Cost Effective Nutrient Abatement in the Baltic Sea

Analyzing Impacts of Climate Change and Technological Development

Martin Lindqvist
Faculty of Natural Resources and Agricultural Sciences
Department of Economics
Uppsala

Licentiate Thesis
Swedish University of Agricultural Sciences
Uppsala 2013

ISBN 978-91-576-9118-7

Print: SLU Service/Repro, Uppsala 2013

Cost Effective Nutrient Abatement in the Baltic Sea- Analyzing Impacts of Climate Change and Technological Development

Abstract

The overall aim of this thesis is to increase the understanding of cost-effective nutrient abatement in the Baltic Sea. This is done under various assumptions about the underlying abatement measures available to the social planner, future changes in nutrient outflow caused by climate change as well as the impact of technical change on the cost of abatement. The thesis consists of three papers, which examines different aspects of cost effective nutrient abatement in the Baltic Sea. Paper I analyses the value of introducing mussel farming as an abatement measure for reduction of nutrients in the Baltic Sea. We aim at determining the value of mussel farming as an abatement measure taking alternative abatement measures, spatial scale and different nutrient load targets into consideration. The result show that calculated marginal cost by mussel farm can be considerably lower than that of other abatement measures, but also relatively high depending on mussel growth, sales options and formulation of nutrient load targets. Paper II examines the impact of climate change, structural changes in the agricultural sector and demographic development on the cost of fulfilling the nutrient abatement targets in the 2007 Baltic Sea Action Plan (BSAP). In paper II we apply a dynamic discrete model of control costs, which also takes the dynamics of nutrients in each marine basin into consideration. The results show that the main drivers of future nutrient loads work in different directions and that climate change may counter some of the increases in costs brought by structural change in the agricultural sector. The aim of paper III is to show the impact of learning-by-doing induced technical change on the costs of nutrient abatement in the Baltic Sea. Learning-by-doing is modeled in a reduced form through the abatement cost function. In this setting increased abatement leads to increased experience, which reduce the cost of abatement. The results show that learning-by-doing induced technical change can decrease costs substantially depending on learning rate.

Keywords: Cost effective, Nitrogen, Phosphorous, Nutrients, Abatement cost, Climate change, Learning by doing, Baltic Sea, Mussels, Dynamic programming

Author's address: Martin Lindqvist, SLU, Department of Economics,
P.O. Box7013, 750 07 Uppsala, Sweden
E-mail: Martin.Lindqvist@ slu.se

"It is good to have an end to journey toward; but it is the journey that matters, in the end."

— *Ernest Hemingway*

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Gren, I-M., Lindahl, O., Lindqvist, M., Values of mussel farming for combating eutrophication: An application to the Baltic Sea. Ecological Engineering 2009; 35: 935-945.

II Lindqvist, M., Gren, I-M., Elofsson, K., A study of climate change and cost effective mitigation of the Baltic Sea eutrophication. Forthcoming in Climate Change / Book 2 edited by Prof. Netra Chhetri, Arizona State University, USA. 2012. ISBN 980-953-307-389-2 (in press).

III Lindqvist, M., Gren, I-M., Cost effective nutrient abatement under learning-by-doing induced technical change. 2012 (Manuscript)

Papers I-II are reproduced with the permission of the publishers.

1. Introduction

The overall aim of this thesis is to increase the understanding of cost-effective nutrient abatement in the Baltic Sea. This is done under various assumptions about the underlying abatement measures available to the social planner, future changes in nutrient outflow caused by climate change as well as the impact of technical change on the cost of abatement. This thesis is composed of three independent papers, which will try to answer different but related issues about cost effective nutrient abatement in the Baltic Sea. Paper I analyses the value of introducing mussel farming as an abatement measure for reduction of nutrients in the Baltic Sea. We aim at determining the value of mussel farming as an abatement measure taking alternative abatement measures, spatial scale and different nutrient load targets into consideration. Paper II examines the impact of climate change, structural changes in the agricultural sector and demographic development on the cost of fulfilling the nutrient abatement targets in the 2007 HELCOM Baltic Sea Action Plan (BSAP). In paper II we apply a dynamic discrete model of control costs, which also takes the dynamics of nutrients in each marine basin into consideration. The aim of paper III is to show the impact of learning-by-doing induced technical change on the costs of nutrient abatement in the Baltic Sea. Learning-by-doing is modeled in a reduced form through the abatement cost function. In this setting increased abatement leads to increased experience, which reduce the cost of abatement.

