Aqua reports 2013:21

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Staffan Waldo, Anton Paulrud, Katja Ringdahl,
Johan Lövgren, Mikaela Bergenius

AgriFood economics centre

SLU
Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Institutionen för akvatiska resurser

Havs och Vatten myndigheten

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Adress:
Swedish University of Agricultural Sciences, Department of Aquatic Resources,
Skolgatan 6, 742 42 Öregrund.

December 2013
SLU, Department of Aquatic Resources.

Aqua reports 2013:21
ISBN: 978-91-576-9192-7 (electronic version).

This report may be cited as:
Waldo, S., Paulrud, A., Ringdahl, K., Lövgren, J., Bergenius, M. (2013). Cod or clupeids? Economic consequences for fisheries operating in different ecosystem states.
Aqua reports 2013:21. Swedish University of Agricultural Sciences, Öregrund. 35 s.

Download the report from:
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E-mail:
Staffan.Waldo@slu.se
Anton.Paulrud@havochvatten.se
Katja.Ringdahl@slu.se
Johan.Lövgren@slu.se
Mikaela.Bergenius@slu.se

This report has been reviewed by:
Andreas Bryhn, SLU, Institute of Coastal Research
Henrik Svedäng, SLU, Institute of Marine Research

Photographs: Front: Dan Tilander. Back: Olof Lövgren.

Summary

In the late 1980s, the cod population in the Baltic Sea declined steeply as a result of overfishing and unfavorable hydrological conditions for reproduction. Since then, restoring the Baltic cod stocks has been a major management objective in Swedish and EU fisheries policies. In addition to ecosystem benefits, restoring fish stocks is expected to have major economic consequences for the fisheries sector. The literature shows that profits from the fishery could increase by recovering the cod stock and reducing fishing pressure on herring and sprat since these are the main prey for the high valued cod.

We explored the economic consequences for the Swedish fishery of fishing cod and clupeids (sprat and herring) at different total allowable catches (TAC) in the Baltic Sea. We compared profits to the fishery by studying combinations of high and low TACs of cod and sprat, respectively, based on biological scenarios. The analysis contributes to the literature by explicitly modeling how changes in the ecosystem could affect the optimal fleet structure and economic performance of different fleet segments. The Swedish fishery was used as a case study within the Baltic Sea, acknowledging that the Baltic Sea is utilized for fishing by all states in the region and that other countries might face other consequences.

Further, the fishing sector is a complex industry characterized by vessels participating in multiple fisheries. Each vessel will exploit several fish stocks enabling the fisherman to choose among stocks. If the fishing possibilities change, the fisherman will look for alternative fishing activities for using the company’s labor and capital assets. Thus - through rational economic decisions made by the fishing industry - a management action in one fishery will lead to effects in other fisheries that might be difficult for managers to predict. The analyses were performed using the Swedish Resource Rent Model for the Commercial Fishery, SRRMCF, which is an economic model covering the entire Swedish fishery.

The main conclusions from the study were that it was more profitable to fish the three species at F_{MSY} than at the current utilization levels and that the economic profitability could be further increased by up to 118 MSEK by increasing the cod stock at the expense of reducing sprat abundance. These effects rely on all stocks being fished at sustainable levels.

Sammanfattning

På slutet av 80-talet minskade populationen av torsk i Östersjön kraftigt som ett resultat av alltför högt satta kvoter och ogynnsamma hydrologiska förutsättningar för fortplantning. Sedan dess har en återhämtning av torskpopulationen varit en prioriterad fråga för förvaltningen i Sverige och EU. Den kunskap som finns idag visar att värdet från fisket skulle kunna öka om torskpopulationen återhämtar sig och om fisket efter sillfiskar (sill och skarpsill) genom dess roll som föda för torsken tilläts minska.

Utgångspunkten i studien är att en reducering av sillfiskar påverkar inte bara bestånden av dessa, utan även bestånden av andra ekonomiskt viktiga arter (framför allt torsk). Utifrån teoretiska modeller och empiriska studier av fisket är det möjligt att bilda en grov uppfattning om hur fisket kommer att utvecklas om bestånden och kvoterna i Sverige förändras. För att studera hur olika fiskesegment förväntas utvecklas krävs dock en modell över fisket som integrerat analyserar både sillfiskar och andra arter. En användbar modell över fisket för detta ändamål behöver beskriva näringens struktur och hur fisket förväntas agera för att företagen ska maximera sina vinster givet de förutsättningar som ges inom fiskeripolitiken och av resurstillgången.

Modellen som används här heter SRRMCF (Swedish Resource Rent Model for the Commercial Fishery). Modellen har tidigare använts vid ett flertal större utredningar av den svenska fiskesektorn. Modellen är utformad för att analysera komplexa samband inom fiskenäringen. I modellen kan fartygen välja mellan olika fisketyper, och vissa fartygssegment består av mycket flexibla fartyg som kan bedriva ett stort antal olika fisketyper. Förändrade förvaltningsåtgärder kan därför ge följdverkningar utanför det fiske som en åtgärd avser. Om man minskar fiskemöjligheterna för en given art kan fartygen välja att börja fiska något annat och på så sätt konkurrera ut det befintliga fisket på dessa arter. Denna typ av följdverkningar kommer fram genom modellen, samtidigt som naturligtvis inte alla specialfall kan beskrivas i detalj.

I studien analyseras ett flertal olika tänkbara scenario med olika nivåer på kvoterna av sillfiskar och torsk i Östersjön. Studien bidrar på detta vis med kunskap om hur olika förändringar av ekosystemet skulle kunna påverka den optimala sammansättningen av fiskeflottan och dess ekonomiska resultat. Den svenska fiskeflottan används här som ett exempel, även om Östersjöns fiskeresurser naturligtvis nyttjas av fler länder.

De huvudsakliga slutsatserna som resultaten visar är att det är mer ekonomiskt lönsamt att fiska på en maximalt långsiktigt hållbart nivå (F_{MSY}) än nuvarande nivå och att det ekonomiska resultatet kan öka ytterligare, med upp till 118 MSEK per år, genom att öka populationen av torsk på bekostnad av minskade populationer av sillfiskar. Resultaten bygger på att alla arter skördas inom uthålliga nivåer.

Table of contents

1 Relevance and potential impact

This project was undertaken as part of a commission from the Swedish Government given in 2007 to the former Swedish Board of Fisheries, now parted into the Institute of Aquatic Resources, SLU and the Swedish Agency for Marine and Water Management, and the Swedish Environmental Protection Agency.

"The Swedish Board of Fisheries shall, in a defined coastal area, conduct an experiment on sprat thinning to evaluate if the method can contribute to create ecological balance in the Baltic Sea. During the first phase of the project (2007), a pilot study and planning should be performed to evaluate alternative strategies, organize international collaborations and conduct stakeholder dialogues. The long-term project should be evaluated to produce knowledge regarding the cost efficiency and ecological consequences of the method, as well as the future possibilities to implement the measures at a larger scale. The commission should be carried out in consultation with Naturvårdsverket (Swedish EPA) and the pilot- and planning phase shall be reported 31 March 2008. A progress report shall be submitted 31 December 2009 and the final report submitted 31 December 2013".

The commission was undertaken in two parallel parts: I) The research project Planktivore management: linking food web dynamics to fisheries in the Baltic Sea (PLAN FISH) and II) Bioeconomic analyses (this project). The main aim of the commission was to contribute to the implementation of an ecosystem approach to management of the Baltic Sea fish stocks.

The PLAN FISH project will provide an increased understanding of the structure and function of the Baltic Sea ecosystem and how fishing may affect the ecosystem aside of the target species. The aim of the bio-economic analyses was to compare the economic consequences of fishing at different total allowable catches (TAC) of cod (*Gadus morhua*) versus clupeids, assuming that the TACs reflect the available biomass of the populations.

