ECONOMIC CONSEQUENCES OF FUEL TAX CONCESSIONS REMOVAL IN NORTHERN BALTIC SALMON FISHERIES

Master's thesis
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Abstract

Fishing vessels run on fossil fuels that produce greenhouse gases, which are harmful to the environment and costly to society. Since fuel use in fisheries is often subsidized through tax concessions, private fuel consumption will be higher than what is socially optimal. Furthermore, fuel tax concessions will lead to greater fishing effort, with overfishing as a possible consequence.

This thesis deals with these negative externalities associated with fisheries. The aim of the study is to elicit the economic and environmental effects from removing fuel tax concessions, and to view these effects in relation to the results of current and optimal fisheries management. To this end, four different fuel cost scenarios are introduced as basis for the analysis. The current situation of the fishery is compared to an optimized fishery with fuel tax concessions maintained and removed, i.e. with fuel costs implemented.

The target of the study is the commercial Baltic salmon fishery, which is a small-scale coastal fishery carried out with trapnets. The analysis employs a bioeconomic model, which accounts for the economic and biological features of this specific fishery.

Results from the analysis conveyed that the fishery is currently unprofitable, and therefore not capable of coping with additional costs imposed on it. However, results from the optimization suggest that economic performance can be improved by managing the fishery in an optimal way, i.e. by adjusting the fishing effort to an efficient level. Furthermore, a movement to optimal management is suggested to be an efficient way of gaining both economic and environmental benefits. An optimally managed fishery is thus better equipped to pay for the external costs from the CO_2 emissions arising from its fishing operations.

Keywords
Atlantic salmon fisheries, fuel subsidies, fuel tax concessions, CO_2 emissions, bioeconomic modeling

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Tiivistelmä

Kalastusalusten käyttämät fossiiliset polttoaineet tuottavat kasvihuonekaasuja, jotka ovat ympäristölle haitallisia ja aiheuttavat kustannuksia yhteiskunnalle. Polttoaineenkäyttöä tuetaan verovapautuksin, jonka seurauksena yksityinen kalastaja käyttää polttoainetta enemmän kuin mikä olisi optimaalista yhteiskunnan kannalta. Verovapautukset johtavat lisäksi kalastusponnistuksen kasvuun, mikä voi osaltaan aiheuttaa liikakalastusta.

Tämä maisterintutkielma käsittelee näitä kalastukseen liittyviä ulkoisvaikutuksia. Tutkimuksen tavoite on selvittää verovapautusten poistosta aiheutuvat taloudelliset ja ympäristölliset seuraukset, sekä verrata näitä nykysäätelyn ja optimaalisen säätelyn alla olevaan kalastukseen. Analyysia varten tarkastelen neljää eri polttoainemaksuskenaariota. Nykykalastusta verrataan optimaaliseen kalastukseen tilanteessa, jossa verovapautukset ovat ennallaan sekä tilanteessa jossa vapautukset poistetaan, eli toisin sanoen implementoidaan polttoainemaksu.

Tämän tutkimuksen tarkastelun kohteena on kaupallinen Itämeren lohenkalastus. Kyseessä on pienimuotoinen rannikkokalastus rysillä. Analyysissä käytetään bioekonomista mallia, joka huomioi tämän kalastuksen taloudelliset ja biologiset erityispiirteet.

Tutkimuksen tulokset osoittavat, että nykyhetken kalastus on taloudellisesti kannattamatonta ja, että se tämän vuoksi ei pystyisi selviytymään polttoainemaksun tuomasta lisäkustannuksesta. Mallinnus toisaalta osoittaa, että optimaalisella säätelyllä, eli asettamalla kalastusponnistus tehokkaalle tasolle, voidaan parantaa kalastuksen taloudellista kannattavuutta. Optimaalinen säätely osoittautuu tehokkaaksi tavaksi saavuttaa sekä taloudellisia että ympäristöllisiä hyötyjä. Optimaalisesti säädellyllä kalastuksella olisi täten paremmat edellytykset maksaa kalastusoperaatioiden CO_2 päästöistä aiheutuvat ulkoiskustannukset.

Avainsanat
Itämeren lohenkalastus, polttoainetuki, polttoaineen verovapautus, CO_2 päästöt, bioekonominen mallinnus

Säilytyspaikka
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Muita tietoja

Foreword

This thesis is based on the Finnish case study, which was conducted within the joint Nordic research project "The Impact of Abolishing Fuel Tax Concessions in Nordic Fisheries" during 2012-2013. The project was a collaboration within the Nordic Council and coordinated by Agrifood Economics Centre, SLU in Sweden. The project included contributors and case studies from all of the Nordic region's nation states and two autonomous territories: Sweden, Denmark, Norway, Iceland, Finland, Greenland and the Faroe Islands. A project report titled *The Impact of Abolishing Fuel Tax Concessions in Nordic Fisheries – An empirical study of* CO_2 *emissions, fleet structure and employment in the Nordic countries* is forthcoming.

First and foremost, I would like to thank my instructor, university lecturer Marko Lindroos at the Department of Economics and Management at the University of Helsinki for giving me the opportunity to participate in this project. I would also like to thank project leader Staffan Waldo from Agrifood/SLU and the rest of the project team for a pleasant and rewarding collaboration. Additionally, I want to express my gratitude to the following researchers for valuable contributions and help in relation to the work with my thesis and the Finnish case study: Maija Holma, Soile Oinonen and Tapani Pakarinen.

Helsinki, February 2014

Fredrik Salenius

Contents

Acronyms

CO_2	Carbon dioxide
EU	European Union
EU ETS	European Union Emissions Trading System
FGFRI	Finnish Game and Fisheries Research Institute
ICES	International Council for the Exploration of the Sea
NPV	Net present value
OECD	Organisation for Economic Co-operation and Development
STECF	Scientific, Technical and Economic Committee for Fisheries
TAC	Total allowable catch
WGBAST	Assessment Working Group on Baltic Salmon and Trout

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1 Introduction

Fossil fuels are the primary energy input to fisheries around the world, therefore making nearly all current fisheries dependent on nonrenewable energy sources. In 2000, global fisheries accounted for about 1.2% of the world's oil consumption, which resulted in more than 130 million tons of carbon dioxide (CO_2) emissions (Tyedmers, Watson & Pauly 2005, 635). Indeed, the Food and Agriculture Organization of the United Nations (FAO 2009, 88) has stated that fisheries and aquaculture make a small but still significant contribution to greenhouse gas emissions. Various attempts have been made to reduce global CO_2 emissions, which is one of the key inducers of anthropogenic climate change (e.g. IPCC 2007, 3&19).

Simultaneously fuel use in the fishing sector is often supported financially (subsidized) in different ways (Martini 2012, 7), causing fishing enterprises to use more fuel, with potentially harmful consequences to the environment (OECD 2006, 108). In most OECD countries fisheries have access to tax-free fuel as a result of fuel tax concessions. The Group of Twenty (G20), which represents 90% of global GDP and 84% of global fossil fuel emissions, has made an appeal for worldwide focus on fossil fuel subsidies as an effort in the mitigation of climate change. The G20 Leaders have expressed a wish that inefficient fuel subsidies be phased out and rationalized over the medium term, since reducing support to fuel use can generate both environmental and economic benefits. Because fuel tax concessions are often less transparent than other support measures, they might easily be neglected when considering policy reforms (Martini 2012, 21). OECD (2011, 1) has stated, apart from that environmental taxes should be targeted to polluters or polluting behavior, that such taxes should preferably not have any exceptions. Further, the World Trade Organization (WTO) has been working for nearly a decade with getting subsidies that promote overfishing under control (Sumaila 2013, 251).

Removing fuel tax concessions means in effect that the cost or harm to society from the use of fossil fuels is included into the price of fuel. The price of tax-free fuel does not contain the cost that befalls society from the use of fossil fuels, such as costs associated with climate change. The fuel cost to private enterprises is thus lower than the cost to society, which will lead to fuel consumption that is higher than what is optimal from society's point of view. There are two principal ways of addressing this problem, namely taxation and emissions trading. These are regulatory instruments that, if implemented correctly, will raise the private cost of fuel and therefore incentivize enterprises to reduce fuel consumption when making their production decisions. The assumption here is that both price controls (corrective taxes) and quantity controls (tradable permits) produce the same economically efficient outcome. However, current fisheries are not subject to such policies and little is known about the overall effects from their implementation.

A step in the direction of obtaining such knowledge has been taken by e.g. the OECD Committee for Fisheries. In 2012 the OECD released a report that identified and measured fuel tax exemptions in the global fisheries sector. The report is a step toward an analysis of the impacts of fuel support and an initial assessment of the consequences of fuel subsidy removal in the fishing sector (Martini 2012, 5). Sumaila et al. (2006, 2008) have previously addressed the topic of fuel subsidies and their effects on fish resource sustainability on the global level. They claimed that the positive effects of recent fuel price increases, which should reduce effort, have been negated by the extensive fuel subsidies provided by national governments. The link between fuel price and economic performance of fisheries has been further studied by Cheilari et al. (2013). Results of this study showed that profitability declined in several EU fishing fleets during the study period in the 2000s, when fuel price increases occurred. Simultaneously, energy efficiency indicators have improved as a result of rising fuel costs. Ziegler & Hornborg (2014) also detected increased fuel efficiency in Swedish trawl fisheries, but concluded that better stock status was the primary explanation, not higher fuel costs. It was further suggested that fuel tax concessions maintain inefficient fisheries, since they favor fuel intensive fishing practices and large fleet capacity.

However, not many empirical studies exist on the effects on fisheries and fishing operations from transforming fuel tax concessions policies (OECD 2006, 107; Martini 2012, 20). Given that fuel is usually a significant part of fishing costs (e.g. Sumaila 2008, 251), fuel support, or the lack of it, will have an impact on the cost of fishing, fishing effort and profitability. Such policy transformations means in effect the implementation of some sort of fuel cost policies, for example fuel taxes. Further, Driscoll & Tyedmers (2010, 353&358) have pointed out that also fisheries policy has the potential to influence fuel use and fleet structure and, consequently, greenhouse gas emissions in fisheries. The nature and scope of the impacts from different management measures on the fishing industry, fuel use and emissions is an empirical question.

1.1 Abolishing fuel tax concessions in Nordic fisheries

This thesis takes these aforementioned topical issues into a Nordic and Finnish context. The thesis is part of a Nordic research project titled "The Impact of Abolishing Fuel Tax Concessions in Nordic Fisheries". The project is funded by the Nordic Council and includes case studies from all Nordic countries, ranging from large-scale offshore trawling to small-scale coastal fisheries using passive gear. The aim of the project is to elicit the effects of removed fuel tax concessions on the fishing industry and on CO_2 emissions, and to view these effects in relation to current and optimal management of the studied fisheries.

The Finnish case studies the commercial Atlantic salmon (*Salmo salar*) fishery in the northern Baltic Sea in the Gulf of Bothnia. This is a small-scale coastal fishery carried out with passive gear called trapnets. Since management of salmon should be based on the assessment of individual river stocks (ICES 2013a, 1), the specific target of this study is the River Tornionjoki (Torne River) wild salmon stock. River Tornionjoki produces one third of the wild salmon in the Baltic Sea, which translates to a salmon catch of several hundreds of thousands kilograms per year to the fishermen in the Baltic Sea region (FGFRI 2013a). Although the salmon fishery is not the most significant in terms of e.g. landing weight or value, it is an important target species for the coastal fisheries (FGFRI 2011a, 6). It is also one of the most controversial fisheries in the region, primarily because most Baltic salmon stocks are endangered (Kulmala et al. 2008a, 3; FGFRI 2013b). Highly differing views among stakeholders (commercial fishermen, recreational fishermen, policy makers, environmental organizations) on issues concerning exploitation of the fishery are not uncommon. Indeed, one of the aims of this thesis is, within the framework of the research questions, to provide a comprehensive overview of the past, present and future economic and biological circumstances of the commercial salmon fisheries in the northern Baltic Sea.

In the project the focus is on two market failures associated with fisheries. Market failures prevent free markets from producing economically efficient outcomes, i.e. they prevent efficient allocation of resources (Hanley, Shogren & White 2001, 16). One market failure is the environmental damage that arises from fishing vessels' use of fossil fuels. Since the tax-free fuel does not include the external cost of this environmental damage, the private consumption of fuel will be higher than what is socially optimal. This sort of market failure is known as a negative externality. The other market failure is the common-property problem of fisheries. This is a situation, where open access to a fishery and the lack of regulation will result in excess effort and overfishing. Both these market failures and the means to address them are dealt with throughout the thesis. From here on, I refer to policies directed at the fuel use externality as fuel cost policy or climate change management, and to policies directed at the common pool problem as fisheries management.

1.2 Research methodology and thesis structure

In our research project we ask what the consequences to different fisheries would be if an additional cost is imposed on fuel, i.e. if the fuel subsidy to fisheries is removed. This means that the fishing enterprises would pay for the external cost, which is a result of their use of fossil fuels. To this end, we introduce four fuel cost scenarios upon which the analysis is built. The scenarios are presented in Table 1, and will be described in more detail later on. The current situation is represented by data on the factual economic performance of the fishery. *Baseline* represents the present situation where fuel use is subject to neither taxation nor emissions trading. *EU* is a cost from a situation where the fishery operates within an emissions trading system. *Stern* is a tax based on an estimation of the social cost of CO_2 emissions. *National* is the cost from national fuel taxes. The first three scenarios are the same for all national case studies, whereas the fourth scenario varies according to country-specific fuel tax legislation.

Table 1. *Fuel cost scenarios.*

Scenario		Definition
0.	Current situation	-
1.	Baseline	Fuel use exempt from costs
2.	EU	EU CO_2 quota price in 2009
3.	Stern	Social cost of CO_2
4.	National	Finnish fuel tax in 2009

I will study the effect of removing fuel tax concessions on the salmon fishery by comparing the four policy scenarios with the current situation. The current situation is the result of present fisheries management. In the four policy scenarios, on the other hand, I will apply optimal management and maximize the net present value (NPV) of the fishery assuming the different fuel costs. I will also look at the impact from introducing fuel costs under current management. I am mainly interested in effects on fishing effort and NPV of the fishery, but also fuel consumption and fuel efficiency as well as CO_2 emissions are considered. Also the sustainability of the salmon fishery is discussed.

In this context, fisheries management implies the amount of effort that is allowed in the fishery. For example, in an open access fishery there would be no restraint on effort. Optimal management, on the other hand, means finding an efficient level of effort that will maximize the NPV of the fishery given economic and biological realities, such as fishing costs and salmon reproduction dynamics. Fisheries economic theory provides different solutions for reaching optimal management, and some of these are briefly presented in the next chapter. However, in this thesis I will not propose means for reaching the desired level of effort; I will merely suggest what this level should be. The regulatory measures are implicit in the concept of optimal management.

A useful tool in the study of fisheries is the bioeconomic model. In this study I will use a bioeconomic model in the optimization of the fishery, and to compare the economic performance in the different scenarios. Essential input into the model is economic and biological data that relate to the salmon fishery, and specifically to the

River Tornionjoki stock. Central output of this specific model is effort, NPV, harvest and steady state fish stock. The unit of effort employed in Baltic salmon assessment and in this analysis is geardays, which is obtained by multiplying the number of fishing days with the number of gear (trapnets) (see e.g. ICES 2012a, 21). Other indicators that are considered in the analysis, but which are not obtained as output from the model, are fleet size, employment, fuel consumption and CO_2 emissions. These are obtained through different estimation procedures, which will be described in the analysis chapter.

