BONUS RETURN
Reducing Emissions by Turning Nutrients and Carbon into Benefits
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Authors	Jari Koskiaho (SYKE), Tomasz Okruszko (WULS) Mikolaj Piniewski (WULS), Pawel Marcinkowski (WULS), Sirkka Tattari (SYKE), Solveig Johannesdottir (RISE), Erik Kärrman RISE) and Maria Kämäri (SYKE)
Contributors	Marta Księżniak (WULS), Marek Gielczewski (WULS), Olle Olsson (SEI)
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EXECUTIVE SUMMARY

There exist numerous ecotechnologies for recovery and reuse of carbon and nutrients from various waste streams before they are lost to runoff. However, it remains largely unknown how growing implementation of such ecotechnologies affect nutrient emissions to surface waters at catchment scale. Here, this knowledge gap is addressed by application of SWAT model in three case study catchments draining to the Baltic Sea: Vantaanjoki (Finland), Fyrisån (Sweden) and Słupia (Poland). Sustainability analysis with Multi-Criteria Analysis was applied in the stakeholder workshops in the case study areas to assess different ecotechnology alternatives. The following ecotechnologies received the highest sustainability scores: in Vantaanjoki anaerobic digestion, based mostly on agricultural residues; in Fyrisån source-separation of wastewater; in Słupia nutrient extraction within the wastewater treatment process. The effect of application of digestate on agricultural soils in the Vantaanjoki catchment was simulated by adjusting the model parameters describing the organic carbon content and physical properties of soil. The results showed small reductions of nutrient loads to the Gulf of Finland. Larger reductions of nutrient loads to Lake Mälaren in Sweden and the Baltic Sea in Poland were achieved as a result of the wastewater treatment upgrades. In the Fyrisån catchment, higher reductions were simulated for TN than TP, and in dry years than in wet years. Although the studied ecotechnologies did not show as high effectiveness in nutrient load reduction as some traditional Best Management Practices reported in literature, they do have other multiple benefits including crop yield increase, electricity, heat and bio-based fertilizer production. In this Bonus Return deliverable (D4.2) the structure and main results of the scientific article (titled "Carbon and nutrient recycling ecotechnologies in three Baltic Sea river basins – the effectiveness in nutrient load reduction"), of which the manuscript was submitted to the *Ecohydrology and Hydrobiology* journal (https://www.journals.elsevier.com/ecohydrology-and-hydrobiology).

1 Introduction

The degradation of the Baltic Sea is an ongoing problem, despite investments in measures to reduce external inputs of pollutants and nutrients from both diffuse and point sources. Available technological and management measures to curb eutrophication and pollution flows to the sea have not been adapted adequately to the contexts in which they are being applied. Furthermore, measures are often designed based on single objectives, thereby limiting opportunities for multiple benefits.

In addition, there is a general sense that measures to address the deterioration of the Baltic ecosystem are primarily technologically-driven and lacking broader stakeholder acceptance – the "experts" who define these measures have little engagement with industry, investors, civil society and authorities. This problem is magnified by governance and management, taking place in sectoral silos with poor coordination across sectors.

As a result, research shows that regional institutional diversity is presently a barrier to transboundary cooperation in the Baltic Sea Region (BSR) and that actions to achieve national environmental targets can compromise environmental goals in the BSR (Powell et al. 2013). The regional dimension of environmental degradation in the BSR has historically received weaker recognition in policy development and implementation locally. However, developments in recent years suggest a new trend with growing investments in environmental protection supporting social, economic, and territorial cohesion.

The BSR is an environmentally, politically and economically significant region and like other regions globally, its rapid growth needs to be reconciled with the challenges of sustainable development in a global setting that demands unprecedented reductions in GHG emissions. This poses a truly wicked problem exacerbated by the fact that many of the challenges in the BSR will also magnify in a changing climate. In order to navigate the uncertainties and controversies associated with a transformation towards a good marine environment, BONUS RETURN will enact an innovative trans disciplinary approach for identifying and piloting systemic ecotechnologies.

The focus is on ecotechnologies that generate co-benefits within other interlinked sectors, and which can be adapted according to geophysical and institutional contexts. More specifically, emphasis is placed on ecotechnologies that reconcile the reduction of present and future eutrophication in marine environments with the regional challenges of policy coherence, food security, energy security, and the provision of ecosystem services.

1.1 Project Objectives

The **overall** aim of BONUS RETURN is to improve the adaptation and adoption of ecotechnologies in the Baltic Sea Region for maximum efficiency and increased co-benefits.

The **specific objectives** of the project can be divided into six categories presented below. These categories are interlinked but for the purpose of providing a step-wise description, the following overview of each category proves useful. BONUS RETURN is:

1) Supporting innovation and market uptake of ecotechnologies by:

- Contributing to the application and adaptation of ecotechnologies in the BSR through an evidence-based review (systematic map) of the developments within this field.

