Rebuilding the Eastern Baltic cod stock under environmental change -

Part II: The economic viability of a marine protected area

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Abstract

This study adds a cost analysis of the Eastern Baltic cod fishery to the existing model presented in Röckmann et al. (forthcoming). As cost data on this international fishery do not exist, available data from Denmark are extrapolated to the whole international fishery. Additionally, unit and total variable costs are simulated and the sensitivity to a set of different cost-stock and cost-output elasticities is tested. The study supports preliminary conclusions that a temporary marine reserve policy, which focuses on protecting the Eastern Baltic cod spawning stock in ICES subdivision 25, is a valuable fisheries management tool to (a) rebuild the overexploited Eastern Baltic cod stock and (b) increase operating profits. The negative effects of climate change can be postponed for at least 20 years – depending on the assumed rate of future climate change. Including costs in the economic analysis does not change the ranking of management policies as proposed in the previous study where costs were neglected.

Keywords: Baltic cod, cost-stock elasticity, cost-output elasticity, sensitivity analysis, climate change scenario, management, policy, temporal marine reserve

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1 Introduction

Recent studies suggest that global climate change affects the marine environment (e.g. Barnett *et al.* 2005; Ottersen *et al.* 2001), including fish stocks (Perry *et al.* 2005; Rose 2004; Worm and Myers 2004)[1]. As a consequence, fishermen and the fishing industry are also affected and may, for instance, benefit from rising profits from an expansion of favourable fish habitat and a resulting increase in stock size (Lorentzen and Hannesson 2005). In contrast, regional climate change may lead to stock extinction, hence, triggering income losses (Röckmann *et al.* forthcoming). However, the outcomes are case-specific and one cannot generalise.

Here, we focus on the Eastern Baltic cod fishery, which is expected to suffer from global warming (MacKenzie *et al.* 2002; Röckmann *et al.* forthcoming). The projected future decrease in Baltic Sea salinity and dissolved oxygen concentration due to increasing temperatures (Meier *et al.* 2004) means a loss in environmentally favourable spawning habitat of Eastern Baltic cod, possibly resulting in increased recruitment failure. A declining stock size will ultimately lead to declining yields and loss in gross revenues, if fishing continues as usual (Röckmann *et al.* forthcoming).

Can fishermen and fisheries managers counteract or mitigate negative consequences of climate change? Röckmann *et al.* (forthcoming) find that a marine protected area (MPA)

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[1] See also articles in Volume 62 of the ICES Journal of Marine Science, October 2005.

(either permanent or seasonal) can reduce the negative consequences of climate change in the Eastern Baltic cod fishery. Such a policy should focus on the protection of the spawning stock in ICES subdivision 25, where environmental conditions are favourable for successful Baltic cod egg development most frequently, thus increasing biological productivity in this subdivision. From a biological point of view, the Eastern Baltic cod stock can be rebuilt by reducing fishing mortality on the spawning stock, allowing part of the stock to spawn successfully and to grow older. Adequately designed seasonal marine reserves are not only a tool to rebuild fish stocks; they also benefit fishermen, who are allowed to target a stock that had temporarily been protected and allowed to grow older and larger. Provided that some fish emigrate from the protected area into the adjacent open areas, such policies may also contribute to sustainable fisheries management in economic terms. With regard to the Eastern Baltic cod fishery, revenues increase not only due to higher catches but also due to the improved age-structure of the stock, with older specimen reaping a higher price per kilogram.

Röckmann *et al.*’s (forthcoming) findings are based on gross revenue; they neglected the costs of fishing, which is equivalent to assuming that harvesting costs are constant. Here, we add a cost analysis to the previous study. We investigate how the incorporation of variable costs influences the ranking of different management policies with regard to maximum operating profits in the Eastern Baltic cod fishery. We additionally perform a sensitivity analysis testing different values of stock and output elasticities of variable costs.

The paper is structured as follows. In section 2, we briefly describe the problem of assessing costs in a fishery. In section 3, the Eastern Baltic cod fishery is depicted and rough estimates of variable costs for the Danish Eastern Baltic cod fishery are calculated and extrapolated to the international Eastern Baltic cod fishery. Section 4 introduces the employed cost function and the concept of cost elasticity parameters. Results of model simulations and sensitivity analyses, testing a range of cost elasticities, are presented and discussed in Section 5. Section 6 concludes and it points out areas that warrant further research.

2 Assessing the costs of fishing

Empirically, it is difficult to determine the costs of fishing for a particular fish species. First, cost data on the vessel level are usually confidential, and the accessible data collected by national administrations often only allow for aggregate analyses. Second, in general vessels target more than just one fish species, but apply the same input factors – at least partly – to produce several outputs. Such multi-species fisheries, where firms use the same input factors to harvest several species, are called a multi-output production and characterised as “joint in inputs” (Squires and Kirkley 1991). At least part of the vessel operating and maintenance costs then have to be considered joint in production of other species; hence, one cannot readily disentangle variable costs and attribute them to one species only. Third, available data differ across regions.

In general, fixed costs (e.g. vessel costs such as depreciation and financial costs) occur as a consequence of all the fisheries which the vessel participates in. They can therefore be considered as “joint in [production] inputs” (Squires and Kirkley 1991). In contrast, variable costs (i.e., cost items necessary to operate the vessel in the short term, such as fuel, lubrication oil, special social fees, bait, ice, salt, packing, social expenses, food, crew wages/shares) can be species-specific. It depends on the form of the production technology whether variable costs in a multi-species fishery are species-specific or occur equally in each specific fishery (Squires and Kirkley 1991).

In the following, we neglect fixed costs, which are joint in production of other fish species, since most vessels/ fleets temporarily change their rigging to target other species, e.g. at times, when the Eastern Baltic cod fishery is closed. As we only look at variable costs, we shorten the 50-year simulation period of the previous study to approximately 30 years.

