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Reducing nutrient loadings from agricultural soils to the Baltic Sea via groundwater and streams

The Baltic Sea Action Plan and the EU Water Framework Directive require substantial further reductions of nutrient loads (N and P) to the Baltic Sea during the coming years. Achievements of these goals will only be possible through fundamental changes in agricultural practices and land use. Between 2014 and 2018, researchers from eight institutions from the EU and Russia have investigated future scenarios, improved modelling capabilities and analysed new strategies to reduce nutrient loads to the Baltic

"There have been great efforts to reduce nutrient loads in the Baltic, but **climate and land use changes** present new challenges.

Spatial differentiation offers a smart, cost-effective approach to reducing nutrient loads."

Key messages

- By 2050, climate change will increase nutrient loads to the Baltic Sea by 4-10 % for nitrogen and 6-20 % for phosphorus at a regional scale, although this will vary significantly between catchments.
- Regional changes to societal activities (e.g. land use and agriculture) can have effects that are as important as climate change. Policy making and management of these activities are pivotal to determining whether nutrient loads will be reduced or increased.
- Spatially differentiated strategies that are adapted to the natural conditions of a particular area make it possible to significantly and efficiently reduce nutrient loads without reducing agricultural productivity.
- At a catchment level, we can determine spatial differences in the nitrate reduction potential of groundwater and surface water systems with reasonable certainty. However, to obtain the full benefits of a spatially differentiated approach, we need detailed information at a local (field/stream) scale which is less reliable.
- New approaches like spatially differentiated regulation should be implemented in alignment and with due respect for regional governance structures and socio-cultural traditions.

Context and project activities

Nutrient loads of Nitrogen (N) and Phosphorus (P) to the Baltic Sea peaked around 1980 after which they decreased, primarily due to improved sewage treatment. Today, the majority of nutrient loads come from agricultural areas. However climate change will lead to higher nutrient loads due to increased precipitation and temperature. A warmer climate also makes it possible to expand the agricultural areas in the northern parts of Sweden, Finland and Russia which could further increase pressures. Using a scenario-based approach, **BONUS SOILS2SEA has assessed how changes in climate, land use and agricultural practice in 2050 will affect nutrient loads to the Baltic Sea**.

Despite the decreases in nutrient loads during the past decades, substantial additional reductions are needed to meet the requirements of the HELCOM Baltic Sea Action Plan and the EU Water Framework Directive. Furthermore, many of the ‘quick wins’ for reducing nutrient loads have already been exploited, requiring new and innovative approaches. **BONUS SOILS2SEA has analysed a new strategy, known as spatially differentiated regulation**. Here, management measures are targeted at areas where natural capacity to remove nutrients is low.

Implementing these new strategies is highly dependent on local society, economy, culture and political systems. Using scenario workshops and ethnographic studies in Denmark, Sweden and Poland, **BONUS SOILS2SEA has explored the potential of a ‘co-governance’ approach to improve nutrient reductions**.

Field work and modelling studies were conducted in four study catchments in Denmark (Norsminde), Sweden (Tullstorp), Poland (Kocinka) and Russia (Pregolya) – **BONUS SOILS2SEA has used local information to improve modelling capabilities** to simulate water flows and nutrient transport for the entire Baltic Sea drainage basin and to predict the effect of spatially differentiated strategies.

Climate, societal and land use change – impacts on the Baltic Sea

> “Climate change is only one of several factors affecting nutrient loads”

Restoring the quality of the Baltic Sea is a complex issue that calls for long term planning and focused actions. The **HELCOM Baltic Sea Action Plan**, adopted in 2007, acknowledged the impact of climate change, stating that the reductions may require “even more stringent actions in the future”. When estimating nutrient loads for the 2050s, climate change is only one of several considerations. Land use and societal changes also have an important role to play. Future climate change scenarios can be described using Representative Concentrations Pathways (RCPs), while trends in society and natural systems can be described using Shared Socio-economic Pathways (SSPs). SSPs provide a combination of narrative storyline and quantified developments of demography, economy and technologies.

BONUS SOILS2SEA explored **how future N and P loads to the Baltic Sea might be affected by societal and land use change** using three SSPs developed for the Baltic Sea region by several BONUS projects (BALTICAPP, SOIL2SEA, SHEBA, and GOHERR). SSP1 (sustainable development) describes a world making relatively good progress towards sustainability with sustained efforts to achieve sustainable development goals. SSP2 (middle of the road) is a world, where trends typical of recent decades continue with some progress towards achieving development goals. SSP5 (fossil fuelled development) is a world that stresses conventional development oriented toward economic growth as the solution to social and economic problems through the pursuit of enlightened self-interest.