The long-term goal of both PLAN FISH and the bio-economic analyses is to contribute with new knowledge to assist managers in the move towards an ecosystem-based approach to fisheries management in the Baltic Sea.

2 Introduction

The Baltic Sea ecosystem has undergone dramatic changes during the last decades (Österblom et al., 2007). From the early 20th century until the peak in 1980, cod biomass may have increased by a factor of 50 (Thurow, 1997), In the late 1980s, the cod population declined steeply as a result of overfishing due to too high quotas and unfavorable hydrological conditions for reproduction (Carpenter et al., 1985; Pace et al. 1999; Casini et al., 2008). Since then, restoring the Baltic cod stocks has been a major management objective in Swedish and EU fisheries policies.

In addition to ecosystem benefits, restoring fish stocks is expected to have major economic consequences for the fisheries sector. The World Bank (2008) estimated that fisheries management annually generates $50 billion less than possible worldwide. The Baltic Sea is no exception, and the economic benefits of restoring the cod stock have been highlighted by e.g. Döring and Egelkraut (2008), and the potential benefits of improved management of the herring (*Clupea harengus*) stock by Kulmala et al. (2007) and Nielsen et al. (2012). These studies do not take species interactions into account, however. Using a model with some species interaction, Lindegren et al. (2010) estimated the change in net present value of revenues (no costs were included in the analysis) from improved management of the stocks, and they concluded that the most efficient strategy would be to reduce the exploitation pressure on cod in order to rebuild the stock. Niemenen et. al. (2011) developed a model including both cod predation on herring and sprat (*Sprattus sprattus*), and the economic revenues and costs of fishing. They showed that profits from the fishery could increase by recovering the cod stock and reducing fishing pressure on herring and sprat since these are the main prey for the high valued cod.

We explored the economic consequences for the Swedish fishery of fishing cod and clupeids at different total allowable catches (TAC) in the Baltic Sea. We compared the profits to the fishery allowing combinations of high and low TACs of cod and clupeids respectively based on potential biological scenarios. The analysis contributes to the literature by explicitly modeling how changes in the ecosystem affect the optimal fleet structure and economic performance of different fleet segments. The Swedish fishery is used as a case study within the Baltic Sea, acknowledging that the Baltic Sea is utilized for fishing by all states in the region and that other countries might face other consequences. By focusing on a national case study it is possible to make a more detailed analysis of the economic effects, including e.g. the impact on small scale fisheries.

Further, the fishing sector is a complex industry characterized by vessels participating in multiple fisheries. Each vessel will exploit several fish stocks enabling the fisherman to choose among stocks. If the fishing possibilities change, the fisherman will look for alternative fishing activities to optimize the use of the company's labor and capital assets. Thus - through rational economic decisions made by the fishing industry - a management action in one fishery will lead to effects in other fisheries that might be difficult for managers to predict. The analyses were performed using the Swedish Resource Rent Model for the Commercial Fishery, SRRMCF (for a description of the model see Waldo and Paulrud, 2013a). This is an economic model covering the entire Swedish fishery. The model has previously been used for evaluating different management issues of the Swedish fishery for example introduction of individual transferable quotas (ITQ) in Swedish Pelagic fisheries (Waldo and Paulrud, 2013b).

In this study we based the biological scenarios on biomass levels that would allow a fishing mortality at maximum sustainable yields (F_{MSY}) and on historically observed levels of spawning stock biomasses of cod and clupeids. In doing so, we did not make assessments of the developments of stocks, individually or through stock interactions, in relation to different TACs. Instead we focused on stock size levels which we have observed historically, and therefore can potentially observe in the future, and the economic profits of these.

3 Swedish commercial fisheries

3.1 Background and current management of cod and clupeid fisheries

The sprat and herring fisheries in the Baltic Sea were primarily small-scale coastal fisheries until the 1950s. The fish were caught with gillnets and traps and the catch was sold for consumption (Sjöstrand 2000). The industrial trawl fisheries for fish meal and fish oil developed in the beginning of the 1950s in the Soviet Union, Poland and East Germany. The landings increased from 100 to 500 thousand tonnes up until the beginning of the 1970s. In Sweden, the industrial fishing for herring and sprat developed as late as the 1990s (ICES 2010). The historical development of the clupeid fishery in the Baltic Sea is not well documented.

Sprat in the Baltic Sea is today primarily caught together with herring using pair-trawling during the winter and spring. There is no management plan accepted for clupeids and the International Council for the Exploration of the Sea (ICES) has based its advice on total allowable catch (TAC) levels relying on the concept of maximum sustainable yield. Multiannual plans are, however, being discussed within the EU. In Sweden, sprat is primarily used for production of fish meal and fish oil, while it is commonly sold for consumption in the Baltic States. The proportion of herring caught in the sprat fishery varies from area to area and by season, and there is uncertainty in the reporting of the proportions of herring to sprat in the fishery logbooks (Sjöstrand 2000; ICES 2010). In the fishery directed at catching herring, fish are mainly caught using pair-trawling and bottom trawling, but also with fixed gear along the coast during the spawning periods.

There are indications that there was a cod fishery operating in the eastern Baltic Sea already in 1550 (MacKenzie, 2007). During the 1910s, the fishery started to be motorized and the first trawls appeared in the 1920s (Eero, 2007). The evolution of fishing techniques allowed the fishery to expand outside coastal areas. The cod fishery increased during and after the Second World War and the exploitation rate was already at a high level in the 1950s (Eero, 2007). The fishery continued to increase and peaked in the beginning of the 1980s when the annual landings exceeded 300,000 tonnes. The stock could not support the intense fishery and landings decreased considerably in the late 1980s and 1990s. The fishing mortality nevertheless remained high until 2007 (eastern Baltic). Fishing mortality has decreased in recent years and the stock is exploited at maximum sustainable yield (F_{MSY}). The spawning stock biomass (SSB) has increased (ICES, 2012). In 2011, the total landings were about 50,000 tonnes. Eastern Baltic cod is primarily caught with trawls but also with gillnets and longlines.

3.2 The Swedish fleet and landings

In 2012, the Swedish fishing fleet consisted of 1322 registered vessels, with a combined gross tonnage of 29 thousand GT and total power of 169 MW and an average vessel age of 32 years (Table 1). Of these, 788 were more active, i.e. they generated income from fishing corresponding to at least twice the Swedish economic baseline amount (approx. SEK 44 000).The size of the Swedish fishing fleet decreased between 2008 and 2012. The smaller decrease of the fleet in 2012 compared to 2011 was due to the implementation of a new rule, that private fishing-right owners must register their vessels. The traditional fleet has decreased after 2011 (STCF, 2012).

Table 1. *Swedish national fleet: 2008-2012.*

	2008	2009	2010	2011	2012
No. of registered vessels	1,507	1,471	1,415	1,359	1,322
Landing weight (thousand tonnes)	214	199	204	173	137
Landing value (million SEK)	1,095	1,062	1,001	1,048	1,079

In 2010, the total catches by Swedish vessels amounted to approximately 204,000 tonnes, which resulted in a landing value of around SEK 1,000 million. During the period 2000-2010 the catch decreased from approximately 340,000 tonnes to below 250,000 tonnes. The overall development in catches is primarily regulated by the catches of pelagic species, which constitutes the bulk of Swedish catch volumes (Table 2).

The pelagic species are overall the economically most important species in the Swedish fishery. Herring and sprat constituted more than one-third of the total gross value of landings during 2010 (Table 2). These species are mainly fished within the pelagic segment. The pelagic segment is characterized by large vessels and catch volumes, but low prices per kg (as a large proportion of the catches is for industrial purposes). Shrimp, cod and Norwegian lobster (*Nephrops* *norvegicus*) are fished in smaller quantities but give a higher price per kg (i.e. consumption fish). Cod and Norwegian lobster in particular, are economically important species for small-scale fishing.