3 The Eastern Baltic cod fishery

The Eastern Baltic cod fishery is very heterogeneous due to its internationality and the multitude of possible cod harvesting technologies employed (static gears, such as trap; active gears such as trawl, purse seine, gillnet) (Anonymous 2003). The main fisheries for cod in the Eastern Baltic use demersal trawls, pelagic trawls and gillnets (ICES 2005). However, with the change in stock age composition towards younger ages since the late 1990s, the share of the total catch of cod taken by gillnets has decreased while that of demersal trawl increased (ICES 2005). Estimated recent landings of Eastern Baltic cod range between 50 and 100 thousand tonnes, although recent estimates are uncertain due to unreported landings: The ICES Advisory Committee on Fishery Management (ACFM) estimates that recent catches have been around 35-45% higher than the officially reported figures. Discarding, especially of age 1 to age 3 cod, is also a severe problem in the Eastern Baltic cod fishery. The amount of discard which has been estimated by use of extrapolation in 2004 is 63% for gillnet and 40% for trawl (ICES 2005).

Eastern Baltic cod have traditionally been taken in a targeted fishery, with limited by-catch of other target species but only some by-catch of flatfish, primarily flounder (ICES 2005). Catches of Eastern Baltic cod as by-catch in pelagic fisheries have been very limited. Hence, variable costs in the Eastern Baltic cod fishery can be considered as non-joint to the production of other species.

The heterogeneity of the fleet calls for a cost analysis with a high level of disaggregation. On the other hand, uncertainty as well as the lack of accessibility to high-resolution economic fisheries statistics compel simplification. To get a rough numerical idea of variable costs in the Eastern Baltic cod fishery, we looked at Danish fisheries statistics (FOI 2006) and extrapolated these to get an estimate of the aggregated variable costs in the international Eastern Baltic cod fishery. Our estimates are based on Danish regionally-specific fisheries statistics for the years 2000-2004. Since 97% of the Danish Eastern Baltic cod catch originates from SD 25 (ICES 2002), the data referring to the Bornholm region can be taken as representative for the Danish Eastern Baltic cod fleet. Furthermore, we assume that variable costs of the Danish Bornholm vessels are representative for the whole international Eastern Baltic cod fleet. For illustration, we show data and rough extrapolation figures for three recent years in Table 1.

According to ICES catch statistics, the Danish share of the total Eastern Baltic cod catch (C) was 11-12% during 2001-2003. We apply this share to extrapolate from the Danish estimate of variable costs per firm in the Bornholm region (E) to get an estimate of the total international Eastern Baltic cod fishery (G).

We calculated total variable costs in the Danish Eastern Baltic cod fishery (F) by multiplying the variable costs (excluding depreciation) per vessel in the Bornholm region (E) with the number of vessels fishing in the Bornholm region (D). Dividing by the Danish share on the international Eastern Baltic cod yield (C) gives an estimate of the international Eastern Baltic cod total variable costs (G). The unit[2] variable costs in the international Eastern Baltic cod fishery (H) are calculated as the quotient of the international Eastern Baltic cod total variable costs (G) and the total international Eastern Baltic cod yield (B). In 2001-2003, the estimated unit variable costs are around 10 *Danske kroner* (DKK) per kilogram (kg). This estimation seems reasonable as unit variable costs lie in the same range dimensionally as the unit price of Eastern Baltic cod, which, depending on fish length, varies between 12 and 34 DKK/kg (Fiskeridirektoratet 2003). Estimates of average variable costs in the Swedish bottom trawl fishery range from approx. 9-16 DKK/kg[3] (Eggert and Tveterås 2004). Eggert &

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[2] Following Sandberg (2006), we use unit cost as a synonym for average cost of fishing one unit [here: kg] of fish.

[3] Original result: 12-20 SEK/kg (exchange rate fluctuated between 0.78-0.83 DKK = 1 SEK over the past years)

Tveterås (2004) estimated unit costs as a function of labour, capital, and fuel consumption, assuming constant marginal cost of effort (or linear total costs). They found large possibilities to reduce unit costs in the Swedish bottom trawl fishery when annual landings are below 400 tons per vessel. Landings above 400 tons do not enjoy scale economies to any extent. For landings above 880 tons, scale diseconomies occur. Eggert & Tveterås (2004) thus described an L-shaped average cost (AC) curve, with large returns to scale in the lower interval and then a flat AC curve.

Table 1: International (A, G, H) and Danish (C-F) fisheries statistics, referring to the Eastern Baltic cod fishery, and rough calculations of annual international unit and total variable costs in *Danske kroner* (DKK).

		2001	**2002**	**2003**	**Source**
A	Eastern Baltic cod Yield (Denmark) [‘000 t]	10	8	8	ICES 2002, 2004
B	Eastern Baltic cod Yield (international) [‘000 t]	91	68	71	ICES 2005
C	**Danish share of international Eastern Baltic cod yield**	**0.11**	**0.12**	**0.11**	**A/B**
D	# vessels (Bornholm region)	141	128	124	FOI 2006
E	Total variable cost per vessel (Bornholm) [‘000 DKK / firm]	717	678	663	FOI 2006
F	**Eastern Baltic cod total variable costs (Danish) [million DKK]**	**101.1**	**86.8**	**82.2**	**E*D/1000**
G	**Eastern Baltic cod total variable costs (international) [million DKK]**	**920**	**738**	**730**	**F/C**
H	**Eastern Baltic cod unit variable costs (international) [DKK/kg]**	**10.11**	**10.85**	**10.28**	**G/B**

4 Cost function and cost elasticities

The variable costs (C) of fishing depend on the costs of the different production factors. It is well known that the fish stock is an important factor of production in the fishery (Clark and Munro 1975; Gordon 1954). Contrary to other input factors, the size of the fish stock is beyond control of the single firm. Hence, the fish stock can be considered an external factor. Apart from the stock size (B), the cost of production of a fishery also depends on the output quantity (Y), market prices of variable input factors (W) such as fuel, ice, labour, and various other factors (O) (e.g. age/experience and skill of the skipper, vessel characteristics): $C = f(B, Y, W, O)$. Here, we reduce this function to $C = f(B, Y)$, based on two assumptions:

(1) Real prices in the input markets are constant, i.e., W = constant.

(2) Unobserved effects of other factors could be neutralised by the fixed effect method, which is equivalent, for instance, to assigning dummies for different vessel types (Sandberg 2006). Here, we assume that a single vessel from Bornholm is representative for the total international fleet targeting Eastern Baltic cod, following Kronbak (2004). Thus, O is assumed to be constant as well.

