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Bio-economic evaluation of implementing trawl fishing gear with different selectivity

Lone Grønbæk Kronbak [a,*,4], J. Rasmus Nielsen [b,1,4], Ole A. Jørgensen [b,2,4], Niels Vestergaard [a,3,4]

[a] Department of Environmental and Business Economics, University of Southern Denmark, Niels Bohrs Vej 9, DK-6700 Esbjerg, Denmark
[b] Technical University of Denmark, National Institute of Aquatic Resources, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark

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ABSTRACT

The paper develops a biological-economic evaluation tool to analyse the consequences for trawl fishers of implementing more selective fishing technologies. This is done by merging a dynamic biological population model and an economic cost–benefit evaluation framework to describe the consequences for the fish stocks, fishermen and society. The bio-economic evaluation is applied to the case of the Danish trawl fishery in Kattegat and Skagerrak, which experiences a high level of discards and bycatches of several species. Four different kinds of selectivity scenarios are evaluated in comparison with a baseline. The results from the evaluation are indicators for the consequences on ecological and economic levels. The results show that implementation of different selective fishing gear in the Kattegat and Skagerrak mixed trawl fisheries generally implies a trade off over time between rebuilding the stocks and economic loss. Moreover, the analysis shows that implementation of more selective gear is not always beneficial.

1. Introduction

"Environmentally friendly fishing" is currently a common political phrase conveying the wish to minimise the negative ecological impacts of fishing (Walsh et al., 2004; Commission of the European Communities, 2004). One example of this new emphasis is the focus on "illegal, unreported and unregulated" fishing as part of the Food and Agriculture Organization of the United Nations (FAO) International code of conduct on responsible fisheries (FAO, 1995). The change in policy orientation from single species management to ecosystem-based management is another example.

The lack of selectivity in many fisheries may lead to discards and bycatches of unwanted species. Discards of undersized or non-commercial species/individuals represent damage to the ecosystem, an additional source of overfishing, and ultimately a waste of resources. Bycatches may increase fishing pressure on species targeted by other fishermen or non-target species such as sea turtles and mammals. This problem is persistent in the Kattegat and Skagerrak Danish mixed trawl fishery, where Norway lobster is one of the most economically important species and there is a high discard rate of undersized Norway lobster and bycatches of other species, including cod.

The purpose of this article is to investigate in a bio-economic model the scope for implementing more selective gear in this mixed Danish trawl fishery. This is done by merging a dynamic biological model and a cost–benefit analysis of the consequences. The bio-economic model is developed in such a way that it can illustrate biological changes and the resulting consequences for both the profits of fisherman and the net-benefit from a social point of view. The results are based on a dynamic age-structured biological model, where it is possible to handle the changes in size and species composition of catches, landings and discards due to changes in selectivity. This is a necessary condition for making quantitative evaluations of the biological and economic impacts of implementing more selective gear.

Cost–benefit analysis (CBA) is a useful economic policy evaluation tool for several reasons (see Arrow et al. (1996)). Economic evaluation tries to assess the social desirability of a regulation compared to a given baseline situation or some other alternative. Therefore, economic evaluation can help public policy by focusing on the need for regulation and finding the appropriate scope and design of that regulation. To assist the formulation of selective gear policy in fisheries, bio-economic modelling using the framework from cost–benefit analysis is a suitable method (Herrick et al.,

* Corresponding author. Tel.: +45 65504182.
E-mail addresses: lg@sam.sdu.dk (L.G. Kronbak), rn@aqua.dtu.dk (J.R. Nielsen), olj@aqua.dtu.dk (O.A. Jørgensen), nv@sam.sdu.dk (N. Vestergaard).
1 Tel.: +45 33963300.
2 Tel.: +45 33963300.
3 Tel.: +45 65504181.
4 Authorship equal between all authors.

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1994). In CBA, the impacts in terms of changes in benefits and costs are systematically determined and compared by transforming as many of the impacts as possible into monetary units.

Implementation of more selective gear is expected to lead to a short-term decrease in catch revenue, but over longer time—due to changes in stock composition and size—higher catch revenue. In many cases the fisheries are multispecies, and therefore changes in catches of different species have to be compared. These two comparisons of impacts on different points in time and on different species can be done in a CBA.

