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Staffan Waldo
Anton Paulrud
Johan Blomquist

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Staffan Waldo[1)], Anton Paulrud[2)], Johan Blomquist[3)]

1) Swedish University of Agricultural Sciences (SLU), Department of Economics, AgriFood Economics Centre. PO Box 730, SE 220 07 Lund. Corresponding author, e-mail Staffan.waldo@slu.se.
2) Swedish Pelagic Federation. Fiskebäckshamn 42, SE 458 48, Västra Frölunda.
3) Swedish University of Agricultural Sciences (SLU), Department of Economics, AgriFood Economics Centre. PO Box 730, SE 220 07 Lund.

Abstract

Growing seal populations are often considered being an example of successful marine management, and the seals are seen as a symbol of a thriving eco-system. However seals are well-known to interact with local small-scale fisheries by feeding from the gears. This causes both lost catches and broken gear which negatively affects the economic viability of the sector. While lost catches are known to be substantial, no information is currently available on costs for mending gear, searching for fishing grounds with less seals, etc. This paper estimates these costs from a questionnaire sent to all Swedish fishermen. The total costs for small-scale fisheries is about € 690 thousand, which corresponds to 7 percent of the expenditure for purchased goods (not labor and capital). Total time spent on seal related work corresponds to about 8 percent of total working time. Combining additional costs with revenue losses due to decreased catches, the economic viability of the small-scale fisheries becomes low which might cause a reduction in fleet size.

Key words: Fisheries, seal

1. Introduction

Growing seal populations are often considered being an example of successful marine management, and the seals are seen as a symbol of a thriving eco-system. E.g. in the Baltic Sea, a seal management plan in the region has been developed under the umbrella of the Helsinki Commission (HELCOM), a governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. HELCOM (2006) proposes the seal management to have long-term objectives for seal population sizes to recover towards carrying capacity levels, for seals to expand to suitable breeding distributions in all regions, and for seals to attain a health status that secures the continued existence of the populations. However, the HELCOM also notes that seals causes catch losses and broken gear for the fishing industry. Indeed the Swedish management plan for grey seal (HaV, 2012) has the objective that the seal population shall have a favorable conservation status and that the impact on human interests should be neutral or positive. The former is considered fulfilled, while the latter is not.

Although the seal interactions are considered to affect the economic viability of fisheries negatively, there are few explicit economic analyses on the topic. An exception is Holma et al. (2014), who study seal interactions in the Finnish salmon fisheries in the Baltic Sea and find a significant negative impact. Economic viability is affected by seal predation in two ways: The first is increased *costs*, e.g. for working time and material for mending and replacing damaged fishing gear. The second is the *loss in revenue* due to seals reducing catches (decreased catchability). Catch losses could either be *visible* to the fishermen (e.g. in the form of half-eaten fish in the gear) or *hidden* from the fisherman (e.g. when the seal removes the entire fish from the gear, or scaring the fish away). A loss in revenue due to reduced catchability could also occur due to seals negatively affecting the stock size of target species (see Varjapuro (2011) for a discussion on the concepts within the seal-fisheries interaction).

In this paper the seal-fisheries interaction is analyzed using Swedish fishery as a case study. Swedish waters contain three species of seals; the ringed seal (*Phoca hispida*), the harbor seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*). The grey seal is the largest species and can grow to about 300 cm and reach a weight of 300 kg. It is also the largest seal population and contains about 40-50,000 individuals. The ringed seal is smaller (< 200 cm) and the population is located in the Northern and Eastern Baltic Sea. In 2014 about 10,000 ringed seals were counted in the Baltic, of which 8,000 were in the Bothnian bay (HaV, 2014). The harbor seal is primarily located on the Swedish west coast (about 15,000 counted seals in 2014) although a smaller population occurs in the Baltic Sea (HaV, 2014).

Two separate analyses are performed in this paper; a ‘vessel segment analysis’ containing economic information by vessel segment and a ‘gear analysis’ focusing on costs induced by seals when using different gear. The split into two analyses is of importance since seals interact differently with different gears, but few fishermen only use one type of gear. The *vessel segment analysis* focuses on different fishing practices (i.e. use of multiple gears by fishermen) and thus keeps the fishing company as the unit of analysis. The fishermen are categorized into vessel segments based on vessel length and primary target species. The analysis combines data on catch losses due to seals eating from nets with cost data on gear maintenance etc. due to seals in order to estimate the impact on economic viability. In the *gear analysis* the seal costs for each of the gear types used in Swedish fisheries are estimated which provides detailed information on the seal induced cost for all major gear types in all major Swedish fishing areas. Focus in both the vessel segment and gear analysis is on small-scale fisheries since seal interaction is almost exclusively focused on small-scale fisheries using passive gear.

This paper contributes to the literature by analyzing a questionnaire sent to all Swedish fishermen, where the respondents were asked to estimate their costs for both additional material and working time necessary for handling their seal interaction. This provides the first estimation of costs facing fishermen and thus contributes to the development of seal management plans that efficiently takes into account both seal conservation and human interests.

The paper continues as follows: Section 2 contains a discussion of the literature on seal-fisheries interaction. Section 3 describes Swedish fisheries and how the seal-fisheries interaction is managed in Swedish fisheries policies. Section 4 outlines the conceptual framework for how seals interact with fisheries and section 5 specifies the empirical strategies for the analyses. In section 6 the data for both the vessel segment analysis and the gear analysis is presented. Section 7 contains the results of the vessel segment analysis and section 8 contains the results for the gear analysis. Section 9 contains a discussion of the results and concluding remarks.