Table 2. *Gross value and volume of the five economically most important species in Swedish landings 2010.*

	Gross value of landings, million SEK	Volume of landings, tonnes
Herring	213	72,528
Sprat	173	84,123
North sea shrimp	166	1,724
Cod	160	13,034
Norwegian lobster	113	1,299

Source: www.fiskeriverket.se (now http://www.havochvatten.se/)

In terms of gross value of landings divided across the different segments of the fleet, the pelagic trawlers represented around 40% of the total gross value of landings in 2008 (Table 3). Trawling for cod, shrimp and crayfish combined represented around 45% of the total value of landings, while fishing with passive gear represented around 15% (Table 3). Vessels fishing with passive gear were generally smaller than trawlers, as indicated by that these two segments made up 15% of the value of landings but 63% of the total number of vessels.

Table 3. *Percentage distribution of value of landings per segment in 2008.*

Gear type	Segment	Share of landings
Active		
	Pelagic trawlers > 40 m	20 %
	Pelagic trawlers < 40 m	20 %
	Shrimp trawlers	15 %
	Nephrops trawlers	10 %
	Other trawlers (incl. cod)	20 %
Passive		
	Passive gear > 12 m	2 %
	Passive gear < 12 m	13 %
	Total	100 %

Source: www.fiskeriverket.se (now http://www.havochvatten.se/)

4 Method

In this chapter, we present the Swedish Resource Rent Model for the Commercial Fishery, SRRMCF (for a more comprehensive description see Waldo and Paulrud, 2013a), used here to analyze the economic consequences of different TACs of clupeids and cod. The SRRMCF is an economic tool designed for performing policy analyses in a setting where the fisher is flexible to change fishing patterns within the limits of gear and management restrictions. The model structure of the fleet segments is described in section 4.1, the métiers, areas, species and fishing periods in section 4.2, and model restrictions in section 4.3. The chapter ends with a description of the data input in section 4.4.

4.1 Model structure

Most vessels in the Swedish fishery participate in multiple fisheries. Thus, each vessel will exploit several fish stocks. When facing a decreasing profitability in a preferred fishing activity, the fishers will look for alternative activities to maximize profit. Thus, through rational economic decisions made by the fishers (as a result of choosing between different areas, gears etc.), a management action in one fishery may have consequences for other fisheries not originally planned for.

The SRRMCF is a numerical model, set up as a constrained optimization programme which covers the major part of Swedish commercial fisheries. Thus, the model will maximize an objective specified by the user. In this study, the objective was to maximize the economic profit from the fishery. The decision variables in the model are number of vessels and number of days-at-sea. The optimization is restricted by the constraints in the model and these set the bounds for how the fishery can develop. Examples of constraints are model restrictions limiting catches from exceeding the quota, the number of days that a vessel can be active at sea, or the number of boats in the fleet, with regards to EU effort regulations, etc. The model is however, flexible with respect to both the objective function and restrictions. The model is structured in five dimensions; fleet segments, area, fishing periods, métiers and species.

In the optimization, the model is set to first allocate fishing efforts to the segment with the most profitable fishery (métier), until one of the constraints limits further fishing. The model is thereafter defined to search for the second most profitable métier, etc.

4.2 Segmentation used, métiers, areas, species and fishing periods

The characteristic of the vessel determines the costs of fishing, as well as possible fishing activities. The vessels are divided into 10 segments according to gear and vessel length. The gear is either demersal trawl, passive gear (e.g. pots and traps, gill-net and hook), or pelagic trawl/seine based on which gear most time is used on. Length classes are based on total length of the vessel according to vessel register. All vessels in a segment are assumed to face the same choice of possible fishing activities, and are assumed to have the same operation costs. The segments used are presented in table 4. The category VL1012 in the table consists of vessels between 10 and 12 meters.

Table 4. *Segments used in the model.*

Segment No.	Fishing gear	Vessel length category
1	Demersal trawl	VL1012
2		VL1218
3		VL1824
4		VL2440
5	Passive gear	VL0010
6		VL1012
7		VL1218
8	Pelagic fisheries	VL1012
9		VL1218
10		VL24xx

The different segments are able to fish different métiers. A métier is defined by the kind of gear used, target species, mesh sizes, etc. An example is "Bottom otter trawl_Crustaceans-90-119_mix". In this métier, bottom trawling for crustaceans is performed using mesh sizes between 90 and 119 mm. Fishing in this métier generates a catch of Norwegian lobster and demersal fish species. The métiers are defined individually in six areas; The Baltic Sea (divided into 3 ICES-areas, see below), the Kattegat, the Skagerrak, and the North Sea. Bottom trawling for crustaceans, as in the example above, will generate a catch dominated of Norwegian lobster and cod (*Gadus Morhua*) in the Kattegat. The same fishing technique in Skagerrak, which is defined as a different métier, will generate catches of e.g saithe (*Pollachius virens*) and plaice (*Pleuronectes platessa*) as well. The same kind of fishing operation in the Skagerrak and the Kattegat is defined as two different métiers, and will thus have different catch compositions. In total 180 different métiers were used in the model.

In total, 41 different species are used in the catch compositions of the métiers. The catch composition in a métier reaches from single species fisheries to fisheries where the catch is a combination of up to 8 different species. In reality, in single species fisheries, some by-catches are unavoidable, but in the model, species constituting less than 1 % of the total catch value are excluded. In the Baltic Sea, large proportions of the herring and sprat landings are used for industrial purposes. The price is however, considerably lower for fish with such purposes than for fish sold for human consumption. In the model, sprat and herring were therefore handled separately depending on whether it was used for consumption or industrial purposes.

The fishery was modelled in 12 periods, each representing a month. Both catch composition and prices per species for the métiers were assumed to be constant over the year. The fishing periods were included to restrict the fishing activities to periods when fishing is either not allowed or when biological constraints prevent fishing. An example of the latter is the fishing for roe (e.g. vendace or lumpfish), which only takes place during spawning season.

4.3 Model restrictions

Specific restrictions implemented in the model for this particular study were physical and market features constraining the fishery. Fishing for crustaceans in Kattegat and Skagerrak is more profitable for small-scale than for large-scale trawlers. However, small vessels are bound to stay closer to the coast and cannot possibly catch the entire quota in a small area. Thus, in reality, all vessels cannot be small-scale while catching the quota. In the model, the fleet structure was therefore restricted in that the small-scale fleet could not expand unlimitedly. As a market restriction, vessels focusing on herring for consumption purposes in the Baltic were limited to the current fishery (catch). The Baltic herring has high levels of dioxin which imposes an EU restriction in the trade for human consumption. The herring might, however, be landed for national consumption.

4.4 Model input

Biological data used in this study were based on compulsory logbooks, coastal journals and sales slips collected in 2009 by the Swedish Board of Fisheries (since July 2011 the Swedish Agency for Marine and Water Management). Data on the costs of fishing were obtained from the economic statistics collected by the Swedish Board of Fisheries in fulfilment with EU data collection regulations (Council Regulation (EC) 199/2008, Commission Regulation (EC) 665/2008 and Commission Decision (EC) 949/2008). All data in the model were based on statistics from 2009. The statistics included the costs of fuel, maintenance, and other variable costs. Variable costs differed among métiers, and fishing operations within a segment therefore had different variable costs depending on gear, target species, etc. Labour costs were assumed to be at the wage rate in alternative employment, except for the owner of the vessel who was assumed to have no alternative employment.

Fixed costs were calculated at a segment level based on the average insurance value of the vessels in the segment. They consisted of a yield requirement on capital investment (6%) and direct depreciation of the vessel's value over 20 years.