CBA has been applied to evaluate fishery policy by Freese et al. (1995) and Herrick et al. (1994). However, these studies look at direct allocation of resources and do not include a dynamic biological component. Brown and Macfadyen (2007) apply a CBA to evaluate management responses to "ghost fishing", but their model does not include a dynamic biological component either. Marlen (2003) conducts an economic evaluation of improving the selectivity of beam trawls in the Netherlands. The economic evaluation compares the weights and values of catches using an experimental net with those using a conventional net, taking into account price differences between species and size-classes. The economic evaluation does not include a dynamic biological component, and thus misses the potential long-term positive economic effects. Marcher et al. (2008) provide a CBA of improving selective measures in a single species fishery in the case of the Norway lobster in the Bay of Biscay. This paper distinguishes itself from other papers available in the literature by not only considering the short-term losses from more selective measures, but also considering the transition paths and the medium-term to long-term benefits of selectivity. Our paper further contributes to this literature by considering a mixed trawl fishery and the bio-economic consequences for the four most important species affected by the selectivity measures in this fishery.

There have been a number of studies of selective fishery for Norway lobster. Casey (1996) studies the mixed demersal fisheries in the Irish Sea, which include the Norway lobster trawlers, although Norway lobster is not among the dominant four species. The study examines the effects of including discards in the assessments and on the yield-per-recruit. Necessity (2008) and Krag et al. (2008) test the selectivity for Norway lobster with different gear types in Kattegat and Skagerrak. Sorting grids became mandatory in the Swedish trawl fishery for Norway lobster in 2004 (Anon, 2006), but the biological and economic effects have yet to be fully evaluated. Eggert and Ulmestrand (2000) analyse the Swedish Norway lobster fishery in a steady-state bio-economic framework with the purpose of finding the optimal steady-state equilibrium level of effort. They account for discards in their model, and they run two scenarios with selectivity (different mesh codends). Since it is a steady-state analysis, however, revenue and costs are only compared for the stock in equilibrium. In their model, they apply an average price that has the consequence that the impact of changes in size-composition on revenue is ignored. Our paper contributes further to the literature by analysing biological and economic consequences of a fishery policy aiming at a better selectivity by changing the gear technology. It is done by investigating certain policy changes assuming that these changes provide the selectivity as described, i.e., the proposed changes are effective. Further, because the paper looks at proposed (i.e., given) policy changes it does not find the optimal gear policy.

The case study analysed, subject to different proposed gear technology changes, is the Danish trawl fishery in Kattegat and Skagerrak. The Kattegat and Skagerrak waters, which are shared among Norway, Sweden and Denmark, are located north of Denmark and correspond to International Council for the Exploration of the Sea (ICES) area IIIa. The trawl fishery in this area is a mixed fishery harvesting Norway lobster (*Nephrops norvegicus*), Atlantic cod (*Gadus morhua*), Common sole (*Solea solea*), European plaice (*Pleuronectes platessa*) and other less economically important species. Norway lobster is considered the main target species for the trawl fishery since it, with its high price and large quantities, is by far the most valuable species, even though species like cod and sole are also of high economic value.

The Danish trawl fishers take approximately 75% of the total catches of Norway lobster. In 2004, Denmark had 91 trawl vessels in the fishery (Kronbak et al., 2007). These vessels were divided into length categories according to the EU standards[5] and are only included in the further analysis if they were categorised as having fishery as their main occupation.[6] The Danish Norway lobster fishery in Kattegat and Skagerrak falls within Denmark's exclusive economic zone (EEZ) and is subject to the Common Fishery Policy (CFP). The fishery is regulated by a set of different management tools. These include output restrictions (quotas and licenses), input restrictions (days at sea) and technical measures (minimum mesh size and minimum carapace length/landing size).

As regards selectivity, the main problems in this fishery are the very high discard level of undersized Norway lobster and the bycatch of cod, which is considered a species on a low or critical level (Eggert and Ulmestrand, 2000; ICES, 2006a,b). For a further description of the fishery, see Kronbak et al. (2007) and ICES (2006a,b). In the fishery there is the mismatch between the minimum landings size (MLS) of Norway lobster and the mesh size which leads to high mandatory discards of undersized catches. This is clearly seen by the fact that the discard of undersized Norway lobster approximately equals the legal landings of Norway lobster in weight (Nielsen et al., 2008). Some of the discard problem could be solved by implementing more selective gears. As cod is a natural part of the harvest in this mixed trawl fishery, and with the cod recovery plan (Council Regulation, 2004), another aspect is that the quantities of the mature fish should be increased while bycatches of younger cod should be avoided.