2. Previous literature

There exist a vast literature on seals containing e.g. feeding habits (Lundström et al., 2010), impact on cod recovery (Cook and Trijoulet, 2016; MacKenzie et al. 2011), development of seal proof gear (Königson et al., 2015; Hemmingsson et al., 2008) and possible management measures such as hunting and economic compensation (Varjopuro, 2011). Hansson et al. (2017) conclude in a survey of competition between fisheries and wildlife that the impact from seals (and birds) are primarily important in coastal fisheries while the impact on stocks of the commercially most important species cod, herring and sprat is limited. However, in this section focus is on the literature estimating the direct economic effects of seal predation.

Holma et. al (2014) develop an economic model with seal interaction for the Finnish salmon fishery in the Baltic Sea. By modelling both the development of seals and salmon over time, the authors show that there is a long-run economic justification for the claim that the fishing sector suffers significant economic losses due to seals. The net present value of the fishery approximately doubles in scenarios without seals. However, they also show that part of the conflict can be reduced by subsidies for investing in seal-proof gear. An interesting result from the analysis is that with a growing seal population, it is economically beneficial to increase effort in the first years of the period – i.e. fishing down the salmon stock before the seals get abundant enough to make the fishery less profitable.

A number of studies have estimated visible and hidden losses of fish from different gear due to direct seal predation. This includes Larsen et. al, (2015) studying Danish fisheries in both the North Sea and the Baltic Sea. In the North Sea two vessels documented their visible losses of cod to 6.4 % and 24.4 % of catches respectively, and in the Baltic Sea around the island of Bornholm estimated visible losses of cod and salmon ranged from 0 to about 20 % of catches.

Könignson et al (2009) estimate both the visible and hidden catch losses in a Swedish cod (*Gadus morhua*) fishery using gill-nets in the Baltic Sea. By marking cod in the nets and returning them to the fishing ground, the authors were able to quantify the number of cod removed by seal predation. In 2005 the hidden losses corresponded to 67 % of landed catch, and in 2006 they corresponded to 19 % for nets with seal interaction. The visible losses in the study were about 11 % of total catches (damaged and intact) on average. Adding hidden and visible losses, the total loss was 82.8 % and 26.5 % of landed intact catch for 2005 and 2006 respectively.

Könignson et al (2007) estimate both visible and hidden catch losses in Swedish herring (*Clupea harengus*) fisheries in the northern parts of the Baltic Sea (north of Stockholm). Official logbooks show that about 30 % of the fishing trips had seal interference, which the authors claim being underreported. Voluntary reporting suggests about 60 %. The catch per unit of effort was 61-88 % lower for trips where seals had been observed, and about 70 % of all marked fish that were planted in nets in a field experiment was eaten by seals.

Fjälling (2005) estimate both hidden and visible catch losses for salmon traps in the northern parts of the Baltic Sea (north of Stockholm). An average day with seal interference had about 47 % of the total catches of salmon (*Salmo salar*), sea trout (*Salmo trutta*) and whitefish (*Coregonus sp.*) compared to a day without seals.

Kauppinen and Suuronen (2005) study the interaction between seals and Finnish salmon fisheries (*Salmo salar*) in the northern Baltic Sea. Their estimation of visible lost catches ranges from almost nothing in some areas to 37 % of total catch in other. They also observed gear damages in between 2 and 17 % of the times the traps were emptied.

Varjapuro (2011) reports fishermen’s self-estimates of seal damages in the Finnish Kvarken region to be between 0 and 80 % of catches, with an average of 45 %.

The Swedish Agency for Marine and Water Management (2014) calculate the total loss in catches based on seal interaction reported in the fishermen’s logbooks and an assumption that the loss in a day with seal interaction is equal to the observed catch that day. This is based on Fjälling (2005) who found catches on days when seal are present to be about half that of days without seals. The SwAM estimates total seal damages per year to be approximately SEK 33 million (about € 3.5 million).

3. Swedish Fisheries

Swedish fisheries management is part of the EU's Common Fisheries Policy (CFP). As part of the CFP, Total Allowable Catches (TAC) is a corner stone in management together with e.g. capacity caps, gear restrictions and subsidies through the European Maritime and Fisheries Fund (EMFF). Swedish fisheries take place both in the Baltic Sea and outside the Swedish west coast in the North Sea, Skagerrak and Kattegat. Important species are cod (*Gadus morhua*), herring (*Clupea harengus*), sprat (*Sprattus sprattus*), North Sea shrimp (*Pandalus borealis*) and Norwegian lobster (*Nephrops norvegicus*). These are fished using either active gear (trawl/seine) or passive gear. Seals primarily interact with passive gear.

Passive gear contains a large set of different gears and fishing methods that will be used in the gear analysis below. Fyke nets (FYK) and stationary uncovered pound nets (FPN) are both fish traps that are primarily used for catching European eel (*Anguilla Anguilla*). Set gill-nets (GSN) and trammel nets (GTR) are anchored nets that are commonly used for demersal fish such as the Baltic Sea cod. Cod is also caught using long lines (LLS) in the Baltic where the baited line is left in the water for the cod to take the bait. Hand lines (LHP) and Troll lines (LTL) are baited lines that are mainly used for coastal fisheries of mackerel in Skagerrak and Kattegat. The lines are operated from the vessel and thus not left in the water for longer periods. Pots (FPO) are traps primarily used in the Kattegat and Skagerrak for catching Norwegian Lobster.