The Baltic Sea is the world´s largest brackish sea and the drainage basin with its fourteen different countries contains more than 85 million inhabitants. (Rönnberg and Bonsdorff, 2004) The Sea is made up of seven different interlinked marine basins with partly unique ecological conditions. The nine countries with coastal access to the Baltic Sea (see figure 1) has taken the major initiatives for the governance of the Baltic Sea as a common resource through the intergovernmental body HELCOM. Eutrophication is one of the major concerns, which HELCOM addresses and action plans against eutrophication has been agreed upon in 1988 and 2007. (HELCOM, 2007) Neither of these treaties has been fully implemented. One reason for this might be the fact that high costs are associated with achievement of the abatement targets in the BSAP and that many easy to implement, low-cost abatement measures has already been implemented (Gren et al., 2008). One important strategy is therefore to evaluate new abatement measures to asses if costs can be saved and/or more abatement can be conducted at the same cost. This thesis contributes to this strategy through paper I where mussel farming as an nutrient abatement measure in the Baltic Sea drainage basin is evaluated.

The point of evaluation for all papers in this thesis is cost effective nutrient abatement, which implies that the environmental target[1], is reached to the lowest possible cost to society. (see e.g., Baumol and Oates, 1988) This means that marginal cost of abatement is equalized across all abatement measures in the drainage basin and the minimum cost solution often implies the inclusion of a combination of different abatement measures in different countries and drainage basins. (Gren, et al., 2008) For the Baltic Sea where emitting sources are located directly at the sea as well as up-streams in drainage basin marginal cost of abatement will be made up of two parts, the cost of abatement at the source and its impact on the environmental target in the marine basins of the Baltic Sea. Data on transportation and transformation of nutrients from the emission source to the coastal water will therefore be needed[2]. For an abatement measure located upstream in the drainage basin this implies ceteris paribus that if 50% of the emitted nutrient is removed during transport to the sea through retention then the marginal cost of abatement at the environmental target will be twice as high as that of an identical measure located directly at the coast.

The dynamics of nutrients in the Baltic Sea where nutrient stocks can reside in marine basins for long time periods, affecting eutrophication point to the value of analyzing cost effective nutrient abatement in the Baltic Sea drainage basin over a longer time period. Today the main emitter of both nitrogen and phosphorous to the Baltic Sea is the agricultural sector which account for approximately 60 percent of nitrogen loads and 50 percent of phosphorous

---

[1] The nutrient reductions needed to achieve the environmental target is for all three papers based on the nutrient reductions targets from the 2007 HELCOM, Baltic Sea Action Plan. (Helcom, 2007)

[2] This implies data on leaching and retention for all emission sources which emits on land in the drainage basin, data on retention for emission sources that emits directly into up-streams waterways as well as data on airborne emissions. (Gren et. al., 2008)