Assumptions were made in the storylines for the SSPs on how land use and agricultural activities including fertilisation would be affected (see Table 1). Similar assumptions were made for population growth, urban developments, sewage treatment and air pollution - other factors that also affect nutrient loadings to the Baltic Sea.

Changes in:	SSP1 Sustainable development	SSP2 Middle of the road	SSP5 Fossil fuelled development
Agricultural land use	- 10%	0%	+ 10%
Livestock density	- 50%	0%	+ 50%
Manure nitrogen efficiency	+ 10%	+ 5%	- 10%
Applied effective nitrogen	- 5%	0 %	+ 5%
Atmospheric deposition of N	-40%	-30%	-15%
Urban wastewater	-35% / -40%*	-20% / -25%*	-16% / -23%*
Rural wastewater	-30% / -30%*	-17% / -17%*	1% / -23%*

*The first number refers to changes in N and the second to changes in P where applicable

Table 1: Assumptions made for changes in agriculture, atmospheric deposition and sewage treatment for the Baltic Sea region within the Shared Socio-economic Pathways

The SSPs by themselves do not include the effects of a changing climate. To incorporate this, a high GHG concentration scenario (RCP 8.5) was combined with all three SSPs to demonstrate the effect of climate change on N and P loads for the middle of 21st century (i.e., 2050s). The climate change impacts shown in Figure 1 are average numbers from four climate model projections.

At the Baltic Sea scale, climate change under RCP8.5 leads to a significant increase in water discharge to the Baltic Sea and consequently significant increases in nutrient loads (in average 8% for nitrogen and 14% for phosphorus). The socio-economic developments, as represented by the three SSPs in Table 1 can exacerbate the average increase to about 10% (SSP5) or mitigate it to levels below the current load (-19% for N and -6% for P) if the society develops towards sustainability (SSP1). These results reflect changes not only in agricultural land use but also in other activities. Although agriculture is a main source of nutrient loads to Baltic Sea with about 40-50% contribution to the total loads, wastewater from urban and rural populations still contributes 15% of N load and 38% of P load based on the modelling results. Changes in population and wastewater discharges can thus also have a significant impact on changes in loads for the SSPs.

N loads are affected more strongly by the socio-economic changes in the SSPs than P loads. This is particularly noticeable for SSP1 with N load reduction of 19% below current level and P load reduction of 6%. The difference is because several assumptions associated with SSPs affect only N loads (N fertilizers or atmospheric deposition). Changes in P loads are mostly due to the assumed changes in the area used for agriculture and changes in population and its wastewater.