- Contributing to the development of emerging ecotechnologies that have the capacity to turn nutrients and carbon into benefits (e.g. bio-energy, fertilizers), by providing an encompassing framework and platform for rigorous testing and analysis.
- Developing decision support systems for sustainable ecotechnologies in the BSR.
- Contributing to better assessment of ecotechnology efficiency via integrated and participatory modelling in three catchment areas in Finland, Sweden and Poland.
- Contributing to methodological innovation on application and adaptation of ecotechnologies.

2) Reducing knowledge gaps on policy performance, enabling/constraining factors, and costs and benefits of ecotechnologies by:
- Assessing the broader socio-cultural drivers linked to ecotechnologies from a historical perspective.
- Identifying the main gaps in the policy environment constraining the implementation of emerging ecotechnologies in the catchments around the Baltic Sea.
- Informing policy through science on what works where and under which conditions through an evidence-based review (systematic map and systematic reviews) of ecotechnologies and the regional economic and institutional structures in which these technologies evolve.

3) Providing a framework for improved systematic stakeholder involvement by:
- Developing methods for improved stakeholder engagement in water management through participatory approaches in the case study areas in Sweden, Finland and Poland.
- Enacting a co-enquiry process with stakeholders into opportunities for innovations in ecotechnologies capable of transforming nutrients and pollutants into benefits for multiple sectors at different scales.
- Bringing stakeholder values into ecotechnology choices to demonstrate needs for adaptation to local contexts and ways for ecotechnologies to efficiently contribute to local and regional developments.
- Disseminating results and facilitating the exchange of learning experiences, first within the three catchment areas, and secondly across a larger network of municipalities in the BSR.
- Establishing new cooperative networks at case study sites and empowering existing regional networks by providing information, co-organizing events and engaging in dialogues.

4) Supporting commercialization of ecotechnologies by:
- Identifying market and institutional opportunities for ecotechnologies that (may) contribute to resource recovery and reuse of nutrients, micro-pollutants and micro-plastics (e.g. renewable energy).
- Identifying potential constraints and opportunities for integration and implementation of ecotechnologies using economical models.
- Facilitating the transfer of ecotechnologies contributing to win-win solutions to multiple and interlinked challenges in the BSR.
- Linking producers of ecotechnologies (small and medium enterprises – SMEs), to users (municipalities) by providing interactive platforms of knowledge exchange where both producers and users have access to BONUS RETURN’s envisaged outputs, existing networks, and established methodologies and services.

5) Establishing a user-driven knowledge platform and improved technology-user interface by:
- Developing an open-access database that maps out existing research and implementation of ecotechnologies in the BSR. This database will be intuitive, mapped out in an interactive

geographical information system (GIS) platform, and easily managed so that practitioners, scientists and policy-makers can incorporate it in their practices.
- Developing methodologies that enact the scaling of a systemic mix of ecotechnological interventions within the highly diverse contexts that make up the BSR and allows for a deeply interactive medium of knowledge.

1.2 Project Structure

BONUS RETURN is structured around six Work Packages that will be implemented in three river basins: The Vantaanjoki river basin in Finland, the Słupia river basin in Poland, and Fyrisån river basin in Sweden.

Work Package 1: Coordination, management, communication and dissemination.
Work Package 2: Integrated Evidence-based review of ecotechnologies.
Work Package 3: Sustainability Analyses.
Work Package 4: Environmental Modelling.
Work Package 5: Implementation Support for Ecotechnologies.
Work Package 6: Innovative Methods in Stakeholder Engagement.

1.3 Deliverable context and objective

The current deliverable (D.4.2) is part of WP4. The objectives of WP4 are to contextualize in each case study the most promising ecotechnologies emerging from WP2 and WP3 through three case study sites in Finland, Poland and Sweden. The objective of this deliverable is to summarize the main findings of the scientific article that was prepared as one deliverable of the project

1.4 Outline of the report

This report is structured as follows: At first (Chapter 1) there an introductory description of the Bonus Return project, and then (Chapter 2) the structure and main results of the scientific article (titled "Carbon and nutrient recycling ecotechnologies in three Baltic Sea river basins – the effectiveness in nutrient load reduction"), of which the manuscript was sent to the *Ecohydrology and Hydrobiology* journal (https://www.journals.elsevier.com/ecohydrology-and-hydrobiology) on 29th Feb. 2020.

2 THE MOST EFFECTIVE ECOTECHNOLOGIES IN RIVER BASINS – OUTLINE OF THE SCIENTIFIC ARTICLE AND ITS MAIN FINDINGS

2.1 Introduction to the work done for the article

In this work ecotechnologies for recovery and reuse of carbon and nutrients from various waste streams were tested in three case study catchments of the Bonus Return project; Vantaanjoki (Finland), Fyrisån (Sweden) and Slupia (Poland), all draining to the Baltic Sea. The choice of one ecotechnology per each case was done through sustainability analysis with Multi-Criteria Analysis applied in the stakeholder workshops in the case study areas in March 2019 (Johannesdottir et al. 2019). In the perspective of this work the main objective of the ecotechnologies is to reduce nutrient loading in runoff waters and thus protect Baltic Sea form eutrophication. However, co-benefits of the ecotechnologies were discussed.