loads[3]. The dominance of the agricultural sector as an emitter of nutrients also follows over to the available nutrient abatement measures where a majority of abatement measures focus on nutrient reduction in the agricultural sector[4].
Structural change in the agricultural sector is together with climate change also considered to be the main driver of future nutrient loads to the Baltic Sea. Climate change will change the precipitation pattern in the Baltic Sea drainage basin, which can have large impacts on nutrient outflow to the Baltic Sea and the agricultural sector can experience structural change due to changes in consumer preferences for animal protein. (Eriksson-Hägg et al., 2010) Accounting for the impact of these future drivers of nutrient loads is therefore important when attempting to asses cost effective nutrient abatement in the Baltic Sea drainage basin in the long run. In paper II we therefor calculate cost-effective solutions to reductions of nutrient loads, according to the environmental goals stipulated in the 2007 HELCOM Baltic Sea Action Plan (BSAP), with consideration taken to future changes in nutrient loads caused by climate change, structural change in the agricultural sector as well as demographic development. This is carried out by means of a numerical dynamic discrete model of control costs for abatement in the riparian countries of the Baltic Sea, which account for the heterogeneity and interconnections of the marine basins of the entire Baltic Sea drainage basin, including both nitrogen and phosphorous and several emitting sectors in the cost effective nutrient abatement.

Over a longer time horizon it is also important to take technological change into consideration, when evaluating environmental problems and policy decisions. This is not the least important since when evaluating environmental problems and policy decisions over a long time horizon, the cumulative effect of technical change is likely to be large and since the implemented environmental policy may alter the process of technical change itself. (Jaffe et al., 2001) In paper III we therefore apply the same numerical dynamic discrete model of control costs for abatement in the riparian countries of the Baltic Sea as in paper II and introduces technical change through learning-by-doing. In this setting we follow Goulder and Mathai (2000), Bramoullé and Olson, (2005), and Rosendahl, (2004) and model learning-by-doing in a reduced form through the abatement cost function, where increased abatement leads to increased experience, which reduces the cost of abatement. This thesis thus contributes both to the evaluation of new abatement measures and to the

[3] Other emitting sources to the Baltic Sea are stationary combustion sources, traffic, ships, and sewage from household and industry. (Gren et al., 2008)

[4] Abatement measures reducing airborne emissions and sewage from household and industry are also included. (Gren et al., 2008)

understanding of long term factors which can have a substantial impact on the future cost of abatement.