There are different possibilities to describe a fisheries production function and the resulting variable costs. Translog functions have been used, e.g. by Weninger (1998), Bjørndal and Gordon (2001). Here, we follow Sandberg (2006) and employ a generalised Cobb-Douglas-type cost function with two explanatory variables, assuming that stock size and output affect unit variable costs (c) multiplicatively (Equation 5.1).[4]

$$c_y = \alpha \cdot B_y^{\beta} \cdot Y_y^{\gamma} \qquad (1)$$

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[4] Sandberg (2006) was the first to investigate empirically the dependence of unit variable costs on both stock size and output.

Subscript y denotes the time step, which is a year. α is a calibration factor. Here, it is tuned such that unit variable costs of the international Eastern Baltic cod fishery during 2001-2003 reach a value of 10 DKK/kg. The parameters β and γ are stock and output elasticities of unit costs, respectively. We expect both elasticities to be negative.

Yearly total variable costs (C_y) are calculated as:

(2) $C_y = Y_y \cdot c_y$ (Y in kg).

Yearly operating profit (π_y) is calculated as:

(3) $\pi_y = \mathrm{I}_y \text{-} C_y$ where $\mathrm{I}_y = Y_y \cdot p$ (cf. Röckmann *et al.* forthcoming).

4.1 Stock elasticity of unit variable costs

In standard fisheries economics, it is assumed that the total cost of fishing is directly proportional to the amount of fishing effort (Gordon 1954). The cost per unit of effort is assumed constant. Furthermore, stock size under equilibrium conditions[5] is a linear function of fishing effort (Schaefer 1957). Consequently, the cost of fishing one unit of fish is linearly related to stock size. Generally speaking, unit variable costs rise with decreasing stock size. Assuming that the fish stock is distributed homogeneously, the Schaefer function, which is linear in both effort and stock size, implies a stock elasticity of output of one. For schooling species, however, it has been recognised that the stock elasticity is significantly less than one (Bjørndal 1987; Bjørndal 1988). Accordingly, for a given effort level, harvest and consequently costs are not very sensitive to changes in stock size, as still fish schools of small stock size can be detected and harvested very efficiently. Recently, Sandberg (2006) reported that even for demersal species such as the Northeast Arctic cod, stock elasticities of unit costs were in the range -0.2 to -0.6, thus different from –1.0. These findings confirm

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[5] I.e., when the catch is exactly equal to the rate of natural increase in population size.

once more that unit costs do not fall linearly with increasing biomass. Previous studies, where a Cobb-Douglas production function was applied, had also reported stock elasticities of output less than 1 (Eide *et al.* 2003; Flaaten 1983; Hannesson 1983).

4.2 Output elasticity of unit variable costs

With respect to the output elasticity of unit costs, economies of scale have been reported to exist, as long as firms produce below their maximum production capacity. Hence, unit variable costs fall with increasing output (e.g. Bjørndal 1987; Bjørndal 1988; Bjørndal and Gordon 2001; Eggert and Tveterås 2004; Eide *et al.* 2003; Sandberg 2006). Sandberg (2006) reported output elasticities in the Northeast Arctic cod fisheries in the range -0.2 to -0.5. In the following cost analysis of the international Eastern Baltic cod fishery, we also assume a negative cost-output elasticity, i.e., unit variable costs decrease when output (yield) increases. Since output in the Eastern Baltic cod fishery is limited by total allowable catch (TAC) quotas, the harvested yield can be assumed to be below the vessels' maximum harvesting capacity. Furthermore, the Baltic Sea fisheries are characterised by overcapacity (Eggert and Tveterås 2004; Lindebo *et al.* 2005), and therefore, production capacity should not be a production constraint.

In general, a negative output elasticity may represent an incentive to highgrade[6]. However, as the cod stock is currently at a very low level, the incentive to highgrade is low. Once the Eastern Baltic cod stock size increases again, the incentive to highgrade might then also increase.

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[6] Discarding of lower valued fish is known as "highgrading". It is a practice to ensure that only the highest-priced portion of the catch is landed and counted against quota.

4.3 Sensitivity analysis of cost simulations

Since no studies exist so far which have empirically investigated cost elasticities in the Eastern Baltic cod fishery, we started out our analysis by assuming that both, stock and output elasticity of unit costs are -0.2 (“base case”). Then we ran sensitivity analyses, testing stock elasticities in the range –0.1 to –0.8 and output elasticities in the range –0.1 to –0.5. Values for the investigated parameter combinations of α, β, and γ, are shown in Table A-1 in the Appendix (Section 8).

5 Discussion of simulation results and sensitivity analysis

5.1 Model and scenario assumptions.

The following simulations are based on population dynamics of the Eastern Baltic cod, modelled by means of an age-structured, area-disaggregated, discrete time model of the Beverton and Holt type (see Röckmann *et al.* forthcoming for complete model description). Here, we show results based on the “medium climate change” scenario, which is characterised by a decrease in mean salinity by 25% over the next century (see Röckmann *et al.* forthcoming).

To provide clarity in the figures, we limit the illustration of policy simulations to three, namely the no-policy option FasU (**F**ishing mortality ‘**as u**sual’), the seasonal marine reserve policy C25qu12 (seasonal **c**losure of SD **25** in **qu**arter **1** and **2**; quarter 3 and 4 are open to reduced fishing), and the permanent marine reserve policy C25 (permanent **cl**osure in SD **25**). The simulations cover a time period of roughly 30 years, starting in year 2005.

