured at Torsebro, where River Helge å enters the floodplain and the Kristianstads Vattenrike Biosphere Reserve. Linear regression using R (www.r-project.org) confirms a linear regression model as a significant fit (adjusted R^2: 0.2573, F-statistic: 133.3 on 1 and 381 DF, p-value: < 2.2e-16). Markers for July and August 2007 and for July and August 2006. Source: Coordinated recipient monitoring (webstar.vatten.slu.se/db.html), hosted by SLU, Sweden.



are land cover change, draining of land, reversed acidification, and climate change (e.g., Worral et al. 2003, Evans et al. 2005, Monteith et al. 2007).

Note that the measure of water color is a generally accepted proxy for DOC but not a direct measure (Worral and Burt 2009). At Torsebro, the point where the River Helge å enters the floodplain (Fig. 2) there are monthly measurements of water color as [mg Pt/l] from 1976 through 2007 (Coordinated Recipient Monitoring, SLU, webstar.vatten.slu.se/db.html).

The increase in DOC is a result of complex processes linked to different drivers of change that lead to either an increase in the stock of available DOC in terrestrial soil, increases in leaching of DOC from soil, or indeed a combination of these (Roulet and Moore 2006). The major sinks for DOC are assumed to be adsorption to mineral soil and biological degradation (Kalbitz et al, 2000). Overall the link between water quality and speed of water flow through soil and landscapes is strong, and storm floods generally lead to poorer water quality (Balmford et al. 2008). The Skåne County Administrative Board has concluded that in 26 of 30 analyzed water bodies in the River Helge å catchment, the trend of increasing water color is significant (Pirzadeh and Collvin 2008).

We addressed the complex issue of brownification in River Helge å using the ecosystem services approach to confirm links in the landscape between drivers of change and ecosystem service benefits downstream, with associated stakeholders. Resilience was then explored using an assessment of response strategies. We addressed the following questions:

1. To what extent could brownification be linked to upstream land use change in River Helge å catchment?
2. To what extent does brownification have an impact on ecosystem service benefits and corresponding stakeholders in the lower part of the catchment, i.e., in the KVBR?

METHODS

This study combines quantitative with qualitative data. There is a series of challenges to interdisciplinary research and one approach to meet these is to base the research on a metatheoretical procedure (Lélé and Norgaard 2005). To articulate a “method for choosing methods” can stimulate and enhance self-reflective behavior during the research process and inform choices regarding appropriate questions and methods. Here we use the “realist synthesis approach,” one of many possible ways to combine qualitative and quantitative data in an analysis (Dixon-Woods et al. 2005). The core of this approach is a search for causality in spite of complex situations making use of different sources of data. A presumption is that to establish causality you need to understand the mechanism that connects cause and effect and the specific context in which this connection takes place (Pawson et al. 2005).

Assessment: change in delivery of ecosystem service

To assess the nature of brownification in the River Helge å catchment we investigated four hypothesized drivers. Land cover change and draining of land were both analyzed using empirical data. Reversed acidification and climate change were analyzed through review of the literature.

Using data on government grants given to drainage enterprises we assessed the extent of new ditches being made yearly from 1906 to 1982 (Swedish Forest Agency, Annual reports 1906-1982). The drainage data, i.e., hectares of drainage systems erected, is aggregated according to county boundaries as they were defined during this period and not specific catchments.

To quantitatively assess land cover change in the watershed we reclassified data on land cover from the Kontinuerlig Naturtypskartering av Skyddad Natur (KNAS) project (data corresponding to the year 2000) produced by the Swedish Environmental Protection Agency (Swedish EPA, *unpublished data*). The KNAS project uses several sources including satellite images and field studies and is used for official Swedish yearly reporting on protected areas for nature conservation (SCB Swedish Statistics, Protected nature 2009, www.scb.se/mi0603). Forest is classified into thirteen classes. For analysis of land cover change these were reclassified into deciduous and coniferous forest. For validation purposes a separate classification was made based on satellite images from 2007 (Landsat 5 May 06, 2007. Path/Row 193/021 and 193/020). We used the Swedish Meteorological and Hydrological Institute (SMHI) delineation of the watershed for River Helge å in all instances. The software package of Idrisi Taiga, release 2009 Clark Labs, was used for segment based image classification. For analysis of satellite images this method can achieve better results than pixel-based classification because information on neighboring pixels is included in the classification process (Yan et al. 2006). All seven available spectral bands were used to achieve maximal resolution in each segmentation. The classes used were deciduous tree cover, coniferous tree cover, wetlands, water, urban area, and open land/grass land. No ground truthing, i.e. validating the classification of land cover made from satellite images by field studies, of this classification was made. Aerial photography formed the basis for identification and classification of segments.