There are two sources of economic subsidies for seal interaction in Swedish fisheries. The first is provided as subsidized investments in seal proof gears within the European Maritime and Fisheries Fund (EMFF). By investing in seal proof gear, the idea is to reduce the damages made by seals. Seal proof gear is primarily possible to use in the salmon fishery where pontoon traps have been developed and are extensively used. For fisheries where seal proof gears are not yet developed, economic compensation for seal damages is provided by national funding. In total, SEK 15 million (about € 1.5 million) is provided annually. The compensation scheme is determined by regional fisheries authorities in collaboration with fisheries representatives. Thus, the compensation scheme will be different in different fishing regions. The allocation of funds from central authorities (SwAM) to the regional fisheries authorities is based on two measures: The region's number of reported fishing trips with seal damages in the logbook, and the total catch value of the fisheries with seal damages. Thus, a region with more reported seal damages and higher catch value will be allocated more funding.

4. Conceptual framework

4.1 Seals and economic profits

The conceptual framework is introduced to structure the effects of seals on the economics of the fishing sector. Equation 1 describes the profit function of the fishery

$$\pi = \sum_{i=1}^{I} p_i h_i(X_i, S) - VC(S) - VC - FC(S) - FC \qquad [eq\ 1]$$

π is the profit in the fishery, p_i is the price of fish for species *i*, $h_i(X,S)$ is the harvest for species *i* that depends on the fish stock (X_i)[1] and the seal population (S), VC(S) is the variable cost that is dependent on the seal population such as replacing and mending seal damaged gear, and VC is all other variable costs. FC(S) is the fixed cost from investments necessary due to seal predation and FC is other fixed costs. The price of fish is assumed to be exogenous and thus not dependent on seals.

The harvest (h) is expected to be negatively affected by the seal population and positively affected by the stock size, i.e. $\frac{\partial h(X,S)}{\partial S} < 0$ and $\frac{\partial h(X,S)}{\partial X} > 0$. Thus, seals eating fish from a net is not a cost in an economic analysis but a reduction in revenues calculated as the lost catch multiplied with the price of fish.

4.2 Total Economic impact of seal predation

The profit function in [1] shows the impact on profits by seals on the fishing company. Of course, some fishermen find it unprofitable to fish when seals are present and prefer exiting the fishery, $\pi < 0$ in equation 1. When estimating economic losses using fisheries data it is only those fishermen remaining in the fishery that are included. Some fishermen would have been profitable in a situation without seals and thus have generated an economic surplus which in the case of seal predation is unrealized. It is likely that the fishermen with highest seal impact will be the ones leaving the fishery.

The framework is summarized in table 1.

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[1] The stock size is not a function of seal abundance in this framework, but could theoretically be modelled as e.g. $X_i(S_j)$ if fish stock *i* is determined by seal species *j*.

Table 1. Economic impact of seal predation

Economic impact	Definition
Costs	All costs associated with seal predations such as mending and replacing fishing gear, including fishermen's time spent on gear maintenance. This could also include time and fuel spent on finding seal-free fishing grounds.
Revenue losses	Value of catch lost due to seal predation, i.e. lost catch multiplied with the price for fish.
Catch losses	
Visible	Catch lost that is visible to the fisherman, e.g. fish with bite marks.
Hidden	Catch lost that is not visible to the fisherman, e.g. fish completely removed from the net by seals and stock reductions due to seal predation.
Fishermen leaving the fishery	Fishermen that would be profitable without seal predation will leave the fishery if costs and catch losses are too high. These fishermen are not included in fisheries statistics.

5. Empirical Specifications

This section contains two parts. The first is the empirical specification of the vessel segment analysis. The second is the empirical specification of the gear analysis.

5.1 Vessel Segment Analysis

The vessel segment analysis starts from the conceptual model presented in equation 1 and table 1. The analysis includes the seals' impact on both revenues and costs for fleet segments. This enables calculations on the total economic effect of seals on Swedish fleet segments affected by seals.

In the empirical specification we use the value added (VA) and the contribution margin (CM) as defined in equations 2 and 3 below. The profit function from [eq 1] is not used due to data limitations on capital costs (see data section for a thorough discussion). The value added is defined as revenues minus purchased goods (i.e. inputs except labor and capital costs).

$$VA = \sum_{i=1}^{I} \boldsymbol{p_i h_i} - \boldsymbol{VC(S)} \quad - \boldsymbol{VC_{maint}} - \boldsymbol{VC_{fuel}} - \boldsymbol{VC_{other}} \qquad [\boldsymbol{eq\ 2}]$$

Total revenue (p*h) is defined as in equation 1. VC(S) is defined as all variable costs that stem from seal interaction except for labor costs. VC_{maint}, VC_{fuel}, and VC_{other} are the maintenance cost, fuel cost and other costs respectively.

The contribution margin is defined as

$$CM = VA - VC(S)_{labour} - VC_{labour} \qquad [eq\ 3]$$

i.e. value added minus the labor costs. CM thus includes both labor costs that are not seal related, VC_{labor}, and the additional labor cost due to seals, $VC(S)_{labor}$.

Scenarios for Seal-Fisheries Interaction

In order to estimate the effect of seal predation on value added and the contribution margin, it is necessary to include both the seal costs (VC(S)) and the visible and hidden revenue losses (the effect on p_i*h_i in equations 2 and 3). This is not directly estimated in this study, but included as scenarios based on results from previous literature. We use five scenarios:

1. Business as usual; current seal costs and current catch loss
2. No seal cost, current catch loss
3. No seal cost, landing increases with visible catch loss of 25 % of total landing
4. No seal cost, landing increases with visible and hidden catch loss of 50 % of total landing
5. No seal cost, landing increases with visible and hidden catch loss of 100 % of total landing

The first scenario is business as usual which simply consists of the current situation. In this scenario seal costs are included since the fishermen enter these cost items in their financial accounting, although not as a separate cost item but included in e.g. gear maintenance. Also, revenue losses due to seals are part of the accounting since only landed and sold fish is registered as income. The second scenario is used for evaluating how seal costs alone will affect the profitability. In this scenario the total costs are reduced by the cost for seals, while visible and hidden catch losses are assumed to remain. The purpose of this scenario is to show the impact of the seal cost alone on the economic viability since this cost has not been estimated previously.