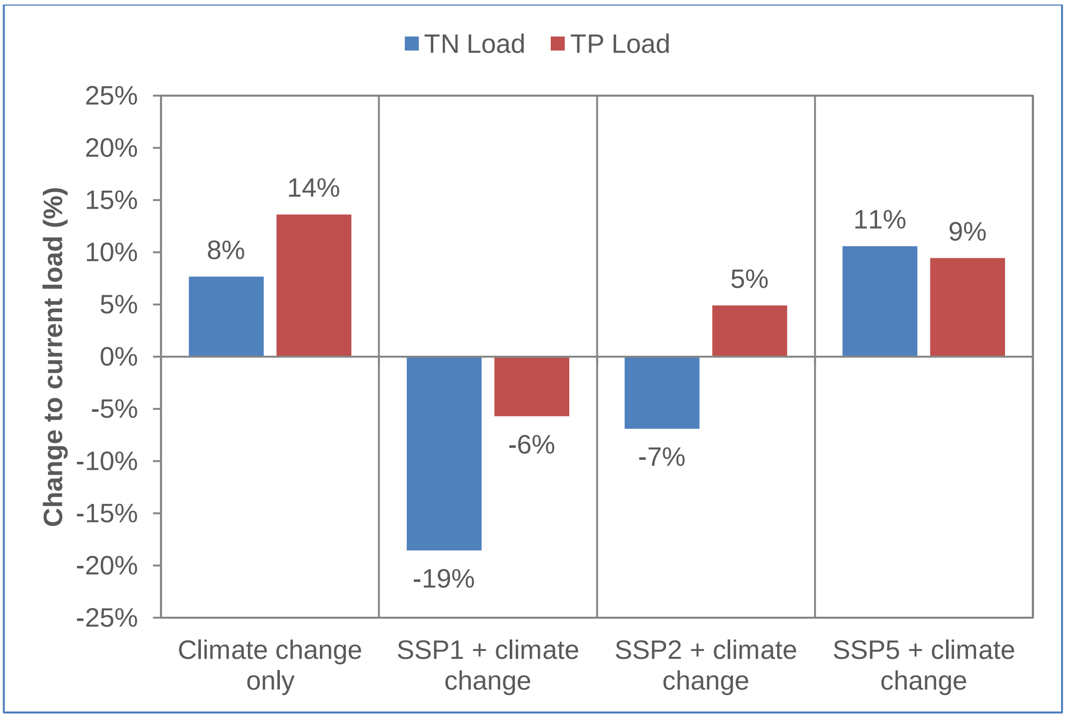


Figure 1: Changes to Total Nitrogen (TN) and Total Phosphorus (TP) loads to Baltic Sea under climate and differing socio-economic scenarios

In addition to the analysis at the Baltic Sea scale, the effects of changes in socio-economic conditions and climate on nutrient loadings was also carried out for two individual catchments (Norsminde in Denmark and Kocinka in Poland) using detailed information on land use and management by applying catchment-based models. The results showed that, **at the local level, the impact of climate change can be much higher** (around 40% increase) than the average impact on the Baltic Sea. Similarly to the Baltic Sea scale, SSPs greatly affected N loads at the two catchments – in one case by over 50%. Such large changes warrant further studies to better quantify the projected changes and their drivers.

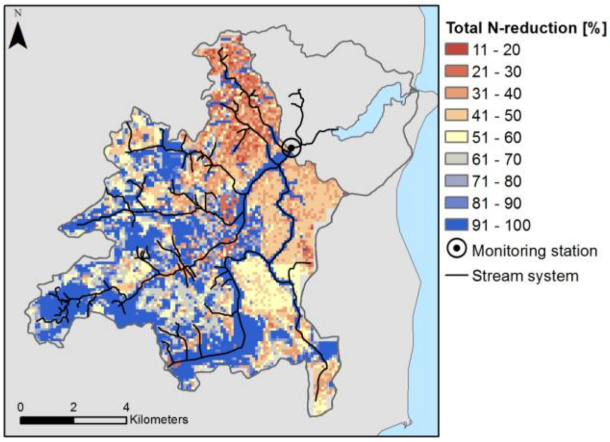
Spatially differentiated regulation

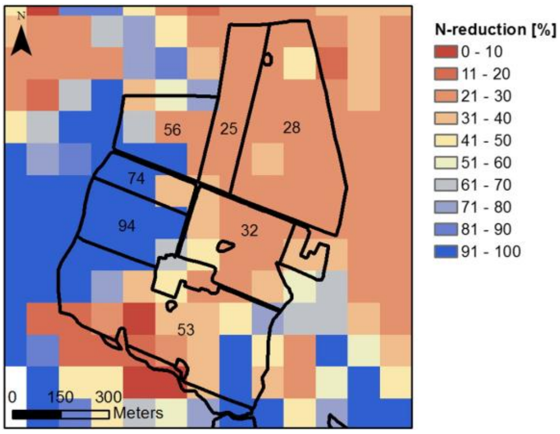
Most of the nutrients leaching from the root zone do not reach the marine environment due to a variety of biogeochemical processes, such as chemical reduction, sorption and sedimentation. In the most agriculturally intensive areas of the Baltic Sea region, 50-80% of the nitrate leaching from agriculture will for instance be removed (nitrate is reduced to atmospheric nitrogen) along the flow paths from the root zone to the sea through groundwater, wetlands, streams and lakes. However, **the natural removal of nutrients takes place unevenly**. The concept of spatial differentiation is to use knowledge of how natural nutrient removal differs in each area - as illustrated in the maps below – to manage nutrient loads. It would, for example, be a waste of efforts to impose restrictions on handling of N on fields where 90% of the N-leaching from the root zone is already removed by natural N-reduction. By the same token, it will be much more cost-efficient to locate mitigation measures on fields with low natural N-reductions of, for example, 30%.

> "Soils and watercourses have differing capacities to remove nutrients depending on their location. **Spatial differentiation** uses knowledge of these differences to pinpoint where management efforts should be focused."

Creating regulations on the basis of spatial differentiation can be done in different ways. One way is to apply N-mitigation measures on target areas with low natural N-reduction and locate constructed wetlands, drain filter solutions or similar measures where nutrient fluxes are high. Another way is to relocate the existing agricultural practice according to the N-reduction capacity, so that crops/practices with high N-leaching are moved to areas with high N-reduction and vice versa.

