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Optimal Management of a Eutrophied Coastal Ecosystem: Balancing Agricultural and Municipal Abatement Measures

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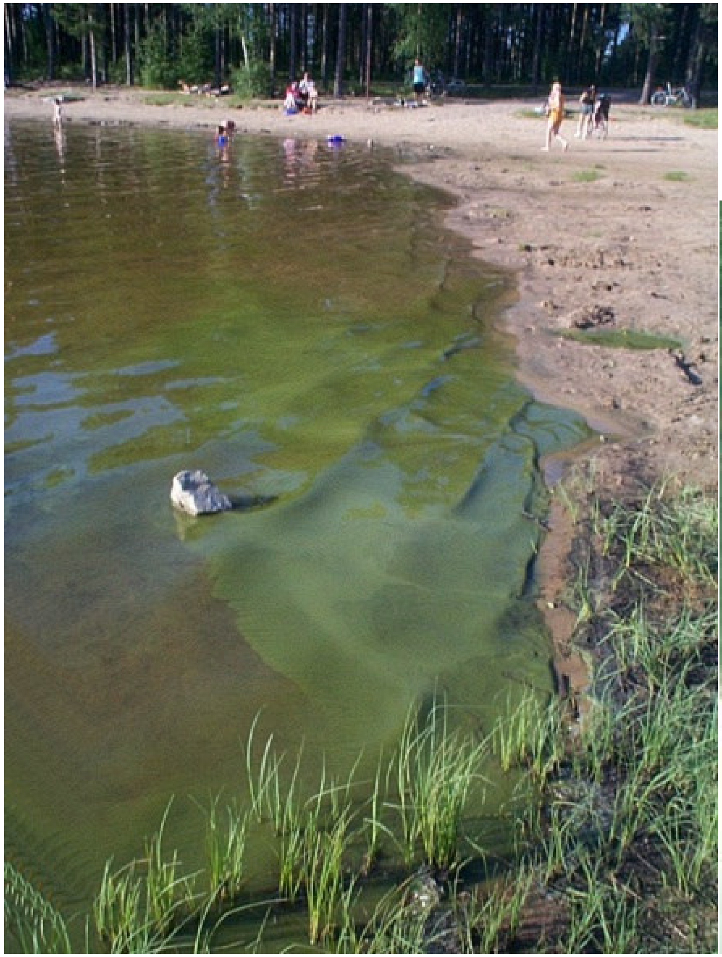
Background

- Reducing the nutrient loads that lead to excessive growth of phytoplankton and eutrophication of water ecosystems is a key environmental concern today
- Eutrophication is manifested as decreased water transparency, disproportionate growth of algae and mass blooms of toxic cyanobacteria
- Valuation studies have attributed significant economic benefits to improving the state of eutrophied coastal zones (e.g. Söderqvist and Scharin 2000, Söderqvist 1996, Markovska and Zylicz 1999)



Nutrient sources

- Many environmental assessments identify agriculture as the major cause of surface water quality problems
- In regions where urban and industrial wastewater treatment facilities are lacking untreated wastewaters remain a significant source of nutrient loading
- For example, in St. Petersburg the wastewaters of some 500,000 residents are released untreated into the Neva River through which they enter the Gulf of Finland

Agricultural and municipal abatement measures

- Agricultural abatement takes the form of reversible small-scale measures such as changes in fertilizer use, crop choice and tillage practices. Marginal costs are increasing.
- Removing nutrients from wastewater is relatively simple and unit costs do not increase markedly when abatement targets are tightened
- Requires an irreversible initial investment to set up treatment facilities and sewage infrastructure to transport wastewater from households to treatment facilities
- The discrete investments impose considerable sunk costs on society, and the investment costs should be accounted for in policy choices

Objectives of this paper

- Study optimal nutrient abatement policies with agricultural and municipal nutrient sources
- Account for the investment needed to set up wastewater treatment facilities and determine the optimal timing of investment
- Augment the present empirical modeling of eutrophication by considering the two nutrients that are necessary for primary production, nitrogen and phosphorus
- Investigate the social optimality of alternative abatement measures by means of a cost-benefit analysis. In addition to the total expected costs, the total expected benefits of abatement measures have been estimated in order to choose the optimal abatement strategy.