Maps from 1865 to 1869, map scale 1:100,000, from the Topographical Corp of the Swedish Armed Forces were used as the historical reference to identify change in land cover. These are the oldest coherent maps available, with sufficient detail, covering the whole catchment (Swedish Forest Agency 2008). These older maps consist of symbols and cannot be simplified or analyzed without using the full extent of the resolution in the map. A buffer zone extending 1000 m (2 km in total width) from the main flow of the River Helge å was used to decrease the scope of the analysis to a manageable sample. We manually digitized the classes of deciduous and coniferous tree cover. The choice of using a buffer zone, as opposed to, e.g., random patches or a transect from north to south, was based on the understanding that the riparian zone is viewed as crucial for regulating quality in stream water (for example, Luke et al. 2007).

Assessment: impact on stakeholders

To evaluate to what extent brownification has an impact on ecosystem service beneficiaries in the lower part of the catchment, i.e., the KVBR, the importance of brownification must be understood in its context. This includes considering (1) additional drivers that are influencing stakeholders, e.g., traditions, changes in the market place, or legislation, and (2) the abilities of stakeholders to respond to change. Arguably, how stakeholders perceive disturbance motivates action (Wilson 1980). We therefore chose to focus on the perception of ecosystem service beneficiaries.

Identifying stakeholders using the ecosystem service approach

What represents legitimacy in defining stakeholders is often based on implicit assumptions, despite the apparent importance of who to include (Friedman and Miles 2002). The term stakeholder has multiple definitions (Reed et al. 2009). In the context of integrated water resources management it is often defined from the perspective of a strategic goal, e.g., implementation of a project (UNDP Cap-Nat 2008). It may then be appropriate to capture all those likely to be affected by or those who can affect the outcome of the intervention (Rietbergen-McCracken and Narayan 1998). For the purpose of the present case study a stakeholder is simply understood as equivalent with a user of an ecosystem service benefit. This provides a transparent delineation of who to regard as a stakeholder. Legitimacy, in the analytical sense, is the use of a concept congruent with a defined set of rules. This set of rules must be analytically easy to interpret and open to scrutiny if nonexperts are to be included in a management process and expected to relate to research results (Cowling et al. 2008).

Table 1. A scoping exercise was carried out to identify ecosystem service benefits possibly affected by brownification. Key informants were contacted and data collected. This was done to identify those ecosystem service benefits most likely affected. Two groups of stakeholders were subsequently chosen for further study. We use "ecosystem service benefits" to mean benefits directly used by humans.

Ecosystem service benefit	Local key informants and data collection	Conclusion
bathing in lakes	head of Kristianstad tourist office: municipality website with data on location and status of water quality for outdoor bathing facilities run by the municipality; interview.	No outdoor bathing facilities run by the municipality are affected by River Helge å. Unofficial outdoor baths not explored.
bathing in the sea	owner of largest shorefront Hotel, head of Kristianstad tourist office, managers Biosphere Office; interview.	No indication of change in bathing number or behavior and no complaints. 15,000 people may visit the beach on a sunny day.
recreational fishing	chair of regional recreational fishing association; two reports from the Biosphere Office on status of freshwater fish, interview.	No indication of change in the number of fishing licenses sold or interest in recreational fishing.
bird watching	manager from Biosphere Office; two reports from the Biosphere Office on bird populations, interview.	No indication of change in birdwatching behavior.
attractiveness of the coastline	owner of largest shorefront Hotel, head of Kristianstad tourist office; municipality data on level of tourism in the region, interview.	No indication of change in tourism to the coast linked to brownification.
grazing and haymaking on the meadows	farmers on the meadows; interview with two farmers.	Brown deposition on grass noticed. Expressed concern for brownification affecting farming.
irrigation for crops	former chair of the largest irrigation system in the area (and Sweden); maps on irrigation systems, interview.	No indication of brownification affecting irrigation behavior.
ecotourism	manager from Biosphere Office, head of Kristianstad tourist office, owner of largest shorefront Hotel; interview, web search.	14 businesses were identified as ecotourism by the tourist office. The link to water quality and brownification was judged weak.
eel fishing	eel fishers; map of placement of fishing gear, interview with two fishers	Strokes of brown water noticed, expressed concern for brownification affecting catch.
drinking water	municipality representative responsible for water; interview, municipality website on water.	No indication of brownification affecting municipality drinking water supply. Kristianstad municipality switched to using ground water in 1941.