2.2 Material & Methods

We addressed the knowledge gaps related to the effectiveness of the ecotechnologies by application of SWAT (swat.tamu.edu, Arnold et al. 1998) model in the case study catchments. The following ecotechnologies received the highest sustainability scores: in Vantaanjoki anaerobic digestion (biogas energy production), based mostly on agricultural residues as feedstock; in Fyrisån source-separation of wastewater; in Słupia nutrient extraction within the wastewater treatment process. The effect of application of nutrients- and carbon-rich digestate on agricultural soils in the Vantaanjoki catchment was simulated by adjusting the model parameters describing the organic carbon (OC) content and physical properties of soil. In the Fyrisån and Slupia case study catchments point sources in both catchment's SWAT applications were decreased according to the information of Johannesdottir et al. (2019).

2.3 Results & Discussion

The soil OC increments in the Vantaanjoki catchment showed small reductions of nutrient loads to the Gulf of Finland. Larger reductions of nutrient loads to Lake Mälaren in Sweden and the Baltic Sea in Poland were achieved as a result of the wastewater treatment upgrades. In the Fyrisån catchment, higher reductions were simulated for TN than TP, and in dry years than in wet years. Although the studied ecotechnologies did not show as high effectiveness in nutrient load reduction as some traditional Best Management Practices reported in literature (Arheimer et al. 2004, Piniewski et al. 2014, Puustinen et al. 2019), they do have other multiple benefits including crop yield increase, electricity, heat and bio-based fertilizer production (Murcia López 2019). The catchment-scale nutrient load reduction percentages achieved by the tested ecotechnologies vs. those by the BMPs are presented in Table 1.

When looking at the OC scenarios in Vantaanjoki, it is good to bear in mind that local effects are much more visible than those affecting to the Baltic Sea. A good example of local agricultural system efficiently recycling nutrients and carbon is presented by Koppelmäki et al. (2019). Propagation of such agroecological systems into common use in rural areas would improve the soil properties of arable land and, consequently, reduce nutrient loading into the nearby waterbodies and eventually to the sea areas. Moreover, the factors behind the historical changes in nutrient loading to the surface waters are slow, long-term processes like e.g. shifts in soil phosphorus content of Finland's agricultural soils (Ylivainio et al., 2014). Similarly, when soil structure and water management in agriculture are improved, instead of quick and dramatic reductions in nutrient loading, long-term slow trend towards the better is to be expected.

Table 1. Phosphorus and nitrogen load reduction achieved by carbon and nutrient recycling ecotechnologies (Koskiaho et al. 2020) and “traditional” agri-environmental best management practices (BMPs, Arheimer et al. 2004, Piniewski et al. 2014, Puustinen et al. 2019) at catchment scale.

Ecotechnology	Catchment name (area, km2)	Phosphorus load reduction (%)	Nitrogen load reduction (%)	Source
Organic carbon increment to agricultural soil	Vantaanjoki (1 688)	<1%	<1%	Koskiaho et al. (2020)
Source separation of wastewaters*	Fyrisån (2 002)	4%	12%	Koskiaho et al. (2020)
Nutrient extraction of wastewaters*	Slupia (1 623)	7%	6%	Koskiaho et al. (2020)
Implementation of BMPs of a WFD plan	Paimionjoki (1 088)	8%	28%	Puustinen et al. (2019)
Constructed wetlands	Genevadsån (224)	no data	6%	Arheimer et al. (2004)
Combination of on-field BMPs	Genevadsån (224)	no data	30%	Arheimer et al. (2004)
Combination of on- and off-field BMPs	Reda (482)	38%**	17%***	Piniewski et al. (2014)

* ”Full” potential without implementation period in modelling scenario
** PO_4-P
*** NO_3-N

2.4 Conclusions

The amounts of OC incremented into the agricultural soil by the implementation of the ecotechnology selected for the case Vantaanjoki are so low that the effects to the nutrient load reductions remain minor at the level of an entire river basin discharging into a sea area like e.g. the Gulf of Finland. However, the percent reductions are higher in smaller, subbasin-level.

Comparisons with traditional, commonly used agri-environmental BMPs revealed that – when used as combinations – the BMPs reduce nutrient loading into the Baltic Sea more than the individual BMPs or the ecotechnologies of this study. Indeed, no single mitigation measure or ecotechnology should be seen as a “silver bullet” for water protection. Instead, numbers of all kinds of well-tried measures, both traditional BMPs and carbon and nutrient recycling ecotechnologies, should be increased with determined and targeted manner where- and whenever appropriate.

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