The framework of the study is illustrated in Figure 1, which portrays the premises and aims of this thesis. The fishery produces benefits to society, but also externalities in form of CO_2 emissions and overfishing. Society can address these problems with policy instruments (solid arrow), but the overall impacts of these measures are not known (dashed arrow). Science, in turn, can address this knowledge gap with the aid of theory and empirical analysis. In this case the goal is to elicit the consequences to the Baltic salmon fishery from having it to account for the emission externalities from its direct fishing operations. Energy use in capture fisheries is mainly the direct use of fuel to power fishing vessels (Cheilari et al. 2013, 18; OECD 2013, 5).

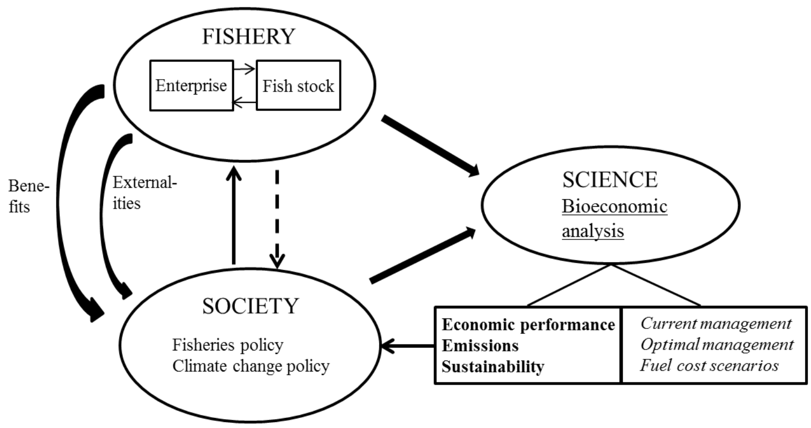

Figure 1. *Framework of the study. Science can provide information to policy makers on how to address the problem of fuel use externalities in fisheries.*

This thesis is laid out as follows. Next, I will elaborate on fuel subsidies in fisheries and on their removal, i.e. the implementation of appropriate climate change management measures. Fuel tax concessions both internationally and in Finland are discussed here, as well as management of both climate and fisheries. I will finish chapter 2 with a literature review on Baltic salmon bioeconomics as an introduction to practical fisheries management. In chapter 3, I will give a quite comprehensive presentation of the Baltic salmon fishery. The biological and economic issues brought up here are important with respect to the actual analysis in chapter 4. This chapter will, however, commence with a more thorough presentation of the fuel cost scenarios. Afterwards, the bioeconomic model is presented. Finally, a presentation of the results (latter part of chapter 4) and the conclusions of the study (chapter 5) will conclude the thesis. For the interested reader, a more in depth description of the salmon population dynamics can be found in Appendix A. Additionally, a detailed description of the procedure behind the estimation of fishing costs can be found in Appendix B.

2 Fuel Subsidies and Environmental Management of Fisheries

Fuel subsidies exacerbate the aforementioned externalities in fisheries by increasing both fuel consumption and fishing effort. Fuel subsidies in both the international context and in Finnish fisheries are discussed in the first section of the chapter. In the second section I will discuss the policy measures available for addressing market failures in fisheries, and provide a theoretical account of the effect of fuel tax concessions under different fisheries management regimes. I will conclude the chapter with an introduction to bioeconomic analysis of Baltic salmon fisheries.

2.1 Fuel subsidies: Tax concessions for the fishing industry

Fisheries subsidies are direct or indirect financial support from governments to the fishing sector (Sumaila 2013, 251). Subsidies can be directed to both the markets of fisheries output (fish) and input (factors of production, e.g. fuel) (Martini 2012, 7). The definitions and classifications of fisheries subsidies may vary, since no single agreement on what defines a subsidy or how it should be measured exists (Khan et al. 2006, 13). Nevertheless, fuel tax exemptions or concessions are defined as a subsidy by both the OECD and WTO (OECD 2006, 20).

Khan et al. (2006, 13-16) identify good, bad and ugly subsidies depending on the subsidy's impact on the sustainability of the fishery resource. Good subsidies will lead to investments that promote optimal resource use. Such subsidies are for example investments in research and fisheries management programs. Some subsidies are tied to environmental protection, such as fishing vessel buyback programs (Shrank 2003, 9), which are meant to reduce overcapacity and fishing pressure. However, a study by Clark, Munro & Sumaila (2005) showed that, when anticipated by the fishermen, buybacks would likely be harmful to both resource protection and economic performance. Vessel buyback programs are consequently defined as ugly subsidies, since their effectiveness in protecting the fish resource is highly questionable. Tax exemptions, on the other hand, is a bad subsidy, since they enhance overcapacity and overfishing through higher profits for the fishers (Khan et al. 2006, 15-16)[1]. Furthermore, support to fuel use will have environmental effects besides those on the target fish stock. These effects, for example higher greenhouse gas emissions, should also be taken into account and given proper attention (OECD 2005, 45).

The majority of governmental support to fuel use is given in the form of tax concessions (expenditures), as opposed to budgetary expenditures. Tax concessions are financial transfers achieved by reducing tax obligations with regard to some benchmark tax. Tax concessions for the fisheries sector are usually implemented by providing reduced rates, rebates or tax exemptions. These concessions can concern value added taxes (VAT) or, more commonly, excise taxes directed at specific fuels. All OECD countries have imposed excise taxes on some fossil fuels. (Martini 2012, 7.)

A special case of support within the EU has been the *de minimis* regulation for fisheries. The *de minimis* aid has granted support to fishing firms of up to €30 000 per three-year period. The aid is not allowed to be used to increase fishing capacity, but can be used to cover variable costs from the use of fishing vessels, such as fuel consumption. It is estimated that EU fishers spent €1.8 billion on fuel in 2008. From this follows, that the *de minimis* aid could potentially cover approximately 13% of the EU fleet's fuel costs in 2008. (Martini 2012, 23-24.)

Fuel tax concessions represent substantial amounts of money in many countries. Sumaila et al. (2006, 47) estimate that fuel subsidies account for about 25% of total fisheries subsidies. The estimated total value of fuel tax concessions in OECD countries was €1.5 billion in 2008. The total amount of fuel consumed amounted to 9.3 billion liters, which includes also non-subsidized fuel (Martini 2012, 10).

Fuel tax concessions are often motivated with reasons related to competitiveness. That is, domestic fisheries need to be supported in order to withstand international

[1] Khan et al. (2006) is a study on non-fuel subsidies, and does not therefore consider fuel tax exemptions. The rationale behind the classification will, however, apply for fuel tax exemptions as well.

competition. In the past, high fuel prices have motivated fuel tax concessions in many countries. This is the case particularly in countries with high tax rates on fuel. Furthermore, fuel prices have been very volatile in recent years, which can make a removal of fuel tax concessions more difficult (Martini 2012, 14-15&20). Nevertheless, Martini (2012, 21) argues that support that is not dependent on the use of inputs, such as fuel, can be a more effective way of income transferal. Support based on income is likely to be more efficient, since it leads to fewer market distortions.

Fuel tax concessions in the Finnish fishing sector

As a member of the EU, Finland is bound by the Energy Taxation Directive, which defines the energy products and lays down the minimum fuel taxation levels in the Member States. However, fuels that are used in certain activities and processes are exempt from taxes. These include fuels used as energy sources in oil refining processes, fuels used in industrial production as raw material, fuels used in the production of goods, fuels used in production of electricity and fuels used for aviation and vessel traffic in other than private leisure use. Commercial fishing falls under this last category. (Finnish Customs 2013a, 1&3.)

In the EU, the Energy Taxation Directive also lays down the rules for tax exemptions. The Directive states that commercial fishing activities can be exempted from fuel taxes in Community waters. In Finland, this is stated in Article 9 of the Act on Excise Duty on Liquid Fuels. The tax exemption covers the full value of the excise duty on fuel. (Martini 2012, 23&25.)

Only fishing vessels used in professional fishing are exempt from fuel taxes. In the Finnish Fishing Act, a professional fisher is defined as a person who earns at least 30% of the regular total income from fishing and processing of the catch. Additionally, a professional fisher has to be included in the register of professional fishermen. Also the vessels used in professional fishing need to be included in the register for fishing vessels. Vessels are registered as coastal fishing vessels (less than 12 in meters length) or offshore fishing vessels (at least 12 meters in length). These registrations must be valid when acquiring or using tax-free fuel. The registers are maintained by the

Centres for Economic Development, Transport and the Environment (ELY Centres), as well as the Government of Åland in the Åland Islands. (Ministry of Agriculture and Forestry 2005; ELY Centre 2011; Finnish Customs 2013b, 2.)

The tax exemption is usually implemented through a refund, which is paid to the fuel user upon application. The refund consists of the total amount of the excise duty at the time of purchase. The refund is applied for from the Customs. Application for refund can be done once or twice a year. In the case of certain vessels, it is a possible to acquire tax-free fuel directly from an authorized warehouse keeper. This concerns certain diesel-powered vessels that run on light or heavy fuel oil. The fishing vessels that this rule applies to are trawlers and vessels of at least 15 meters in length. Fishers, who acquire tax-free fuel in this way, must each year report to the Customs the quantities of fuel purchased and used. Furthermore, the fishers are obligated to keep accounts of the quantities of tax-free fuel acquired and used. (Finnish Customs 2013a, 12; Finnish Customs 2013b, 6.)

In Finland, the fuel tax exemptions for professional fishers amounted to €310 000 in 2008 and €260 000 in 2009 (OECD 2012, 229). Table 2 exhibits the values of tax concessions and volumes of fuel consumed in the Finnish fishing sector in 2008.

Table 2. *Fuel tax concessions for Finnish fisheries, 2008.*
Source: data from Martini 2012, 25.

Fuel type	**Tax concession value, €**	**Fuel consumed, l**
Motor gasoline	234 600	374 400
Diesel oil	5 700	15 800
Fuel oil	72 400	836 500

2.2 Taxes and quotas as instruments in environmental policy

2.2.1 Climate change management

Taxation of fuel is one of many ways for governments to collect tax revenue in order to fund public spending. Motor fuel taxes are especially suitable for this purpose due to the relatively low elasticity of fuel demand in the short run. This means that a price increase in fuel tends to have only a modest effect on demand. However, fuel taxes may also be used as a policy instrument, with the aim of steering behavior in a certain direction (OECD 2011, 2&6). The price elasticity of fuel is in fact quite high in the long run, which means that fuel taxes can be a powerful instrument in environmental policy. Historically, however, environmental considerations have not been the primary reason for imposing taxes on fuel (Sterner 2006, 3194-95).

The stated reasons or motives for fuel taxes may vary considerably (Sterner 2006, 3195). The purpose of raising revenue and environmental reasons has been mentioned. In some countries, fuel taxes are earmarked for specific purposes, such as road building and maintenance. This, in turn, is sometimes used as an explanation to why certain sectors are exempt from fuel taxes. Fishing vessels, for example, do not operate on publicly financed roads, therefore making the fishing sector's contribution to the tax base unmotivated (Martini 2012, 9; OECD 2012, 52).

Taxes that are used in environmental policy are called environmental taxes. Overall, environmentally related taxes account for about 5% of total tax revenue in OECD countries (OECD 2011, 8). An environmental tax is for example the corrective or Pigovian tax. It is designed to take into account the negative externalities of certain actions (for example the use of motor fuel), so that the cost of the environmental damage is incorporated into market prices, and therefore affects the decisions of the consumers (Hanley et al. 2001, 29). The size of the tax should ideally correspond to the scope of the environmental damage. Several countries have implemented considerable taxes on fuel because of the negative effects associated with the use of fossil fuels, such as global warming and air pollution (OECD 2011, 1-2). In Europe, the policy of high fuel taxation has restrained growth in fuel demand, resulting in lower CO_2 emissions. These policies in Europe and other high tax countries have had a detectable effect on the carbon content of the atmosphere. Therefore, a discussion of an extension of the use of fuel tax policies to other sectors, notably industry, is called for (Sterner 2006, 3201).

An alternative to putting a price on CO_2 emissions via a tax is to restrain the quantity of emissions allowed, and to let the actors trade the rights to emit on the open market. This is the idea behind tradable quotas and emissions markets, which will in effect create a value to the CO_2 emissions as well. When a restricted amount of emission permits is allocated to the market actors, who are allowed to buy and sell these permits freely, an incentive to pollute less is created. The idea of tradable permits was introduced in the mid-1960s and first implemented in the 1990s (Hanley et al. 2001, 30-31). An example of a tradable permit market is the European Emissions Trading System (ETS), which was launched in 2005. The system covers about 45% of the greenhouse gas emissions in the EU, including primarily the power generation and manufacturing industry (European Commission 2013a). The fishing sector is an industry, which has not been subject to climate policies, such as emissions trading or taxation.

2.2.2 Fisheries management

Management and regulation are required in order to achieve desired biological and economic objectives of a fishery (Clark 1990, 245). Managing fisheries is often a question about regulating fishing capacity or fishing effort. Capacity comprises primarily the number and size of fishing vessels, whereas effort is related to the use of vessels in fishing activity. Regulation measures may be divided into input (effort) and output (catch) regulations, as well as technical regulations. Fisher licenses, effort quotas and engine power limitations are examples of input controls. Output controls are represented by different kinds of harvest quotas, such as quotas on total harvest and individual fisher quotas. Technical regulations include gear regulations, minimum fish size and restricted fishing seasons and areas (Flaaten 2010, 30-31).

Open access is a theoretically important concept in fisheries economics, but largely non-existent in national fisheries. In OECD countries most fisheries can be characterized as regulated open access fisheries or, increasingly so, as quota fisheries. In the former, regulations may include total allowable catch (TAC), permissions and technical regulations. In the latter, quotas may be allocated to individual fishers or vessels or to fisher/vessel groups (Martini 2012, 16). However, the biological and economic outcomes of different management strategies are not necessarily obvious to the fisheries manager (Clark 1990, 245).

There is no one ideal solution to optimal management of fisheries. Individual transferable quotas (ITQs) have admittedly many advantages, particularly in the ability to produce economically efficient outcomes in the long run. Nonetheless, there are also problems associated with ITQs, relating to initial quota allocation as well as to monitoring and enforcement. However, other common management measures, such as limited entry or TACs, are problematic since they do not succeed in maintaining profitable fisheries over the long term. As a side note it can be mentioned that taxation, although not used in practical fisheries management, produces the same economically efficient outcome as ITQs. However, with taxation the resource rents from the fishery are picked up by the taxation authority and not by the fishermen. (Clark 1990, 255&259-260.)

2.2.3 Fuel subsidies and fisheries management

The effect of tax concessions on the fishery will depend on the management system in place. In this section, I will look at the effect of fuel subsidies on the fishery from a theoretical point of view. A natural starting point in this sort of analysis is the open access fishery. In the Nordic countries the most commonly used management scheme is property rights in different quota systems, such as ITQs (Waldo et al. 2013, 10), therefore the case of ITQ management is also examined. Last, I will look at the TAC managed fishery, since the salmon fisheries in the Baltic Sea are managed through a TAC.