Details of species specific landing prices were collected by the Swedish Board of Fisheries. The prices were assumed to be exogenously derived, as the Swedish catches make up a small part of the world market, i.e. the quantity landed did not affect the price received by the fisher. The prices were assumed to be identical within a métier during the period when the métier could be operated, but varied among métiers. The reason for this is that different fishing methods result in catches of different quality, size, etc. and thus of different value.

5 Scenarios

5.1 General background

The economic benefit of different stock levels is dependent on the efficiency of the fisheries management system in place. In an open access fishery, the long term profit is expected to be zero, while an optimal management system might generate considerable profits. In this analysis we assumed that Sweden has implemented a system with ITQs in all fisheries. Sweden introduced ITQs in the pelagic fishery in 2009 and several proposals for an extension of the system have been made on a national level (Swedish Board of Fisheries, 2010; SOU, 2010:42) in addition to the EU commission`s proposal for a mandatory EU regulation with tradable fishing concessions (EU Commission, 2011), supported by the Swedish government (Landsbygdsdepartementet, 2012).

The analysis contains four scenarios with different quota levels for cod, herring and sprat. The quotas are based on biological considerations and are not developed to maximize the long run economic performance. As an example, the F_{MSY} scenario maximizes the sustainable catch, but this does not imply that it is the most economically profitable fishing mortality.

One assumption in all scenarios is that the catch per unit of effort (CPUE) is assumed to be equal independent of stock size. The main reason for making this assumption is that the relationship between stock size and CPUE is not straight forward. Cod has for example been shown to hyperaggregate when stock size is decreasing (Rose and Kulka, 1999) resulting in increased CPUE. The catch process for pelagic fisheries (i.e. sprat and herring fisheries) is divided into two distinct events. The first is the search event, were the fishing vessels actively are searching for schools of fish. Once the fish are detected, the trawls are set and the catch is taken. The search process is usually by far the most time consuming and varying (ranging from hours to days). Vessels may further help each other out to find the schools. The CPUE is thereby not only affected by the amount and behaviour of the fish but also on the behaviour of the vessels. It is thereby difficult to predict how the CPUE will change with different stock sizes. We have therefore in our scenarios assumed that CPUE is independent of stock size.

5.1.1 Baseline ITQ Scenario

A baseline scenario was constructed based on available information regarding how ITQs may be implemented in Sweden. The baseline thus represents how the fishery would perform in an ITQ system and the current (2009) mix of cod and clupeids. The biological scenarios discussed below represent possible future states of the ecosystem (based on experiences from history) and these are compared to the baseline in order to get information regarding the economic effects of fishing in an ecosystem with alternative stock levels. In the baseline scenario Swedish quotas for cod (10,375 tonnes), herring (48,032 tonnes), and sprat (76,270 tonnes) were used (Table 6), representing 23, 33 and 19 per cent of the total TAC respectively.

5.1.2 Scenario of a fishery at maximum sustainable yields

The International Council for the Exploration of the Sea (ICES) MSY framework for advice uses both fishing mortality and biomass reference points, F_{MSY} and MSY $B_{trigger}$. F_{MSY} is the fishing mortality that will maximize average yield in the long term. The MSY $B_{trigger}$ is a biomass reference point that triggers a cautious response when stocks fall below a certain trigger level (ICES, 2012). In this scenario, we simulated the exploitation of cod, sprat and herring in the Baltic at a level of F_{MSY} and modelled the economic outcome of the resulting Swedish quotas from the simulation. See Appendix 1 for a further description.

For cod, there is a management plan in place, allowing increases up to 15 % of the cod quota each year as long as the fishing mortality is below F_{MSY}. The implementation of the cod plan has also been applied in this scenario. The Swedish quotas and fishing mortalities at F_{MSY} for the different species are found in Table 6 and 5.

Table 5. *Fishing mortalities at F_{MSY} for cod, herring and sprat (from ICES 2011).*

	Cod	Sprat	Herring
F_{MSY}	0.30	0.35	0.16

5.1.3 Scenario of a fishery in a cod or sprat dominated ecosystem

The TACs used for the scenarios with a high cod level (HighCod) and a high sprat SSB level (HighSprat) respectively, were based on the findings by Casini et al. (2009). They identified two different ecosystem configurations in the Baltic Sea using time series data from four different levels in the food web (cod, sprat, zooplankton and phytoplankton) in 1974-2006. A cod dominated phase existed during 1978-1988, and is described as a system with a high abundance of cod, low abundance of sprat, high abundance of zooplankton and a low abundance of phytoplankton. In 1992-2006, on the other hand, the ecosystem was characterized by low cod and zooplankton abundances, and high sprat and phytoplankton abundances (Casini et al, 2009).

We used averages of historical Swedish quotas for all three species during the cod dominated period in 1978-1988 and the sprat dominated phase 1992-2006, respectively (Table 6).

Table 6. *Swedish quotas in tonnes for ICES areas 25-29+32 for cod and herring, and ICES areas 22-32 for sprat.*

Scenario	Cod	Sprat	Herring
Baseline (2009)	10,375	76,270	48,032
F_{MSY}	21,238	51,900	27,809
HighCod	34,719	3,964	56,581
HighSprat	16,066	109,700	45,553

6 Results

In the presentation of the results we show four model runs following the scenarios. The first run represents a Swedish ITQ system used as the baseline scenario and the second represents the F_{MSY} scenario. The other two scenarios were undertaken to investigate the economic consequences of fishing in an ecosystem dominated by sprat (scenario HighSprat) or cod (HighCod), respectively.

6.1 Baseline ITQ scenario

In table 7, we present the economic performance and the fleet structure for the actual fishery in 2009 (only including vessels defined as active) and for the baseline scenario. The fishery is presented as 10 segments based on gear and length of the vessels.

Table 7. *Fleet structure and economic performance in 2009 and baseline ITQ system.*

Gear	Vessel length category	N^o vessels 2009[1]	N^o vessels Baseline
Demersal trawl	VL1012	36	30
	VL1218	83	35
	VL1824	58	28
	VL2440	28	1
Passive gear	VL0010	296	273
	VL1012	110	81
	VL1218	16	5
Pelagic	VL1012	24	36
	VL1218	10	0
	VL24xx	29	17
Total		690	506
Profit (MSEK)		175	436

1 The number of vessels 2009 does not contain less active or non-active vessels.

In an ITQ system, the economic profit would increase considerably as compared to the 2009 fishery, from SEK 175 million to SEK 436 million, due to structural adjustments in the fishery. Due to current excess capacity the fleet was reduced from 690 vessels to 506, still maintaining a majority of the performed days at sea. ITQs were introduced in the pelagic system in the autumn of 2009 so this fishery had an on-going structural change in the modelled period. The model estimated that 17 large scale vessels were maintained in the fishery, and in 2011 the fleet consisted of 20 vessels. The smaller pelagic vessels are primarily fishing for vendace, which is a separate management system. The small-scale fisheries using passive gear was reduced from 422 to 359 (15%), while the demersal trawls were reduced from 205 to 94 vessels (54%). The latter resulted in a considerable reduction in capacity, which was expected since demersal trawling was the segment in which the bulk of Swedish excess capacity was present.

6.2 Scenario FMSY

In the F_{MSY} scenario the cod quota was greater and the sprat and herring quotas lower than the quotas in the baseline (see Table 7). In Table 8, the F_{MSY} and baseline scenarios are compared.

Table 8. *Fleet structure and economic performance in scenario F_{MSY}.*

Gear	Vessel length category	N^o vessels Baseline	N^o vessels F_{MSY}
Demersal trawl	VL1012	30	29
	VL1218	35	35
	VL1824	28	41
	VL2440	1	1
Passive gear	VL0010	273	269
	VL1012	81	141
	VL1218	5	5
Pelagic	VL1012	36	36
	VL1218	0	0
	VL24xx	17	12
Total		506	569
Profit (MSEK)		436	491

In In the F_{MSY} scenario, both the number of vessels and the total profit increased compared to the baseline. Segments using demersal trawls and passive gear increased due to the large cod quota, while the large-scale pelagic segment decreased due to low pelagic quotas. In total, the increase in the demersal and passive segments outweighed the losses in the pelagic segments, both in the number of vessels and economic performance.