The third to fifth scenarios simultaneously reduce costs and increase landings. The third scenario departs from the estimates of visible catch losses. Kauppinen and Suuronen (2005) find variation from 0 to 37 % of salmon catches depending on region, while Larsen et al. 2015 observed from 0 to 24 %. We use 25 % for scenario 3, which implies that we add another 25 % catch value for trips with seal damages (observe that we do not have individual trip data on the catch value, but assume that all trips have the average catch value). Scenario 4 includes both visible and hidden catch losses that are estimated to be 50 % of landings for trips with seal interaction. This is a rough average of the two years calculated in Königson et al 2009 (the average is 43 %, but this is based on total landings (including seal damaged fish) while the economic calculations are based only on sold fish). In the fifth scenario the catch losses are assumed to be equal to the observed landings (100 % of landings). This corresponds to the results in Fjälling (2005) who estimates catches to be approximately half for fishing trips with seal interaction. It is also the figure used for seal damage calculations used by SwAM (2014).

Since the landing obligation in the European Common Fisheries Policy (EU, 2013) was not implemented when data was collected for our study, it is assumed that all seal damaged cod has been discarded and thus not included in landing statistics. Since visible and hidden catch losses are estimated for fishing trips with seal interaction in the literature, the figures must be scaled down with the actual share of fishing trips having seal interaction. This is done by using logbook statistics where fishermen report if a trip has been affected by seals. For each segment the share of trips with seal interactions are calculated on average for 2013 and 2014. If 10 % of trips have a seal interaction, it is assumed that 10 % of catches for that segment have seal interaction.

5.2 Empirical Specification for Gear Analysis

The gear analysis focuses on the cost side of the seal-fisheries interaction. I.e. no estimates of revenue losses are calculated. Instead, a more detailed focus on costs for different gear is performed.

The gear analysis is performed using a regression analysis where the cost of seals is regressed (using OLS) on fishing area and the days the fishermen use different gear in each area. This is expressed in equation 4

$$Cost = \sum_k \gamma_k \text{Area}_k + \sum_l \beta_l \text{GearInArea}_l + \varepsilon \qquad eq[4]$$

Where *Cost* is the annual cost of seals, $Area_k$ is a dummy for the fishing area, and $GearInArea_l$ is the number of fishing days in each area that where the fisherman used fishing gear *l*. From this it is possible to identify general differences in seal costs between sea areas (depending on area specific characteristics such as seal abundance), and differences in costs for fishermen using specific gear in each of the areas compared to area average. The latter shows how vulnerable for seal interaction a specific gear is in each of the studied areas.

6. Data

The data section starts with a presentation of the data sources used in the analyses. After that, more specific data topics for the vessel segment analysis and the gear analysis are presented as separate sections.

Data is obtained from three sources

1. Fishermen's self-estimated cost for seals
2. Economic data from the EU's Data Collection framework
3. Logbook data

The first source, *fishermen's self-estimated cost for seals*, is obtained in the survey used for the EU's Data Collection (see below) and included as two additional questions; "*How much of your costs during 20XX, excluding VAT, were due to damages made by seals (new equipment, etc.)*" and "*How much extra time did you spend during 20XX with work that has been caused by seal* *damages (mending broken gear, etc.)*”. The survey is mandatory. However, we acknowledge that this is a self-estimate made by the fishermen and might thus be biased. Survey data is from 2013 and 2014.

The second data source, *economic data from the EU DCF* (Commission of the European Communities, Decision 2010/93/EU) is available on segment level. The data is split on more and less active vessels, where more active vessels fish at least € 8000 per year). The data contains economic information about revenues, costs and working time.

The third data source, *logbook data* for 2013 and 2014, is available for each vessel and contains data about the fishing trip such as gear used, fishing area, and catches. Seal interaction is coded in two different ways in the logbook, either as a specific species code (MAF-code) or as a note in the logbook indicating seal interaction. A specific trip is defined as having seal interaction if either the species code or the note (or both) indicates seal interaction. For the segments with vessels below 10 meters the logbook only contains information per month and not per trip. A month could contain multiple trips. For these vessels the share of months with seal interaction is used. This might overestimate the total shares since it is possible that not all fishing trips that month actually had seal interaction. On the other hand, Königsson et al (2007) estimates that the reporting in the logbook is underestimated as discussed in the literature section.

6.1 Data used in vessel segment analysis

The analysis of vessel segments combines the self-estimated seal costs with the economic variables from the DCF. Remember that the cost data in the DCF includes *all* costs as discussed in section 5, i.e. the cost for seals are included in the DCF statistics. In the conceptual framework in this paper, the variable cost of seals is separated out from total costs as VC(S). Thus, VC(S) contains two variables not separately reported in the DCF; costs (excluding labor) for replacing and mending seal damaged gear etc., and labor cost caused by seal interaction.

Revenues are calculated without subsidies for seal interaction.