In open access, fuel subsidies lower the cost of fishing, resulting in increased effort and lower stock level at equilibrium. The subsidies do not lead to bigger profits for the fishers, because the profits are competed away through the increased effort. On the other hand, a removal of the fuel subsidies might force some of the less efficient fishers to leave the fishery, which in turn could increase profitability for the remaining fishers. However, according to fisheries economic theory, in an unregulated fishery effort will continue to increase as long as revenues are positive. This will go on until total revenues equal total costs, a state called the bionomic equilibrium. In this situation both industry profits and resource rents have been depleted. This feature of the open access fishery was first described by Gordon (1954). (Khan et al. 2006, 14; Martini 2012, 16.)

Under fishing quota schemes (e.g. ITQs) fuel subsidies are not likely to affect the number of fish caught by individual fishermen. Possible higher profits would be capitalized into the value of the fishing quotas. However, there may occur substitution of factors of production, if this is economically rational. For example, fuel support could be an incentive to fish for longer periods of time, but with less gear or manpower. Substitution of production factors might also take place in fisheries regulated with effort controls. For example, if number of fishing days is limited, fishers could switch to bigger vessels or more powerful engines. This might in fact raise the total fishing effort, and simultaneously lead to higher greenhouse gas emissions. (Martini 2012, 17-18.)

A binding TAC system represents the situation of the Baltic salmon fisheries management. This situation is shown graphically with a basic Gordon-Schaefer bioeconomic model in Figure 2. Here there are two possible scenarios. If there is a limited entry, positive profits can be earned from the fishery. The size of the profits will be determined by the level at which the TAC is set. If the TAC is set at maximum sustainable yield (MSY), profits in the initial situation will be $R\text{-}C_1$, and with fuel tax concessions $R\text{-}C_2$. This implies that a fuel subsidy under this kind of management would lead to increased profits, because costs are lower but effort and stock levels are unchanged. (Martini 2012, 16.)

On the other hand, if entry is unlimited, profits are expected to be competed away, as in open access. This is not because of increased effort (the TAC prevents that), but because the unlimited entry would bid up the costs of inputs such as fishing vessels. Thus, a fuel subsidy would lower variable costs, but then be capitalized into the value of fixed fishing costs. This is illustrated in Figure 2, with the cost curve TC_3

intersecting the revenue curve TR at TAC/MSY. In this situation a removal of fuel subsidies could prove difficult, since the fishers have invested the value of the subsidies in capital and would suffer real losses if the subsidies were removed. (Martini 2012, 17-18.)

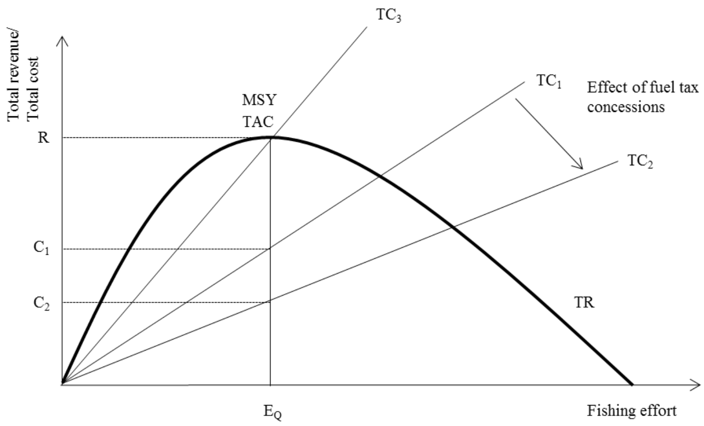

Figure 2. *The effect of fuel tax concessions under TAC management.*
Source: modified from Martini 2012, 17.

Finally, the issues of climate change management and fisheries management in the context of this study is illustrated in Figure 3. Again, we have the basic bioeconomic model with effort on the x-axis and revenues and costs to the fishery on the y-axis. The figure shows to what extent effort is reduced and the impact on profits from optimizing the fishery and removing fuel tax concessions, respectively. In this example, the effect on effort and revenues is larger from moving to optimal management (maximum economic yield) than when accounting for the emission externality. However, this will depend on the extent of the externality and the state of current fisheries management, i.e. if the fishery is closer to open access (E^{OA}) or optimal management (E^{*}) (Waldo et al. 2013, 12). The comparison of the relative size of these effects in a particular fishery is an empirical question.

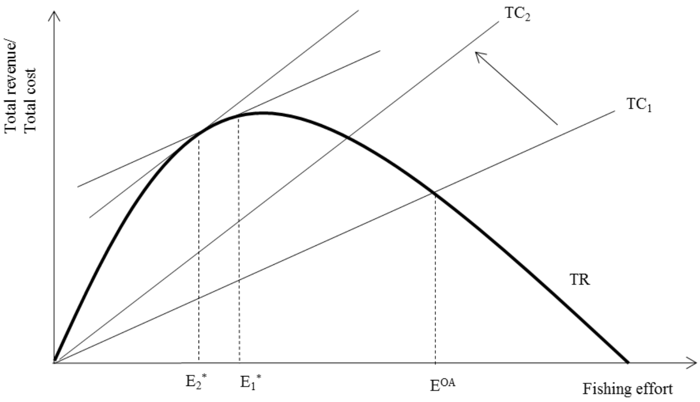

Figure 3. *The impact of climate change management and fisheries management on effort, costs and revenues in a fishery.*
Source: modified from Waldo et al. 2013, 11.

2.3 Bioeconomic modeling as a tool in practical fisheries management

In the previous section I utilized a bioeconomic model to describe basic features of a fishery in order to predict results of certain management actions. Fisheries bioeconomics studies the relationships between fish stocks and the enterprises that exploit them. Areas of interest are among others fish population dynamics, the relationship between harvest and stock size and, given prices and costs, the relationship between fishing effort and profits. Naturally, these are issues that will vary depending on the characteristics of the fishery, such as type of the fish stock or the harvest technique used (Anderson & Seijo 2010, 12). For example, Atlantic salmon is a migratory fish species that is caught mainly with passive gear. I will here review some previous bioeconomic studies on Baltic salmon fisheries, which thus take into account the distinct features of this specific fishery.

The Baltic salmon fishery is characterized by its sequential nature, i.e. the salmon is targeted by different fisheries during its life cycle. Therefore, the question of optimal allocation of catch between the different fisheries has been an essential research topic. Laukkanen (2001) developed a bioeconomic model in order to find the optimal allocation of the northern Baltic salmon catch between offshore, inshore, estuary and recreational river fisheries. The results suggested substantial gains from moving to optimal management, which would mean a closure of almost all commercial fishing and a reallocation of the catch to recreational use. For future studies on catch allocation, the author called for more information on the value of recreational river fishing.

Research on the optimal management of sequential Baltic salmon fisheries was continued by Kulmala, Laukkanen & Michielsens (2008b). This study presented a bioeconomic model that coupled economic models with the age-structured stock assessment models currently used by ICES for providing management advice. This was done in order to bridge the gap between economics and biology, and thus address the issue of overrepresentation of natural science as the basis of present salmon management. A numerical analysis was conducted with data from the River Simojoki salmon stock, which included valuation data on the benefits of recreational harvest. This study also found that net benefits from the salmon fishery could be increased markedly by reallocation of the catch. In this case all offshore fisheries would be closed down and only the coastal trapnet and river fisheries would remain active.

Both aforementioned studies assumed that the fishery is managed by a single authority. A game theoretic approach to the subject was adopted by Laukkanen (2003), where the cooperative and non-cooperative behavior of two fleets under recruitment uncertainty was studied. In the paper by Kulmala et al. (2008a) the bioeconomic study of the Baltic salmon fishery was extended and carried out in an international context. The researchers used game theoretical methods to study the Baltic salmon fishery using biological data from 21 salmon stocks and economic data from four countries fishing with different types of gear in the Baltic Sea region. This study as well found substantial gains from moving to optimal management, where the four countries cooperate with the common goal to maximize the net present value of the fishery. If the fishery had been managed in this optimal way, the authors claim that the NPV during the period 1995-2005 would have amounted to €3.3 million, instead of the factual loss of €3.7 million.

Newer studies on the optimal management of Baltic salmon include e.g. Kulmala et al. (2013), where the game theoretical application is further developed. It is shown that the current international management is nonoptimal, and that the equilibrium is in fact full non-cooperation. A somewhat different approach, than all the above mentioned, to the matter of salmon management can be found in Holma, Kulmala & Lindroos

(2013). Here the optimal management of conflicting species, namely grey seal and salmon, in the Baltic Sea is studied. The topic is highly relevant because of the negative effects that seals have had on the coastal Baltic salmon fisheries. The target of the study was, as is in this thesis, the River Tornionjoki wild salmon stock.

3 The Atlantic salmon Fishery in the Baltic Sea

In this chapter I will review the Baltic Sea salmon fishery. A special emphasis will be put on the River Tornionjoki stock, which is the target of my study. I will begin by looking at the biological aspects of the salmon stocks. From there, I will move on to a discussion of the fishery from an economic and social point of view. Here I will address matters relating to the fishing and management of the Baltic salmon stocks. The focus will be on the Finnish commercial salmon fisheries. Many of the biological and economic issues brought up here will play a key role when presenting the bioeconomic model and conducting the analysis in the next chapter.

3.1 The Baltic salmon fish stocks

The Atlantic salmon living in the Baltic Sea is geographically and genetically isolated from the North Atlantic salmon populations. Migration between the two areas is not common (Romakkaniemi et al. 2003, 329; Romakkaniemi 2008, 6). Salmon is an anadromous fish species, which means its life cycle consists of both marine and fresh water (river) phases (Kulmala et al. 2008a, 5). In the past, salmon is known to have inhabited about 100 rivers in the Baltic drainage area. Today, wild salmon stocks can be found in less than 30 rivers. The decrease in the number of spawning rivers has been caused by human activities, such as pollution, damming and overfishing (Romakkaniemi 2008, 6). For Scandinavian salmon stocks, the rapid expansion of hydroelectric power production since the 1940s has been especially detrimental (Karlsson & Karlström 1994, 66). Hydropower companies are therefore obligated to release reared juvenile salmon, called smolts, in order to compensate for losses in wild smolt production (Romakkaniemi et al. 2003, 329-330). All Baltic salmon stocks are listed as endangered (FGFRI 2013b).

The northern Baltic Sea consists of the Gulf of Bothnia and the Gulf of Finland. The northernmost part of the Gulf of Bothnia is called the Bothnian Bay. It is here where the River Tornionjoki flows into the Gulf of Bothnia. The Baltic Main Basin refers to the central and southern parts of the Baltic Sea (Romakkaniemi et al. 2003, 330). My area of interest is the Gulf of Bothnia and the Main Basin, which constitute the migration and feeding grounds for northern Baltic salmon stocks (Karlsson & Karlström 1994, 64). Here the salmon is also targeted by fisheries (see Figure 4). Of the original nearly 50 wild salmon rivers flowing into the Gulf of Bothnia, only 13 rivers remain (Romakkaniemi et al. 2003, 329). In Finland, wild salmon stocks can today only be found in the rivers Tornionjoki and Simojoki (FGFRI 2013b).

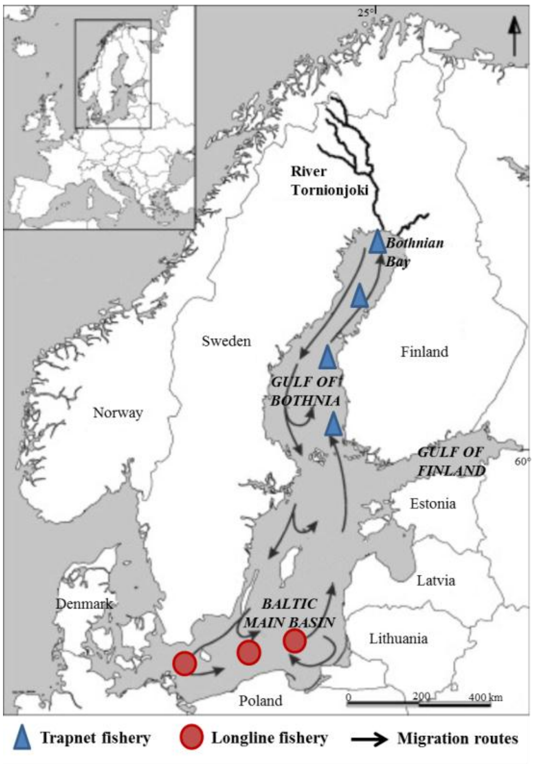

Figure 4. *Migration routes and main fisheries of northern Baltic salmon stocks. Source: modified from Kulmala et al. 2008b, 717.*

The River Tornionjoki salmon stock

The River Tornionjoki is the northernmost river basin flowing into the Bothnian Bay, and it runs along the national border between Finland and Sweden. The River Tornionjoki is the largest unregulated river system in Western Europe, and also one of the largest spawning rivers for Atlantic salmon in the world. Accounting for about 30% of the wild smolt migration, it is the largest producer of wild salmon in the Baltic Sea. The Tornionjoki salmon stock was especially weak in the 1980s, and was even considered to be close to extinction. In the 1990s, however, the stock showed signs of rapid recovery, largely because of stricter fisheries regulation in the Baltic Sea. Today, the River Tornionjoki produces a salmon catch of several hundreds of thousands kilograms per year to the fishermen in the Baltic Sea region. (Romakkaniemi 2008, 6&9; FGFRI 2013a).

Already in the 1970s, fisheries scientists and managers in Finland and Sweden had become concerned about the decline in northern Baltic salmon stocks. Therefore, a Finnish-Swedish hatchery program for reared Tornionjoki salmon was established to secure smolt production. Annual smolt stocking increased throughout the 1980s, and peaked in the late 1990s. In 2002, however, stocking of reared salmon in River Tornionjoki was abolished, because the stock was considered sufficiently recovered (Romakkaniemi 2008, 9). Overall, there has been a significant increase in total wild smolt production in the northern rivers of the Baltic Sea. It is worth mentioning that the present wild smolt production is always dependent on the spawning runs several years ago (ICES 2013a, 1).

The life cycle of Baltic salmon

Any further exploration of the salmon fishery in the Baltic Sea warrants a look into the life pattern of salmon. This information is crucial for understanding fishing and management practices. Figure 5 illustrates the life cycle stages, and sums up the more detailed description that follows below.

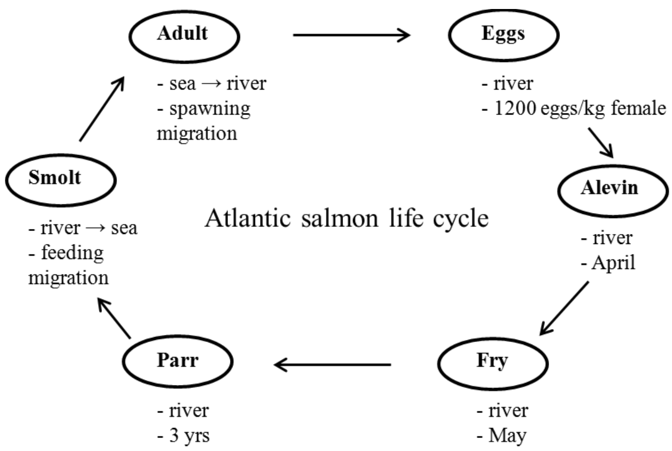

Figure 5. *The different freshwater and marine stages of Atlantic salmon.*

Wild salmon spawn in September to November in rivers with rapids. Fecundity is assumed to be about 1100-1200 eggs per kg female. For rivers flowing into the Gulf of Bothnia, hatching occurs in April-May. The newly hatched alevins receive nourishment from the yolk sac. The next stage, called fry, starts external feeding in May-June. The subsequent parr stage is territorial, and lasts throughout the freshwater phase. In River Tornionjoki the parr stage lasts for 2-6 years. This phase ends when the smolt feeding migration to the sea commences in the spring. The feeding grounds are reached by the end of the year. (Karlsson & Karlström 1994, 62-63; Romakkaniemi 2008, 8.)