6.3 Scenario HighCod

In scenario HighCod the cod quota was set at 34 thousand tonnes while the sprat quota was only about 4 thousand tonnes. This deviated considerably from the 2009 situation which has implications for the fishing possibilities. More specifically, the low sprat quota limited the pelagic fisheries since these stop in the model when the quota for one of the target species is fished. Therefore, the HighCod scenario was modelled as a situation where the pelagic fleet could target herring without by-catches of sprat in the eastern Baltic. This is motivated by the low abundance of sprat in the scenario, and applied to two métiers in the pelagic segment for VL24XX. In 2009 these métiers were used for the vast majority of the Swedish catches of sprat and herring in the area. The baseline scenario is included as a point of reference.

Table 9. *Fleet structure and economic performance in scenario HighCod.*

Gear	Vessel length category	N^o vessels Baseline	N^o vessels HighCod
Demersal trawl	VL1012	30	33
	VL1218	35	34
	VL1824	28	44
	VL2440	1	11
Passive gear	VL0010	273	243
	VL1012	81	216
	VL1218	5	5
Pelagic	VL1012	36	36
	VL1218	0	0
	VL24xx	17	10
Total		506	631
Profit (MSEK)		436	554

The economic performance of the fishery increased from SEK 436 million (in the baseline scenario) to 554 million, and the number of vessels increased from 506 to 631 (Table 9). This was due to the increased cod stock. As shown in table 9 the number of demersal trawlers category VL1824 and vessels using passive gear increased, while the large scale pelagic trawlers decreased. The latter was due to reduced pelagic quotas.

6.4 Scenario HighSprat

In scenario HighSprat, the cod quota was 16 thousand tonnes, the sprat quota 109 thousand tonnes, and the herring quota 45 thousand tonnes. As was the case in scenario HighCod, changes to the species mix in two métiers were necessary to catch the quota. A high sprat quota generated an additional complexity to the modelling, since the sprat sold for consumption purposes was limited by the small current market for direct consumption of sprat. Thus, the fishery had to adjust to a higher share of industrial sprat in order to catch the quota. In Table 10 we present results where 72% of the catch was assumed to be sprat (i.e. the total catch per unit of effort was the same, but the share of sprat increased from 63 %), and that 85 % of the sprat was assumed to be caught for industrial purposes (see section 6.5 for a discussion).

Table 10. *Fleet structure and economic performance in scenario HighSprat.*

Gear	Vessel length category	N^o vessels Baseline	N^o vessels $S2_{flexible}$
Demersal trawl	VL1012	30	30
	VL1218	35	35
	VL1824	28	35
	VL2440	1	1
Passive gear	VL0010	273	273
	VL1012	81	112
	VL1218	5	5
Pelagic	VL1012	36	36
	VL1218	0	0
	VL24xx	17	22
Total		506	549
Profit (MSEK)		436	464

In the HighSprat scenario, the number of vessels increased by 43 compared to the baseline, and the economic performance increased from 436 to 464 MSEK. This was largely due to an increase in the cod quota compared to the baseline scenario.

6.5 Sensitivity analysis of baseline scenario

While the landings and prices were calculated for each métier, the costs were only available at the segment level. In this section we performed a sensitivity analysis of how the model results would change with respect to changes in the variable costs. The starting point was the baseline ITQ scenario. The sensitivity analysis was outlined as the proportional changes to the variable costs in five model runs: -40 %, - 20 %, baseline, +20 %, and +40 %. The number of vessels that used active and passive gear at the different settings as well as the total fleet and profit are presented in figure 1.

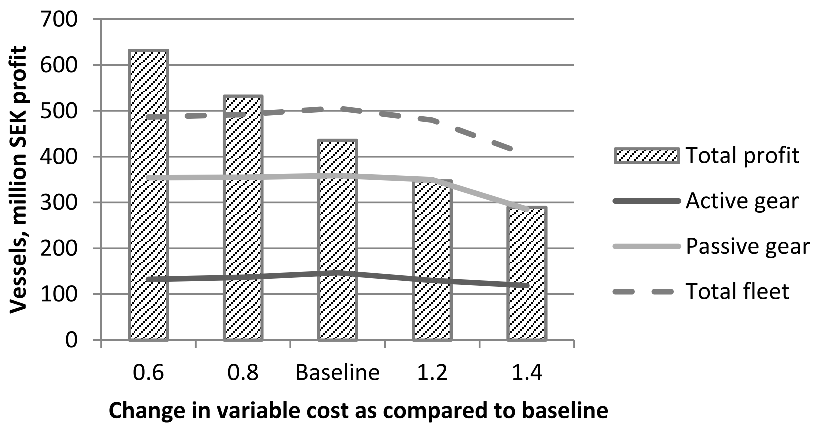

Figure 1. *Sensitivity analysis with respect to variable costs.*

In In the baseline scenario, the total fleet was 506 vessels and the total profit SEK 436 million. As expected, increasing costs resulted in lower profits and decreasing cost in higher profits. An increase in costs further implied fewer vessels, especially vessels using passive gear. This was because some fisheries became unprofitable. Lower costs also implied fewer vessels, although marginally. The fishery could not expand even if the costs were lower due to the quota restrictions, and the number of vessels was slightly reduced due to some reallocations of fishing activities among the active vessels.

A large share of the sprat and herring quota was caught in two pelagic métiers which both have a fixed amount of herring and sprat per fishing day in the baseline scenario. In the scenarios HighCod and HighSprat the quotas changed considerably compared to 2009. When, as in the HighCod scenario, the sprat was at a very low level the quota was filled in a few days. This stopped the pelagic fishery also for herring since it was not possible in the model to catch herring without a by-catch of sprat. In the analysis in sections 6.3 and 6.4, we assumed that it is possible to change the species mix in the pelagic métiers. Below, we perform a sensitivity analysis of this assumption.

In the HighCod scenario, the assumption that it was possible for the large scale pelagic fleet to catch herring without by-catch of sprat generated an additional 6 large scale pelagic vessels and an additional profit of SEK 28 million, compared to a model run without this assumption. The reason for this is that the assumption made it possible for the vessels to catch the profitable herring quota. The utilization of the herring quota in the HighCod scenario was highly dependent on the mix of herring and sprat in the catches in relevant métiers. In figure 2, the line shows the share of herring quota being fished with different shares of herring in the catch. The bars show the contribution margin (revenues (R) minus variable costs (VC)) for the pelagic fisheries in the eastern Baltic Sea (ICES areas 25-29+32).[1]

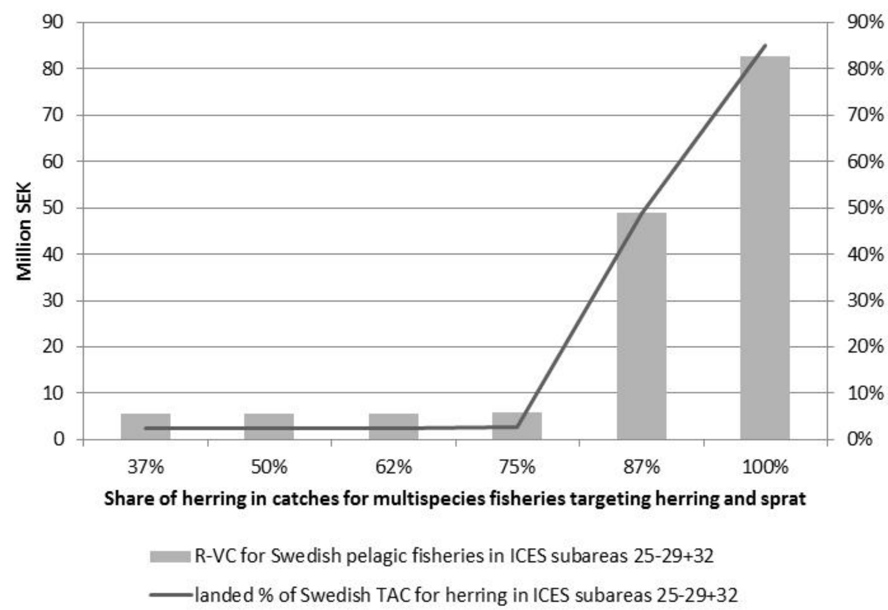

Figure 2. *Contribution margin and landed share of Swedish herring quota for different catch compositions.*