The model

- An environmental planner seeks to control nutrient loading in order to minimize the total environmental damage and the cost of nutrient abatement over time
- Two potential phases of nutrient abatement: prior to investment in wastewater treatment facilities, only agricultural nutrient loads can be controlled
- If the necessary outlay is made and wastewater treatment facilities are built, nutrient loads from both agricultural and municipal sources can be reduced

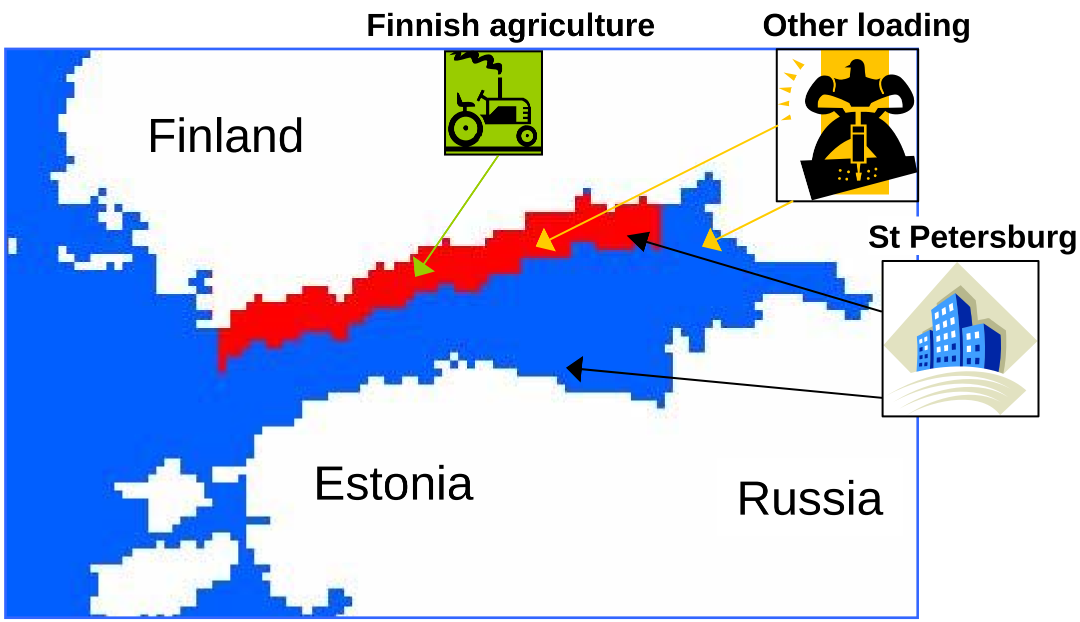
The model…

- Two stage dynamic optimization problem
- Nutrient load reductions in agricultural and municipal sources are control variables
- Stock dynamics described through a nutrient turnover model
- The required investment outlay is fixed
- Construction time and final capital outlay are uncertain

Environmental planner's problem

- When should investment in wastewater treatment be undertaken and what determines the optimal time?
- What should be the abatement rate in agriculture?
- What should be the rate of purifying wastewater?
- Solved using a dynamic programming approach and numerical methods

Empirical application: a sub-basin of the Gulf of Finland along the Finnish coast



Empirical application…

- The principal external nutrient sources are agricultural runoff from southwestern Finland and municipal wastewaters from the St. Petersburg region
- One of the most eutrophied sub-basins of the Baltic Sea
- Along the Finnish coast all municipal wastewater is treated but agriculture remains a significant nutrient source
- Sewage infrastructure is lacking in St. Petersburg and significant investments will be required to enable the removal of nutrients from all municipal discharges

Empirical application…

- Environmental damage depends on the level of eutrophication, which is governed by the total amount of nutrients measured in nitrogen equivalent units
  $E=N+7.2P$
- The environmental damage takes an exponential form, approximating a case where threshold effects are present
- Quadratic costs of agricultural abatement
- Linear costs of wastewater treatment

Data sources

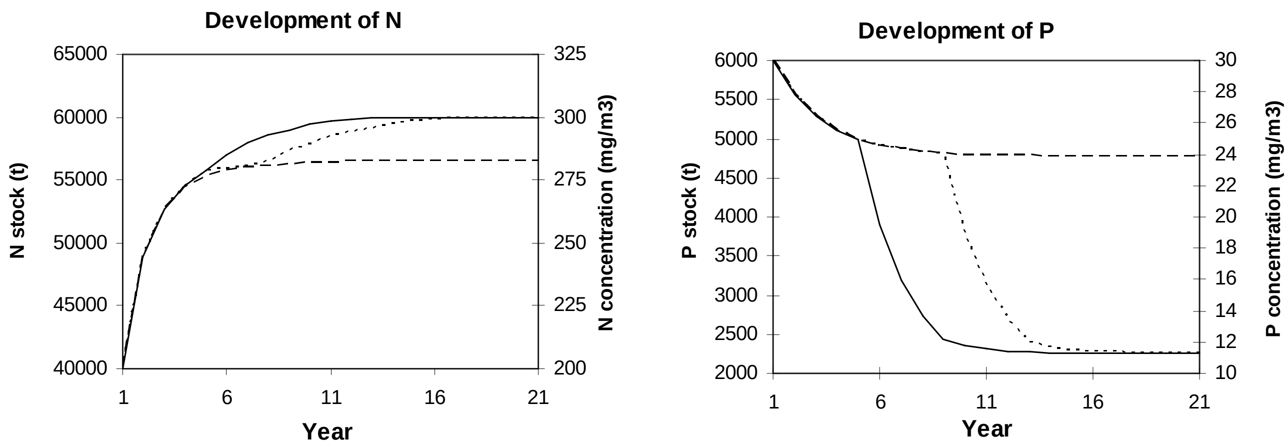
- Stock dynamics: ecosystem models and information provided by the Finnish Environment Institute
- Agricultural loads and abatement costs: estimates from a programming study by Helin et al. (2006)
- Wastewater treatment costs and municipal nutrient loads: information from Vodokanal (supplier of water management systems in St. Petersburg) and the Finnish Environment Institute
- Damage from eutrophication: calibrated based on a contingent valuation study by Söderqvist (1996)