The post-smolt survival greatly influences later abundance of salmon in the sea. Post-smolt mortality means mortality during the first year of feeding migration (FGFRI 2011b, 45) Factors that are known to affect post-smolt survival are herring and seal abundance. Herring are food for smolts and seals, in turn, feed on smolts. Also changes in sea temperature may influence post-smolt survival. It can be noted that decreased post-smolt survival has undone some of the positive effects on salmon abundance that is a result of decreased exploitation rates since the 1990s. Post-smolt survival declined throughout the 1990s up until the mid-2000s, after which improvements have been noticed (ICES 2013a, 1-2).

The Main Basin is the primary feeding area for almost all Baltic salmon stocks. However, a minor proportion of the Gulf of Bothnia stocks stays within the Bothnian Sea. When the salmon has reached a length of about 25 cm, they start eating fish. Sprat is the main food in the Main Basin, while herring is more common in the Gulf of Bothnia. The feeding period for the Tornionjoki salmon lasts for 1-4 years, after which they start their spawning migration to their native river along the coast of the Gulf of Bothnia. The migration begins in April-June, and the salmon enter the river from June to August. The majority of the spawners are multi-sea-winter (MSW) spawners, i.e. salmon that has spent more than one winter at sea. These MSW spawners ascend the river from June to mid-July. Salmon that has spent only one winter at sea, known as grilse, enter the river later, in July and August. Repeat spawners are rare because of the fishing pressure, and normally account for 5-10% of the spawners. (Karlsson & Karlström 1994, 64; Romakkaniemi 2008, 8-9.)

The M74[2] syndrome is a reproductive disturbance that has been detected among Baltic salmon since 1974. M74 affects females that return to the rivers to spawn. Mortality among the offspring of affected females is nearly 100% (Karlsson & Karlström 1994, 77). Mortality caused by M74 increased rapidly in the 1990s, but decreased in the 2000s (FGFRI 2013b). In 2011, the proportion of Baltic salmon females whose offspring suffered from M74 was on average 5%. For River Tornionjoki these figures in 2009 and 2010 were 4% and 12%, respectively (ICES 2013b, 129). The mortality levels vary among different rivers (Romakkaniemi et al. 2003, 333). Prediction of future mortality rates is difficult, since the exact cause of the syndrome is still unknown. Because M74 mortality has varied in the past, similar variations can also be expected in the future (European Commission 2009, 8).

The scientific assessment of salmon stocks

The sustainable harvest of fish requires accurate information about fish population dynamics. The gathering of this information is called fisheries stock assessment (Kuparinen et al. 2012, 135). In the case of Baltic salmon, knowledge on the status of salmon stocks is needed as the basis for sustainable management practices. ICES provides stock assessments for the Baltic Sea salmon fisheries. ICES advises that the salmon fishery management should be stock-specific, i.e. based on the status of individual river stocks (ICES 2013a, 1). To this end, ICES has established assessment units, where stocks in the same unit exhibit similar biological and genetic characteristics as well as similar migration patterns. Since these stocks are targeted by the same fisheries, they are expected to respond similarly to the same kind of management. For example, the River Tornionjoki is part of an assessment unit containing the northeastern Bothnian Bay salmon stocks (ICES 2013a, 7-8).

In the evaluation of stock status ICES uses the smolt production in individual rivers compared to the potential smolt production capacity (PSPC). Reaching a smolt production of at least 75% of the PSPC has been suggested as the goal if salmon populations are to be sustained at an MSY-level (ICES 2012b, 1&4). Thus, the advice

[2] ”M” stands for ”miljö” (the Swedish word for environment), suggesting that the cause of the syndrome is some environmental factor. “74” refers to the year the syndrome was first detected (Karlsson & Karlström 1994, 77).

provided by ICES is based on an MSY approach. According to a survey done by ICES in 2011, River Tornionjoki, and several other rivers flowing into the Bothnian Bay, have stocks approximately at the MSY-level. However, ICES has advised that the fishing mortality for these stocks should not be allowed to increase (FGFRI 2011b, 6).

The scientific basis for the stock projections is a Bayesian state-space assessment model. The Bayesian modeling framework allows for different sources of information to be included in the model, which makes it biologically more realistic (Kuparinen et al. 2012, 136). Bayesian methods for Baltic salmon stock assessment have been used in several studies, for example in Mäntyniemi & Romakkaniemi (2002) Michielsens et al. (2006) and Michielsens et al. (2008). The former study by Michielsens et al. presents a model that has been implemented by ICES' Assessment Working Group on Baltic Salmon and Trout (WGBAST). It is also used in e.g. Kulmala et al. (2008a, 2008b), and is also applied in this thesis. I will return to the topic of population modeling in chapter 4.

Input data in the ICES model include catch and effort data, electrofishing surveys, smolt-trapping, spawner counts and tag returns from fisheries. The PSPC estimations are based on information provided by experts and estimates on stock-recruit relationships. The Bayesian approach makes it possible to express uncertainties in the model as probability distributions. One important uncertainty associated with the model is post-smolt survival. Also the incorporation of misreporting and unreporting of salmon landings causes uncertainty in the modeling, but simultaneously improves the assessment. This unaccounted fishing has a notable effect on ICES' catch recommendations (ICES 2013a, 1&6-7). For example, in 2011 about 30% of the total salmon catch was estimated to be mis- or unreported (ICES 2012b, 1).

The spawning runs into Tornionjoki have been monitored since 2009 using a sonar technique known as DIDSON[3]. The recorded number of ascending Tornionjoki salmon in 2009-2012 has been as follows: 31 800, 17 200, 23 100 and 61 500 salmon (ICES 2013b, 72-73). The primary reason for the weak spawning runs in 2010 and 2011 was

[3] Dual frequency IDentification SONar.

probably cold winter conditions, which postpones the maturation of salmon. This is likely to result in a weaker smolt production in the near future (ICES 2013a, 1-2).

3.2 Fishing of Baltic salmon

Salmon fishing in the past and present

Salmon fishing in the Baltic Sea was originally mainly river fishing, where the ascending spawners were targeted. The river fishery dominated until the end of the 19th century (Karlsson & Karlström 1994, 69), after which the exploitation moved gradually to the sea. The offshore fishery, which targets feeding salmon, became the dominant type of fishery during the latter half of the 20th century. Since the 1980s, however, coastal and river fisheries have increased their proportion of the total catch (Romakkaniemi et al. 2003, 331). In Finland, the majority of the commercial catch is taken by coastal fisheries (ICES 2013a, 10). The coastal fishery targets the salmon that are migrating to their spawning rivers (Romakkaniemi et al. 2003, 331). Thus, Baltic salmon is harvested by different fisheries along its whole migration route (Romakkaniemi 2008, 9) (see Figure 4). The major part of the catch consists of wild salmon, which accounts for over two thirds of the catch in the Gulf of Bothnia. The amount of reared salmon in catches has decreased since the mid-1990s. In the past years, the largest share of the Baltic salmon catches have been reported by Finnish and Swedish professional fishermen (FGFRI 2011b, 21&52).

Total catches of salmon in the Baltic Sea was 1139 tons in 2012. The Finnish commercial marine salmon catch was 330 tons (FGFRI 2013c, 12). Figure 6 shows how the Finnish catches have declined since 1990 (2 058 tons), and how they were at their lowest level in 2010 (215 tons). This has been the trend for the whole Baltic Sea salmon fishery (ICES 2013b, 9). The decreasing exploitation rates have been explained by e.g. the adoption of stricter regulatory measures and by the increased damages to catch and gear caused by seals (ICES 2013a, 2). Additionally, some fishing methods have recently been prohibited.

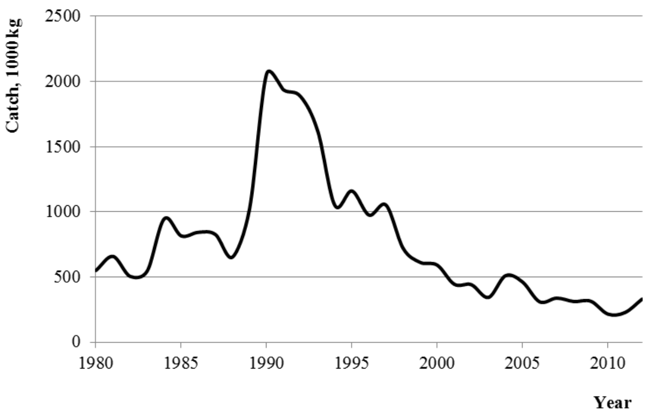

Figure 6. *The Finnish commercial marine salmon catch in 1980-2012.*
Source: data from FGFRI 2011b, 53.

Figure 7 shows the salmon catches in the Gulf of Bothnia in the 2000s, as number of salmon. This data includes catches from the Archipelago Sea, which is situated south of the Gulf of Bothnia between the Åland Islands and the mainland. It appears as the catches have varied quite a lot during the last decade in the study area.

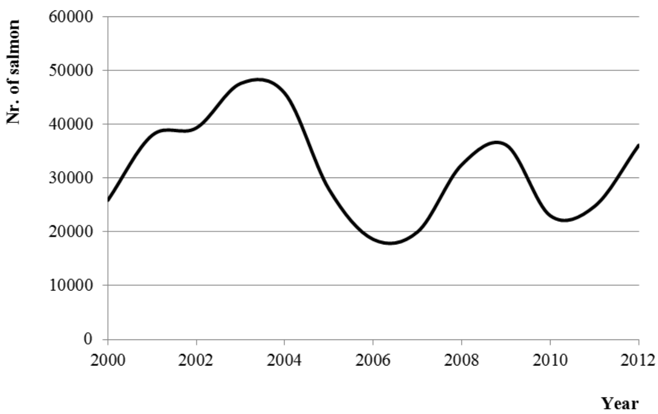

Figure 7. *Gulf of Bothnia salmon catch in 2000-2012.*
Source: data from Pakarinen 2013, personal communication.

The Finnish commercial catch amounted to a value of €1.0 million in 2012. In recent years the annual landings value has varied between €1-1.2 million (FGFRI 2013d). The producer price for wild salmon in 2012 was on average 3.50 €/kg, which meant a 35% decrease from the year before. The price has been on average 4.38 €/kg during the past seven years. The producer price does not include value added tax, which was 13% for fish in 2012. The average prices refer to gutted salmon (FGFRI 2013e, 6).

Sequential fisheries

Finnish fishermen use trapnets for catching salmon in *coastal areas*. Salmon from the northern Baltic rivers, such as River Tornionjoki, are caught in the Gulf of Bothnia. The coastal fishery underwent technological improvements in the late 20th century (Romakkaniemi et al. 2003, 331), e.g. seal safe trapnets were developed (Hemmingsson, Fjälling & Lunneryd 2008, 357). The major part of the catch is caught with salmon trapnets, whitefish trapnets and push up trapnets (FGFRI 2013d). The trapnet fishery takes place in June and July, when the mature salmon migrate to their natal rivers to spawn (Kulmala et al. 2008b, 718). The major part of the catch consists of two- (2SW) and three-sea-winter (3SW) salmon with an average weight of 6-7 kg (FGFRI 2013b).

In recent years roughly 150 fishermen and 400 trapnets have been engaged in the Gulf of Bothnia salmon fishery. This includes the Åland Islands and the Archipelago Sea (Pakarinen 2013, personal communication). The fishing effort, expressed in geardays, in the past decade is pictured in Figure 8. Effort has been around 18 000 geardays annually in recent years. The catch per unit of effort (cpue) has varied on a yearly basis in the long run, and a slight growing trend has been detected (FGFRI 2011b, 59). In 2012, the coastal trapnet fishery accounted for 83% of the total commercial salmon catch in Finland (ICES 2013b, 10). Before 2008, driftnets were also used in the coastal fishery, but as of 1 January 2008 the EU has banned all use of driftnets in the Baltic Sea (ICES 2012a, 27).

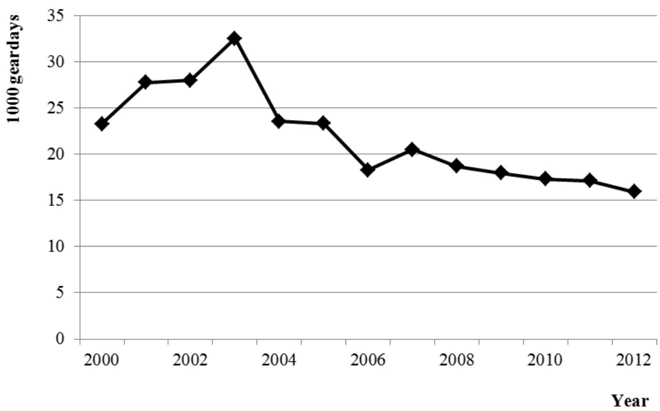

Figure 8. *The effort of the coastal salmon fishery in the Gulf of Bothnia in the past twelve years. Source: data from Pakarinen 2013, personal communication.*

The driftnet ban affected the *offshore salmon fishery* as well. After 2008, only longlines were used to catch salmon in the Main Basin, which lead to a substantial increase in this fishery. Indeed, harvest rates for the longline fishery in 2011 was as high as the driftnet and longline harvest rates combined in the early and mid-2000s (ICES 2012a, 1). In Finland, the longline harvest rates have been fairly constant in recent years, and the share of the total catch has varied a little above and under 15% since 2008 (FGFRI 2013d). However, before the driftnet ban, in 2007, the total catch share of the longline fishery was only 7% (FGFRI 2008, 26).

In 2012, 19 Finnish vessels still fished salmon with longlines, though only two vessels operated down in the Main Basin (ICES 2013b, 10). The Baltic Sea longline fishery is concentrated to the most southern part of the Main Basin (FGFRI 2013f). In contrast to the trapnet fishery, the longline fishing is carried out during the winter months. In theory, longline fishing could be possible in the Bothnian Sea was well, but in practice, seals and busy ship traffic prevent fishing in this area (ICES 2012a, 146). As of 2013 both Finland and Sweden have closed down their offshore longline fisheries (ICES 2013b, 23-24). Now only Denmark and Poland catch salmon with longlines in the Main Basin (Pakarinen 2013, personal communication).

The Baltic Sea *river fishery* is recreational, in contrast to the commercial marine fishery. Angling is the predominant fishing technique (FGFRI 2011b, 66), and in River Tornionjoki, specifically, rod fishing by rowing dominates (ICES 2013b, 72). There are also recreational fishermen fishing at sea with nets, trapnets and other gear. There is no obligation to report recreational catch, so catch estimates are based on different survey methods (ICES 2012a, 24).