Due to Swedish tax regulations it might be beneficial for fishermen to keep down remuneration to own labor. Since all segments used in the analysis primarily contain small firms with a high share of own labor the account statistics in the DCF on wages might be downward biased. In order to account for this a standardized wage per hour worked is imputed corresponding to average wage in Swedish “agriculture, forestry and fisheries” estimated by Statistics Sweden.

6.2 Data used in gear analysis

In the gear analysis, the fishermen’s self-estimated cost of seals has been matched with the use of gear (available in the logbook). Seal cost is available by year, and accordingly the fishing days are aggregated to number of fishing days per gear and year. Further, the data is split into four fishing areas; Northern Baltic Sea (Bothnian Sea), Central Baltic, Southern Baltic, and the Skagerrak and Kattegat. Thus, for each vessel there is information on both the fisherman’s estimated cost of seals per year, which areas he/she has fished in, and on the number of days per year the fisherman has fished for each fishing gear used in each area. The variables are presented in table 2.

Table 2. Variable definition for gear analysis

Variable	Area	Gear	Comment	Important target species
Seal cost	All	All	Fishermen's self-estimated cost for seals	
NorthBS	Bothnian Sea	-	ICES area 30-31	-
CentralBS	Central Baltic	-	ICES area 27-29,32	-
SouthBS	Southern Baltic	-	ICES area 22-26	-
SK	Skagerrak and Kattegat	-	ICES area 20-21	-
SK_SouthBS	Skagerrak, Kattegat and Southern Baltic	-	ICES area 20-24	-
South_Central_BS	Southern and Central Baltic	-	ICES area 22-29,32	-
Central_North_BS	Central Baltic and Bothnian Sea	-	ICES area 27-29, 30-31	-
South_North_BS	Southern Baltic and Bothnian Sea	-	ICES area 22-32	-
NorthBS_FPN	Bothnian Sea	FPN	ICES area 30-31, Stationary uncovered pound nets	Eel
NorthBS_FYK	Bothnian Sea	FYK	ICES area 30-31, Fyke nets	Eel
NorthBS_GNS	Bothnian Sea	GNS	ICES area 30-31, Set gillnets (anchored)	Mixed
NorthBS_FPO	Bothnian Sea	FPO	ICES area 30-31, Pots	Salmon
CentralBS_FPN	Central Baltic	FPN	ICES area 27-29, 32, Stationary uncovered pound nets	Eel
CentralBS_FYK	Central Baltic	FYK	ICES area 27-29, 32, Fyke nets	Eel
CentralBS_GNS	Central Baltic	GNS	ICES area 27-29, 32, Set gillnets (anchored)	Mixed, cod
SouthBS_FPN	Southern Baltic	FPN	ICES area 22-26, Stationary uncovered pound nets	Eel
SouthBS_FPO	Southern Baltic	FPO	ICES area 22-26, Pots	Cod
SouthBS_FYK	Southern Baltic	FYK	ICES area 22-26, Fyke nets	Eel
SouthBS_GNS	Southern Baltic	GNS	ICES area 22-26, Set gillnets (anchored)	Mixed, cod
SouthBS_GTR	Southern Baltic	GTR	ICES area 22-26, Trammel nets	Mixed, cod
SouthBS_LLS	Southern Baltic	LLS	ICES area 22-26, Set longlines	Cod
SK_FPO	Skagerrak and Kattegat	FPO	ICES area 20-21, Pots	Norw. Lobster, crab

SK_FYK	Skagerrak and Kattegat	FYK	ICES area 20-21, Fyke nets	Wrasse[a]
SK_GND	Skagerrak and Kattegat	GND	ICES area 20-21, Driftnets	Mackerel
SK_GNS	Skagerrak and Kattegat	GNS	ICES area 20-21, Set gillnets (anchored)	Mixed
SK_GTR	Skagerrak and Kattegat	GTR	ICES area 20-21, Trammel nets	Mixed
SK_LHP	Skagerrak and Kattegat	LHP	ICES area 20-21, Handlines	Mackerel, cod, seith
SK_LTL	Skagerrak and Kattegat	LTL	ICES area 20-21, Troll lines	Mackerel
NorthBS_other	Bothnian Sea	Other	ICES area 30-31, Other gear	-
CentralBS_other	Central Baltic	Other	Other gear	-
SouthBS_other	Southern Baltic	Other	ICES area 22-26, Other gear	-
SK_other	Skagerrak and Kattegat	Other	ICES area 20-21, Other gear	-

a) Skärsnultra (*Symphodus melops*) and Berggylta (*Labrus berggylta*)

In total data consists of 616 observations split on 373 vessels fishing either 2013, 2014 or both years. Summary statistics of the variables are presented in appendix B. Observe that the data is pooled so there is no distinction between the years in summary statistics or regression models. The average number of observations in a gear/area combination is 54.

7. Results for the Vessel Segment Analysis

The total direct cost for maintenance due to seals is estimated to approximately 743 thousand Euros per year on average for 2013 and 2014. This corresponds to about 1 % of total cost for purchased goods[2] in the Swedish fishery. Working time spent on seals are estimated to approximately 27 full time equivalents corresponding to 3 % of total work force. However, this includes both active and passive gear. Active gear, which is the major part of Swedish fisheries, is not affected by seal predation and thus a more relevant population for the analysis would be fisheries using passive gear.

The vessels using passive gear had on average for 2013 and 2014 a total cost for maintenance due to seals of 690 thousand Euros per year corresponding to 7 % of total purchased goods and 26 full time equivalents corresponding to about 8 % of total working time. This group of vessels is used for the rest of the vessel segment analysis.