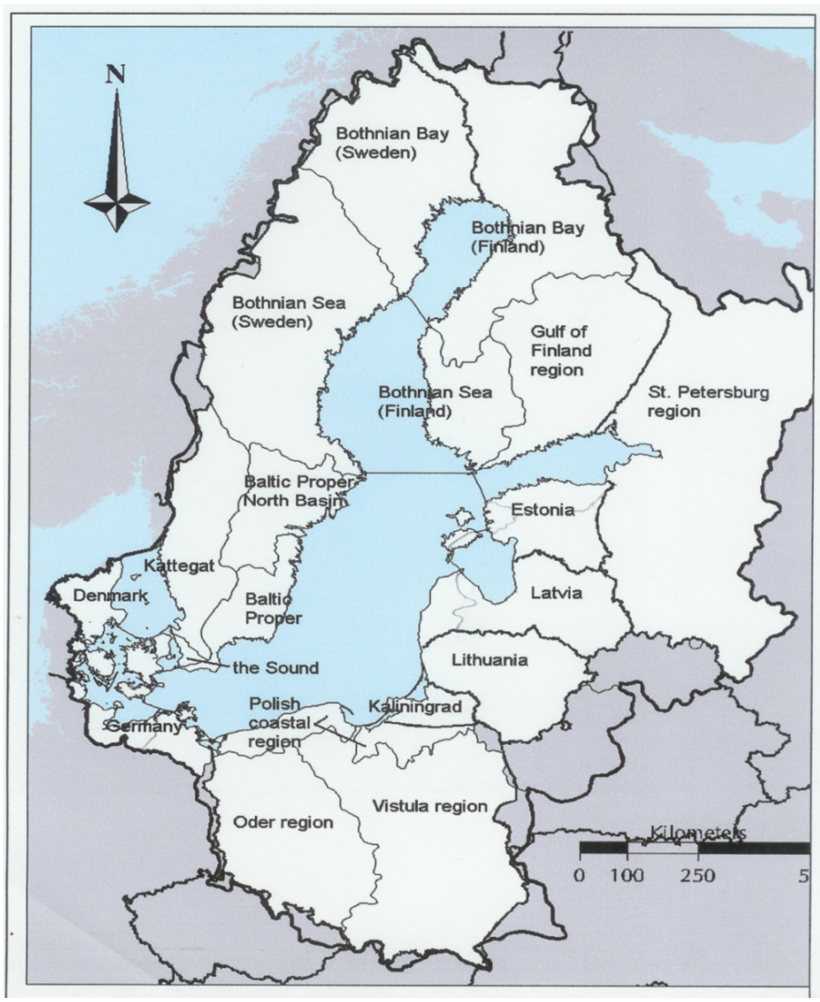

Figure 1: *Drainage basins of the Baltic Sea (originally from [41]). (Drainage basins in Denmark (2). Germany (2). Latvia (2). and Estonia (3) are not provided with names. but are delineated only by fine lines)*

2. Summary of the Appended Papers

In this section a short summary of the main results in paper I-III will be given. The full papers are appended for the interested reader.

2.1 Summary of Paper I

The purpose of paper I is to estimate the value of mussel farming for reducing nutrient content in the Baltic Sea, which is done in a cost effectiveness framework. Bivalve species has been recognized for their nutrient regulating abilities since the 1950s (e.g. Suzuki, 1957; Seki, 1972; Ryther et al., 1972; Haamer, 1996; Gifford et al., 2005). In the previous literature there are just a few attempts at estimating the value of mussel farming as a nutrient abatement measure and these studies usually just applies a simple comparison of unit abatement costs with other abatement measures, most often sewage treatment plants.(Lindahl et al., 2005). This approach is appropriate if sewage treatment plants are the only available alternative abatement measure. However at the Baltic Sea scale there are a number of different additional abatement measures available, such as changes in land use and fertilizer practices in the agricultural sector, and increased cleaning by households and industries not connected to common sewage treatment.

In paper I the value of mussel farming for combating eutrophication in the Baltic Sea is estimated with the so called replacement cost method, where the value of mussel farming is established by the cost savings obtained by the replacement of abatement measures with higher cleaning costs. This is done by the use of a non-linear cost minimization programming model where costs and impacts of mussel farms are compared with other abatement measures in the Baltic Sea drainage basin. Minimum costs solutions are thus calculated for the fulfillment of the nutrient abatement targets as stipulated in the 2007 Baltic Sea Action Plan and the value of mussel farming as an abatement measure is determined by the difference in total minimum costs with and without mussel farming. The entire Baltic Sea basin is divided into 24 drainage basins in the cost minimization model to account for differences in climate, hydrology and biological conditions. Apart from mussel farming the cost minimization model includes 20 abatement measures which affect agriculture, industry, transport and household, (see Gren et al., (2008) for details).

Ideally net costs which include investments and operational costs of mussel farming minus the impact of all other effects would be used to calculate the cost of nutrient abatement with mussel farms. Due to data limitation this has not been possible and the cost estimates in paper I therefore rely on partial calculation of costs, which includes investment and operational cost and the value of mussels as human or animal food source. Crucial for these cost calculations is the growth rate of mussels, which is dependent on the salinity content in the marine basins and whether or not the mussels can be sold as human or animal food source. In the brackish Baltic Sea the salinity content decreases towards the north-east and in the most northern and eastern basins mussel farming is not possible. A comparative advantage for mussel farming as an abatement measure is on the other hand their dual abatement of both nitrogen and phosphorous, where when harvested live mussels contain 8.5-1.2 g of nitrogen and 0.6-0.8 g of phosphorous. This implies that if mussels are included in a cost effective nutrient abatement of e.g. nitrogen some phosphorous abatement will also occur "free of charge". Mussel farming also has an advantage by being located in the marine basins, which is the environmental target of concern. The total amount of nutrient abatement conducted by mussel farming will thus affect the environmental target and the large nutrient pools which has already been emitted to the marine basins of the Baltic Sea.