In the past decades, damming of rivers and high fishing pressure at sea effectively restrained the fishing in rivers. In the 1990s, the river fishing started to increase as a result of stricter regulation of the offshore and coastal fisheries (FGFRI 2011b, 65). The Finnish recreational catch in 2012 was 135 tons, which is almost twice as much as in 2011. The main increase was in River Tornionjoki, which recorded its largest catch in decades. The catch was over 100 tons; a level that has not been experienced since the early 20th century. Also cpue increased markedly, indicating significant increases in spawner abundance (ICES 2013b, 72). Recreational fishing is not considered in the analysis of this study.

3.3 Management of the Baltic salmon fishery

A brief history of Baltic salmon management

Acknowledgement of the need for fisheries regulation in order to conserve Baltic salmon stocks date back to the late 19th century (Romakkaniemi et al. 2003, 332). International regulation began taking form in the 1950s and 1960s and was highlighted by the ratification of the Baltic Salmon Fisheries Convention in 1966. The articles of the convention were adopted by the International Baltic Sea Fishery Commission (IBSFC), a decision-making organ established in 1976 (Karlsson & Karlström 1994, 70). During these decades, different regulatory measures were introduced: minimum landing, hook and mesh size, and restrictions to the number of fishing gear per boat. Also closed seasons were introduced. Many of these management measures are still in use. However, the regulations did not seem to work that well, since the Baltic salmon stocks decreased almost continually up until the end of the 1980s (Karlsson & Karlström 1994, 70; Romakkaniemi et al. 2003, 332). In 1993, TACs were implemented for the first time by the IBSFC (ICES 2012a, 141).

In 1997, the IBSFC together with the Helsinki Commission launched the Salmon Action Plan (SAP) in order to achieve long-term management goals for Baltic salmon. The key issue in the SAP is the protection of wild salmon populations and the rebuilding of stocks (Helsinki Commission 2011, 15-16). The wild smolt production has increased significantly since the adoption of the SAP (ICES 2013a, 1). The IBSFC ceased to exist in 1997, but the SAP was in operation until 2006. Presently, the international Baltic salmon management is run by the EU by means of TACs, size regulations and closed seasons. National river regulation is carried out according to the former SAP. In 2009 the European Commission committed to establishing a new management plan for Baltic salmon, but the plan has not yet been accepted. The new plan proposes that the TAC be set according to a constant fishing mortality rate of 0.1

in marine fisheries (European Commission 2013b; STECF 2012a, 22; ICES 2013a, 2). Next, I will go through the present international and Finnish management measures.

Current management measures

The annual *TAC* quota is allocated by the European Commission between the Baltic Sea countries. There are two management areas: the Gulf of Bothnia and the Main Basin constitute one, the Gulf of Finland another (ICES 2012a, 141). The Commission's decisions are based on scientific advice provided by ICES. However, these are only recommendations, and in recent years the quotas set at the political level have been considerably higher than those suggested by the scientists (see e.g. FGFRI 2011b, 7). Nevertheless, the TAC of Baltic salmon has been reduced several times in the past years. For 2013, the Commission proposed a TAC of 108 762 salmon for the Gulf of Bothnia and the Main Basin. The TAC for 2014 will be slightly smaller with around 106 000 salmon (Ministry of Agriculture and Forestry 2013).

The annual catches have in the past been below the catch quotas, which means the TAC has not in effect regulated the salmon fishery. In 2012, however, Finland actually exceeded its quota of that year (32 000 salmon), which was made possible by a quota swapping with Latvia (ICES 2013b, 11) Additionally, in March 2012 the offshore fisheries of Finland and Sweden fulfilled their share of the national quotas, and were therefore closed down. Also in the early and mid-1990s the quotas decreased offshore fishing, thus contributing to the recovery of northern Baltic salmon stocks (ICES 2012a, 146).

The *minimum landing size* of Baltic salmon is 60 cm. An exception is the Bothnian Bay fishery, where the minimum size has been decreased to 50 cm. The minimum landing size is important in the offshore fishery. This was especially true after the driftnet ban, since the longline fishery does not have the same size selectivity as driftnets. However, size regulation does not play an important role in the coastal fishery, because the majority of spawners are 60-90 cm long. As a matter of fact, the result of this regulation is that the least valuable part of the stock, i.e. the smallest salmon, is left unexploited. (ICES 2012a, 146.)

There is a *summer closure* of the salmon fishery in the Gulf of Bothnia and the Main Basin from 1 June to 15 September. This closure does not concern the trapnet fishery (ICES 2012a, 141). However, there are national restrictions on the coastal fishery, in order to save a proportion of the spawning migrators from the coastal harvest. Finland has set time restrictions on the salmon fishery in its economic zone in the Gulf of Bothnia. The closure begins 1 April and ends depending on the zone as follows: 16 June in the Bothnian Sea, 21 June in the Quark, 26 June in the southern Bothnian Bay and 1 July in the northern Bothnian Bay. However, professional fishermen may start fishing one week earlier with two trapnets. Three weeks after the opening of the fishery five trapnets per fisherman is allowed. After this, for another three weeks, eight trapnets per fisherman is allowed (ICES 2012a, 143&147).

4 Analysis

This is the main chapter of the thesis, where I seek to find answers to the research questions set up for this study. I will begin by introducing the fuel cost scenarios that represent different approaches to incorporating the fuel use externality into the costs of fisheries. Next, the bioeconomic model used for the optimization and numerical analysis is introduced, with some extensions and elaborations placed in the appendices. Finally, in the last section, all results of the study are presented.

4.1 Fuel cost scenarios

The number one aim of this thesis is to investigate the consequences of removing fuel tax concessions to the coastal salmon fisheries in Finland. The underlying idea here is that the fishery would pay for the external costs caused by CO_2 emissions from its direct fishing activities. The theory behind environmental and climate policy was discussed in chapter 2. Here I will present some hypothetical scenarios, through which such policies could be implemented. These are scenarios put forward in the research project that this study is part of. The scenarios used in the analysis are labeled as current situation, *Baseline, EU*, *Stern* and *National*, and are again exhibited in Table 3.

Table 3. *Fuel cost scenarios.*

Scenario	Definition
0. Current situation	-
1. Baseline	Fuel use exempt from costs
2. EU	EU CO_2 quota price in 2009
3. Stern	Social cost of CO_2
4. National	Finnish fuel tax in 2009

The current situation is not a scenario per se, but is a representation of the fishery under current management, i.e. the fishery is not optimized. Baseline is the first actual scenario, since the fishery is optimized, although the fuel tax concessions are left in place. The three scenarios, where an additional cost is imposed on fuel use in fisheries are discussed below.

The EU scenario

This scenario represents a situation where fuel tax concessions for fisheries within the EU would be abolished. In this scenario the fishery is assumed to operate within an emissions trading system, and specifically the EU ETS. This means that the fishing enterprises are obligated to buy CO_2 quotas that correspond to the amount of emissions they emit. Prices for emission allowances are obtained from the European Energy Exchange (EEX), which is a leading market place in Europe for energy and related products, such as power, natural gas, coal and CO_2 emission rights. The base year, as decided within the research project, is 2009. For this year the average quota price was €13.03 per ton CO_2 (EEX 2013).

The price per ton CO_2 has fluctuated quite a lot since the launch of the EU ETS. Starting at around €5, the price quickly rose and remained at €20-30 for about a year. When it became clear that the initial allocation had been too large, the price crashed. After a short recovery, the price began a decline that finally hit zero by mid-2007 (Hintermann 2010, 43). Since then the price has risen somewhat again. However, the current price is considerably lower than what it was in 2009. The last couple of years the price has been approximately within the range of €4-8 per ton CO_2 (EEX 2013).

The Stern scenario

The Stern scenario represents a situation where a cost for CO_2 emissions is imposed on the fishing sector on the global level. The scenario gets its name from the well-known "Stern Review on the Economics of Climate Change", issued by economist Nicholas Stern and his team for the British government in 2006. The Review by Stern (2006) examines the economic impact of climate change, and considers the different policy measures available for carrying out a transition to a low-carbon economy. The Stern Review has an international perspective and emphasizes the need of international actions against the global threats of climate change.

The report stresses the need to put a price on carbon through taxation, emissions trading or regulation. In this scenario the external cost from fuel use in fisheries is internalized by a global CO_2 tax. The fuel tax is based on the estimated social cost of CO_2 today if the world remains on a business-as-usual (BAU) trajectory. The social cost describes how much the damage one ton of CO_2 is worth to society. BAU means that measures are not taken to mitigate climate change and that emission levels therefore remain as before. The cost proposed in the Stern Review is $85 per ton CO_2, which is higher than what had previously been suggested in the literature. The cost is also significantly different from the cost used in the EU scenario, which is beneficial for the analysis. Using the yearly average exchange rate from USD to EUR in 2009 (European Central Bank 2013), the cost €60.93 per ton CO_2 is obtained.

The National scenario

This is a scenario where the fuel used by the fishing sector is taxed according to Finnish legislation. As a member of the EU, Finland is bound by the Energy Taxation Directive from 2004[4]. This directive defines the energy products and lays down the minimum fuel taxation levels in the Member States (Finnish Customs 2013a, 1).

Excise duty is collected according to the Act on Excise Duty on Liquid Fuels from 1994. The taxation is carried out and controlled by the Finnish Customs. Taxable fuels are for example motor gasoline, small engine gasoline, diesel oil and light and heavy fuel oil. As of January 2011, the taxation of fuel is carried out through taxation of fuel components. These components are energy content tax and CO_2 tax, which consider the fuel's energy content and CO_2 emissions respectively (Ministry of Finance 2012; Finnish Customs 2013a, 1&3&6). In the case of motor gasoline and diesel oil, as well as their bio-based substitutes, the CO_2 tax is calculated based on the CO_2 equivalent emissions that arise during the fuel's life cycle. Thus, the tax on these fuels is graded

[4] In April 2011 the European Commission presented its proposal for a renewal of the rules on taxation of energy products in the EU. The new way of taxation takes into account both CO_2 emissions and energy content of energy products. This revision supports the Commission's ambition to promote energy efficiency and consumption of more environmentally friendly products (European Commission 2013c).

according to the fuel's environmental impact. This is the ruling as of 1 June 2012 (Finlex 1472/1994; Ministry of Finance 2012).

Table 4 shows current excise duty rates as cents per liter of fuel for fuels used by Finnish fishing vessels. There is also a strategic stockpile fee that is carried out on liquid fuels and other energy products. This fee is meant to cover the government's expenses caused by emergency stockpiling and other measures carried out to secure energy supplies (Finnish Customs 2013a, 1).

Table 4. *Excise duty rates on fuels used by fishing vessels, as of 1 January 2013.*
Source: Finnish Customs 2013a, 2.

Product	**Energy content tax**	**Carbon dioxide tax**	**Strategic stockpile fee**	**Total**
Motor gasoline c/l	50.36	14.00	0.68	65.04
Diesel oil c/l	30.70	15.90	0.35	46.95
Light fuel oil c/l	9.30	9.34	0.35	18.99

Again, as in the EU scenario, I will here use data from 2009 in accordance with what was decided within the research project. In 2009, before the energy tax reform, the fuel tax in Finland consisted of basic duty and additional duty as well as a stockpile fee (Ministry of Finance 2009, 129). However, the basic and additional duty can here be thought of in terms of an energy and CO_2 tax. In the analysis I assume that the fishery uses motor gasoline (see Appendix B). In Table 5 are exhibited the different components and total amount of the excise duty for motor gasoline in 2009.

Table 5*. Excise duty rate on motor gasoline in 2009.*
Source: Ministry of Finance 2009, 129.

Fuel	**Basic duty**	**Additional duty**	**Strategic stockpile fee**	**Total**
Motor gasoline c/l	57.24	4.78	0.68	62.70

Summary of fuel costs

I now know the size of the fuel cost in the National scenario. In the calculations the national tax exemption is based on the excise duty in 2009, which amounted to 62.70 cents per liter of gasoline (Ministry of Finance 2009, 129), or €620.70 per 1000 liter (m^3) gasoline. Next, I must calculate this cost for the EU and Stern scenarios as well. To do this, I need to know how much CO_2 emissions are produced from the combustion of motor gasoline. The number used here is 2.33 kg CO_2 per liter of gasoline (Biomass Energy Centre 2013). When multiplying this with the cost per ton CO_2 introduced in respective scenario, the cost of CO_2 in 1000 liter of gasoline is obtained (see Table 6).

Table 6. *CO_2 and gasoline costs in 2009.*

Scenario	**€/ton CO_2**	**€/m^3 fuel**
National		627.0
Basic duty		572.4
Additional duty		47.8
Stockpile fee		6.8
EU	13.03	30.36
Stern	60.93	141.96

Finally, in Table 7 are the actual fuel prices paid by the fishermen in the different scenarios. The price for gasoline (98 octane) used here is €1.322 per liter, which is an average of the consumer price in 2009 (Maskula 2013, personal communication). This means that the price contains the full value of the excise tax, i.e. no tax concessions exist. Thus, this is the price paid by the fishermen in the National scenario. To obtain the price for the current situation and the Baseline, the amount of the excise duty (see Table 5) is subtracted from the National fuel price. In the EU and Stern scenarios the CO_2 costs amount to 3.036 cents and 14.196 cents per liter of gasoline, respectively. To obtain the fuel price for these scenarios, the aforementioned costs are added to the Baseline fuel price.

Table 7. *The price per liter of gasoline paid by the fishermen in the different scenarios.*

Scenario	**€/liter**
0. Current situation	0.70
1. Baseline	0.70
2. EU	0.73
3. Stern	0.84
4. National	1.32

4.2 Bioeconomic model

In this section I will present the bioeconomic model used in the optimization of the salmon fishery. Both the biological and economic part of the model and the links between them are discussed. If necessary, the reader is advised to revisit chapter 3, where background information on several issues addressed in this section can be found.

4.2.1 Population model

The fish stock is the natural capital of the fishery. The size of the stock is affected by the recruitment of new individuals and the growth of existing individuals, as well as natural and fishing mortality. In the basic Schaefer model (see e.g. Figure 3) the stock is measured in terms of biomass, and the net effects of recruitment, growth and natural mortality are depicted in one simple equation. Although useful for analytical and pedagogical purposes, such biomass models are often too simplistic for describing real life fisheries. A more realistic view of fish population dynamics can be obtained with age-structured models that treat recruitment, individual growth and natural mortality independently (Anderson & Seijo 2010, 11&73). Even though accounting for the different age-classes adds considerable complexity to the modeling, such addition of biological realism is warranted in the economic research of fisheries. For example, Tahvonen (2008, 547) claims that not only will age-structured models bring new insights to the field of optimal harvesting studies, but also increase the contribution of economics in practical resource management.

In this study I apply a discrete age-structured population model that was presented by Michielsens et al. (2006), and is used by ICES WGBAST. ICES uses this model in its salmon stock assessment and as a basis for the management recommendations it provides. The model was adopted by Kulmala et al. (2008a, 2008b, 2013) in order to bring forth a biologically realistic bioeconomic model that could be applied to Baltic salmon management. The population model forms the constraint in the economic optimization of fishery.

An age-structured population model considers the life cycle of salmon and thus allows for an analysis of economically significant age groups, i.e. age groups that are harvested by fisheries. The model is calibrated with data for the River Tornionjoki wild salmon stock. The stock data originates from the 2010 report by ICES WGBAST.