Scoping

A scoping exercise was performed in two steps to identify stakeholders that may be affected by brownification. First a brainstorming exercise was held with four managers at the Biosphere Office, representing extensive local ecological knowledge. Three of them have been part of the long process of creating Kristianstad Vattenrike Biosphere Reserve (established in 2005 according to the Man and Biosphere program by UNESCO) out of the Eco-museum of Kristianstads Vattenrike, established in 1989 (Schultz et al. 2007). Ecosystem service benefits within the Biosphere Reserve that were possibly affected by upstream brownification of the river water were listed (Table 1) as well as key informants. As a second step these key informants were contacted, most by telephone and some in person, and data collected.

Two ecosystem service benefits were identified as being most likely affected by brownification and selected for further study: eel (*Anguilla anguilla*) fishing along the coast and farming, i.e., grazing and haymaking, on the seasonally flooded meadows. There are 50 to 60 farmers active on the 1620 ha of seasonally flooded meadows within the Biosphere Reserve. Nine farmers were interviewed. Respondents were chosen to include a diverse set of farming activities. Because saturation in the answers was observed, no further interviews were conducted. In 2009 there were only 11 fishers along the culturally significant "Eel Coast," in the Bay Hanöbukten, with a license for commercial fishing of eel. They were all approached and nine fishers were available for interviews.

Qualitative interviews

A semistructured interview approach based on open ended questions was applied (Leech 2002). The interviews were centered on (1) the respondents' operation, experience, and local ecological knowledge, (2) the consequences of brownification, i.e., to what extent does this affect their utilization of ecosystem services, and (3) strategies to cope with this disturbance. All interviews were conducted by telephone. They were recorded and detailed notes were taken.

Transcripts were written based on notes and audio recordings. The transcripts were subject to a series of readings without conscious effort of analysis followed by clustering of the information through the technique of “cutting and sorting,” a technique for identifying categories, or themes, by constantly comparing snippets of text and using emerging categories for sorting these quotes into a meaningful structure (Ryan and Bernard 2003). This inductive coding provided the basis for data analysis and comparisons within the two groups and between them. This analysis follows an established series of steps of data treatment within inductive coding (Thomas 2006).

Data analysis using resilience thinking

To estimate the extent of the impact of brownification on stakeholders, the resilience framework was tailored into an analytical tool based on a typology of response strategies, that is, coping, adaptation, and transformation strategies. As is often observed, and is in this case, stakeholders hit by a disturbance react on two parallel tracks, short-term coping and longer term adaptation (Thomas et al. 2007). Coping is understood as the process of relying on an insurance such as accumulated capital, to cope with the disturbance; for a farmer it can be the bank account or temporarily accepting degradation of soil. The disturbance is seen as a passing anomaly with the implication that after the event has passed, business can continue as usual and stocks of capital are rebuilt. An adaptive response occurs when the disturbance is not perceived as an anomaly and hence that the present strategy will not be sufficient in the future. In this case, the stakeholders need to revise and change strategy for meeting disturbance. The “coping range” (Smit and Pilifosova 2003) of a system describes an interval confining the amplitude of disturbances within which the actor/system will cope, i.e., not have to change and still retain system function and identity (Folke 2006). The coping range may change over time so that the system/actor “fails” even though they have managed that kind of disturbance in the past (Nelson et al. 2007). The third order response is transformation in which the system changes to such a degree that we shift from one kind of system to another. A transformation strategy is used when the focus of interest is given up for one of greater importance, i.e., to save the system scale above the focal scale a transformation is actively pursued. In this way social response strategies are nested within scales and what is a transformative change on one level of organization can be described as an adaptive response on a higher level.

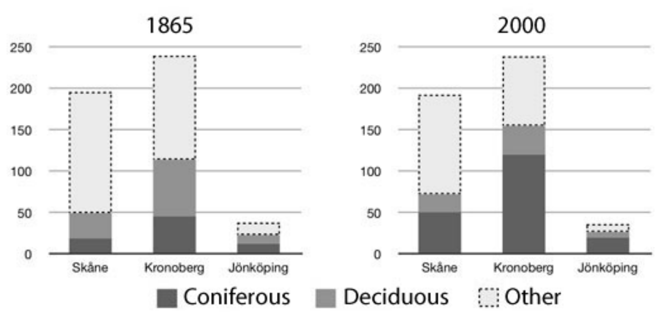
RESULTS AND DISCUSSION

Change in delivery of ecosystem service

Hypothesis: land cover change

Change in land cover in the catchment from grazing/farmland to more forest coverage increases the soil carbon pool and this predicts the concentration of DOC in streams (Aitkenhead et al. 1999). In the River Helge å catchment, land cover has changed in the last century toward an overall greater coverage of forest from 39% to 54%, in which deciduous forest has decreased and coniferous forest has increased. The shift toward coniferous forest is especially marked further upstream in the catchment, i.e., Kronoberg County, with an increase from 19% to 65% land cover (Fig. 3). A comparison of land cover for 2007 in the whole catchment and in the buffer zone indicates that the buffer zone underestimates total forest cover by approximately 10%, mostly attributed to an underrepresentation of coniferous forest cover (Fig. 4). A sensitivity analysis of the accuracy of this observed land cover change cannot be done because the historical baseline is uncorroborated. Without a third empirical reference, e.g., through paleoecological analysis of soil profiles, an estimate of the degree of uncertainty in the data cannot be calculated.