In 2009, 37 % of the catch in the métiers consisted of herring and with this species mix only a few percent of the herring quota were fished in the HighCod scenario (some trawling and the small-scale coastal quota caught with gill-net). Revenues minus variable costs were SEK 5.6 million. Increasing the share of herring in the

[1] We do not use profits since the Baltic fishery is only part of the vessels activities and for calculating profits we would need to define a rule for allocating fixed costs among activities.

catch to 87 % generated a utilization rate of about 50 %, while a pure herring fishery in these métiers generated a utilization of about 85 % of the herring quota. If 75 % or less of the catch per unit of effort in the large-scale pelagic fleet consisted of herring it was not profitable enough for these vessels to fish for other than small volumes of consumption fish in the eastern Baltic due to the low sprat quota limiting catches. This explains the low catch volumes to the left in figure 2.

In the HighSprat scenario, neither the sprat nor the herring quotas were fully utilized when using the species mix in the baseline scenario, due to the modelled restriction on sprat for consumption. The total profit was SEK 469 million in this case. In order to get a utilization rate of (almost) 100% for both herring and sprat, the fishery needed to be able to change the species mix such that 72 % of the catch would be sprat, and 85 % (as compared to 75 % in 2009 observed catches) of the sprat would be caught for industrial purposes. This is the case modelled in the scenarios above. In figure 3 the line shows the utilization rate of the sprat quota dependent on the share of sprat caught for industrial purposes. The bars represent the contribution margin.

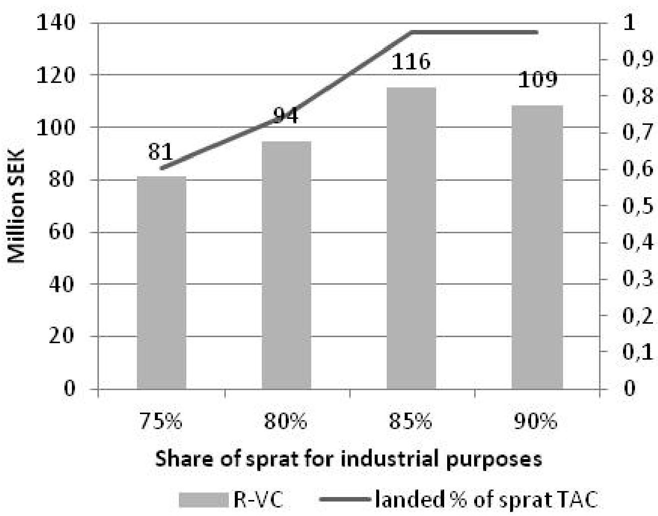

Figure 3. *Economic performance and utilization rate of the sprat quota.*

The analyses revealed that the sprat quota was fully utilized when the share of sprat for industrial purposes reached 85 % and this also generated the greatest contribution margin. With a larger share of industrial sprat the total value of the fishery decreased, since this assumption implied that some fish that could have been sold as high valued consumption fish was sold for industrial purposes. This is not an economically realistic situation and therefore we assumed 85 % in the main analysis.

7 Discussion

The results for all scenarios are summarized in figure 4. The number of vessels for demersal trawl, passive gear and pelagic fisheries are presented separately, and below each scenario the total profit and total number of vessels for the sector are shown.

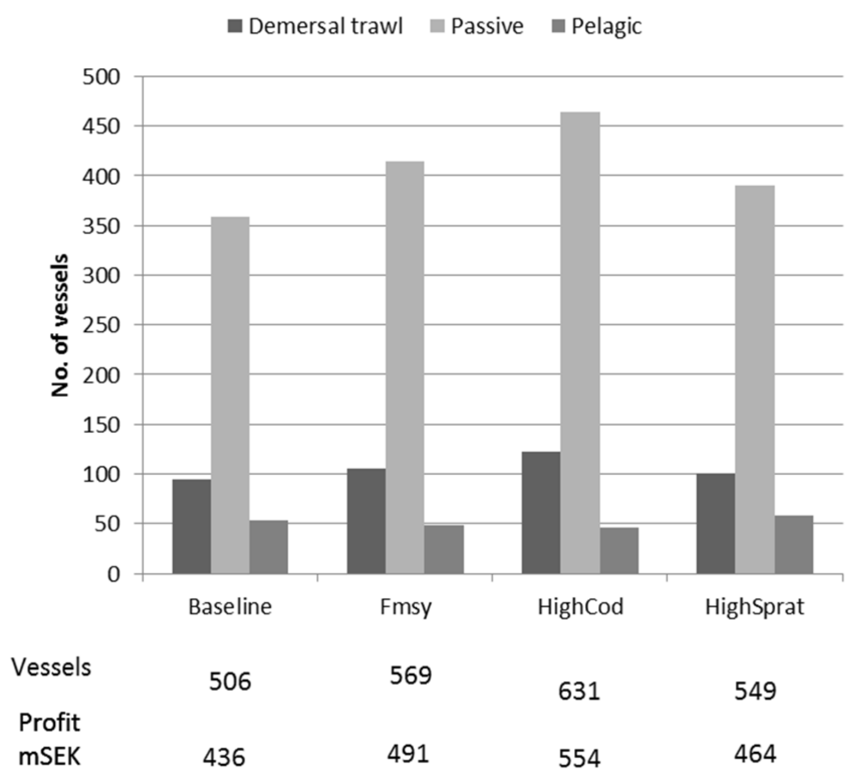

Figure 4. *Number of vessels and profits.*

The baseline scenario is modelled as an ITQ-system with 2009 quotas. The scenario generated 506 vessels and a total profit of SEK 436 million. This is a decrease in capacity and an increase in profitability as compared to the current management system. The majority of the vessels in the baseline scenario were small scale using passive gear, but the fleet also contained about 150 trawlers fishing for both demersal and pelagic species.

A considerable capacity reduction and increased profits of implementing the ITQ system are in line with the results in Waldo and Paulrud (2013b) who analysed this system for Swedish demersal fisheries, as well as in Steinshamn (2005) for Norwegian fisheries, and Andersen et al (2010) for Danish fisheries. The number of pelagic vessels in the baseline scenario was in line with the current number of vessels in the pelagic ITQ system. The segment for vessels using passive gear had the lowest capacity reduction. This was expected since many of these vessels (but not all) had quotas enough to utilize their capacity in the current management system. The economic profits in our analyses were derived in an ITQ-system where profits were maximized. With a less economically efficient system the profits are expected to be lower. In the Baltic fishing nations, ITQs are in place in Denmark and Estonia.

Both the profit and the size of the fleet increased when the TACs were determined according to the F_{MSY} approach. The economic gain compared to the baseline scenario was about SEK 55 million, and the fishery supported a fleet of 569 vessels of which more than 400 were small-scale. There were some ecosystem considerations made in the F_{MSY} calculation of herring and sprat, through the influences of cod spawning stock biomass on the natural mortality of herring and sprat. There were, however, no effects of sprat and herring on cod growth or natural mortality, or on any other levels in the ecosystem that may through feedback mechanisms affect herring, sprat or cod stock sizes and thereby sustainable TAC levels. Thus, there is a possibility that the TACs levels determined based on the F_{MSY} used here would have been different if the effects of species interactions would have been accounted for. Performing further analyses as this information becomes available are important.