Since mussel farming is a relatively recent innovative technology for cleaning, there is a lack of data with respect to production cost, mussel sales options for human or animal consumption, and growth under different conditions. The study therefore calculated marginal cleaning cost of mussel farms with and without mussel sales options, high and low mussel growth rates and contents of nutrient in mussels. The calculated constant marginal cost then varied between Euro 0 kg^{-1} nutrient cleaning and Euro 63.5 and 900 kg^{-1} for nitrogen and phosphorus cleaning, respectively. The low marginal cleaning cost occurred for the Kattegat and the Sound marine basins under the assumption that mussels could be sold as human food source, whereas the largest costs were found in the Northern Baltic Proper basin, under the assumption that mussels could not be sold as human or animal food source.

The estimated values, calculated as the difference in minimum costs for given nutrient reduction targets with and without the inclusion of mussel farming as a cleaning option, show a large variation, between 0.1 and 1.1 billion of Euros per year. An evaluation of mussel farming as a cleaning device under the HELCOM Baltic Sea Action Plan revealed that the inclusion of mussel farming could decrease total abatement cost by approximately 5 percent. The results are also sensitive to assumptions of mussel farming capacity in the Baltic Sea.

The main contribution of this paper is to estimate the value of mussel farms for combating eutrophication in a wider context with respect to alternative abatement measures, spatial scale and different nutrient load target. This has to the best of our knowledge not been done in any previous study.

2.2 Summary of Paper II

In paper II we shift the point of focus from the static- to the dynamic setting introducing scenarios for climate change, structural change in the agricultural sector as well as demographic development. Climate change is together with structural change in the agricultural sector considered to be the most important drivers of future nutrient outflow to the Baltic Sea and careful consideration needs to be taken to these future drivers of nutrient outflow in any cost - effective nutrient abatement scheme, which attempt to evaluate nutrient abatement in the Baltic Sea over a longer time scale. A longer time scale is justified by the dynamics of the Sea, where nutrient stocks in the entire sea have a response time scale of 60-70 years. It is also shown in a flushing out experiment conducted by Savchuk and Wulff (2007) that a new balance where nutrient loads are reduced to pre-industrial levels did not occur even until after 130 years. In paper II we therefor assume that nutrient load reductions as stipulated in the 2007 HELCOM Baltic Sea Action Plan are to be achieved at the latest in year 2100 and sustained for 70 years.

In paper II we develop the dynamic model developed in Gren et al., (2010) by introducing scenarios for future nutrient loads in the Baltic Sea drainage basin. Compared to the static model used in paper I this model accounts for the heterogeneity of the marine basins of the entire Baltic Sea drainage basin. The dynamic model accounts for the fact that the ecological conditions of the marine basins differ and that the marine basins of the Baltic Sea are coupled so that nutrient load reduction to one marine basin affect the nutrient concentration of all marine basins of the Baltic Sea. This means that both spatial and dynamic distribution of abatement needs to be taken into consideration when identifying cost effective timing and location of nutrient abatement.