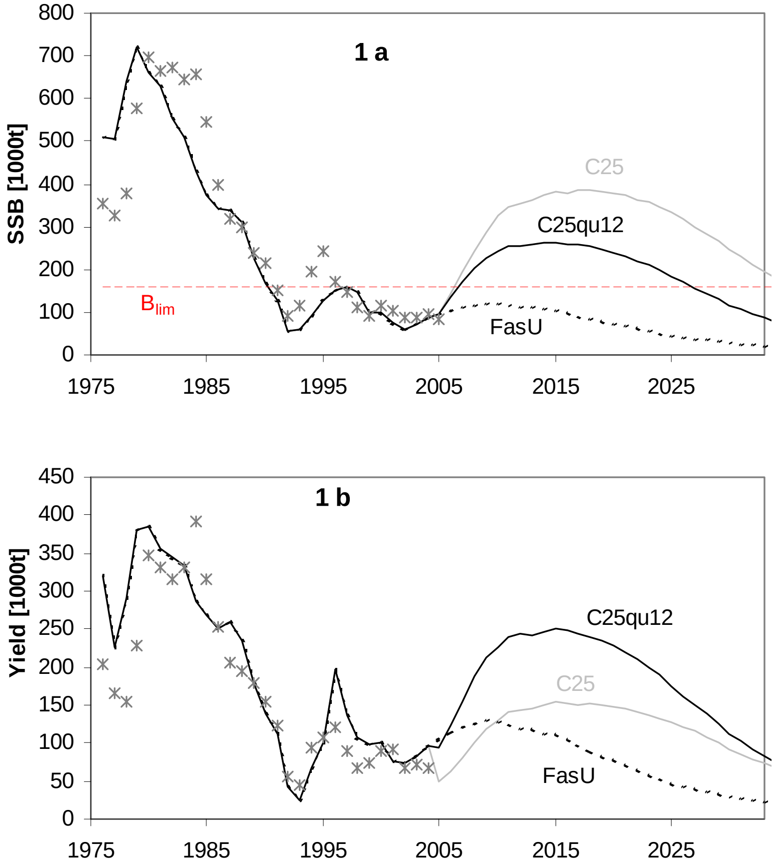


Figure 1: Simulated development of (a) SSB [1000 t] and (b) yield [1000 t] under the medium environmental change scenario for three different management policies: C25 = permanent closure of SD 25, no fishing effort redistribution; C25qu12 = seasonal closure of SD 25 in quarter 1 and 2; quarter 3 and 4 are open to reduced fishing; FasU = Fishing mortality as usual. Stars show historic ACFM data of SSB and yield.

“Base case” simulations

Figures 1a and 1b show the development of the Eastern Baltic cod spawning stock biomass (SSB) and yield, respectively, under the medium climate change scenario, averaged over 50 model simulations with random parameter realisations. Stars represent corresponding estimates of standard ICES stock assessment which illustrate that our model can well reproduce historic SSB and yield estimates (ICES 2005). While the permanent marine reserve policy (C25) yields the largest stock size in the simulation period, yield is highest under a temporal marine reserve policy (C25qu12). The fishing as usual policy (FasU) leads to inferior outcomes, both from the biological as well as from the economic point of view.

As there is no historic time series of revenue and cost data available, which would allow a validation of our model calculations, Figures 2a, 2b as well as all figures hereafter focus on the approximately 30-year simulation period only.

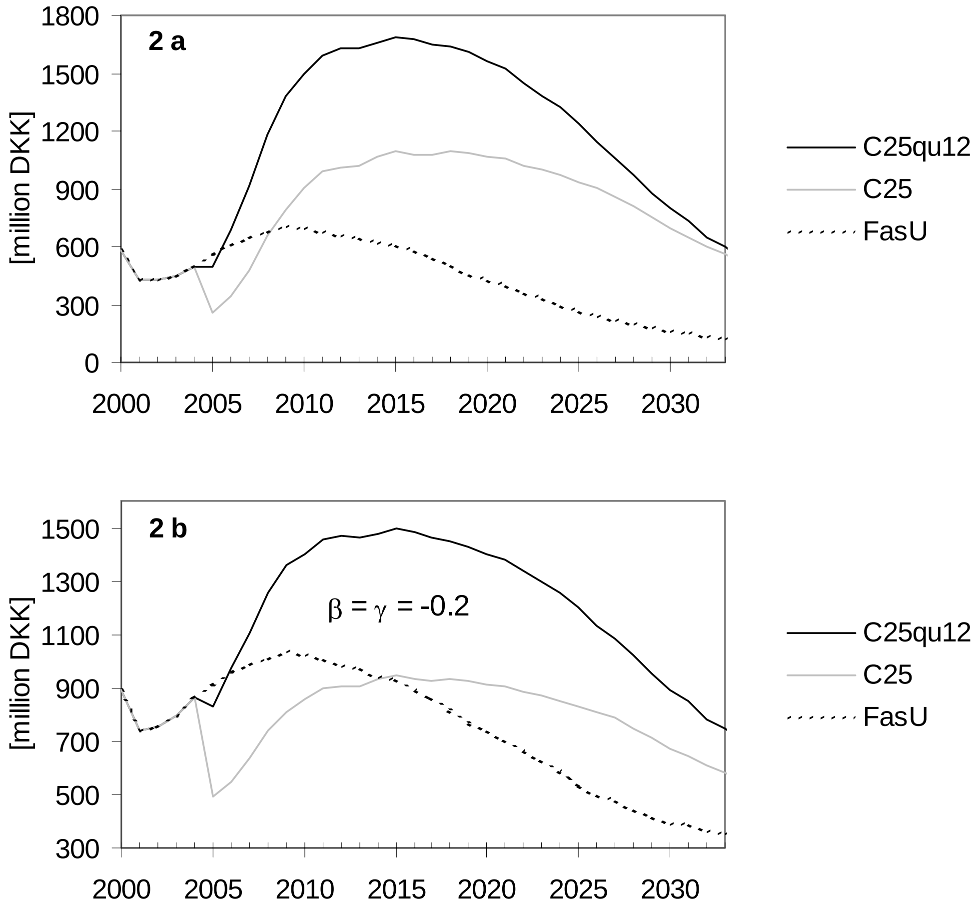


Figure 2: Simulated development of (a) gross revenues, and (b) "base case" total variable costs in million *Danske Kroner* (DKK) under the medium environmental change scenario for three different mangagement policies (see text for further explanation)

Gross revenues (Figure 2a) and total variable costs (Figure 2b) show similar dynamics to yield in the simulation period. Recall that both variables are a function of yield. In the initial year of the simulations, revenues and costs are highest under the FasU policy. But as the stock recovers over time under the marine reserve policies, the reduced fishing mortality under these policies leads to higher yields and revenues than does a higher fishing mortality of the FasU policy on a smaller stock. Gross revenues (Figure 2a) are influenced by the stock's age-structure, because larger, and thus older, fish reap a higher price per kilogram. We point out that our revenue estimates represent lower boundaries only, for they are computed applying minimum prices (cf. Röckmann *et al.* forthcoming).