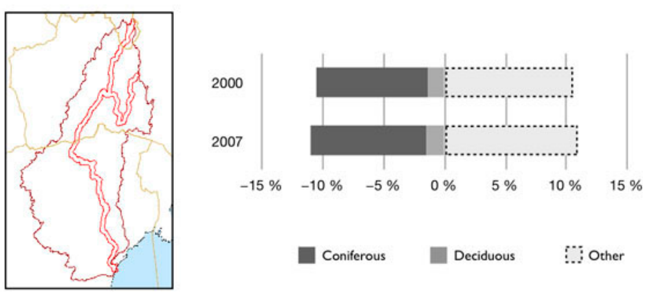
Fig. 3. Land cover in River Helge å catchment within a buffer of 1000 m extending from the Helge å River main flow. A comparison between a composite of maps from 1865 to 1869 (Topographical Corp of the Swedish Armed Forces) and data from 2000 based on classified satellite images (Kontinuerlig Naturtypskartering av Skyddad Natur [KNAS] project, Swedish EPA, *unpublished data*). Data show an increase of total forest cover and an increase in coniferous forest cover (km²).



In the medium time frame, land cover will be predicted by the land cover of today. Today the land cover in the upstream area of River Helge å is characterized by southern boreal forest dominated by Norway Spruce (*Picea abies*) and Scots pine (*Pinus silvestris*). It is often projected that as a response to global warming, deciduous nemoral forest and agriculture may infringe upon the south boreal forest in southern Fennoscandia (Chapin et al. 2007). For the second half of this century, uncertainty is high and land cover depends to a large extent on choices made by forest owners driven by fluctuating market prices, new economic mechanisms like payments for carbon sequestration, and changes in regulatory frameworks. There are inconsistent views on the role of forest type and release of

DOC (Sleutel et al. 2009, but see Amiotte-Suchet et al. 2007). However, it is well documented that water percolating through fresh leaf litter contributes to increased DOC levels more than through older material and organic soils. Interestingly, even though deciduous forest may play an important role for a high annual mean production of DOC, coniferous forest is the major contributor for DOC leached during the summer period (Hongve 1999).

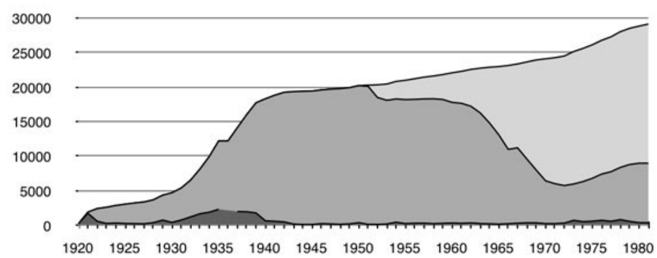
Fig. 4. Comparing land cover within a buffer of 1000 m extending from the Helge å River main flow with the land cover in the whole catchment. Forest cover in buffer underestimates forest cover in the catchment. Data from 2000 is based on classified satellite images (Kontinuerlig Naturtypskartering av Skyddad Natur [KNAS] project, Swedish EPA, *unpublished data*) and data for 2007 is based on classified satellite images (Landsat) using segment-based image classification in Idrisi Taiga. Map shows catchment, buffer zone, and county borders (difference = percentage land cover in buffer - percentage land cover in whole catchment).



Hypothesis: draining of land

Increase in drainage of forests and wetlands is expected to increase run-off as well as increase the stock of mobile organic carbon because of oxidation of soil organic matter (Worrall et al. 2003). Draining of land to increase forest production has been extensive with considerable variation between years (Fig. 5). Sweden has records, accessible in annual reports from the Swedish Forest Agency, of grants and permissions given by the state through regional boards from 1906 to 1982. These records do not cover all drainage work that has taken place. Notes in the historical records state that the board is aware of several large drainage systems being constructed without permission and without state grants. Following new regulations imposed in 1986 large scale drainage of land is no longer permitted (Swedish Forest Agency, *personal communication*). Noteworthy is that restoring and keeping old drainage systems in good shape is not prohibited, and that temporary drainage of land following timber harvesting is permitted.