Climate change is expected to change the precipitation pattern in the drainage basin. This is expected to lead to an increase in mean annual river-flows in the north and a decrease in mean annual river-flows to the south (HELCOM, 2007; Graham, 2004). Changes in run-off and river flows explain 71-97 percent of the variability in land-sea fluxes of nutrients (HELCOM, 2007). Climate change will therefore affect the magnitude of future nutrient loads to the Baltic Sea. We apply four different climate change scenarios based on a high and a low future CO2 emission scenario from IPCC and boundary conditions from two different global circulation models. (Graham, 2004) The high emission scenario corresponds to a change in CO2 equivalent content from the 1990 level of 353 ppm to 1143 ppm in the future. Correspondingly the low emission scenario implies an increase to 822 ppm (Nacicénovic´ et.al., 2000). Population growth and demographic shifts to the coastal zone will act as an indirect driver of eutrophication which will add to other drivers of future nutrient loads e.g. climate change. In this context changes in nutrient loads close to the coast will affect the environmental target, in the marine basins of the Baltic Sea more since changes in nutrient loads, which take place further inland will also be affected by retention. We create a demographic change scenario which takes both the absolute change in population as well as the distance to the Baltic Sea coast into consideration. For the agricultural change scenario we apply the nutrient load change projected in (Eriksson-Hägg et.al., 2010). Eriksson-Hägg et.al (2010) applies a scenario for future nutrient loads from the agricultural sector based on assumed increase in protein consumption for the year 2070. A crucial assumption in Eriksson-Hägg et.al (2010) is that the projected increase in protein demand is met totally by an increase in domestic animal production, which implies that the projections might be somewhat upward biased. The basis for the increase in nutrient outflow in the projections from Eriksson-Hägg et.al (2010) is that all counties in the Baltic Sea drainage basin will have a protein consumption equal to the mean of the EU-15 countries in 2070 (see Eriksson-Hägg et.al. for details). We apply cost effective calculations for the fulfillment of the nutrient load reductions stipulated in the 2007 BSAP, with climate change scenarios in isolation as well as together with scenarios for structural change in the agricultural sector and demographic development and make comparison to the reference case without scenarios.

The results from the cost effective achievement of the BSAP under different scenarios indicated that climate change can lead to substantial cost decreases for all scenarios as compared to the reference case. This happens despite the fact that nutrient outflow increases to all basins of the Baltic Sea but the Baltic Proper under climate change. It is only the size of the Baltic Proper basin and the stringency of the nutrient abatement targets for the Baltic Proper, especially for phosphorous where reductions of over 50 percent are needed, which leads to this result. An interesting feature of the climate change scenarios is that costs are decreasing with the severity of climate change so that the largest cost decrease is occurring during the high future CO2 scenario, independent of which global general circulation model is used for boundary conditions. The demographic scenario implies a decrease in total abatement cost and the agricultural change scenario implies large increases in total abatement costs. An interesting aspect is that the two major drivers of future nutrient loads in the Baltic Sea drainage basin, climate change and structural change in the agricultural sector work in different directions and the large anticipated cost increase by structural change in the agricultural sector could be somewhat offset by changes in nutrient outflow caused climate change.

This paper contributes to the literature on dynamic cost effective nutrient abatement by introducing scenarios of climate change to the spatial and temporal perspective. The impact of climate change on cost effective nutrient abatement has been analyzed before in a static setting and for a single sub-basin of the Baltic Sea in Gren (2010). However none of the previous studies on cost effective nutrient abatement in the Baltic Sea has included the entire drainage basin as well as structural change in the agricultural sector and demographic development into the analyses.

2.3 Summary of Paper III

The purpose of paper III is to introduce induced technological change in a dynamic, cost effective, Baltic Sea nutrient abatement model, in order to analyze the impact of technical change on abatement costs over time. In doing this we use the same dynamic discrete cost minimization model as in paper II, originally developed in Gren et al., (2010), which accounts for both the heterogeneity of the marine basins and for the fact that the marine basins are coupled so that nutrient abatement to one marine basins affect all other basins.

In paper III we argue that learning by doing, a process where costs decline over time as firms gain experience in using a technology is the most relevant way to model technological change in nutrient abatement technology in the Baltic Sea drainage basin. Learning by doing is most often described as a function of the production process where repeating the production process leads to efficiency gains, but can also in an environmental context occur through abatement activities, since cutting back on emissions usually means that new, cleaner technologies are adopted. (Rosendahl, 2004)