Similarly, a differentiated regulation strategy applied to wetlands and streams would locate remediation measures where the nutrient removal is largest. This means that measures such as re-meandering of streams, sediment traps, levelling of stream banks, flooding areas alongside the main stream channel and implementation of play grounds for fish should be targeted to specific stretches along the stream, according to where they have the highest efficiency. Streams show the largest removal capacity in the smallest streams, because of particularly long residence times and effective exchange of stream water with microbiologically active zones along and beneath the stream bed (hyporheic zone). Hence, remediation actions in streams are most effective in the upper parts of streams that drain agricultural areas





Maps can help identify areas of low retention where additional measures have a potential to reduce N load significantly. From left to right: N-reduction map for Norsminde catchment (Figure 2) and the spatial distribution of N-reduction for a farm within the Norsminde catchment (Figure 3).

With the existing data, the N-reduction maps in Figures 2 and 3 are highly uncertain at field level (1-10 ha), but much more reliable for average reductions over larger areas such as a farm or a subcatchment (100-1,000 ha). However, to exploit the full potential of spatially differentiated regulations, maps with a fine spatial resolution (100m – 500m) are required. If we for instance use N-reduction values averaged over the entire farm (Figure 3) the considerable benefit of differentiation within that farm disappears.

N-reduction maps with fine spatial resolution are necessary to exploit the potential benefits of spatially differentiated regulation, but the **uncertainties of maps with such fine resolution are so large** that they appear to prevent authorities from using them within existing governance regimes. This paradox poses a major challenge. This problem is closely related to handling of uncertainty. With an existing governance regime, where central authorities make all decisions and impose very specific regulations of what farmers are allowed to and must do in their fields, the government implicitly takes the responsibility for the uncertainty. Farmers, on the other hand, take many decisions under uncertainty, e.g. related to daily and seasonal weather and market conditions, but this is at their own risk.

While there is little delay in the nutrient fluxes from drainwater, groundwater flows have **long time lags**. This means that the results of a remediation measure targeting the nutrient flux from recharge to the groundwater may not be visible in the stream water coming from groundwater for many years. Quantification of lag times of nitrate between root zone and recipient surface water bodies relies, similarly to the assessment of N reduction, on a thorough knowledge of soil and geological properties at appropriate spatial resolution. This poses a **challenge to monitoring and evaluating the effects of remediation measures**. Nevertheless, evaluation of these lag times should become an indispensable part of N management schemes in catchments.

> "BONUS SOILS2SEA results suggest that differentiated regulation strategies hold a **potential for substantial reductions** of N loads without sacrificing agricultural production."

BONUS SOILS2SEA results suggest that differentiated regulation strategies hold a potential for substantial reductions of nutrient loads without sacrificing agricultural production. For example, estimates of the full potentials show that N-load from agriculturally intensive groundwater dominated catchments in Denmark may be decreased by 8-26% by relocating crops. Optimally placed drain flux measures can further reduce loads. N-loads, primarily nitrate, in Sweden may be decreased by up to 40% by stream remediation measures. In practice, it will not be possible to exploit the full potential, but **even a partial success can provide a substantial contribution to realising the Baltic Sea environmental goals**.

Implementing a spatially differentiated approach in practice

> "**Co-governance** is a transparent and flexible approach that allows farmers to directly participate in catchment management activities and supports the application of a spatially differentiated approach in practice."

The socio-political and ethnographic studies carried out by the project team highlight that for spatially differentiated approaches to be successful, implementation must be embedded within existing governance systems and socio-cultural contexts. Workshops were conducted with farmers and other stakeholders at local case study level and at a regional level with stakeholders from across the Baltic Sea region. The findings from these workshops show that a differentiated approach can, in theory, be applied in different governance settings. However, the most promising application of spatial differentiation can be expected within a co-governance approach.

Under co-governance, farmers (and other stakeholders) in a defined area (catchment or sub-catchment level) can determine differentiated mitigation measures using local knowledge of the area and N-reduction maps as supporting (rather than regulatory) tools. In comparison with the traditional top-down approach, **the co-governance approach shifts a large amount of responsibility to local farmers or to catchment councils**. While the responsibility would not include the definition of the reduction targets, it does include the responsibility for fulfilling reduction commitments. This includes designing and implementing mitigation measures (placing of wetlands, change of land-use, etc.), collaboration among the farmers within the catchment, as well as the monitoring of measures and loadings. Trust, along with a repetition of the situation (same people and activities) and the reputation of others' past actions are crucial to the success of such collective action. The reason a co-governance approach has the most potential for differentiated regulation is because it allows for a transparent and flexible approach that can be adapted according to the uncertainties in the basic data, the impacts of climate and land-use change, technological advances as well as socio-economic drivers and emerging political priorities.