The initial population size and age-specific parameters are gathered in Table 8a. The age groups considered are egg, alevin, fry, parr, smolt and 1SW-5SW mature salmon. Homing rate is the proportion of each age class that begins its spawning migration. Sex ratio is the proportion of fecund females in each age class, i.e. females that are able to produce offspring. Fecundity is the age-specific number of eggs produced per female. The catchability coefficient describes the fishery's efficiency to catch salmon, which in the case of trapnets is assumed to differ depending on the age group (Michielsens et al. 2006, 328). As such, the catchability coefficient represents the fishing technology that is used to harvest the fish (Anderson & Seijo 2010, 18).

Table 8a. *Initial population size and age-specific biological parameters.*

Age group *a=1,2,…,10*	**Initial population** ($n_{a,1}$)	**Homing rate (*hr*)**	**Sex ratio (*sr*)**	**Fecundity (*fe*)**	**Catchability coefficient (*q*)**
Egg	175600000	0	0	0	0
Alevin	175600000	0	0	0	0
Fry	175600000	0	0	0	0
Parr	175600000	0	0	0	0
Smolt	1192500	0	0	0	0
1SW	107100	0.15735	0.02	7070	0.000018
2SW	59730	0.31855	0.5	9998	0.000018
3SW	22375	0.5203	0.5	13590	0.000017
4SW	5774	0.5016	0.5	20000	0.000017
5SW	2341	1	0.5	26750	0.000017

Table 8b exhibits the parameters that are constant and do not vary between the age classes. The recruitment parameters are used to describe the recruitment of new individuals (see Appendix A), which is one of the most important and difficult estimation tasks when making fish stock projections (Anderson & Seijo 2010, 81). To account for natural mortality among the salmon the model contains values for survival in the post-smolt and adult stages, as well as a value for M74 survival. For a more detailed description of the population dynamics, see Appendix A.

Table 8b. *Constant biological parameters.*

Parameter	**Symbol**	**Value**
Recruitment parameter	α	51.57
Recruitment parameter	β	0.000496
Post-smolt survival	*ps*	0.0841
Adult natural survival	*s*	0.9307
M74 survival	*m74*	0.94

4.2.2 Economic model

If the fish stock is the fishery's natural capital, then the fishing fleet is the man-made capital of the system. The purpose of the fleet is to make profit by harvesting the stock and providing fish for the market. Central components of the economic model are the costs of inputs, the price of fish, and the relationship between fishing effort and harvest, which is described by the production function. Fishing effort and fleet size tend to vary with the net returns obtained from the fishery, in such a way that greater profits increase effort and fleet size, and vice versa. This is particularly the case in an unregulated open access fishery. One of the key purposes of bioeconomic modeling is, given biological and economic realities, to propose a desired level of fishing effort. (Anderson & Seijo 2010, 11-12.)

The economically efficient use of a fishery over time is an optimal control problem. The fish stock is the state variable that has the potential to produce a flow of benefits through time. Fishing effort is the control variable with which a social planner can adjust the state variable, given the population dynamics of the stock. Over time, the size of the fish stock is affected by both natural and fishing mortality, which will determine to what extent revenues can be earned from the fishery in the future. The social planner's task is thus to control the state variable through changes in effort in a way that will maximize the net present value of the fishery. (Anderson & Seijo 2010, 51&59.)

The economic realities of the Baltic salmon trapnet fishery are presented in Table 9, which exhibits the economic parameters utilized in the model. Mean cost per unit of effort is the average scenario-specific unit cost of fishing. Fishing effort is measured in geardays, which is calculated by multiplying the number of fishing days by the number of gear (trapnets). The cost parameter is defined as € per trapnet day. Four different unit costs are utilized in the analysis, one for each fuel cost scenario: Baseline, EU, Stern and National. The fishing costs have been estimated by interviewing Finnish fishermen that participate in the Gulf of Bothnia salmon fishery. The variable costs considered are gear price, gear maintenance, vessel maintenance and labor and fuel costs. Taking into account these expenses I have calculated the cost of fishing with one trapnet for one day. For a more detailed description of the cost estimation procedure, see Appendix B.

Age-specific catch price has been calculated based on average producer prices over a period of ten years. This price information is available in the annual statistical publication "Producer Prices for Fish", issued by FGFRI. Because the model is calibrated with data for the River Tornionjoki stock, a parameter is needed to ensure that the effort in the model is targeted to this specific stock. ICES (2010, 42) provides estimates on the proportion of individual river stocks in the Atlantic salmon catches from the Baltic Sea. Median offshore longline survival describes the proportion of salmon that is not harvested in the Main Basin and is therefore potential catch for the coastal trapnet fisheries. The estimate 0.77 is used by Holma et al. (2013, 6). The parameter for gutted fish proportion implies that 75% of the fish is left after gutting, which is an estimate also used by Holma et al. (2013, 11) and is taken from a study by FGFRI (2007, 9).

Because I am interested in the long-run value of the salmon fishery, a discount rate needs to be considered when calculating the net present value. In order to obtain a

NPV, all future benefits and costs need to discounted, i.e. given a present value. The discount rate used here is 5%, which is in accordance with other studies on optimal resource management (Kulmala et al. 2008b, 721).

Table 9. *Economic parameters.*

Parameter	Symbol	Value
Mean cost per unit of effort[a] (€/gearday)	c_B	47.55
	c_E	47.71
	c_S	48.29
	c_N	50.83
Age-specific catch price[b] (€/fish)	p_a	10.6; 26.4; 41.2; 41.6; 48.5
Proportion of River Tornionjoki salmon	j	0.3
Median offshore longline survival	oll	0.77
Gutted fish proportion[c]	g	0.75
Discount rate	r	0.05

[a] Subindexes B, E, S and N denote the different scenarios.
[b] The catch price is for gutted fish.
[c] This parameter describes the proportion of fish that is left after gutting.

The control variable in the optimization problem is fishing effort E. I am seeking the level of effort that will maximize the discounted net benefits from the salmon stock over time, given variations in fishing cost due to different fuel cost policies. The timespan used in the model run is 50 years. The solution to the optimization problem is obtained through numerical analysis. I apply open-loop optimization, where the control variable is fixed in the first period and is therefore constant. The state variable (stock size) and harvest are constraints and are defined dynamically through time. Thus, the model can be defined as a semi-dynamic bioeconomic model. The optimization and numerical analysis is executed in Matlab, using the fmincon toolbox, which is an optimization algorithm.

Below, two fundamental equations of the economic model are presented, namely the harvest and objective functions. The harvest function (4.1) gives the number of fish harvested at time t

$$h(t) = hr_a N(t)(1 - e^{q_a E}) , \tag{4.1}$$

where hr is age-specific homing rate, N the amount of fishable salmons at time t and $(1 - e^{q_a E})$ the harvest rate. How N is defined over time is explained in Appendix A. The harvest rate specifies the fishing mortality depending on the age of the fish by multiplying the age-specific catchability coefficient with the fishing effort.

The purpose of the objective function (4.2) is to calculate the net present value of the salmon fishery over the 50 year time period. The revenue to the trapnet fishery is defined as $p_a h(t)_a$, i.e. age-specific catch price times harvest. Cost is defined as scenario-specific cost times fishing effort: $c_{sc}E$. When subtracting costs from revenues and taking into account the discount rate, the profit function that gives the total net economic benefit for the salmon fishery can be written as follows

$$P(t) = \sum_{t=1}^{50} [p_a h(t)_a g - (c_{sc}\, Ej)]/(1+r)^{t-1} \qquad (4.2)$$

where scenario-specific cost $c_{sc} = c_B, c_E, c_S, c_N$. g is the parameter for gutted fish, j is the River Tornionjoki stock parameter and $(1+r)^{t-1}$ is the discount factor.

4.3 Results

In this last section of chapter 4, the results from the analysis are compiled. Here are results both from the bioeconomic analysis as well as estimations of the current situation of the fishery. Hence, it is important to realize when the fishery is optimized and when it is described in the light of present management. For a reminder of what is intended by fisheries management and climate change management, see chapter 1 and 2. Keeping these issues in mind, comparisons between the following situations of the fishery are made

1. fishery under present management vs. fishery under optimal management, and

2. current fishery under climate change management vs. optimal fishery under climate change management.

4.3.1 Current fisheries

First up is the description of the current fishery. This is done in two ways, namely by looking at the whole Gulf of Bothnia fishery and by looking at only the River Tornionjoki stock. Keep in mind that the Tornionjoki stock comprises about one third of the Gulf of Bothnia fishery[5]. At this point I will only examine the fishery in the Gulf of Bothnia. Later, when optimizing the fishery, the target of interest will be the Tornionjoki stock. Table 10 shows economic, fleet and fuel data for the Gulf of Bothnia fishery. Fleet data is obtained from FGFRI (Pakarinen 2013, personal communication). Economic and fuel data is based on my calculations and estimations, which I will elaborate on next.

The total Finnish commercial salmon catch in 2010 was 215 tons and the landed value amounted to €922 000 (FGFRI 2011c, 12). From this, one can calculate the value per landed kg to be €4.3. Multiplying this with the catch in the Gulf of Bothnia results in a landings income of €609 000. The total cost is obtained by multiplying the unit cost of fishing (see Table 9 and Appendix B) with the number of trapnet days. The fishery's net profit is the difference between landings income and total costs. As can be seen, the salmon fishery is currently unprofitable, with a yearly net loss of €216 000. The fuel subsidy is taken into account in this result, i.e. tax concessions remain in place.

Last, I estimated accumulated fuel use based on my interviews with the fishermen. The average yearly consumption (1600 liters) is multiplied with the number of fishers, and thus a consumption of 240 m^3 of fuel per annum is obtained. CO_2 emissions are calculated by multiplying the fuel consumption with 2.33 kg CO_2/liter gasoline (see p.37). From this the fuel efficiency indicators kg catch/liter and landings value/liter can then be derived.

[5] The coefficent used here is 0.3 (see Table 9).

Table 10. *Physical and economic data for the Finnish salmon fishery in the Gulf of Bothnia, 2010.*

Indicator	**Value**
Fleet	
Number of fishers/vessels	149
Number of gear	448
Effort (trapnet days)	17 342
Days at sea	39
Harvest (1000 kg)	142
Harvest (nr. of fish)	23 028
Economic data (€1000)	
Income	
Landings income	609
Costs	825
Fuel	63 (7.6%)
Labor	186 (22.6%)
Other variable costs	576 (69.8%)
Net profit	-216[a]
Fuel	
Cubic meters (m^3)	240
CO_2 emissions (tons)	559
Kg catch/liter	0.59
Landings value (€)/liter	2.54

[a] Excluding non-fuel subsidies.

Here follows some notes regarding the validity of the estimated economic indicators. Because the Finnish salmon fishery does not constitute a fleet segment of its own, data on expenditures is not easily available. This is why I have estimated the costs myself. The salmon fishery belongs to the fleet segment: vessels <10m using passive gear. This segment has been unprofitable, with poor economic results. This is most probably caused by a high cost structure compared to fish market prices. Although a direct parallel cannot be drawn between the whole segment and the salmon fishery, a relation between the two is discernible. In 2010, this segment reported losses of about €2.7 million. The segment consists of approximately 1500 vessels, and had a landings value of €8.1 million in 2010 (STECF 2012b, 140). Considering that I do not account for the trapnet fishery in the Gulf of Finland[6], it seems that the salmon fishery in total makes up for about one tenth of this fleet segment. As seen above, the Gulf of Bothnia fishery accounts for 150 vessels, €609 000 in landings value and €216 000 in losses.

[6] The catch in the Gulf of Finland in 2010 was 34 000 kg, with a landed value of €146 000 (FGFRI 2011c).

This provides confirmation that the cost estimations used in the profitability calculations here are feasible.

The next set of results is presented in Table 11 below. This shows the effects on profitability of the fishery from introducing fuel cost policies in the current situation. This means that everything remains as before, except that fuel costs increase as a result of climate change management. The added cost is obtained by multiplying the €/m^3 fuel (see Table 6) with the amount of fuel consumed, which is here assumed to be 240 m^3 in all scenarios. When adding an additional cost to the already unprofitable fishery, the net loss only increases. Naturally, the high tax in the National scenario has the largest impact, whereas the effect of the other fuel cost policies is less significant. In the National scenario the fuel tax implies an 18% increase in costs, and to a subsequent 69% increase in loss.

Table 11*. Economic effects from introducing fuel cost policies in the current situation in the Gulf of Bothnia salmon fishery, 2010.*

Indicator	**Current management**			
	1. Baseline	2. EU	3. Stern	4. National
Fuel				
Cubic meters (m^3)	240	240	240	240
Added cost (€1000)	0	7	34	150
Economic data (€1000)				
Landings value	609	609	609	609
Costs	825	832	859	975
Net profit	-216	-223	-259	-366

4.3.2 Optimal fisheries

Next, the aim is to compare the optimized and current fishery, and further to examine the effects of climate change management, as represented by the different fuel cost scenarios. Table 12 shows the effects of the different fuel cost policies on selected indicators under optimal fisheries management. These effects are to be compared to the current situation, which is depicted on the left hand side of the table. Key indicators that are studied are effort, net present value and CO_2 emissions. All indicators and changes in them when moving from current to optimal fisheries management and as result of climate policy are presented in Table 12. The optimization results apply to the River Tornionjoki stock fishery. Also the current situation is here represented by data for this specific stock, thus fishing effort is approximately one third of that in the whole Gulf of Bothnia. The current effort level used here is the mean yearly effort during the period 2000-2010[7] (data from Pakarinen 2013, personal communication). In order to obtain a comparable figure for profitability in the current situation, the bioeconomic model is run with the present effort, and thus an approximation for current NPV is obtained.

Table 12. *Long run effects in scenarios 1-4 from fuel cost policies on net present value, fishing effort, fuel consumption and CO_2 emissions. River Tornionjoki stock, 2010.*

Indicator		**Optimal management**			
	0. Current situation	1. Baseline	2. EU	3. Stern	4. National
Fleet					
Effort (trapnet days)	6858	3312 (-52%)	3190 (-4%)	2751 (-17%)	857 (-74%)
Number of fishers/vessels	59	29	28	24	7
Economic data (€1000)					
Net present value	-5	42	39 (-7%)	29 (-30%)	3 (-93%)
Fuel					
Cubic meters (m^3)	95	46	44	38	12
CO_2 emissions (tons)	221	106 (-52%)	103 (-3%)	88 (-17%)	28 (-74%)
Kg catch/liter	0.30	0.33	0.33	0.33	0.34
Landing value (€)/liter	1.31	1.40	1.40	1.41	1.46
Other					
Harvest (nr. of fish)	4674	2411	2328	2023	652
Harvest (1000 kg)	28.84	14.88	14.36	12.48	4.02
Stock size (1000 fish)	155	161	161	161	164

[7] 22861*0.3=6858 geardays.

Effects on effort, fleet and employment

A movement to optimal fisheries management will have implications for the amount of effort allowed, which might subsequently have an impact on fleet size and employment. The effects on number of fishers and vessels are shown in Table 12. Maximizing NPV would imply a 52% decrease in effort from the current level. If on top of this fuel cost policies were introduced, there would be further decrease in effort, but of various extents. The impact of the EU and Stern policies is quite moderate in comparison: only 4% and 17% decrease from the Baseline, respectively. On the other hand, it seems that the fuel tax in the National scenario would cut effort by up to 74% compared to the Baseline scenario. These relative effects on effort from the different management measures are depicted in Figure 9.