The total variable cost simulations shown in Figure 2b are based on the "base case" ($\beta=\gamma=-0.2$). Cost elasticities around –0.2 were found in several Norwegian cod fisheries (Sandberg 2006). The values of β and γ in the Eastern Baltic cod fishery are unknown, though, and therefore, the cost estimates are hypothetical. This uncertainty is naturally passed on to the calculation of operating profit. Hence, instead of showing simulations of operating profit employing the "base case" cost elasticities here, we first perform a sensitivity analysis to illustrate the effect of employing a range of cost-stock and cost-output elasticities on variable cost, total cost, and operating profit (Figure 3 a-c).

5.2 Sensitivity analyses

Figure 3a-c show simulated unit variable cost, total variable cost, and operating profit, respectively, under the seasonal marine reserve policy (C25qu12) for a range of cost-stock elasticities (β). Parameter values referring to the analyses' names are defined in Table A-1 in the Annex. Since the sensitivity analysis of different cost-output elasticity values (γ) shows comparable dynamics to those presented in Figures 3a-c, we do not show additional figures here.

High negative values (close to –1) of the two cost elasticities β and γ produce the largest amplitudes in the unit variable cost figure (Figure 3a). When assuming a high cost-stock elasticity (β is close to –1), unit costs are very sensitive to stock size and therefore fall/rise strongly when stock size increases/decreases. On the other side, if cost-stock elasticity is assumed to be low (β is close to 0), one cannot expect a big gain/loss from an increase/decrease in stock size, as unit costs fall/rise only little. The same dynamics of cost-stock elasticities can be observed for different assumptions of cost-output elasticities in terms of sensitivity of variable costs to output quantity.

Note that the absolute values of total variable cost and operating profit have a large variability depending on the chosen cost elasticity values. Total variable costs as well as operating profits may differ by 1 billion DKK (Figure 3b,c). The absolute values thus have to be considered as very uncertain. For our purpose, the relative results, i.e., the ranking of the different management policies, are important, though. Under most of the analysed combinations of stock and output elasticities, the seasonal marine reserve policy C25qu12 produces highest operating profits during the first 20-25 years (Figure 4a,b,c). This ranking is robust for all elasticity combinations, except for very low negative values of β and γ (Figure 4d). In the latter case, unit variable costs are hardly sensitive to neither stock size nor yield. Thus, total costs are lower under the permanent marine reserve policy than under the seasonal reserve policy, because lower yield causes lower total costs.

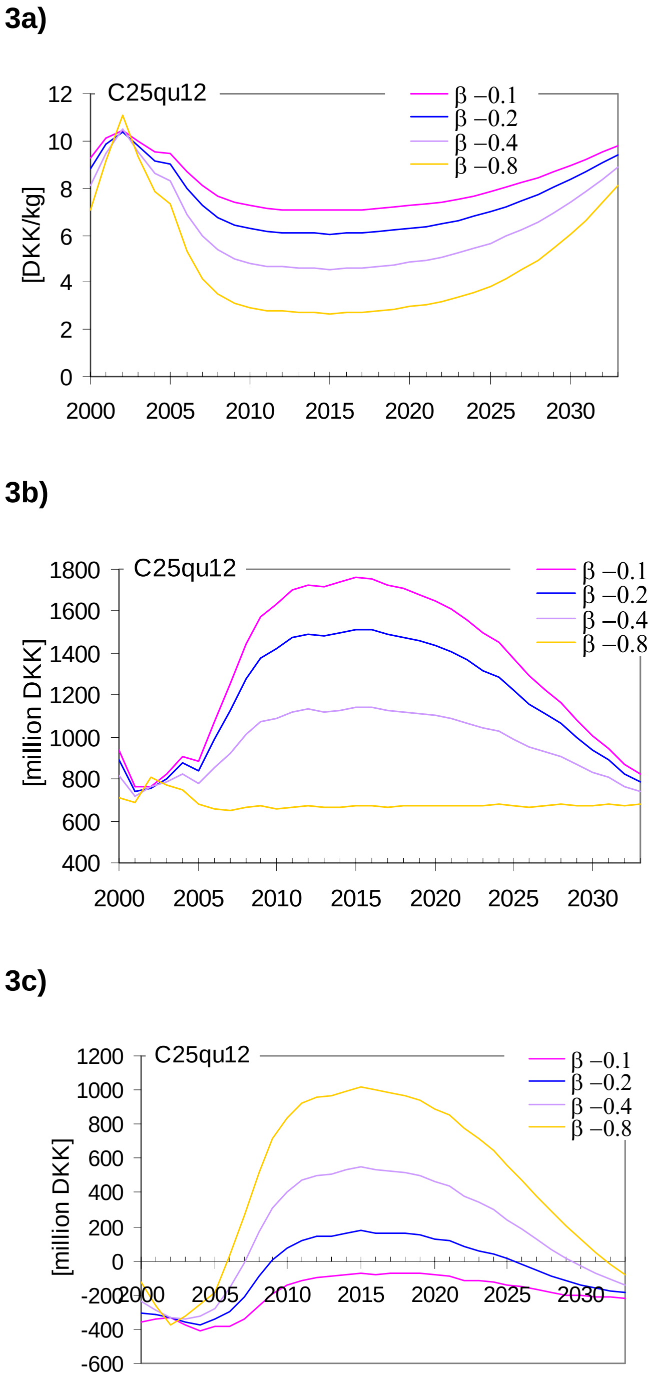


Figure 3: Sensitivity of (a) unit variable costs, (b) total variable costs, and (c) operating profit [million DKK] to different cost-stock elasticities under the seasonal marine reserve policy C25qu12.