In addition to the F_{MSY} scenario and the baseline scenario, which reflects the current state of the ecosystem, we have analysed two states of the ecosystem where either cod (HighCod) or sprat (HighSprat) was the dominant species. The HighCod scenario could sustain a fleet with 631 vessels and a total profit of SEK 554 million. The HighSprat scenario sustained a fleet with 549 vessels and a total profit of SEK 464 million.

The stock level combination of sprat, herring and cod in the HighCod scenario generated the largest fleet and the highest total profit of all scenarios. The profit was based on a high cod stock but a sprat stock that may be below biologically safe limits. Thus, the high economic profit could in the worst case jeopardize the biological sustainability of the ecosystem. Moreover, a sprat stock collapse will have negative effects on the cod stock since cod feed on sprat, and thus the economic sustainability of the system may be jeopardized as well. In the F_{MSY} scenario all stocks were fished at a maximum sustainable yield and were thus biologically viable in the long run. However, the result showed that increasing the cod fishery at the expense of sprat fisheries was profitable, e.g. by utilizing the sprat as food for cod rather than for yield in fisheries.

The results are derived assuming constant CPUE which means that all scenarios have the same CPUE as the baseline scenario regardless of the fish abundance.

The baseline scenario had the lowest cod stock, which implies that if CPUE increases with fish abundance the economic profits in the cod fishery is under-estimated in the scenarios. The sprat and herring stocks are more stable over the scenarios, and the effect on CPUE is expected to be small in fisheries with schooling fish (Bjørndal, 1987) In the HighCod scenario where the sprat stock was very low the species mix in pelagic fisheries was changed to reflect the low abundance. In summary, taking additional effects on CPUE into account is expected to primarily result in an increase in the profitability of the cod fishery in all scenarios except the baseline, while pelagic fisheries would be less affected.

The economic calculations were based on the Swedish fishing on a shared resource and we acknowledge that the economic consequences might deviate from other countries. The large benefits from a cod dominated ecosystem in the Swedish fishery are due to a tradition of cod fisheries. Other fishing nations, especially in the eastern part of the Baltic, have a tradition of herring fisheries and might thus make an economic loss in a cod dominated system compared to a sprat dominated one. Also, changes in the ecosystem will affect the distribution of economic benefits within the Swedish fishery. For example, in the HighCod scenario the number of pelagic vessels decreased substantially compared to the baseline scenario.

In this analysis we show how different states of the Baltic ecosystem could affect the economic performance of the Swedish fishing fleet. Single stock management decisions will have economic effects. EU’s cod management plan (Council Regulation (EC) 1098/2007) is for example, changing the state of the ecosystem in a direction where we expect economic profits to increase for the Swedish fleet. However, profits might not increase for all segments or for all Baltic countries.

8 Conclusions

The aim of this study was to compare the economic profitability for the Swedish fisheries sector when fishing in three different ecosystem states of the Baltic Sea. Each state represented a unique composition of the three main species caught: Cod, herring and sprat. The main conclusions were:

- It was more profitable to fish the three species at F_{MSY} than at the current utilization levels.
- The economic profitability could be increased further by up to 118 MSEK per year by increasing the cod stock at the expense of reducing sprat abundance. These effects rely on all stocks being fished at sustainable levels.

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Appendix 1 - Fishing levels at FMSY

To obtain correct estimates of the total allowable catch (TAC) of cod, herring and sprat exploited with a fishing mortality in accordance with F_{MSY}, a software used by the ICES working groups was used, Multi fleet deterministic projection (MFDP). This software was developed for computing short term forecasts with different management options, i.e. increases or decreases in the catches.

The basic data required for the short term catch predictions are:

1) Starting population numbers and fishing mortalities derived from catch-at-age stock assessment analyses from ICES (2013).
2) Estimates of weights at age, natural mortality, maturity at age.
3) Estimates of recruitment during the prediction period, which may be available externally or from stock-recruitment relationships.

The primary output from the forecast program is estimates of yield (landings), fishing mortalities and spawning stock biomass (SSB) and total biomass for the intermediate and final year.

There are some top-down ecosystem effects included in the F_{MSY} calculation of herring and sprat. This is manifested in a in a positive relationship between cod SSB and the natural mortality (m) of sprat and herring (Fig. A1:1.), i.e. reflecting the predation of cod on these species. There are however, no positive or negative effects of sprat and herring on cod growth or natural mortality modelled in MFDP.

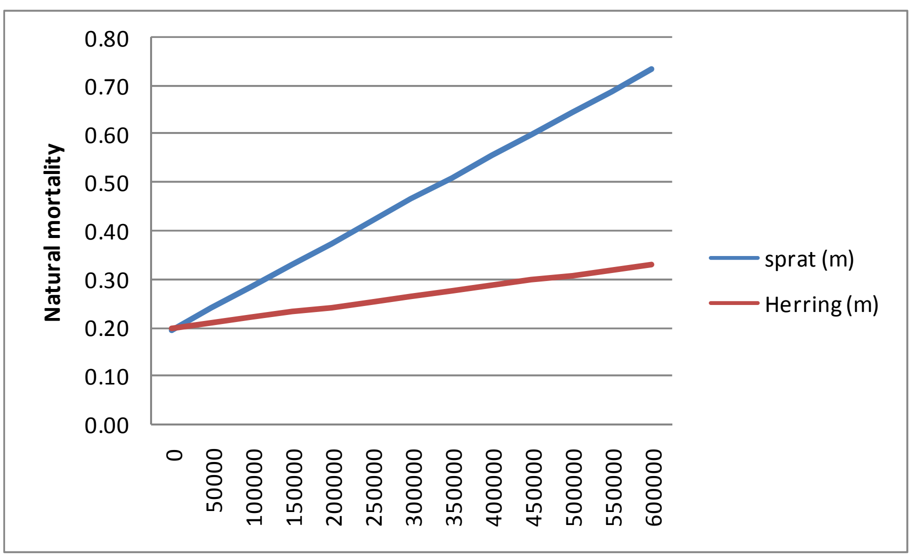

Figure A1:1. *The correlation between cod spawning stock biomass (SSB;x-axis) and natural mortality (m) of sprat and herring.*

The data described in point 1 to 3 above, available from the ICES Baltic Fisheries Assesment Working Group (WGBFAS; ICES 2013) for the assessment 2011 of cod in subdivision 25-32, herring in subdivision 25-29, and sprat in subdivision 22-32, were used in order to calculate the landings and subsequent Swedish quotas of cod herring and sprat for the years 2011 to 2015.The 5 year forward projection follows the short term projection standards in ICES working groups. The settings of the parameters for the simulations of cod, herring and sprat are the same as those used in the simulation of these species in ICES 2011, with the exception of the cod SSB dependent natural mortalities of herring and sprat.

The starting species of the simulation was cod, as the resulting cod SSB would affect the natural mortality and thus the outcome of the simulation of sprat and herring. Table A2:1 shows the outcome of the simulation when the quota of cod increases each year by 15 %.

Table A1:1. *Spawning stock biomass (SSB), Total allowable landings (TAC) and fishing mortality (F) for the years 2011-2015 of cod in the Baltic Sea.*

Year	SSB (tonnes)	TAC (tonnes)	Fishing mortality (4-7)
2011	308787	64457	0.21
2012	368241	74125	0.22
2013	405919	85243	0.26
2014	416243	96486	0.30
2015	407708	84951	0.28

The simulated values of cod SSB were then used to calculate the natural mortalities for sprat and herring (Fig. A1:1).These were then introduced in the simulation together with the restriction that the fishing mortality would be equal to F_{MSY}. The results of the simulation of sprat and herring are shown in Table A1:2 and A1:3. Note that the sprat biomass and landings decrease even when they are fished at F_{MSY} since the increase in natural mortality (due to the increase in cod SSB) is extensive.