The paper proceeds as follows. Materials and methods, including the respective settings for the biological and economic model, respectively, are described in Section 2. Section 3 describes the results from the four different scenarios. In Section 4 the robustness and the uncertainties are discussed. Finally, Section 5 concludes the paper.

2. Materials and methods

The CBA is carried out for four different scenarios where each gear type alternative is compared to a baseline scenario. This means that all results from the analysis are described as changes relative to the baseline. The model covers two fleets, i.e., the Danish trawl fleet in question and an "other fleet" component that is comprised of the Danish gillnet fishery and international (Swedish) fleets. The relative changes are calculated as changes in biomass, changes in harvests and changes in discards for the four different species: Norway lobster, cod, sole and plaice. Based on the changes in the value of the harvest of the four species and the private costs of gear switch, we calculate the net present value of the producers' surplus to the Danish trawl fleet. The timeframe for evaluation is ten years, which ensures the stock biomass' are in equilibrium. The baseline scenario is defined as a status quo over the period for evaluation. The baseline is assumed to be characterised by the year 2004,

[5] <12 m, 12–15 m, 15–18 m, 18–24 m, 24–40 m and >40 m.

[6] For fishery to be a main occupation, the revenue must exceed the limit of 230 000 Danish kroner per vessel. 100 DKK corresponds to app. 13 Euro or app. 20 USD (August, 2008).

where the Norway lobster was primarily harvested by trawls with a 90 mm codend. The aim of all the scenarios is that the gear technology implemented should be more selective than the gear type applied in the baseline scenario. Fig. 1 summarises the four scenarios. The selection of scenarios is based partly on what is relevant in relation to the current regulation (90 mm codend with 120 mm mesh panel) and on recent experimental selectivity trials (90 mm codend with 120 mm mesh panel, and 90 mm codend with grid, i.e., two of the scenarios model the same gear sets as have been used in experimental hauls: the former two in Fig. 1) and partly based on scenarios where the aim is to reduce the mortality rate of the younger year classes of both Norway lobster and cod (the latter two in Fig. 1).

Scenario 1
90 mm codend with mesh panel
Compulsory use of 90 mm codend with 120 mm mesh panel in the trawl fishery with Norway lobster as main target in Kattegat and Skagerrak.

Scenario 2
90 mm codend with grid
Compulsory year round use of 90 mm codend with grid with 35 mm between bars in lower part of grid and 80 mm between bars in upper part of grid in the trawl fishery with Norway lobster as main target in Kattegat and Skagerrak.

Scenario 3
100 mm codend
Compulsory use of 100 mm codend in the trawl fishery with Norway lobster as main target in Kattegat and Skagerrak.

Scenario 4
120 mm codend
Compulsory use of 120 mm codend in the trawl fishery with Norway lobster as main target in Kattegat and Skagerrak.

Fig. 1. The four scenarios to be compared to the baseline (90 mm codend).

2.1. The biological model

2.1.1. General description

The biological model used to evaluate different scenarios of gear technology changes for mesh size and selectivity parameters is, at the outset, an adjusted version of the TEchnical MAnagement measureS (TEMAS) model described in Sparre (2008a,b) and Ulrich et al. (2007). TEMAS is a fleet-based, bio-economic management evaluation simulation tool implemented in Visual Basic/Windows Excel.

Based on input of initial stock size recruitment and fishing mortality for fish fully recruited to the fishery in year t, the model calculates stock size (biomass and numbers) and total fishing mortality per age group in year $t+1$, as well as fleet-specific partial fishing mortalities and landings and discards per age group by fleet (definition of parameters is given in Section 2.1.2). Thus, the partial fishing mortalities in the model are divided into a discard and landing fraction per fleet based on observed discard ogives from at sea sampling programs covering the commercial mixed Norway lobster fishery in the area (see below). After conditioning and calibration of the model to the initial year, the forecast is run repeatedly with constant recruitment for ten forecast years until equilibrium is reached (in the setup where ten age groups are used). Consequently, the model can estimate both the relative short-term and long-term effects of the different scenarios.