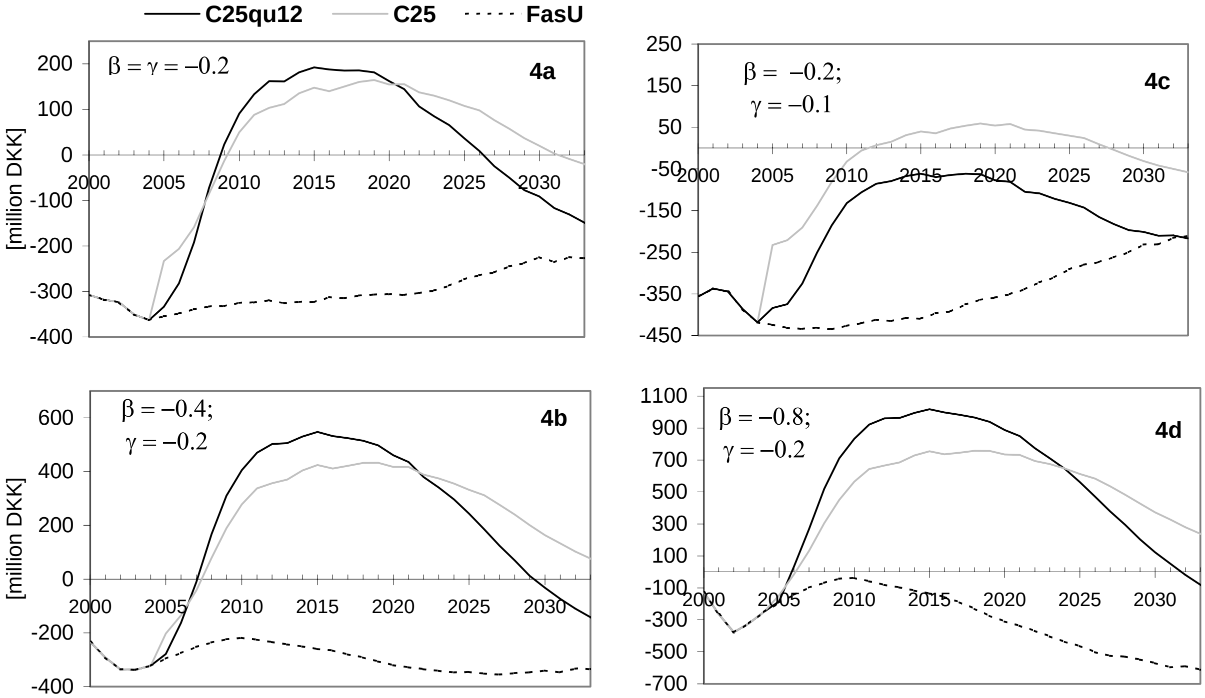
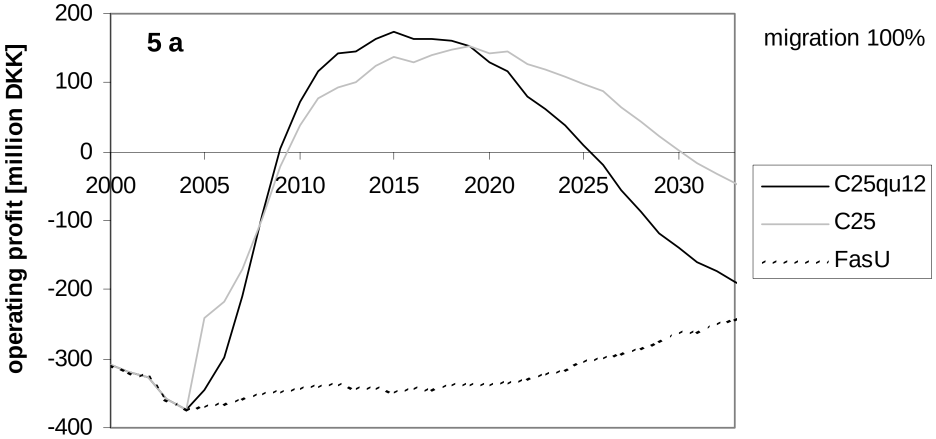


Figure 4: Sensitivity of operating profit [million DKK] to different cost elasticities (a) "base case" and (b-d) alternative cases of cost elasticities β and γ for the three selected management policies (see text for further explanation).

We also tested the sensitivity of our results to different assumptions of Eastern Baltic cod migration between subdivisions. Röckmann *et al.*'s (forthcoming) calculations of how many fish migrate between subdivisions are uncertain because quantitative data of cod migration are still not available. Figure 5a-c illustrates that the "base-case" operating profit under the permanent marine reserve policy decreases more than proportionately if migration is 20% (Figure 5b) or 50% (Figure 5c) less than originally calculated (Figure 5a). Therefore, the seasonal marine reserve policy is more favourable from the economic point of view than the permanent reserve policy. Operating profit under C25 crucially depends on fish migration out of the protected area into the adjacent regions which are open to fishing, whereas C25qu12 allows fishermen to target the stock in the protected area during a limited time of the year, which is more efficient in terms of operating profit. In summary, this analysis shows that the absolute values of our simulation results are sensitive to the underlying migration estimates, but our conclusion concerning the usefulness of a seasonal marine reserve policy is robust. Additionally, we can state that a permanent reserve policy is more favourable in terms of increasing operating profits the higher the cod migration out of the protected area.

Our model simulations are strongly driven by future environmental conditions, which are unknown, generated randomly in our model realisations (cf. Röckmann *et al.* forthcoming). In order to test whether policies do indeed generate different results in each of the n random model runs, we calculated the differences in outcomes between two contrasting policies, namely C25qu12 and FasU, for 50 individual simulations. We calculated the average and the standard deviation of the 50 differences (graphical results are given in Figures A-1 to A-4 in the Appendix). All means including standard deviations are different from zero. Therefore we conclude that despite the uncertainties regarding environmental variability in the model realisation, a seasonal marine reserve policy leads to better economic results than continuing fishing as usual.