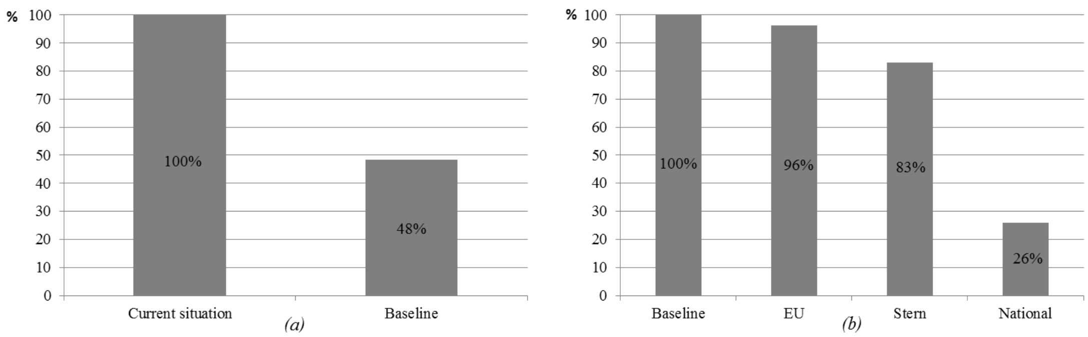

Figure 9*. Impact on effort from optimizing the fishery (a) and from implementing fuel cost policies (b).*

In order to provide compatible results for our research project, I have also estimated effects on fleet size and employment. Employment, which is known (see Table 10), is simultaneously a good estimate for fleet size, since the typical small-scale coastal fishing enterprise usually consists of one fisherman (Pakarinen 2013, personal communication). However, the changes in number of fishers/vessels are estimated based on the changes in effort, and must therefore be taken with reservation. Knowing that 149 vessels share among them 17342 geardays (see Table 10), I have assumed that one vessel stands for 116 geardays. Given the amount of effort, a corresponding number of vessels is then derived from this.

Economic effects

The net present value gives the value of the fishery over the 50-year timespan. As can be seen from Table 12, the current fishery has a negative NPV of €5000. This is in line with the results I obtained from the profitability calculations with respect to the Gulf of Bothnia fishery. However, given that the River Tornionjoki stock comprises about one third of the Gulf of Bothnia fishery, this loss seems quite moderate in comparison. Looking at the fuel cost scenarios 1-4, the model suggests that by moving to optimal management the fishery could be made slightly profitable. The profit is €42 000 when maximizing NPV in the Baseline scenario. As for the remaining fuel cost scenarios, the result is similar to what it was in the case of effort. The effects of the EU and Stern policies are small compared to the effect from moving from the current situation to the Baseline. Again, the National scenario has a more significant impact on profits than the other policies. Nonetheless, the NPV stays positive in all fuel cost scenarios when optimizing the fishery. The effects on profitability discussed above are illustrated in Figure 10 below.

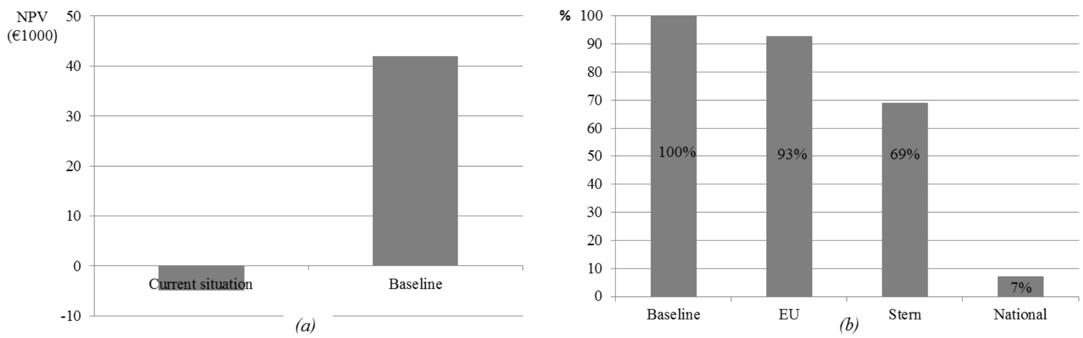

Figure 10*. Impact on profitability from optimizing the fishery (a) and from fuel cost policies (b).*

Fuel consumption and CO_2 emissions

The fuel consumption and subsequent CO_2 emissions are estimated based on effort. Given that 17342 geardays of effort is fueled by 240 m^3 of gasoline (see Table 10), I make the assumption that approximately 14 liters of fuel is consumed per gearday. The nature of the changes in both of these indicators as a result of the different management measures is the same as with the previously discussed indicators. There is a significant decrease in fuel consumption and CO_2 emissions from a movement to optimal management. The EU and Stern scenarios cause decreases of a lesser magnitude, whereas the impact of the National scenario is more significant. The percentage changes in CO_2 emissions and fuel consumption are the same, since the emissions are obtained by multiplying the consumption with the constant 2.33 kg CO_2/liter fuel. The relative changes in CO_2 emissions, shown in Figure 11, resemble those shown for effort, since the emissions are contingent on the amount of effort.

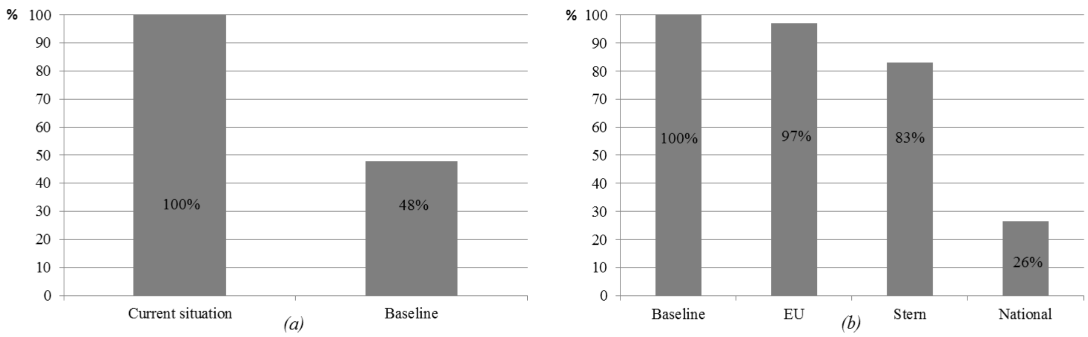

Figure 11. *Reduction in CO_2 emissions from fisheries management (a) and climate change management (b).*

Table 12 also includes two indicators relating to fuel efficiency. These indicators describe how much output the fishery can produce per a given amount of fuel. The fuel efficiency indicators originate from the research project, and are kg catch/liter and landing value/liter. The landing value is calculated by multiplying the catch in kg with €4.3 (see p.44). When maximizing NPV, both kg catch/liter and landing value/liter increase. There occurs additional increase in these indicators when introducing the fuel cost in the National scenario. In the EU scenario, which has the lowest fuel cost, there is no movement in these indicators compared to the Baseline. With the slightly higher Stern cost, kg/catch is again equal to the Baseline, whereas landing value/liter moves a fraction up.

Finally, Table 12 shows indicators, which besides effort and NPV are direct outputs of the bioeconomic model. These indicators are harvest level and stock size at which the fishery stabilizes in the long run. With the harvest levels, there is again a notable change from the current situation to the optimal. The effect of the EU and Stern scenarios is small, whereas in the National scenario a clear impact is discernible. In the case of stock size, there is no difference between the EU and Stern scenarios and the Baseline. In the National scenario, the very modest level of harvest is explained by the low fishing effort.

4.3.3 Sensitivity analysis

I conclude the analysis by conducting a sensitivity analysis in order to assess the impact on key model outputs from changes in some of the important input variables. The output indicators observed here are effort, NPV and CO_2 emissions. Changes are made in fishing cost, catch price, offshore longline survival and post-smolt survival. These variables represent central economic and biological inputs in the bioeconomic model. The results from the sensitivity analysis are exhibited in Table 13, along with data for the current situation and Baseline as points of reference.

***Table 13**. Current situation, optimal policy (Baseline) and sensitivity analysis.*

Current situation			**Baseline**		
Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)	Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)
6858	-5	221	3312	42	106
25% increase in fishing costs			**25% decrease in fishing costs**		
Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)	Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)
0	0	0	12178	520	392
25% increase in catch price			**25% decrease in catch price**		
Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)	Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)
10979	533	353	0	0	0
10% increase in OLL survival			**5% decrease in post-smolt survival**		
Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)	Effort (trapnet days)	NPV (€1000)	CO_2 emissions (tons)
11381	535	366	1305	6	42

From the results of the sensitivity analysis it becomes clear that the present fishing costs are very high. A 25% increase in costs renders the fishery unprofitable. A further sensitivity analysis revealed that the NPV is zero when the unit cost of fishing is €52 or above. Correspondingly, a decrease in costs significantly improves profitability and raises the optimal effort level as well as fuel use and CO_2 emissions. However, a 25% decrease in costs would imply a unit cost of €35.66/gearday, which is below the lowest of the costs I obtained based on the interviews with fishermen (see Appendix B). A unit cost this low therefore seems quite unlikely. Figure 12 illustrates the relationship between fishing costs and NPV of the fishery, from which it becomes clear how high the fishing costs are presently.

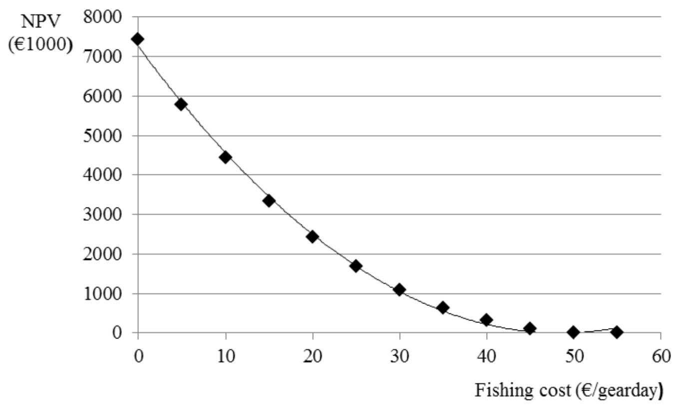

***Figure 12**. The relationship between fishing cost and net present value of the fishery.*

Offshore longline survival also seems to have quite a big impact on optimal effort and profitability. A 10% increase in this parameter means that less salmon is fished by the offshore fleet in the southern Baltic Sea, and more salmon is available for the coastal trapnet fisheries. Some increase in this parameter might be realistic, because Finland and Sweden have closed down their offshore fisheries since 2010, the year from which the model data originates. Finally, I have tested the impact of a decrease in post-smolt survival. This is an important biological parameter in the analysis, because post-smolt mortality is the most significant factor affecting salmon stock size after reproduction (e.g. Kulmala et al. 2008b, 725). Only a 5% decrease in post-smolt survival has a large impact, and significantly lowers profitability of the fishery.

5 Conclusions

Growing use of fossil fuels and its connection to global warming and climate change are continually pivotal topics on the world agenda. These climate issues have not traditionally been linked to the environmental impact of fisheries. However, fuel use and resulting greenhouse gas emissions are important factors affecting both environmental and economic sustainability of fisheries (Driscoll & Tyedmers 2010, 353). World fisheries are completely dependent on fossil fuels for fishing operations that provide livelihood to tens of millions of people and food to billions of people around the globe (FAO 2012, 5&10).

Global fisheries are subsidized substantially by national governments, and the proportion of support that is given in the form fuel subsidies is significant (Sumaila et al. 2006, 47; Sumaila 2013, 251). Following the global attention that has recently been directed at fuel tax concessions in the fishing sector (see e.g. Martini 2012), a study on the impact of fuel tax concessions removal in Nordic fisheries has been conducted. This thesis represents the Finnish case study within this research project. I will here sum up the results from my thesis and also briefly present the conclusions drawn from the joint study.

The aim of this study was to assess the effects of fuel tax concessions removal on the coastal salmon fishery in the northern Baltic Sea. The idea was to elicit the economic and climate benefits from managing the fishery in an optimal way and from implementing different fuel cost policies. The current situation of the fishery is thus compared to the

i. current situation if fuel cost policies are introduced,
ii. optimal fishery where tax concessions are maintained, and
iii. optimal fishery under climate change management.

The results can provide valuable information to policy makers on efficient ways of addressing externalities associated with fisheries.

The framework of the study at the same time allowed for a comprehensive assessment of the commercial salmon fishery in order to relate possible future scenarios with the present and past economic and biological conditions. The salmon fishery is currently unprofitable, and therefore not fit to bear the burden of additional costs imposed by climate change management measures. However, results from the bioeconomic analysis suggest that by moving to optimal management, i.e. by adjusting the fishing effort to an efficient level, the fishery could be made profitable over the long term. Furthermore, an optimally managed fishery would have a positive net present value even if fuel cost polices were implemented, and could thus potentially pay for its external costs caused by CO_2 emissions. However, it seems that economic and climate benefits can be reached by simply managing the fishery in an optimal way. This can be observed by examining the development of key indicators, such as the fishery's NPV and CO_2 emissions when implementing fisheries management and climate change management, respectively.

The conclusion of the research project was that optimal fisheries management can be an efficient way of mitigating the environmental impact of fossil fuel use in Nordic fisheries. Simultaneously, the economic performance of the fisheries is improved. Today, many Nordic fisheries are in a state far from optimal management, and some even have negative net profits, such as the Baltic salmon fishery. Climate change management will further decrease emissions, but to a lesser degree. On the aggregate Nordic level, a movement to optimal management would decrease the fishing fleet by 45%, improve economic performance with 100%, and reduce CO_2 emissions with nearly 30% (Waldo et al. 2013, 37&39).

The Finnish results differ somewhat from the other case studies when it comes to the impact of climate change management. In the case of the EU and Stern scenarios, the results are broadly similar to the aggregate results, i.e. that the impact of these policies are minor compared to the impact of optimizing the fishery. However, with the National scenario there is some discrepancy, since the Finnish fuel tax seems to have a bigger impact than in the other cases. There are two reasons for this: first, the Finnish case assumes the use of gasoline, which is more expensive and is taxed more heavily than diesel, which is used in the other case studies. Because the consumer price of gasoline often includes a higher excise duty than diesel (e.g. Martini 2012, 8; Finnish

Petroleum Federation 2013), the impact of removing tax concessions will be more prominent for gasoline users than for diesel users. Second, because the fishing costs are already very high for the Baltic salmon fisheries as it is, even a marginal rise in costs may have a significant impact on optimal effort and profitability (see Figure 12).

Although the results suggest that the salmon fishery could be made profitable through a movement to optimal management, the present high fishing costs and low fish market values will not allow any substantial profits to be gained. For example, boycotts of Baltic salmon, initiated by WWF, have resulted in a decline in producer prices of salmon (see e.g. Helsingin Sanomat 2012). Additionally, for example rising fuel costs (see Appendix B) have had a notable effect on both coastal and offshore fishery businesses. Overall, investments in Finnish coastal fisheries have increased, but this has not led to increased profits (STECF 2012b, 144).