2.1.2. Biological input parameters

The initial population size is obtained from the ICES assessment (ICES, 2006a,b). Natural mortality, M, values are those used in the ICES stock assessments and are kept constant for all ages (ICES, 2006a,b). Fishing mortality is mortality caused by fishery. Fmax is fishing mortality for fish fully recruited to the fishery.

The overarching principle in the adjusted model version of TEMAS is the use of an Fmax for the oldest age groups and largest fish in the stock. The Fmax for the oldest age groups used in the model is assumed not to be influenced by gear selection and discard/sorting selection on board, as these fish are so big and valuable that they all are retained in the gear, above minimum landing size and not discarded. Fmax is the basic F to which all age groups are exposed, but for the younger and smaller fish, there are impacts of both gear selection and sorting/discard selection. Consequently, Fmax is multiplied first by an estimated gear selection ogive over ages and then by a sorting ogive by age reflecting estimated discard. From this, a resulting exploitation pattern (F-distribution at age) is obtained in the model reflecting catch, landing and discard. Fig. 2 describes the species- and scenario-specific exploitation patterns. Fmax being the average of F-values at age for the oldest age groups is estimated for a given stock from the 2006 analytic assessment in ICES (2006a,b).

F is split into partial F for Danish trawlers and partial F for "Others" according to the relative distribution of landings at age between fleets, $F_{a,t}(\text{tot}) = F_{a,t}(\text{trawl}) + F_{a,t}(\text{other})$. Further, F is subdivided into F-landings and F-discard by fleet, e.g., $F_{a,t}(\text{trawl}) = F_{a,t}(\text{land,trawl}) + F_{a,t}(\text{disc,trawl})$. Discard is not always included in the estimation of F in the ICES stock assessments. The TEMAS model estimates F-discard and number discarded by age group from stock in number by age and fitted sorting (discard) ogives by stock and fleet. The estimated sorting (or discard) ogives are obtained from information about discard sampled on board commercial vessels by the National Institute of Aquatic Resources (DTU Aqua), Technical University of Denmark (DTU). Discard parameters are obtained from the DTU Aqua discard database following the standard EU trip based at sea sampling design from the commercial fishery (EU Data Collection Regulation, DCR). The length where 50% of the fish are discarded and 50% retained on board (L_{50}) is estimated from a linear regression between the length where all specimens are discarded and the length where all specimens are kept on board. The estimation of L_{75} (length where 75% of the fish are retained on board) is based on the same regression.

Finally, F is also based on the gear selection ogive and selection parameters. Here input parameters are gear mesh size, a selection ogive resulting from the input selectivity parameters L_{50} and selection range, SR, where L_{50} is the length of the fish where 50% of the fish escape the net and 50% are retained by the net and SR is $L_{75} - L_{25}$. The selection factor, $\text{SF} = L_{50} * (10/\text{MS})$ where MS is mesh size. The actual selection parameters used by evaluated scenario is described in Section 2.1.3.

A constant yearly recruitment is a precondition for a population dynamic equilibrium model. The recruitment at age 0 is estimated by calculating "backwards" from the recruitment estimated from the analytical assessment (ICES, 2006a,b), which typically is recruitment at age 2, by means of total mortality ($Z = F + M$).

It is assumed that the growth of all species in the analysis follows the von Bertalanffy growth equation:

$$L = L_\infty * (1 - \exp(-K*(\text{Age} - t_0))),$$

where L = length, L_∞ = maximal fish length (L-infinity), K = curvature parameter, which determines how fast the fish approaches L_∞, and t_0 = the point in time where the fish has zero length.

The parameters K, L_∞ and t_0 are included in the model and are fitted to give a realistic correlation between length and age. The fitted values are all within the range given in the literature (FISH BASE, http://www.fishbase.org/search.php).