Despite the positive arguments for co-governance, it is the local context and governance systems which determine whether it is viable in practice. The ethnographic study showed that perceptions, values, beliefs about the status and changes in the environment differ in the case study areas and determine stakeholder needs, acceptance and uptake of measures and regulations.

In the case study area of Norsminde, **Denmark**, the farmers who participated in discussions were highly informed and showed substantial interest in spatial differentiation through a co-governance approach. The currently used low-resolution N-reduction maps (15 km^2 or coarser) provide a reliable large scale picture of N-reduction, but allows only to exploit a fraction of the potential in differentiated strategies. The use of high-resolution N-reduction maps for spatially differentiation regulation in the Danish case was met with some scepticism, because of the large uncertainties associated to N-reduction at field or farm level. Due to this uncertainty, farmers preferred to use the high-resolution N-reduction maps for informative, rather than controlling purposes, complemented with local knowledge and measures adapted as part of a co-governance approach.

Sweden already has a long national history of cooperative governance and in the case study area of Tullstorp, top-down systems of governance were not seen as an appropriate way of reducing N loads. The Tullstorp Stream Economic Association is an example of a group built up through a bottom-up process and provides a good basis for experimenting with more innovative solutions such as spatial differentiation. Furthermore, the factors leading to the success of this initiative could potentially be used to inform the design of co-governance approaches to implement differentiated regulation in other contexts and at wider scale.

At the local level in Sweden the primary benefit of co-governance was seen to be the increased autonomy of farmers. At a national level workshop, stakeholders viewed co-governance in a positive light due to its communicative and adaptive approach. It was seen as an opportunity to build up trust – a vital component of co-governance approaches - and result in more productive working partnerships between authorities and catchment stakeholders.

In terms of practical application, it was suggested that the national authority (in this case the Swedish Agency for Marine and Water Management) could be responsible for setting the overall frame of a co-governance approach, providing funding and defining rules and regulations. Different approaches and measures could then be tested and applied at the catchment level. While fully shifting responsibility from the national to catchment level was seen as problematic; transferring a certain level of legal autonomy to catchment councils/officers was seen to be necessary to implement a co-governance approach effectively.

In the case study of Kocinka, **Poland**, a differentiated approach was seen as possible, but stakeholders in this area demonstrated a lack of support for bottom-up processes. For historical reasons (i.e. predominance of small-scale and part-time farming and general mistrust of cooperative approaches), stakeholders in the case study area preferred to work within the existing governance system with a top-down approach with clear and fair regulation. Given the current issues of uncertainty (in highly detailed maps) or usefulness (of low resolution maps), a top-down approach to spatial differentiation is not currently a preferable option for Kocinka. In order to nevertheless reduce N loads in the context of the existing governance system, alternative policy options that involve less of a regime shift could be implemented (e.g. awareness raising, financial support and incentives for environmentally friendly agriculture).

Policy-relevant messages

- Latest findings on climate change impacts on the Baltic Sea region are not yet accounted for in policy documents. Owing to the significant impact that climate change is now projected to have on nutrient loads, it is essential that these are fully considered and integrated in the updates of the WFD and HELCOM Baltic Sea action plan.
- A range of measures exists to reduce nutrient loads (e.g. growing catch crops or restoring wetlands). When determining which approaches to choose, a long-term (30-year) perspective is important for finding measures that are resilient to future climate and land-use changes and that are therefore truly cost-effective.
- Nutrients can take from a few weeks to several decades to travel through subsurface/groundwater to the Baltic Sea. For this reason it is essential that mitigation measures are planned, implemented and monitored with these lag-times in mind.
- Spatial differentiation is a promising approach for reducing nutrient loads. Nevertheless, to be effective, it requires a finer spatial resolution on hydrogeological, soil physical and vegetation properties at a local (field and stream) level than is currently available. To make this possible, citizens should be encouraged to contribute to data collection, and data should be made freely accessible with the opportunity to integrate data from different sources.
- Co-governance approaches applied at a catchment/local level that are adapted to the local context have the potential for building more productive working partnerships by allowing stakeholders to engage and in cooperation with government more effectively implement spatially differentiated regulation strategies for nutrient reduction.

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