In our modeling context this means that learning by doing is modeled in a reduced form through the abatement cost function. (Goulder and Mathai (2000); Bramoullé and Olson, (2005); Rosendahl, (2004)) Abatement thus leads to increased experience in using an abatement technology which leads to cost decrease. The learning rate is defined as the cost decrease in percentage for each doubling of abatement/experience. In paper III we run scenarios for different learning rates in order to analyze the impact of technical change on the cost of abatement. To the best of our knowledge there exist no studies, which conduct learning curve studies for all abatement technologies with relevance for the Baltic Sea. Studies from the climate, energy and manufacturing fields are therefore used together with studies for environmental abatement technologies. (McDoald and Schrattenholzer, (2001); Dutton and Thomas, (1984); Rasmussen,(2004); Oosterhuis (2007))

We calculate minimum cost solutions for the fulfilment of the nutrient abatement targets in the 2007 BSAP, under both the business as usual scenario and under different scenarios with technical change. Due to uncertainty with regard to the learning rate, we conduct extensive sensitive analysis to analyse the impact of different learning rates. The planning period in the simulations of cost effective nutrient abatement under technical change is here based on the guidelines in the most recent Helcom BSAP, where the planning period is set to 2021. However since the dynamics of the Sea with respect to the response time of nutrients in the marine basins is estimated to be 60-70 years the nutrient targets are set to be achieved at the latest 2100 and then sustained for 70 years.

The results from the cost minimization calculations show that technical change through learning by doing can have a substantial impact on total abatement costs depending on the learning rate. We run scenarios where costs decrease with 0,5%, 5% and 12% for each doubling of experience/abatement. These learning rates are set to represent a low, medium and high learning rate scenario. From these scenarios it can be seen that costs decrease substantially with about 44% with a technological learning of 12% for each doubling of experience/abatement. The 5% learning rate gives an average cost decreases of

24,5 % and the pessimistic learning scenario of 0,5% learning rate yields cost decreases of 2,8%. The cost decreasing effect of technical change through learning-by-doing is largest for Poland, which bears the largest cost burden in any nutrient abatement scheme. Inclusion of technical change in the analysis show that costs could be decreased substantially in both absolute and relative terms for Poland. This could in turn increase the possibility of a successful implementation of the BSAP since the large cost burden of Poland might be viewed as unfair, not the least by Poland itself.

References

Baumol,W., Oates,W., 1988. The Theory of Environmental Policy: Externalities, Public Outlay and the Quality of Life, 2nd edition. Prentice-Hall, Englewood Cliffs, NJ.

Bramoullé, Y. & Olson, L.J. Allocation of pollution abatement under learning by doing. Journal of public economics. 2005; 89 1935-1960.

Dutton, J.M., Thomas, A., 1984. Treating progress functions as a managerial opportunity. Academy of Management Review 9, 235.

Eriksson-Hägg, H., Humborg, C., Mörth, C-M., Medina, M.R., Wulff, F. Scenario Analysis on protein consumption and climate change effects on riverine N export to the Baltic Sea. Environmental Science and Technology 2010; 44(7): 2379-2385

Gifford, S., Dunstan, H., O'Connor, W., Macfarlane, G.R., 2005. Quantification of in situ nutrient and heavy metal remediation by a small pearl oyster (Pinctada imbricata) farm at Port Stephens, Australia. Mar. Pollut. Bull. 50, 417–422.

Grant, J., Hatcher, A., Scott, D.B., Pocklington, P., Schafer, C.T., Winters, G.V., 1995. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. Estuaries 18, 124–144.

Goulder, L.H. and Mathai, K. Optimal CO2 abatement in the presence of induced technical change. Journal of Environmental Economics and Management. 2000; 39 1-38.

Graham, L. Phil. Climate Change Effects in River Flow to the Baltic Sea. Ambio 2004; Vol 33 No. 4-5, June: 235-241.

Gren, I-M., Savchuck, O., Jansson T. Dynamic cost effective mitigation of eutrophication in the Baltic Sea with coupled hetereogeneous marine basins. Journal of Environmental Management 2010; in review

Gren, I-M., Lindqvist, M., Jonzon, Y. Calculation of costs for nutrient reductions to the Baltic Sea – technical report 2008; Working paper no. 1. Department of Economics, SLU, Uppsala.