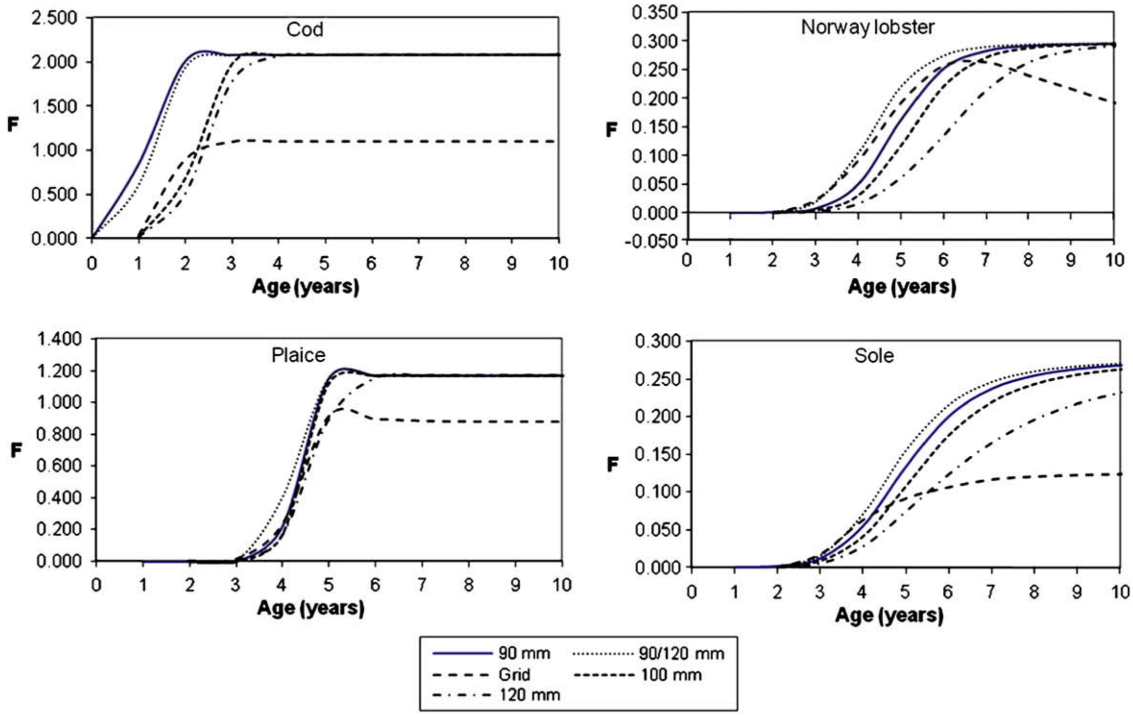

Fig. 2. The species- and scenario-specific exploitation patterns.

The condition factor (q), where $\ln(q) = \ln(a) + \ln(b) * \ln(L)$, is used to estimate the weight at a given length (age) estimated from the von Bertalanffy growth equation. a and b are constants estimated from a length/weight relation: $W = a * L^b$, where W is weight and L is length. In the model, a and b, and, hence, q are fitted so that the estimated weight at age is realistic. That is to say, the estimated weight of the landings (the sum product of the estimated number of fish at a given age times the weight of fish at that age) should be equal to the catch weights used in the stock assessment by ICES (ICES, 2006a,b). The values are in good agreement with condition factors estimated from ICES research surveys in Kattegat and Skagerrak. The initial stock size and the growth, condition, recruitment, and natural mortality parameters are kept constant in the model simulations.

2.1.3. The trawl experiments and selectivity estimation

The trawl selection parameters L_{50} and SR in the baseline and in scenarios 1 and 2 were estimated based on 57 experimental trawl hauls carried out in Skagerrak and Kattegat in September–October 2005 in connection with the EU-project Necessity (Norway lobster and Cetacean Species Selection) (Necessity, 2008), in which three different experiments were conducted:

1) One experiment involved a standard twin trawl rigged with 90 mm mesh in the codend commonly used in the fishery for Norway lobster in 2004 and a reference trawl with 40 mm stretched mesh in the codend assumed to retain all Norway lobster and fish in the relevant size groups. The selection parameters for the 90 mm trawl could, hence, be estimated by comparing the catches in the two trawls. The selection parameters for the 90 mm trawl are used as reference parameters for the remaining part of the experiments.
2) Another experiment used with a twin trawl rigged with one trawl with a 120 mm mesh panel mounted at the top of the codend that had a mesh size on 90 mm and a reference trawl with 40 mm mesh in the codend used as reference trawl.
3) The third experiment featured a twin trawl rigged with one trawl with a separator grid with bars spaced 35 mm in the lower $3/4$ part of the grid and 80 mm in the upper part. A fine meshed bag was mounted behind the lower part of the grid. The catch in this bag was used to estimate selectivity. A hole was cut in the upper panel of the trawl in front of the grid allowing fish to escape. The purpose of the grid was to select Norway lobster from fish in order to avoid bycatch of fish. The other trawl was a reference trawl with 40 mm mesh in the codend.