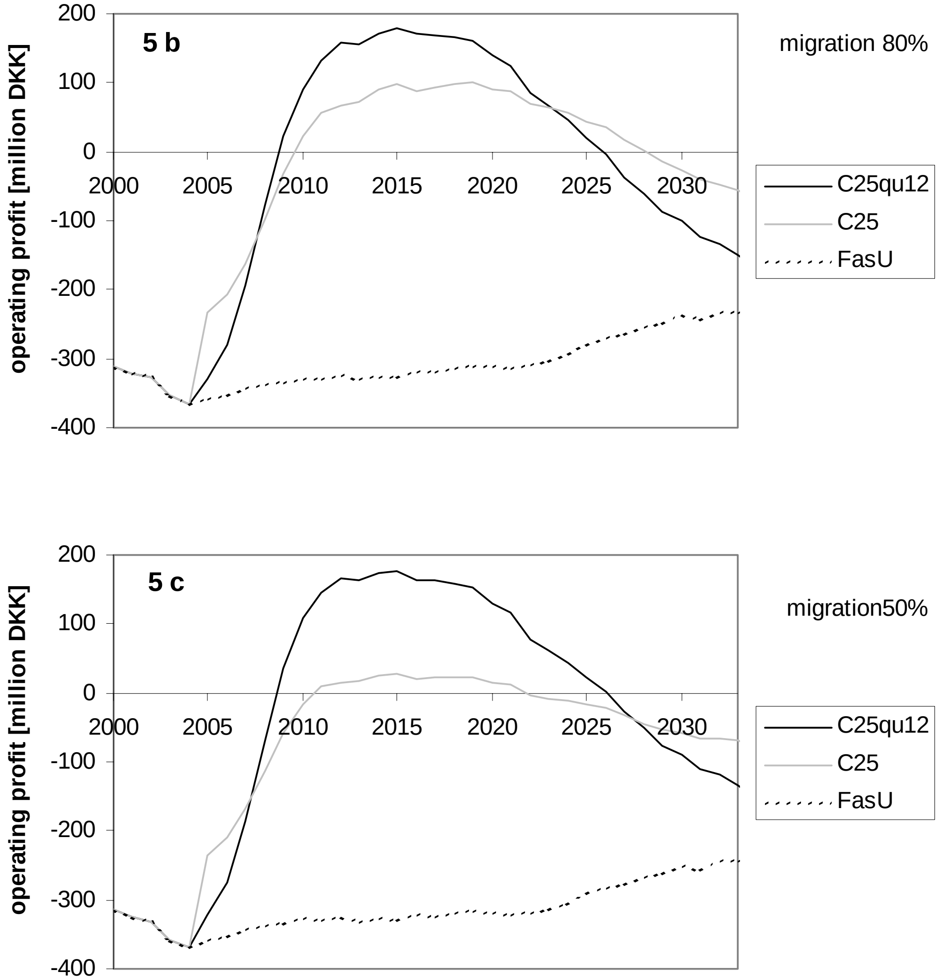


Figure 5: Sensitivity of operating profit [million DKK] to reduced migration rates for the three selected management policies (see text for further explanation): (a) original calculation according to Röckmann *et al.* (forthcoming); (b) reduction of the originally calculated migration by 20%; and (c) reduction of the original by 50%.

Caveats

We only looked at variable costs here. Ideally, one should also include fixed costs, for fishermen can adjust their fleet size to an increased or decreased stock size over the longer term. As fishermen can sell their vessels, this also represents an opportunity cost.

Overcapacity has been reported to exist in the Baltic Sea (Eggert and Tveterås 2004; Lindebo 2001). The majority of the Baltic Sea fishing vessels are old, though. It is likely that a number of vessels will be decommissioned or scrapped in the near future, which will result in a reduction of the total fleet size, if no additional new vessels are bought. Subsidies for building new ships or the renewal of engines have been banned since the reform of the European Common Fisheries Policy in December 2002 (EC 2002). A transition period of two years allowed that "public aid for the renewal of fishing vessels […] [could still be] granted until 31 December 2004" (EC 1999, Article 9). Since 1 January 2005, however, there have been no more subsidies at all for fleet or engine renewal and modernisation. Hence, it is likely that the total fleet size in the international Baltic cod fishery will decrease. Therefore, unit costs may even decrease further, as the remaining smaller fleet can fish more efficiently.

Our analysis is based on the assumption that fishermen perfectly obey the management policies, thus lacking possible dynamics/responses between stock size and fishing effort and yield. Incorporating assumptions on fishermen behaviour (e.g. maximisation of net present value of operating profit) should be the next step in this research.

The cost analysis is simplified, because we implicitly assume that all vessels are identical and have the same cost and revenue structure. A typical vessel for the Danish cod fishery in the Eastern Baltic Sea was depicted by Kronbak (2002; 2004). This "Bornholm vessel" has a tonnage of 49.34 BRT, which is a medium to large vessel in the Baltic Sea. The vessel is a trawler, which is the most common type of vessel catching cod in the Baltic Sea (Frost and Andersen 2001). Sandberg (2006) showed that responsiveness of unit variable costs to output and stock size differs between different vessel types. Hence, optimal stock and fleet management differs between vessel groups. It was outside the scope of this study to look at individual firms and optimal fleet size. However, this represents an area where future research is warranted. The international fleet fishing in the Baltic Sea is very heterogeneous. Our estimates are derived based on rough calculations from Danish statistics. As the majority of the total international vessels may be smaller than the average Danish vessels, the financial results of smaller vessels are likely to be affected differently by management policies to counteract climate change.

Smaller vessels may benefit more from increasing harvests, as, for example, fuel costs decrease if harvest and revenues are higher. On the other hand, if additional small boats start fishing, unit variable costs will increase with increasing harvest.

Finally, we also expect differences in stock-output elasticity depending on the gear type (trawl versus gillnet). As a consequence, the relative profitability of gear types changes when the stock biomass rises or falls.