Table A1:2. *Baltic Sea herring. Natural mortality (m), spawning stock biomass (SSB), total allowable quota (TAC) and fishing mortality at maximum sustainable yield (FMSY; ICES 2013) for the years 2011-2015 .*

Year	Natural mortality (m)	SSB (tonnes)	TAC (tonnes)	Fishing mortality (3-6)
2011	0.27	538686	79567	0.16
2012	0.28	537149	81768	0.16
2013	0.29	546086	83062	0.16
2014	0.29	555328	85607	0.16
2015	0.29	563736	85059	0.16

Table A1:3. *Baltic Sea sprat natural mortality (m), spawning stock biomass (SSB), total allowable quota (TAC) and fishing mortality at maximum sustainable yield (FMSY; ICES 2013) for the years 2011-2015.*

Year	Natural mortality (m)	SSB (tonnes)	TAC (kilotonnes)	Fishing mortality (3-5)
2011	0.47	726	239	0.35
2012	0.53	621	208	0.35
2013	0.56	565	187	0.35
2014	0.57	524	181	0.35
2015	0.56	502	173	0.35

Finally, the Swedish share of the total TAC was calculated using the average proportion of Swedish quotas of the total TAC over the years 1991-2010 (Table A1:4).

Table A1:4. *Swedish quotas for the years 2011-2015 of sprat, cod and herring.*

Year	Sprat (tonnes)	Cod (tonnes)	Herring (tonnes)
2011	71700	16114	25461
2012	62400	18531	26166
2013	56100	21311	26580
2014	54300	24122	27394
2015	51900	21238	27809

Appendix 2 - Sprat Reduction

In addition to analyzing the different states of the ecosystem as presented in the main text, we also performed a sprat reduction scenario. The aim with the scenario was to estimate the economic costs and benefits of an intensive fishery on sprat with the aim of changing the state of the ecosystem to the advantage of the cod stock. That is, we assume that by reducing the sprat stock we would "unlock" the current sprat dominated ecosystem state by decreasing the negative impact that sprat has on cod, and thus improve the conditions for the cod.

In the reduction scenario (SpratRed) we used the quotas of cod and herring from 2009. For sprat, we used the highest amount of sprat fished in the period 1992 to 2006 by the Swedish fishing fleet (150,000 tonnes). The scenario is presented in Table A2:1.

Table A2:1. *Swedish quotas in tonnes for ICES areas 25-29+32 for cod and herring, and ICES areas 22-32 for sprat.*

Scenario	Cod	Sprat	Herring
SpratReduction	10,375	150,000	48,032

In the scenario it was important to catch the entire sprat quota since it aimed at simulating a sprat reduction fishery. In order for the quota to be caught at maximum economic benefit as much as possible of the catch should be sold for consumption purposes. This is obtained where 77 % of the catch per effort is sprat (63 % in baseline) and 91 % of the sprat is caught for industrial purposes (75 % in baseline). The results are presented in Table A2:2.

Table A2:2. *Fleet structure and economic performance in scenario SpratRed.*

		Nº vessels	
Gear	Vessel length category	**Baseline**	**SpratReduction**
Demersal trawl	VL1012	30	30
	VL1218	35	25
	VL1824	28	35
	VL2440	1	1
Passive gear	VL0010	273	273
	VL1012	81	81
	VL1218	5	5
Pelagic	VL1012	36	36
	VL1218	0	0
	VL24xx	17	27
Total		506	513
Profit (MSEK)		436	421

In this scenario, we ‘forced’ the vessels to catch a higher share of sprat for industrial purposes with the aim of catching the entire quota. The consequence of this was that the fishery was less profitable than if they fished according to the quotas in the baseline scenario. The only change in the quotas was the higher sprat which was not accompanied by higher abundance since the scenario was based on the 2009 stock levels. Thus, our results show that the baseline fishery is possible, and would most likely be preferred by the industry due to a higher profit. The SEK 15 million in profit reduction from the baseline scenario to the SpratRed scenario was thus due to the increased sprat fishing in order to reduce the quota and could be viewed as the annual cost of the sprat reduction program.

Some of the herring is caught with demersal trawl, and in the SpratRed scenario, the high quotas affected the demersal fleet as well. Increased fishing for herring using trawlers 18-24 meters, in combination with cod fishing, increased this segment on the expense of demersal trawlers 12-18 meters.

The scenario showed some interesting results. First, using the same mix of landings of herring and sprat for the major métiers as in the baseline scenario the sprat quota was not caught. To be able to catch the entire quota, it was necessary for the pelagic fishery to be able to flexibly alter their fishing behavior regarding both the species mix and the share of individuals caught for industry vs. consumption. We do not evaluate the ability of the pelagic fishery to do this, but assumed that it was possible to alter the behavior. In the SpratRed scenario, 10 pelagic vessels were required to catch the additional quota available compared to the baseline quota. However, the total profit from the sector was reduced by SEK

15 million. Thus, the analysis showed that it is more profitable to have a high share of herring and consumption fish in the catch than to utilize the entire quota. The reason for this is that the revenues minus variable costs from the sprat reduction fishery did not cover the capital costs of the vessels. That catches for consumption are more valuable than quota utilization could explain the underutilization of the Baltic sprat quota over the past few years. Swedish fisheries have utilized 93 % of the Swedish total quota for 2006-2009, while the average utilization of the total TAC for Baltic sprat has been about 86 % (ICES, 2011).

The cost for reducing the sprat stock was SEK 15 million per year, i.e. the decrease in profit between not catching the entire sprat quota and catching it. Reducing the sprat stock to a level at which the low level would persist, due to the feedback mechanisms resulting from an increased cod stock (sensu Anon 2008), might, however, take several years. We have not estimated the entire reduction process due to the lack of knowledge about the short-term effects of the reduction on herring and cod. Thus, we cannot predict the TACs for these species for the entire process. However, both the HighCod and F_{MSY} scenarios have a considerably higher economic profit per year than the baseline scenario; SEK 118 million for HighCod and SEK 55 million for F_{MSY}. In an equilibrium scenario, these profits would remain over the years and could consequently motivate a multiannual sprat reduction program if the present value of the additional profits exceeds the present value of the costs. We calculated the net present value using a 4 % discount rate. The cost for reducing the sprat was SEK 15 million annually for five years, and in year six, the cod stock was assumed to be recovered so that it could be fished at F_{MSY}, and in the calculation this lasted for a total of 15 years. Under this assumption the sprat reduction would generate a net present value of about SEK 400 million, i.e. the investment is highly profitable. The fishing effort spent on sprat reduction is a short run activity and if idle capacity would be available for fishing, a positive contribution margin (revenues minus variable costs), which we have, would be sufficient to motivate the fishers to undertake the activity. That is, with idle capacity the fishery does not need to cover the fixed costs but only the variable costs for the fishery to be economically viable in the short run. Fishing capacity could in theory be made available by utilising the current excess capacity in the fleet to catch the quota. The costs are based on the average vessel, but the Swedish fishery contains vessels predominantly fishing for industrial purposes, thus being able to fish sprat more efficiently than the average vessel used in the model estimates (i.e. the cost for reducing the stock would be lower than calculated). However, the specialized vessels might not be able to expand their effort enough to catch 150 thousand tonnes. In this case, vessels that are less cost-efficient will need to be active in the reduction fishery. Another alternative would be to use vessels that have recently left the fishery. The Swedish pelagic system was recently restructured, with a capacity reduction from 80 vessels to about 20. Some of these vessels may be available to reduce the sprat stock.

References:

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