The rest of the result section is structured as follows. First the costs due to seal are presented for “more active’’ and “less active” (as defined in the data section) vessels separately. This gives a picture of how severe the seal damages are to gear used by fishermen that are fully active and fishermen that either are about to quit fishing or only have fisheries as a minor part of their income.

Secondly, the same statistics are presented for more active vessels split into different segments. This gives a picture of how high the seal costs are for different types of fisheries.

7.1 More and less active vessels using passive gear

In table 3 the share of total cost and the share of working time that is due to seal are presented for less and more active vessels respectively.

Table 3. Shares of seal costs and working time, average for 2013-2014.

	Seal costs / total purchased goods	Working time seals/total
Less active vessels	17%	13%
More active vessels	5%	5%

The table shows that for less active vessels, both the shares of repair costs due to seals and the share of working time due to seals are considerably higher than for the more active vessels. In both cases more than twice the share; 17 % compared to 5 % for costs, and 13 % compared to 5 % for working time.

[2] Purchased goods are used as reference in order to visualize the cost for seals. Purchased goods are the cost items used when calculating the value added for an industry.

7.2 More active vessels by segment

The interaction with seals is expected to vary over different kinds of fisheries depending on gear used and the spread of the seal populations in different fishing areas. In table 4, the cost of seals is presented by segment for more active vessels using passive gear. The segments are based on vessel length and target species.

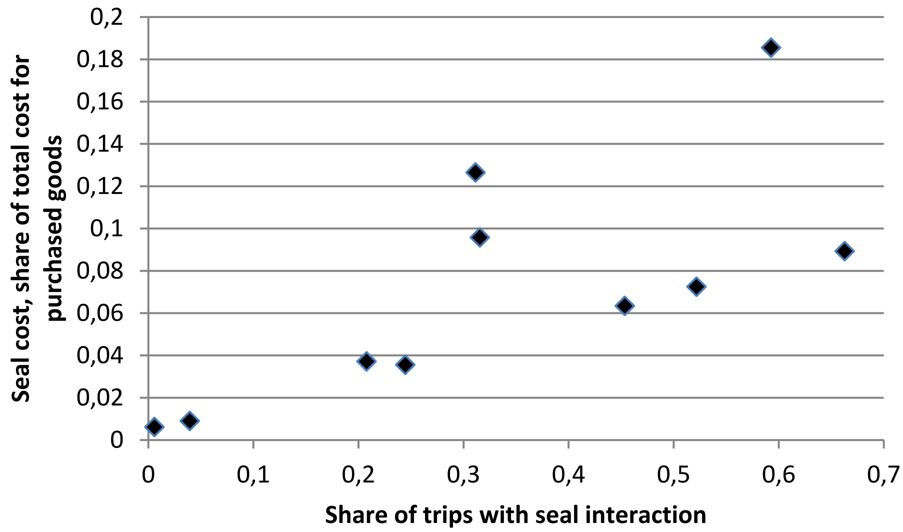
Table 4. Seal costs for more active vessels (using passive gear) by vessel length and target species. Average 2013-2014.

Vessel length	Target species	Vessels	Shares	
			Seal costs / total purchased goods	Working time seals/total
0-10	Norwegian lobster	50	1%	1%
0-10	Salmon	16	19%	17%
0-10	Mixed	73	6%	8%
0-12	Vendace	13	9%	16%
0-10	Cod	26	13%	7%
0-10	Eel	37	7%	5%
10-12	Norwegian lobster	21	1%	1%
10-12	Mixed	24	4%	4%
10-12	Cod	29	10%	9%
12-	Mixed	16	4%	3%
Total		304	5%	5%

The seal costs follow the expected distribution across vessel segments. Fishing for Norwegian lobster has very small interactions with seals. This fishery takes place outside the Swedish west coast in Skagerrak and Kattegat and the main gear is pots and targets a species not being preferred by seals. Seal interaction is much larger in the fisheries for cod, salmon and vendace. All of these fisheries primarily take place in the Baltic Sea where the grey seal population has increased considerably during the last years.

Figure 2 shows the interaction of stated seal costs in the questionnaire and stated seal interactions in the logbook. The vertical axis shows the seal costs' share of total costs for purchased goods and the horizontal axis shows the share of trips with seal interaction from the logbook.

Figure 2. Seal costs and trips with seal interaction (average 2013-2014).



The share of seal interactions in the logbook reaches from almost zero for some segments to almost 70 % for others. There is a clear relationship between high costs and high share of trips with seal interaction, i.e. segments where the vessels claim to have high cost for seals in the questionnaire also have high seal interaction according to the logbook.

7.3 Profit distribution with and without seals

The contribution margin (equation 3) by segment is presented for each of the scenarios 1-5 in table 5 below. Corresponding figures for the value added is presented in appendix A.

Table 5. Contribution margin by segment for seal scenarios, thousand Euro average over 2013 and 2014

Vessel length	Target species	Vessels	Scenario 1 Observed	Scenario 2 Seal cost	Scenario 3 Seal cost+ loss 25 %	Scenario 4 Seal cost + loss 50 %	Scenario 5 Seal cost + loss 100 %
0-10	Norwegian lobster	50	-132	-112	-91	-70	-29
0-10	Salmon	16	-106	-16	45	106	228
0-10	Mixed	73	-701	-460	-149	162	784
0-12	Vendace	13	-24	33	109	184	336
0-10	Cod	26	-290	-179	-111	-43	93
0-10	Eel	37	-558	-455	-296	-137	180
10-12	Norwegian lobster	21	372	386	390	394	402
10-12	Mixed	24	-29	16	77	137	258
10-12	Cod	29	-352	-206	-107	-7	192
12-	Mixed	16	107	149	231	313	477
Total		304	-1 714	-842	98	1 039	2 921

As is clear from the table the overall contribution margin is negative in the observed situation. Thus, with current costs for seals and current catch losses the fisheries are economically un-viable. The negative figures should, however, be interpreted carefully since they are based on imputed labour costs. If the wage of a fisherman in the observed segments is lower than the imputed wage the presented economic result will be higher. The contribution margin is negative also in the scenario only taking seal costs into account, i.e. reducing costs with the stated costs for seals will not generate positive results. However, when taking catch losses into account the total contribution margin for the studied segments will be positive although also in these cases some segments show negative figures.