6 Summary and Outlook

This study adds a cost analysis of the Eastern Baltic cod fishery to an existing study by Röckmann *et al.* (forthcoming), who simulated the population dynamics of Eastern Baltic cod, yield, gross revenues, and net present values of gross revenues in the Eastern Baltic cod fishery. As cost data specifically on this international fishery do not exist, we made a first attempt to get rough cost estimates. Additionally, we simulated unit and total variable costs and tested the sensitivity of our simulations to a set of different cost-stock and cost-output elasticities. The following conclusions can be drawn:

This study confirms previous findings by Röckmann *et al.* (forthcoming) that a seasonal marine reserve policy, which focuses on protecting the Eastern Baltic cod spawning stock in ICES subdivision 25, is a valuable fisheries management tool to (a) rebuild the overexploited Eastern Baltic cod stock and (b) increase operating profits, thus avoiding the negative effects of overfishing. The negative effects of climate change can be postponed for at least 20 years – depending on the assumed rate of future climate change. Including variable costs in the economic analysis does not influence the ranking of management policies, which Röckmann *et al.* (forthcoming) proposed in their preliminary approach, where they neglected costs.

The performed sensitivity study, analysing the effects of applying different cost-stock and cost-output elasticities on simulated variable costs and operating profit, confirms expectations: Under high negative values of elasticities, there is a strong response between stock size and unit costs and between output and unit costs. The lower the cost elasticity, the less sensitive are costs to stock size. Therefore, under very low negative values of cost-output and cost-stock elasticities (close to 0), a permanent marine reserve policy, which restricts fishing mortality more strongly and thus reaps lower yields than a seasonal reserve policy, turns out better than a seasonal one. Assuming high elasticities, a seasonal marine reserve policy is better than a permanent one for a time period of about 20-25 years.

We have already mentioned and discussed some assumptions which might be too simple. In the future, various aspects of our analysis should be improved and new data should be collected to allow for more sophisticated analyses. These aspects are as follows:

- The spatial and the temporal resolution of the cost function should be increased. Variable costs should vary over subdivision and quarter, taking account of the Eastern Baltic cod's spawning concentrations and heterogeneous feeding migrations. Seasonality and intra-annual variation in catchability, as reported by Eide *et al.* (2003) for the Norwegian bottom trawl cod fisheries, may very likely occur in the Eastern Baltic cod fishery as well.
- Due to the heterogeneity of the fishing fleet, cost-stock as well as cost-output elasticities are likely to vary not only over season and region, but also depending on vessel type and fishing gear.
- Although the sensitivity analysis regarding migration estimates supports our general conclusion that a seasonal marine reserve policy is effective in both rebuilding the cod stock as well as ensuring future harvests and operating profits to fishermen, the uncertainty in the applied migration functions and parameters call for empirical studies to

investigate the Eastern Baltic cod’s migration patterns *in situ*. Such field studies might also give insight into differences in catchability depending on time and region.

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8 Appendix

Table A-1: Parameter values for calculation of unit variable costs, according to: $c_y = \alpha \cdot B_y^{\beta} \cdot Y_y^{\gamma}$ [B and Y in kg].

Sensitivity analysis name	α	β	γ
β -0.1	2340	-0.1	-0.2
β -0.2	14000	-0.2	-0.2
β -0.3	84500	-0.3	-0.2
β -0.4	510000	-0.4	-0.2
β -0.5	3100000	-0.5	-0.2
β -0.6	19000000	-0.6	-0.2
β -0.8	700000000	-0.8	-0.2
γ -0.1	2340	-0.2	-0.1
γ -0.3	85000	-0.2	-0.3
γ -0.4	520000	-0.2	-0.4
γ -0.5	3200000	-0.2	-0.5

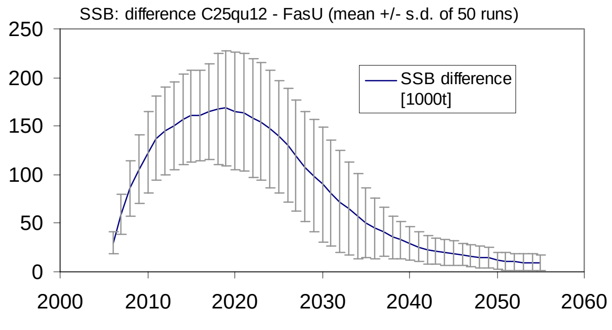

Figure A-1: Mean and standard deviation of difference between SSB under C25qu12 and FasU of 50 random model runs.

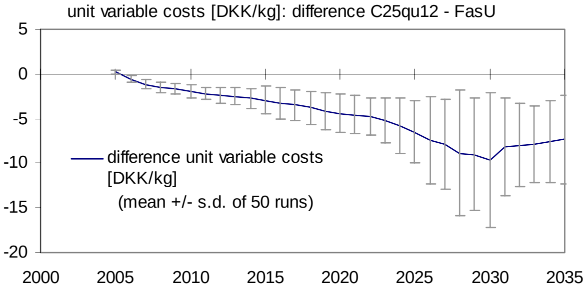

Figure A-2: Mean and standard deviation of difference between unit variable costs under C25qu12 and FasU of 50 random model runs.

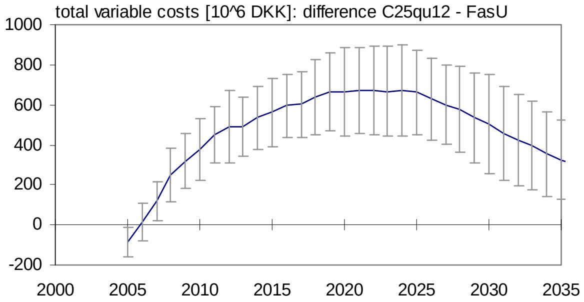

Figure A-3: Mean and standard deviation of difference between total variable costs under C25qu12 and FasU of 50 random model runs.

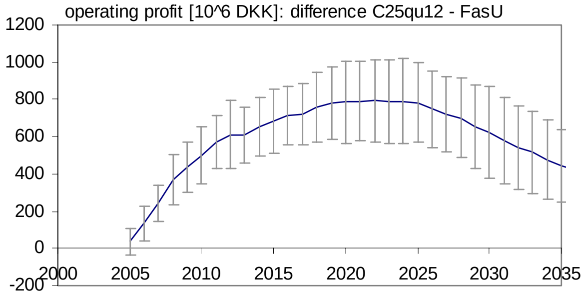

Figure A-4: Mean and standard deviation of difference between operating profit under C25qu12 and FasU of 50 random model runs.

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