Fig. 5. Hectares of drainage systems yearly erected in the Kronoberg County 1920 to 1982. Data on drainage areas for which government grants have been given for the year they have been inspected. Before 1920 quantitative data is rare. Data displayed as yearly addition, cumulative over 30 years, and cumulative over the whole period. Source: annual reports from the Swedish Forest Agency 1906—1982.



Hypothesis: reversed acidification

Reversed acidification is a regional scale transnational process that refers to the decrease of sulfate content in atmospheric deposition. This is proposed to make organic matter in soil more mobile and increase leaching by increasing the solubility of soil organic matter by change in acidity or the ionic strength in soil solutions (Monteith et al. 2007). This reasoning has been contested (see e.g., Worrall et al. 2008, Sarkkola et al. 2009).

This factor is expected to still have a potential to contribute to increased brownification before leveling out. Deposition is expected to continue to decrease toward 2-3 kg/(ha*yr) in 2020 according to SMHI, Deposition scenario CLE (Pihl Karlsson et al. 2008). It is possible that the increased acidification during the 1960s and 1970s has masked an underlying tendency of an increase in DOC caused by the other drivers.

Hypothesis - climate change

Climate change is a global scale process that in many areas of the world is expected to change precipitation patterns toward increased frequency of heavy precipitation, increased storm water flows, and increased leaching of DOC as a result. Storm water flows are likely to move through soils with high carbon content and flow rapidly through the landscape decreasing time for biological degradation. It is shown that catchment topography influences speed of water flow and predicts DOC in headwater streams (Andersson and Nyberg 2008). In addition, higher temperatures in soil have been shown to affect the release of DOC possibly mediated through changes in soil biota (Briones et al. 1998).

According to modeling efforts by the SMHI Rossby Centre (Swedish Governmental Official Reports 2007), an increased variability in surface water flows is predicted because of

Table 2. A future scenario for brownification, increasing water color due to increasing levels of DOC in surface water, in the River Helge å catchment based on four drivers of change.

Driver of change	Mechanism for contribution to brownification	Future contribution to brownification (as increase, stable, decrease) in the medium term (2050)	Scale and type of intervention
Climate change (1)	increase leaching of DOC through 100-year flows "much more often" and through increased soil temperatures.	+ increase in coming decades	Global agreements and regional actions. Measures to slow down water flow in the upper parts of the watershed
Reversed acidification (2)	increase leaching of DOC through decreasing deposition	+ to 0 increase in next decade then level out	-
Land cover change (3)	increase stock of DOC through increased forest cover and increased coniferous forest cover	+ to - stable/increase in coming decades than possibly decrease	Regional. Measures to slow down water flow in the upper parts of the watershed
Drainage of land (4)	increase leaching of DOC through increased run-off, increase stock of DOC through increased decomposition	+ stable/increase in coming decades	Regional. Measures to slow down water flow in the upper parts of the watershed

climate change. The frequency of extreme events with high water flows, 100-year flows, will change more than the yearly mean flow. Changes in frequency for 100-year flows are estimated for 41 rivers in Sweden. River Helge å is one of six rivers for which the occurrence of what is today considered a 100-year flow is estimated to happen "much more often" when comparing the periods 1961 to 1990 and 2071 to 2100.

A new disturbance regime

The effects of brownification on ecosystem service benefits in KVBR is associated with fast pulse disturbances with greater than average water flows in combination with high color during summer. This causes flooding of meadows with a residual deposition on grass and long strokes of brown water that follows the coastline reaching the stationary gear for fishing. What is new, in this landscape that is accustomed to flooding, is the combination of severe summer flooding and brown water. This is not a combination that occurs by chance and thus would be expected to be rare. On the contrary, high concentrations of DOC have been linked to severe flooding events indicating that precipitation characteristics are an important driver (Vidon et al. 2008). The temporal character is important to note because both eel fishing and farming on the meadows are seasonal activities. Delivery of the ecosystem service water quality must be temporally matched with these activities to support the beneficiaries.

All four drivers (Table 2) are of predominately anthropogenic origin in which land managers are located at often long distances from the ecosystem service beneficiaries in the River Helge å catchment. The change in DOC as measured by water color over the last 25 years in the River Helge å is consistent with patterns revealed by historical data on the suggested drivers of change (Table 2). Considering present knowledge, none of the four drivers are likely to contribute to a decline in brownification in the next 30 years and three out of four will likely contribute to an increase.

It is plausible in KVBR to expect extreme water flows much more often than the system is accustomed to today and that these water flows will be highly affected by brownification. This suggests that the system can be described as having moved into a new disturbance regime, defined as change in the frequency, amplitude, variability, or timing of disturbance. A new disturbance regime requires adaptive strategies by stakeholders under the assumption that present strategies were attuned to the present disturbance regime.