8. Result from the Gear Analysis

The result from the regression of self-estimated seal costs on number of fishing days with different gear (equation 4) is presented in table 6. The area variables show the extra cost (€) fishermen fishing in the different areas have stated regardless of gear, i.e. this is an area specific effect.[3] The variables under gear/area represents fishing with a specific gear in an area. The coefficients estimates the cost associated with one extra day of fishing with a specific gear in a specific area compared to the area average. Explanations about gear codes and areas are available in the data section.

Table 6. Regression results. Seal costs as dependent variable.

Area variables		
North BS	1750	***
Central BS	1544	***
South BS	2161	***
SK	1168	***
SK_South BS	1338	***
South_Central_BS	2152	***
Central_North_BS	2215	***
South_North_BS	2418	***
Gear/area		
NorthBS_FPN	2.48	
NorthBS_FYK	-0.20	
NorthBS_GNS	-2.07	*
NorthBS_FPO	-1.67	
CentralBS_FPN	-3.51	*

[3] Note that all vessels are categorized into one unique subarea which implies that no constant is used in the regression.

CentralBS_FYK	-2.36	
CentralBS_GNS	0.95	
SouthBS_FPN	-10.14	***
SouthBS_FPO	-14.35	***
SouthBS_FYK	-10.11	***
SouthBS_GNS	2.00	*
SouthBS_GTR	0.08	
SouthBS_LLS	0.76	
SK_FPO	-6.20	***
SK_FYK	0.55	
SK_GND	3.24	
SK_GNS	2.44	*
SK_GTR	1.76	
SK_LHP	7.09	**
SK_LTL	8.69	***
NorthBS_other	9.45	
CentralBS_other	-16.93	**
SouthBS_other	4.66609	
SK_other	0.44	
N obs	610	
Adj R2	0.55	

Fishermen in all the geographical areas have stated costs for seals that are significantly larger than zero. E.g. fishing in the northern Baltic Sea is associated with a stated seal cost of 1750 Euro per year. An important result is the high costs in the southern Baltic Sea (Euro 2161) which is the area to which seals have most recently spread to. Notably, the highest stated seal costs are for vessels splitting their efforts between two areas. The change in fishing areas could be a response to high costs. Alternatively, seal populations could be high in local fishing grounds that are on the border between two areas and fisheries takes place on both sides of the boarder. Notably only few vessels have more than one area.

In the southern Baltic the major fishery is for cod using set gillnets (GNS) or long lines (LLS). Vessels targeting cod have high costs for seal interaction (which is shown in the vessel segment analysis), and this explains the high general cost for fishing in that area. However, fishing for eel using stationary uncovered pound nets (FPN) or fyke nets (FYK) is associated with lower stated costs. So is the pot fishery for cod (FPO), which is a minor fishery. In the Skagerrak and Kattegat, fishing with pots is associated with low stated costs. This is primarily fishing for crab and Norwegian Lobster, species that are not targeted by seals. Fishing for mackerel using troll lines (LTL) shows higher costs than the average fishery in the area. For the Northern Baltic fishing with set gillnets (GNS) is associated with about € 2 less costs per day than the average fishing activity in the area. GNS is a mixed fishery in the Northern Baltic. FPN and FYK in the area primarily target eel, while FPO target salmon. Notably, the salmon traps are not associated with neither higher nor lower costs than the area average.

9. Discussion

Seals are a natural part of the fauna in Swedish coastal waters and have become a symbol for thriving eco-systems. Seal populations are e.g. part of the EU habitat directive as species of community interest. At the same time, it has been recognized that seals interact with local small-scale fisheries (see the Växjö declaration by the Nordic Council of Ministers (2008) and the Swedish management plan for grey seals (Hav, 2012)). Seals affecting the viability of small-scale fisheries might negatively affect other objectives such as flourishing coastal areas (Swedish Environmental Protection Agency, 2012) and local employment opportunities. If local small-scale fisheries cannot be viable with current seal populations, there is a risk of goal conflicts.

In this paper, the vessel segment analysis clearly shows that the seal interaction has a significantly negative impact on the economic viability of Swedish small-scale fisheries. However, the magnitude of the interaction varies substantially with gear, target species and fishing area. The fishery for Norwegian lobster in the Kattegat and Skagerrak has very low interaction with seals. The vessel segment analysis shows that costs are negligible for vessels in this segment and that the economic viability is only marginally affected by seal interactions. This is confirmed by the gear analysis where fishing in Skagerrak and Kattegat has lower stated costs for seal interaction than other areas in general, and this is emphasized when the fishery uses lobster pots. Actually, it could be argued that the lobster fishery benefits from seals if the seals prey on cod thus reducing natural predators on Norwegian lobster.

