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Any payoff to ecological engineering? Cost-benefit analysis of pumping oxygen-rich water to control benthic release of phosphorus in the Baltic Sea

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ABSTRACT

This paper examines the economic aspects of pumping of oxygen-rich water to anoxic bottoms of the Baltic Sea from two different angles. Drawing on the recent pumping experiments in the Swedish archipelago (Lännerstasundet) and in the Finnish archipelago (Sandofjärden), we generalize the findings to the anoxic coastal areas of the Gulf of Finland. For nutrient policies we find that under the current abatement levels and abatement costs in WWTPs, reduction of external loads produces higher annual net benefits and higher present value than oxygenating anoxic bottoms by pumping in the coastal areas of the Gulf of Finland. For pumping a means of speeding up the recovery after a hypothetical heavy reduction in nutrient loads we find that it might provide positive net benefits in the coastal anoxic bottoms in the Gulf of Finland but not in the open Gulf of Finland.

1. Introduction

In large part of the Baltic Sea, sediment oxygen consumption exceeds the transport of oxygen from surface water to deep layers resulting in oxygen depletion and increases phosphorus release from sediments. As demonstrated, for instance, in Conley et al. [2], and Pitkänen et al. [3], variation in phosphorus release from sediments plays in the scale of a single or few years a more important role in eutrophication than changes in external loading from the catchment area. This permanent feature has created discussion on the possibilities to impact directly phosphorus release using ecological engineering technologies. The idea suggested is as follows: if a radical reduction of external loads is combined with a strong decrease of sediment nutrient release by engineering technologies, the marine system might turn to a new stable state associated with oxygen in deep waters.

In this thinking, the use of engineering technologies, if proved workable, can alleviate phosphorus release. The fundamental reasons of phosphorus release from bottom sediments lies in the excessive loading from external sources and the strong stratification of the water in the Baltic Sea. Ultimately, according to our present knowledge, the only sound solution for the Baltic Sea is to considerably reduce loads from external sources. Thus, the question of the possible use of engineering methods can be raised only in very restricted contexts. Two hypothetical contexts suggest themselves. First, could these methods be of help and become part of

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nutrient policies in restricted coastal basins, in which countries have reduced strongly external loads already but which annually suffer from eutrophication, among other things due to movements of nutrient-rich water mass from outside sea areas? Second, could engineering methods be used to speed the recovery of the Baltic Sea, given that even a radical reduction in external nutrient loading shows up slowly in the quality of water in the Sea. We would like to emphasize that neither of the cases currently exists.

Pumping of oxygen rich surface water to surface layer has received much attention. Stigebrandt and Gustafsson [14] discuss possibilities of pumping oxygen rich water onto the deep water layers to improve oxygen conditions and sediment phosphorus retention. They argue that a large scale pumping can be arranged in the Baltic Sea with relatively small energy needs. Conley et al. [4] provide a comprehensive review of the pros and cons of ecological engineering methods. They end up with a more pessimistic conclusion than Stigebrandt and Gustafsson [14]: based on the existing knowledge, none of ecological engineering methods provides a sustainable solution to the prevention of sediment phosphorus release. They do not rule out testing, however. Small scale experiments may be useful to produce a deeper scientific understanding of the mechanisms present in and created by pumping. In a recent note, Conley [5] concludes that a full scale pumping in the Baltic Proper, which suffers most of phosphorus release, is not recommendable.

Based on recent small scale pumping experiments, made in Lännerstasundet, in the Swedish archipelago off Stockholm and Sandöfjärden, in the Finnish archipelago of the western Gulf of Finland, we examine the economic aspects of pumping of oxygen-rich water. The importance of this study rises from the fact that besides ecological aspects, pumping technology, energy needs and costs have been an integral part of the discussion concerning the ecological engineering methods. For the first time in this debate, we shed light on these specific issues. Drawing on the measured impacts on nutrients in the experiment sites, we examine the social costs and benefits of pumping at local and regional scales. We first define the net social benefits from pumping experiments in the site of Lännerstasundet and Sandöfjärden and then generalize the analysis to the net benefits in the Gulf of Finland focusing on anoxic bottom areas in the deeper coastal areas and in the Gulf of Finland deep.