Gren I-M. Climate change and the Water Framework Directive: Cost effectiveness and policy design for water management in the Swedish Mälar region. Climatic Change 2010; 100(3) 463-484.

Haamer, J., 1996. Improving water quality in a eutrophied Fjord system with mussel farming. Ambio 25, 356–362.

Helcom 2007. HELCOM Baltic Sea Action Plan. Helsinki Commission, Helsinki, Finland. http://www.helcom.fi/BSAP (accessed 20.08.2011)

Jaffe, A., Newell, R.G., Stavins, R.N., Environmental policy and the technical change. Environmental and resource economics. 2002; 22: 41-69

Lindahl, O., Hart, R., Hernroth, B., Kollberg, S., Loo, L.-O., Olrog, L., Rehnstam-Holm, A.-S., Svensson, J., Svensson, S., Syversen, U., 2005. Improving marine water quality by mussel farming—a profitable solution for Swedish society. Ambio,131–138.

MacDonald, A. & Schrattenholzer, L. Learning rates for energy technologies. Energy Policy. 2001; 29 255-261.

Nakic´enovic´, N. et al. Special Report on Emissions Scenarios (SRES);Intergovernmental Panel on Climate Change (IPCC), 599 pp, 2000

Oosterhuis, F. Cost decrease in environmental technology: evidence from four case studies. Report number R-07/05. Institute of environmental studies, Vrije Universiteit, De Boelelaan 1087, 1081HV Amsterdam, The Netherlands

Rasmussen, T.N. CO2 abatement policy with learning-by-doing in renewable energy. Resource and energy economics. 2001; 23 297-325.

Rosendahl, K.E. Cost-effective environmental policy: implications of induced technical change. Journal of Environmental Economics and Management. 2004; 48 1099-1121

Ryther, J.H., Dunstan, W.M., Tenore, K.R., Huguenin, J.E., 1972. Controlled eutrophication:increased food production from the sea by recycling humanwastes. Biol.Sci. 22, 144–152.

Rönnberg, C and Bonsdorff, D Baltic Sea eutrophication: area-specific ecological consequences Hydrobiologia 514: 227–241, 2004.H. Kautsky & P. Snoeijs (eds), Biology of the Baltic Sea. 2004 Kluwer Academic Publishers. Printed in the Netherlands.

Savchuk, O.P., and Wulff, F. Modeling the Baltic Sea eutrophication in a decision support system. Ambio 2007; 36(2-3): 141 – 148.

Seki, M., 1972. Studies on environmental factors for the growth of the pearl oyster, Pinctada fucata, and the quality of its pearl under the culture condition. Bull. Mie Prefectural Fish. Exp. Stations, 32–143 (in Japanese with English summary).

Suzuki, K., 1957. Biochemical studies on the pearl oyster (Pinctada martensi) and its growing environments. Bull. Natl. Pearl Res. Lab. 2, 57–62 (in Japanese with English summary).

Acknowledgements

There are several people who have contributed to the making of this thesis and I would like to take this opportunity to thank them in turn. First of all I would like to thank my supervisor Ing-Marie Gren for constructive criticism and fruitful discussions during the thesis work. I would also like to thank my assistant supervisor Katarina Elofsson for encouragement and good advice during the thesis work. I would also like to give a special thanks to Torbjörn Jansson for supportive programing and modeling advice. Thanks should also be directed to Mattias, Miriam, K-A and Rob for feedback during the research process.

I would also like to thank all my PhD-friends, especially those who started the PhD-program together with me in 2008 Marit, Miriam, George, K-A, Sverrir as well as Mattias Carlsson whom I have shared office with over the last years, life as a PhD-student has been much more interesting and stimulating thanks to you.

A collective thanks should also be directed to all friends and colleagues at the department of economics, lunch- and coffee breaks has been long and enjoyable thanks to you.

I would also like to direct a large thank you to my family and friends who have supported me and encouraged me over the years.