Impact on stakeholders

Validation of interview data by triangulation using external sources of data was not possible because of lack of precision in external data, e.g., the official statistics on the eel catch do not have the scope nor the precision needed for relevant comparison. The study does to a large extent rely on the perception of stakeholders. However, validation within group, between stakeholders, and other comparisons did not reveal inconsistencies in the answers.

The impact on downstream ecosystem service benefits

When asked how the summer of 2007, with its record high water tables and high coloration of water, affected the eel catch, answers diverged. Some remembered it as a particularly bad year and others that conditions were not particularly bad but "...the fishing is always bad nowadays." The fishers suspect River Helge å to be a factor behind the recent decline in catch. They refer to the eel catch being relatively successful both north and south of the bay and this despite the general decline in the Baltic population of eel: "it must be something with the water here." Depending on weather and currents the visibly brownish water from River Helge å is either turning north or south from the outlet following the coastline. "If the current turns northwards I will have advantages compared to XX. If the current turns south I will get the brown water and no eel."

The year 2007 is firmly rooted in the minds of the farmers working on the seasonally flooded meadows in the KVBR. The meadows were flooded in mid July, before hay could be harvested, and grazing animals were moved to higher ground: "...it was unique not to have access to your land for two months." When the water receded there was a coating left firmly on every individual straw of grass, "some brown substance," "you could scrape it off with your nail" and harvesting was low to nonexistent, "...in July the water table was so high that we didn't dare use the machines at all - you would damage the soil..." This old grass both hindered new grass from growing and was mixed into the harvest of 2008 resulting in "low quality of hay in 2008." Farmers lost harvest of hay, used for winter fodder, as well as grazing during the summer of 2007: "we could not let the animals back [after the flooding] as the grass was not suitable fodder" and "we had neighbors ... [whose animals had access to the affected grass] but the animals would not graze that grass." One respondent also noted that "grass that was not grazed in 2007 was left untouched also after the season of 2008."

How this affected farmers varied from marginal to more severe effects. The farmers interviewed were all using the meadows but to a different degree and for different purposes. The land was used for breeding of beef animals suitable for grazing on low-yielding land, breeding of race horses, and raising dairy animals. Also, for some, conservation was a major part of their business plan. The increase in cost was mainly due to the need to buy supplemental fodder for the summer and/or for the following winter. The decrease of income was a consequence of slower growth for those with beef cattle, the summer period being the most important for growth, and leading to a lowering of the slaughter weight: "The average weight at slaughter dropped from 312 kg to 274 kg" and "There were fewer animals ready for slaughter." The disturbance of 2007 had residual effects on the following years and some reported that the harvest of hay was still reduced in 2009: "...surprisingly the harvests in 2009 were lower than 2008, approximately 1000 kg/ha compared to 1700 kg/ha a normal year."

Response to disturbance

The farmers are used to shifting seasons and in this case seasonal flooding. However, the combinatory effect of severe summer flooding and high water color constituted a challenge of both new quantity and of new quality: "If it is clean water, and then recedes it's not such a disaster. But with this brown coating, the grass is unusable that year."

An array of coping and adaptation strategies was displayed by the farmers (Table 3). This indicates that most of the interviewed farmers' ability to cope with a future disturbance has increased; they have increased their coping range by employment of adaptive strategies. Some farmers admit that they have not adapted appropriately and confess they are "worse off today... with less land on higher ground." This indicates that appropriate adaptive strategies are sometimes not readily attainable.

For some farmers the income from grants is as important and even more important (up to 3:1) than the value of the harvest of hay. The importance of conservation is underlined by the statement that "... have two business ideas... One is breeding and the other is conservation." This can also be regarded as source of security because "The interest from EU [to support nature conservation through payments] seems fairly permanent." If the flooding event of 2007 becomes increasingly common in the future "... the conditions will be less favorable for grazing... it will be less meat production and more pure conservation."

There are some limitations to the adaptations mentioned. Fewer animals on the meadows is not an option "because a high pressure of grazing is essential on these meadows to maintain good quality grazing." One respondent concludes that although the consequences are more severe with a bigger volume, fewer animals could decrease vulnerability but that "...is not profitable due to advantages of scale." The outlook on the future differs among the farmers. The oldest respondent expressed a casual view and referred to his age saying that "I shrug my shoulders ... it always turns out all right in the end" although he noted that it's different for the young. One respondent who has recently taken over a farm expressed more concern, "...it only took one event like this [summer 2007] for you to hear colleagues talking about whether it's worth it to continue on these meadows". He added that, if there was to be even higher flooding, valuable land beyond the meadows could be affected. He concluded that it would have severe economic implications "...if you can't risk growing capital intensive crops ... that would radically lower the price of real estate." He notes that, "...it could be a reality for my generation."