To define the social benefits, we need an interpretation of what status society gives to the impacts of pumping on nutrient retention. This task is complicated due to several reasons. First, the measured impacts on nutrients only reflected the short-term effects and the duration of the experiment was too short to find any impacts of bottom fauna and fish stocks. Second, how phosphorus stock in bottom sediment behaves remains uncertain, as the time period of experiments did not facilitate closer examination mechanisms concerning the stock. Third, even though we can measure the change in the amounts of nutrients in the sea water caused by pumping, the long-term effects on water quality, for example in terms of reduced algal biomass, remain uncertain.

Because of these ambiguities, we analyze pumping from two different hypothetical angles. First, we assume that all nutrients in sea water have the same status be they from external sources or from the bottom sediment (“internal loading”). We motivate this angle by noting that at any point of time when nutrient reach the euphotic surface water layer, they play an identical role with nutrients of external origin in causing eutrophication, while acknowledging that external loading has an accelerating effect on sediment nutrient release, and in the long run sustainable solution entails reducing external loads. Thus we ask: if society decides to allocate more money to the protection of the Baltic Sea, would this money produce higher benefits when allocated to further reductions in external sources or to ecological engineering to increase sediment nutrient retention? We then focus on the recovery aspect of the Baltic Sea and ask: does pumping of anoxic bottoms as a means of speeding the recovery of the Baltic Sea, once nutrient loads have been reduced, produce positive net benefits?

2. Conceptual framework of analysis

The economically efficient target for reducing external nutrient loading to the Baltic Sea is defined by setting the aggregated marginal abatement costs of all countries equal to the aggregate marginal benefits of all countries. An efficient solution determines the overall reduction goal, while the level of marginal costs in each country defines their individual reduction requirements. Countries in the Baltics Sea region have agreed upon the Baltic Sea Action Plan (BSAP) that defines country-based reduction recommendations for reducing external nutrient loads. BSAP aims at establishing a good ecological condition into the Baltic Sea, and reducing external loads as the key role in achieving this goal.

The current water policies of the Baltic Sea countries entail reducing both point and nonpoint loads. Save Russia, the EU's Urban Waste Water directive provides the minimum reduction requirements of 70% for nitrogen and 80% for phosphorus for waste water treatment plants. The HELCOM recommendations suggest a higher abatement rate of 90% for phosphorus. These figures provide relevant targets for the abatement in industrial point sources as well. The reduction of phosphorus is very high (more than 95%) in Finland and Sweden, and improving in Russia and Estonia. For agriculture, only voluntary participation schemes exist and, for instance, in Finland the goal is to reduce 30% of both phosphorus and nitrogen loads. Yet, hardly any country has so far been successful in reducing agricultural nonpoint sources.

While the above measures reduce external loading, and phosphorus release only in the long-run, oxygenation pumping provides an instrument to reduce directly phosphorus release from anoxic bottoms (the so-called internal loading of phosphorus). Should oxygenation pumping be successful at a larger scale (the Baltic Proper), it would speed up the recovery of the Baltic Sea. In contrast, successful local pumping in coastal waters would improve water quality only locally. Policy-wise, introducing oxygenation pumping in national coastal waters would be a decision within national jurisdiction. But pumping in the high open seas would require cooperation and financial arrangements between countries making oxygenation pumping more difficult to establish.

We employ cost-benefit analysis to assess the feasibility of oxygenation pumping as a different type and new measure both at a local and larger scale. Cost-benefits analysis is a social decision making tool, which determines first the project (pumping), counterfactual (status quo of current measures targeting external loading), and all physical impacts of the projects. Then, by putting