The results of this study apply to the River Tornionjoki salmon stock, and they are therefore only directional with respect to other Baltic salmon fisheries. The River Tornionjoki stock counts among the more vital salmon stocks in the Baltic Sea. Coastal fisheries are, however, not stock-specific and might therefore pose a threat to more weak salmon stocks. According to advice given by ICES (2013a, 1), fishing effort in such fisheries should be reduced. This is in line with the policy recommendations provided by this study. Additionally, the results indicate that compared to the Gulf of Bothnia fishery as a whole, the River Tornionjoki stock fishery is economically more sound. This would further support a movement to more stock-specific harvesting. However, since this sort of harvesting is possible only in rivers and estuaries, this would probably have serious economic and social implications for the commercial coastal fisheries. The low profitability of commercial salmon fisheries and the high status of recreational fishing in rivers have been the cause of continuous debate among different stakeholders in Finland and other Nordic countries.

It should be noted that the sensitivity analysis revealed that the results are not particularly robust with respect to the investigated parameters. However, how likely such changes in these parameters are, is a question that remains unanswered at this point. Sufficient to say, fishing costs, which are thoroughly explored throughout this thesis, are in the light of the findings not likely to decrease significantly in the near future. It ought to be acknowledged, though, that economic and climate considerations do not necessarily go hand in hand. If optimal management implies increasing fishing effort, this will lead to greater fuel consumption and CO_2 emissions.

Although it is obvious that a small-scale coastal fishery is not the biggest contributor to greenhouse gas emissions in the fishing sector, this does not diminish the value of the lessons that can be drawn from this study. The assumption here is that the hypothetical fuel cost policies are implemented to the whole capture fisheries sector. Therefore, it is of interest how this would affect different types of fisheries. Further, the results of this thesis and the research project illustrate the potential of fisheries management to influence both economic and climate impacts of fisheries. With the present high fishing costs for the Baltic salmon fisheries, improving profitability means decreasing fishing effort. On the other hand, as the sensitivity analysis revealed, a substantial decrease in costs would imply an increase in the optimal amount of effort. This indicates that the primary cause of low profitability is high fishing costs and not, for example, poor stock status. Again, this is the case for this specific fishery, and highlights the importance of fishery- and stock-specific assessments when studying the effects of management measures directed at the whole fisheries sector.

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APPENDIX A. Population dynamics

The model assumes that eggs develop straight into smolts after four years, thus the different river stages (alevin, fry, parr) can be left outside the modeling framework. The smolts migrate to the Baltic Main Basin, where they feed for a number of years (1SW-5SW) before returning to their natal river to spawn. A fixed proportion of the stock is assumed to be harvested by the offshore longline fishery in the Main Basin. The returning spawners are targeted by the coastal trapnet fishery in the Gulf of Bothnia.

Next, I need to know how the salmon stock evolves over time, since it will be the constraint in the long-run economic optimization. In the case of an age-classified population, the stock is examined with the aid of a population projection matrix. First, the state variable, or salmon stock, must be described as a vector. This expresses the number of age-specific individuals

$$N = \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ \vdots \\ n_{10} \end{bmatrix} \tag{A1}$$

The different age classes' survival to the next class is then described by portraying age-specific fecundity and probability of survival in a population projection matrix, known as a Leslie matrix. Note that fecundity for the five first age-classes is zero, and that survival rate for age-classes 1, 2 and 3 is 100%. The Leslie matrix is written as

$$A = \begin{bmatrix} fec_{1,t} & fec_{2,t} & fec_{3,t} & \dots & fec_{10,t} \\ sur_{1,t} & 0 & 0 & \dots & 0 \\ 0 & sur_{2,t} & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & sur_{9,t} & 0 \end{bmatrix} \tag{A2}$$

The number of fishable individuals at time $t+1$ is obtained by multiplying the matrix A with the vector N, which portrays the number of individuals at time t

$$N_{t+1} = AN_t \quad \text{(A3)}$$

Using matrix notation (A3) can be written as

$$\begin{bmatrix} n_{1,t+1} \\ n_{2,t+1} \\ n_{3,t+1} \\ \vdots \\ n_{10,t+1} \end{bmatrix} = \begin{bmatrix} fec_{1,t} & fec_{2,t} & fec_{3,t} & \dots & fec_{10,t} \\ sur_{1,t} & 0 & 0 & \dots & 0 \\ 0 & sur_{2,t} & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & sur_{9,t} & 0 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ \vdots \\ n_{10} \end{bmatrix} \quad \text{(A4)}$$

Next, the entries into matrix A are listed hereunder. First, the proportion of eggs produced by the spawning stock at time t is given by

$$fec_{a,t} = fe_a sr_a hr_a e^{-q_a E} \quad \text{(A5)}$$

where E denotes the fishing effort. *fe*, *sr*, *hr* and q are age-specific biological parameters.

The eggs will all survive the next three stages, thus

$$sur_{1,t} = 1 \quad \text{(A6)}$$

$$sur_{2,t} = 1 \quad \text{(A7)}$$

$$sur_{3,t} = 1 \quad \text{(A8)}$$

The recruitment parameters α and β are used in a Beverton-Holt stock-recruitment function that describes the relationship between the number of eggs and the number of smolts (Kulmala et al. 2008b, 726). The parameter denoting M74 survival is also an important part of the recruitment function, which is here written as follows

$$sur_{4,t} = \frac{m74}{(\alpha+\beta n_{4,t}/1000)m74} \tag{A9}$$

The proportion of 1SW-5SW salmon surviving to the next age-class is given by the following equations

$$sur_{5,t} = (1 - hr_6)ps \tag{A10}$$

$$sur_{6,t} = (1 - hr_7)s \cdot oll \tag{A11}$$

$$sur_{7,t} = (1 - hr_8)s \cdot oll \tag{A12}$$

$$sur_{8,t} = (1 - hr_9)s \cdot oll \tag{A13}$$

$$sur_{9,t} = hr_{10}\, s \cdot oll\ , \tag{A14}$$

where *hr* is age-specific homing rate, *ps* is post-smolt survival, *s* is adult natural survival and *oll* is offshore longline survival.

APPENDIX B. Estimation of trapnet fishing costs

Previously existing and published cost data for the Baltic salmon trapnet fishery is scarce (Kulmala et al. 2008a, 16). Therefore, one of my tasks in relation to this study was to estimate and update the fishing cost data. Kulmala et al. (2008b) estimated fishing costs based on interviews with fishermen participating in the Finnish salmon fisheries. Based on questions regarding gear price, gear maintenance as well as fuel and labor costs, an average unit cost of fishing was calculated. The cost obtained was €24.1/gearday, which thus describes the cost of fishing with one trapnet for one day. My estimation is considerably higher, primarily because I assume the use of expensive seal safe gear. For example, Holma et al. (2013, 11) have based their costs on Kulmala et al. (2008b), but when assuming the use of seal safe gear the obtained cost is €43.84/gearday.

The cost I obtained for the current situation and Baseline is €47.55/gearday, i.e. the scenario where tax concessions are held in place. I adopted the same cost estimation procedure as in Kulmala et al. (2008b). I interviewed nine fishermen per telephone in February 2013. The answers and the costs calculated based on the answers are gathered in Table B1. However, when calculating the average cost based on the answers, I left the costs of two fishermen (nr. 8 and 9) unconsidered. I did this because these costs were exceptionally high and outliers compared to the rest of the reported costs. The high cost for these two fishers is explained by the low number of fishing days and gear. Because the costs are always calculated per gear and per fishing day, these two factors will have a significant impact on the cost of fishing.

Table B2 summarizes the results from Table B1, thus showing the fisher-specific cost with respect to the current situation and Baseline. Table B3 shows again the average scenario-specific costs familiar from chapter 4, but also shows the average individual cost items. All cost items apart from fuel cost remain constant in all scenarios. The variations in cost are thus caused by the scenario-specific fuel prices (see Table 7).

The variable costs considered are gear price, gear and vessel maintenance, as well as fuel and labor costs. Background information includes fishing area, salmon catch per year and the length of the fishing trip. This data has also been inserted into Table B1. As mentioned above, the number of fishing days is an important piece of information for determining the costs. Salmon fishing with trapnets in the Gulf of Bothnia is allowed only during a relatively short period in the summer. Next, there is information about the fishing gear, which is also important in determining the total cost. All the considered fishermen used seal safe gear, i.e. push up trapnets or modified traditional trapnets. The gear price is by far the largest share of the total unit cost. The cost is determined by the gear price[8], the number of fishing days and the number of years the trapnet can be used. The amount of gear is usually restricted to 2-8 trapnets per fisherman depending on when the fishing takes place (ICES 2013b, 23). According to ICES (2012a, 27) almost all gear presently used in the salmon fishery is seal safe gear.

For the cost of gear and vessel maintenance, I have only considered the amount of labor that is taken up by the maintenance work. The fishermen usually do their own maintenance and spare parts can even be self-made. Engine service is included in the vessel maintenance. In addition to the service of vessel and gear, there is the labor taken up by the actual fishing activity. The working day includes the boat trips as well as the setting and emptying of the trapnets. The choice of labor cost (€12,5/h) is to some extent arbitrary. It is somewhat higher than the cost used by Kulmala et al. (2008a), but lower than the €15,5/h found in a report by Tschernij (2007) on the use of the pontoon trap[9] in coastal fisheries. According to Statistics Finland (2013), in 2011 the average monthly wage for skilled workers in agriculture and fisheries was €2215. This would roughly translate to €13,8/h. The cost used in my estimations is somewhere between these wages.

Finally, there is the cost of fuel. I assume here that all fishers use motor gasoline as fuel and 98 octane gasoline more specifically. This is a reasonable assumption, since a considerable part of the fishing vessels that operate in the coastal fishery are small vessels (<10m) using outboard engines that mainly run on gasoline. This was evident from my interviews, and can also be observed from Table 2 (p.11), where one can see that a considerable part of the fuel consumed by the Finnish fishing fleet is gasoline.

[8] The price for a push up trapnet is around €15 000 (see Table B1).
[9] The push up trap is also known as pontoon trap.

In fisheries, fuel costs often constitute a significant part of the cost of fishing (see e.g. OECD 2006, 107), although this proportion will vary depending on the type of fishery, such as target fish stock and if passive or active fishing gear is used. Cheilari et al. (2013, 20), who assessed the fuel efficiency of a large part of the EU fishing fleet, found that for small vessels using passive gear, fuel costs represented 5% of total costs. Passive gears are typically less fuel intensive than active gears (e.g. OECD 2013, 22). In my estimations for the Finnish salmon fleet, the fuel cost stands for 7.6% of the total fishing costs in a situation without additional fuel costs. Figure 13 shows the development of gasoline price during the last decade. Observe that the depicted price is the ordinary consumer price, i.e. no tax concessions are considered. Nonetheless, it gives an idea of how the price of fuel has risen over that last ten years.

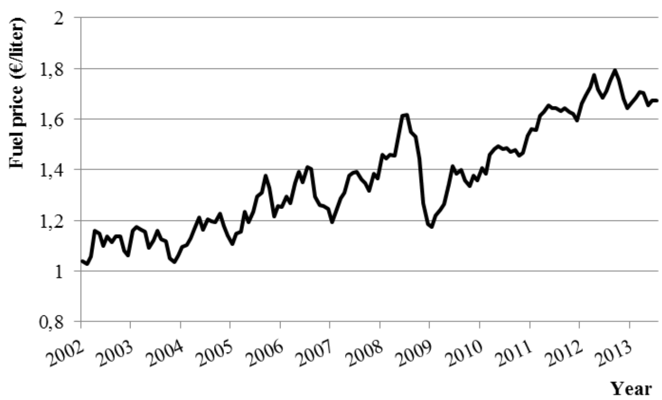

Figure 13. *Consumer price of motor gasoline (98 octane), 2002-2013.*
Source: data from Maskula 2013, personal communication.

In Table B4 are displayed the proportion of the cost items in the different scenarios. In the current situation and Baseline, fuel is only the fourth largest cost item (7.6%), after gear price, labor and gear maintenance. This same cost structure prevails in the EU and Stern scenarios. In the National scenario, however, fuel cost is the third largest cost item (13.6%), slightly exceeding the cost of gear maintenance. From these results, it is obvious that also the overall labor costs constitute a significant part of the fishing costs.

Table B1. *Calculation table for trapnet day cost in the current situation and Baseline.*

Fisher	1	2	3	4	5	6	7	8	9
Area	Bothnian Bay	Bothnian Bay	Bothnian Sea	Bothnian Sea	Bothnian Bay	Bothnian Sea	Bothnian Bay	Bothnian Sea	Bothnian Sea
Kg catch/year	10000	6000	5000	3000	2000	1000	(*)	2400	500
Driving distance (km/trip)	28	40	29	30	15	44	45	55	37
Fishing days/year	70	55	60	70	50	50	50	40	45
Trapnet	Push-up	Salmon	Push-up	Push-up	Whitefish	Push-up	Salmon	Push-up	Whitefish
Quantity	6	5	4	5	2	6	5	4	1
Working life (years)	10	10	10	10	15	10	8	10	15
Price (€)	14000	15000	15000	15000	10000	15000	10000	15000	13000
€/trapnet/day	20	27,27	25	21,43	13,33	30	25	37,50	19,26
Gear maintenance (h/gear/year)	31	35	48	24	24	24	31	20	80
€/trapnet/day	5,54	7,95	10	4,29	6	6	7,75	6,25	22,22
Vessel maintenance (€/year)	250	25	210	218,75	100	350	150	210	1000
€/day	3,57	0,45	3,50	3,13	2	7	3	5,25	22,22
Fuel consumption (liters/year)	1000	3000	1500	600	300	2500	1000	3000	200
€/trapnet/day	1,66	7,59	4,35	1,19	2,09	5,80	2,78	13,04	3,09
Workday length (h)	3	4	3	3	3	4	6	5	4
€/trapnet/day	6,25	10	9,38	7,50	18,75	8,33	15	15,63	50

(*) No catch data was provided by the fisher.

Table B2. *Summary of the total fishing costs per fisher in the current situation and Baseline.*

Fisher	1	2	3	4	5	6	7	8	9
Gear	20	27,27	25	21,43	13,33	30	25	37,50	19,26
Gear maintenance	5,54	7,95	10	4,29	6	6	7,75	6,25	22,22
Vessel maintenance	3,57	0,45	3,50	3,13	2	7	3	5,25	22,22
Fuel	1,66	7,59	4,35	1,19	2,09	5,80	2,78	13,04	3,09
Labor	6,25	10	9,38	7,50	18,75	8,33	15	15,63	50
Sum €/trapnet day	37,01	53,27	52,22	37,53	42,17	57,13	53,53	77,66	116,80

Table B3. *Average scenario-specific cost items and total fishing cost.*

Cost item	**Current situation, Baseline (€)**	**EU (€)**	**Stern (€)**	**National (€)**
Gear	23,15	23,15	23,15	23,15
Gear maintenance	6,79	6,79	6,79	6,79
Vessel maintenance	3,24	3,24	3,24	3,24
Fuel	3,64	3,79	4,38	6,91
Labor	10,74	10,74	10,74	10,74
Total	47,55	47,71	48,29	50,83

Table B4. *Cost items and their share of total cost in the different scenarios.*

Cost item	**Current situation, Baseline (%)**	**EU (%)**	**Stern (%)**	**National (%)**
Gear	48,7	48,5	47,9	45,5
Gear maintenance	14,3	14,2	14,1	13,4
Vessel maintenance	6,8	6,8	6,7	6,4
Fuel	7,6	8,0	9,1	13,6
Labor	22,6	22,5	22,2	21,1
Total	100	100	100	100