A possible transformation strategy, abandoning the seasonally flooded meadows, was also expressed. Because hay making

Table 3. Responses to disturbance following the flooding of 2007 according to farmers. There are nine respondents. Data was collected using semistructured interviews by telephone in 2009.

Status	Coping strategies	Adaptation strategies	Transformation strategies
Applied strategies	buy fodder grow winter fodder on other lands move animals temporarily stubbornness luck diversified income (real estate business, grow crops/vegetables) low costs, inexpensive land diversified land; low laying and more elevated, low fraction is on the meadows claim “force majeure” toward management contract entitling subsides	learning what to do until next time better mentally prepared acquire land unaffected by flooding more observant to signals in nature will not keep heifers on meadows dialogue on flooding prevention with authorities have agreement with neighbor for building a pen on his land in case of emergency	–
What if more often “2007 events”...	buy fodder don’t believe that “2007-event” will come more often	reduce number of livestock leave some land on the meadows and shift for higher ground	can’t buy fodder every other year - leave the meadows entirely

and grazing are central components in the active management of landscapes and biodiversity in the Kristianstads Vattenrike Biosphere Reserve, a decision to discontinue this practice would have serious ramifications for the wider system, the Biosphere Reserve, of which farming on the meadows constitutes a subsystem.

The eel fishers are under multiple stressors (Table 4) and they display limited adaptive capacity. The year 2007 does not stand out as an exceptionally difficult year and did not warrant any special activities. The fishers’ local ecological knowledge and expressed concern is congruent with scientific literature regarding the connection between eel catch and presence of river water, but the decline of the eel population is a European wide phenomenon with other causes (IUCN Red List; www.iucnredlist.org/apps/redlist/details/60344/0). Though there are no studies linking levels of DOC specifically with the movement of eel, it is established that migrating eel is sensitive to disturbances of olfaction (Barbin et al. 1998, Westin 1998). It is reasonable to assume that the character of the sea water, as perceived by eel, changes in strokes of water from Helge River. As migrating eel in the Baltic typically swim close to the surface, more than 90% of the time less than one meter deep, they would come across the brownish river water when entering the estuary of River Helge å (Westerberg et al. 2007) because river water will float on top of the more dense sea water. This may cause eel to actively avoid the brownish water or seek out water with other qualities. A causal relationship between the color of water, or content of DOC, and migration patterns of eel is not established by this reasoning but a testable hypothesis is made plausible. To support or reject this hypothesis would require additional research using experimental design.

The fishers note that the eel catch is unpredictable and highly dependent upon weather and currents. Also, both the water table and the color of water had receded from their maximum in time for the fishing season. On the other hand this community is vulnerable to disturbance with limited resilience. The fishers did not refer to any kind of adaptation strategies except diversified income to meet the future. It is likely that displayed adaptation to decline in catch, e.g., by arranging traditional eel-feasts, setting up a professional a camping site, driving a truck at night, is a precursor of a transformative change toward switching from full-time to secondary income. This may be accompanied by selling eel-

Table 4. Summary of drivers of change for eel fishing according to stakeholders structured into four classes of drivers. Nine respondents. Comments reflect number of respondents falling into the category and number of examples given.

Categories	Example quotes	Comment
Environmental drivers	"Rainy summers are not good - the more rain upstream the browner the water" "... it is something with the water" "... the agricultural landscape is covered with drainage systems nowadays"	9 respondents 35 examples
Market drivers	" ... there is no demand for eel because it's red-listed" "I really should replace a major part of my gear... but it's not worth it. Too much work." "it's offensive not to be payed more than 50 sek/kg for eel!"	3 respondents 6 examples
Social drivers	" ... it's a culture that is disappearing." " ... only a few have the skill to construct new gear." " ... we are losing gear all the time. [Unused gear] is burnt by the sun."	4 respondents 10 examples
Administrative drivers	"Now you have to guess when the eel arrives" [because of restriction of 90 consecutive days allowed for fishing] "Today there's a limit on 400 kg that you must catch to get a license... I hope we reach that." "I feel like you have to have your papers 110% in order. If you make one mistake your fishing days are over despite having been fishing for generations."	4 respondents 7 examples

huts for rebuilding into recreational cabins on the shore, for which there is great demand with high prices according to fishers, essentially locking in this particular resource needed for eel fishing into other uses. Also, the knowledge on how to build fishing gear is in decline: "...the latest gear is from 1980s, when XX was alive and others who knew this ... since then we have only repaired." Eel that pass the fishers along the " Eel Coast" may be caught somewhere else or they may not be caught at all, which would be in alignment with the conservation goals in EU and Sweden for this critically endangered species. From the stakeholder perspective diminishing catch threatens their livelihood, their identity as eel fishers, and the wider social-ecological system, the cultural heritage known as the "Eel Coast" of Sweden.