The optimal policy

- When wastewater treatment is possible, abatement consists primarily of removing nutrients from wastewater
- As the nutrient stocks approach their optimal steady state levels, the optimal treatment rate falls to approximately 90% of the maximum treatment allowed by the projected capacity
- Significant cost savings through wastewater treatment; damage decreases 90% from the situation without wastewater treatment
- It is optimal to invest immediately

The optimal policy…

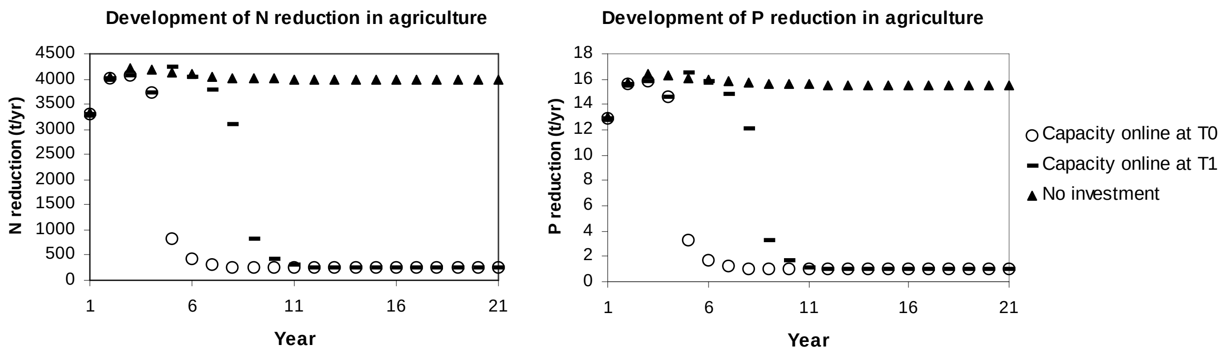
- Development of nutrient stocks over time



Capacity online at T0 ------ Capacity online at T1 – – – – No investment

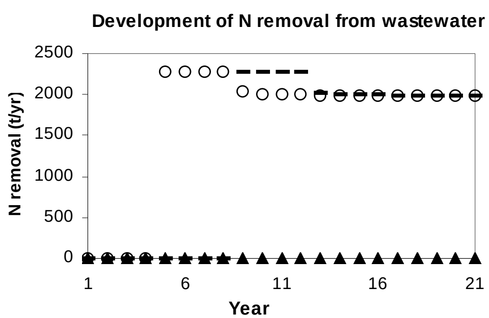
The optimal policy…

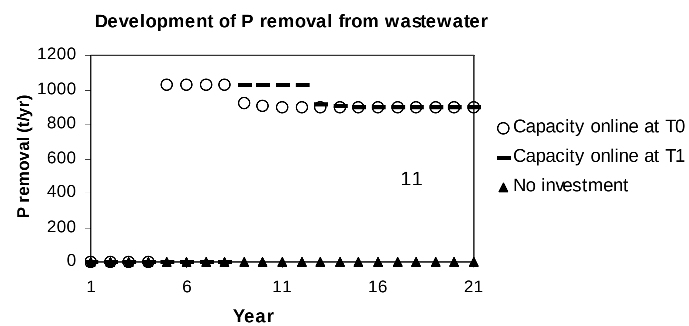
- Development of agricultural nutrient abatement



The optimal policy…

- Development of nutrient removal through wastewater treatment





Sensitivity analysis

- A 10% decrease in nutrient loads in the absence of abatement, annual carry-over of phosphorus, or agricultural abatement costs renders it optimal to refrain from investment
- The decision to invest is instead robust to changes in the willingness to pay for reduced eutrophication: immediate investment is optimal even if the willingness to pay is reduced by 50%
- Marked increases in the maximum construction time or the probability of delay did not affect the investment decision

Concluding remarks

- While immediate investment in wastewater treatment facilities is optimal in the empirical application, the result is not self-evident where other abatement measures are also available
- The optimal allocation abatement effort was found sensitive to the ecological parameters
- Economic and ecological models need to be reconciled to provide guidelines for nutrient abatement policies that are sound in both areas
- Need to develop dialog between valuation studies and optimization models