However, for many of the other segments the seal interaction is crucial for the long run viability. Calculating revenue losses from seals being equal to revenues for affected fishing trips (the calculation method used by SwAM) almost all segments show positive contribution margins, and also when assuming lower revenue losses most segments are economically viable. Thus, it could be argued that Swedish fisheries with passive gear would be in an economically far better condition without seals interacting with the fishing gear. In total the contribution margin for the small-scale fishery is negative, € -1.7 million, which roughly corresponds to the total payments in the Swedish seal compensation scheme (€ 1.5 million). The subsidies are not included in the calculations the contribution margin in this paper, and they will therefore improve the economic outcome compared to the calculated results. Thus, although the compensation scheme does not cover the full cost of seals, the calculations indicate that it is an important contribution to the economic viability of the small-scale fleet.

We note that the estimated costs should be interpreted with great care. First, the costs are self-estimated by the fishermen and might be upward biased. This is the case if the fisherman for some reason state higher seal costs in the survey than he/she actually has. A reason for doing this might be to point out the problem with seals that fishermen face but which they do not believe that authorities acknowledge. On the other hand, the estimates might be downward biased due to adaptive behavior of the fishermen. The fisherman will avoid seals and thus the estimated costs are only for fishing in locations where the fisherman thought it was worth-while setting the gear. Thus, expanding the fishery might force fisheries to areas where seals are more abundant and costs are higher. Further, the calculations do not take any adaptive behavior of the fishermen into account. In practice, a scenario with lower seal damages will of course cause fishermen change behavior in a way that might affect both costs and revenues (see e.g. Holma et al 2014).

It is possible that some fishermen that would have been profitable without seal interactions had already left the fishery in the studied period due to high cost for seal interactions. These fishermen are not present in fishery statistics and thus not part of this analysis. It is beyond the scope of the paper to estimate the dynamic behavior of fishermen adapting to the seal presence. However, information is available to identify more and less active fishermen. Less active vessels have higher seal costs than more active vessels which might be an indicator that fishermen with high seal interaction are cutting down on their activities. However, from the table we cannot make any conclusions about the causality, and an alternative explanation could be that fishing is less important to less active fishermen and that they therefore do not put as much effort into avoiding seals.

The information of both costs and revenue losses due to seals are scarce in the literature, and results from available studies are facing great uncertainty. This paper provides one of few estimates of the economic impact of seal predation. Fishermen have expressed great concerns about the topic for years, and the results clearly show that these concerns should be taken seriously.

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Appendix A. Value added by segment (Euro, average 2013-2014)

Vessel length	Target species	Vessels	Observed	Seal cost	Seal cost+ loss 25 %	Seal cost + loss 50 %	Seal cost + loss 100 %
0-10	Norwegian lobster	50	1 109 528	1 118 606	1 139 357	1 160 109	1 201 611
0-10	Salmon	16	232 638	265 703	326 578	387 453	509 203
0-10	Mixed	73	1 155 986	1 256 580	1 567 457	1 878 333	2 500 086
0-12	Vendace	13	184 495	208 778	284 400	360 021	511 263
0-10	Cod	26	296 814	369 747	437 733	505 719	641 691
0-10	Eel	37	619 278	662 563	821 214	979 865	1 297 168
10-12	Norwegian lobster	21	1 384 926	1 393 579	1 397 567	1 401 556	1 409 533
10-12	Mixed	24	451 228	477 888	538 511	599 135	720 382
10-12	Cod	29	493 075	566 624	666 037	765 450	964 276
12-	Mixed	16	680 444	704 002	786 086	868 170	1 032 338
Total		304	6 608 413	7 024 069	7 964 940	8 905 810	10 787 552

Appendix B

Table B1. Summary statistics for variables used in gear analysis

Variable	Unit	Mean	Min	Max
Seal cost	€/year	1345.17	65.13628	3347.303
NorthBS	1 if fishing in area, 0 otherwise	.1493506	0	1
CentralBS	1 if fishing in area, 0 otherwise	.0974026	0	1
SouthBS	1 if fishing in area, 0 otherwise	.237013	0	1
SK	1 if fishing in area, 0 otherwise	.4545455	0	1
SK_SouthBS	1 if fishing in area, 0 otherwise	.0340909	0	1
South_Central_BS	1 if fishing in area, 0 otherwise	.0194805	0	1
Central_North_BS	1 if fishing in area, 0 otherwise	.0064935	0	1
South_North_BS	1 if fishing in area, 0 otherwise	.0016234	0	1
NorthBS_FPN	DAS/year	2.206169	0	210
NorthBS_FYK	DAS/year	.788961	0	87
NorthBS_GNS	DAS/year	6.163961	0	224
CentralBS_FPN	DAS/year	5.11526	0	122
CentralBS_FYK	DAS/year	5.076299	0	122
CentralBS_GNS	DAS/year	7.011364	0	267
SouthBS_FPN	DAS/year	3.647727	0	141
SouthBS_FPO	DAS/year	.3668831	0	108
SouthBS_FYK	DAS/year	1.701299	0	89
SouthBS_GNS	DAS/year	18.28896	0	197
SouthBS_GTR	DAS/year	2.173701	0	212
SouthBS_LLS	DAS/year	2.832792	0	201
SK_FPO	DAS/year	35.98052	0	236
SK_FYK	DAS/year	3.339286	0	133
SK_GND	DAS/year	2.394481	0	75
SK_GNS	DAS/year	5.107143	0	169
SK_GTR	DAS/year	2.573052	0	215
SK_LHP	DAS/year	1.922078	0	78
SK_LTL	DAS/year	2.219156	0	71
NorthBS_other	DAS/year	.7743506	0	116
CentralBS_other	DAS/year	.3392857	0	53
SouthBS_other	DAS/year	.237013	0	46
SK_other	DAS/year	1.24513	0	80

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