General implications for governance of ecosystem services

Sense-making of slow changing variables

What does brownification signify in this case? Water color is a proxy for levels of DOC, which in the case of farmers has a visible direct impact with deposition on the meadows. Brownification also signals that a change in water quality is taking place with effects that are likely difficult to predict as riverine floodplains are social-ecological systems that are highly complex, dynamic, and diverse (Tockner et al. 2010). Fishers have a strong suspicion that brownification signals a deterioration of possibilities to have a livelihood as a fisher. In the case of Hanöbukten Bay it is burdened with emissions from local industry, intensive agriculture, and historical emissions, mentioned by fishers as potential drivers (Table 3).

How these may interact with brownification is a cause for concern because effects may be synergistic, as in the case of brownification and flooding, antagonistic, or additive.

There is a need to monitor change in slow changing variables so as not to be surprised by the impact of a fast variable, such as a storm, fire, or flooding event, with which the system had previously been able to cope. Because slow changing variables are expressed on long temporal scales and variability may be high, they are not easily detected by local stakeholders in the landscape and thus pose a challenge for managing institutions. Stochastic extreme events, such as storms, are often in focus when trying to understand consequences such as crop failure and other impacts on benefits provided by ecological processes. Clearly, monitoring water color has been in place for decades in the River Helge å catchment but even so, downstream ecosystem service beneficiaries and managers of the Kristianstad Biosphere Reserve were surprised by the combinatory effect of flooding and brownification. Managing slow changing biophysical variables may in some cases be an underrated management option but to make sense to stakeholders in the landscape there needs to be a connection with "ecosystem service benefits." Stakeholders are much more concerned with use values than with other biophysical properties (Rodriguez et al. 2006). The responsibility for this sense-making falls heavily on regional managers because their outlook is on the required temporal and spatial scale. They, and few others, have (1) the capacity to identify changes in slow changing variables and regional processes and (2) the competence to link those to local ecosystem service benefits.

Response strategy assessment

Knowledge of response strategies employed by stakeholders can increase our understanding of resilience of social-ecological systems. We have used a typology of three distinct response strategies to code qualitative empirical data and thus go beyond a binary measure in which systems either cope or fail. The manner of how stakeholders, or systems, respond to disturbance indicates actual context specific resilience and is not a prediction of resilience where predictors of resilience have been transferred from one system to another. Thus an analysis of response strategies would complement the considerable research made into determinants of adaptation and vulnerability (Smit and Wandel 2006), in which features of systems are explored as to how their presence or absence influence resilience and how they can be managed.

CONCLUSION

The research questions posed were policy driven and based on real concern of local managers. With transparency regarding choice of evidence we draw the following conclusions:

- A range of coping and adaptation strategies were displayed by the farmers but also a possible transformation strategy, i.e., abandonment of the seasonally flooded meadows. Because hay making and grazing are central components in the active management of the Kristianstads Vattenrike Biosphere Reserve, to discontinue this practice would have system-wide ramifications for the Biosphere Reserve.
- To increase incentives among local stakeholders to invest in monitoring of slow variables, clear links to ecosystem service benefits are required. The responsibility for this and for matching of social and ecological scales falls heavily on regional managers.
- An analysis of response strategies can be used as a measure of resilience for a social-ecological system by observing local stakeholders' actual actions and anticipated actions based on their perception of challenges ahead.

SPECULATION

Assessment of land cover change and drainage of land, in combination with previously published data on reversed acidification and projections of climate change effects on precipitation suggests that Kristianstads Vattenrike Biosphere Reserve will experience extreme water flows much more frequently than the system is accustomed to today, and that these water flows will be highly affected by brownification. This would represent a new disturbance regime and as such would require adaptive strategies by local stakeholders.

RESPONSES TO THIS ARTICLE

Responses to this article are invited. If accepted for publication, your response will be hyperlinked to the article. To submit a response, follow this link. To read responses already accepted, follow this link.

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APPENDIX 1. Definitions of key terms as used in this paper.

Stakeholder
= A person who is affected by a change in a property of the system in focus.

Manager
= A person with an explicit responsibility, self-proclaimed or appointed, for relevant management.

Actor
= A person who by deliberate action shapes or alters the state of the system in focus.

Driver
= A factor that changes the state of the system in focus.