2.1.4. Calibration and conditioning of the model

In the model the selectivity parameters are changed according to different scenarios, i.e., the model is run with different gear mesh sizes and selectivity parameters for the Danish trawl fleet to evaluate relative effects of the scenarios on stock and on fleet-based landings and discards.

The model is conditioned with an initial population corresponding to the estimated total landings and fishing mortalities in 2004 for all species covered in the present study (ICES, 2006a,b). The conditioning was made for the Danish trawl fleet in the Norway lobster fishery in Skagerrak-Kattegat according to fleet-specific landings as estimated in the ICES Assessments for plaice in ICES area IIIa, sole in Kattegat, cod in Kattegat and Norway lobster in IIIa (ICES, 2006a,b), with a supplement of fleet-based information from Fishframe data[7] where necessary. In 2004, the fishery for Norway lobster with 70/90 mm mesh size in the area stopped, and the 90 mm mesh size (codend) gear became the dominant mesh size in the fishery. Accordingly, the study covers a period where there was no influence of selectivity from the 70/90 mm gear. Furthermore, the fishing mortalities by stock/species for 2004, estimated in the later years in the ICES assessments, did not vary significantly, and

[7] http://www.fishframe.org (August, 2007).

Table 1
Biological and selection parameters for 90 mm codend and 90 mm codend with 120 mm mesh panel.

	Common sole[a]	European plaice	Atlantic cod	Norway lobster
Biological parameters				
von Bertalanffy[d]	$K=0.26$, $L_\infty=43$ cm	$K=0.13$, $L_\infty=73$ cm	$K=0.156$, $L_\infty=105$ cm	$K=0.15$, $L_\infty=69$ mm
Condition factor[e]	0.0108	0.0105	0.012	0.0007
Min. landing size	24.5 cm	27.0 cm	35.0 cm	39.8 mm
Natural mortality[f]	$M=0.1$	$M=0.1$	$M=0.2$	$M=0.2$
Partial fishing mortality[f]				
Trw.	$F=0.153$ (age 10)	$F=0.29$ (age 10)	$F=0.98$ (age 7)	$F=0.22$ (age 8)
"Others"	$F=0.127$ (age 10)	$F=0.88$ (age 10)	$F=1.096$ (age 7)	$F=0.075$ (age 8)
Recruitment (age 0)[f]	7 457 000	53 500 000	8 260 000	1 010 000
Selection parameters				
Discard ogive[g]	$L_{50}=23.1$, $L_{75}=24.1$	$L_{50}=25.4$, $L_{75}=26.2$	$L_{50}=34.7$, $L_{75}=35.4$	$L_{50}=37.6$ mm, $L_{75}=39.0$ mm
Selection factor[h]	Trw. 0.289	Trw. 0.243	Trw. 0.256	Trw. 0.300
90 mm codend[b]	O. 0.289	O. 0.243	O. 0.256	O. 0.300
Selection range with SE	Trw. 8.58, 1.57	Trw. 2.49, 0.70	Trw. 6.97, 0.80	Trw. 12.29, 2.49
	O. 8.58, 1.57	O. 2.49, 0.70	O. 6.97, 0.80	O. 12.29, 2.49
L_{50} with SE	25.97, 1.78	21.91, 0.33	23.02, 1.28	27.08, 0.94
Selection factor	Trw. 0.198	Trw. 0.157	Trw. 0.225	Trw. 0.190
90 mm codend/120 mm mesh panel	O. 0.289	O. 0.243	O. 0.256	O. 0.300
Selection range with SE	Trw. 12.08, 3.13	Trw. 5.11, 2.25	Trw. 10.93, 0.91	Trw. 8.11,[c]
	O. 8.58, 1.57	O. 2.49, 0.70	O. 6.97, 0.80	O. 12.29, 2.49
L_{50} with SE	23.74, 2.69	18.79, 1.27	27.05, 1.31	22.76[c]

Note: Trw. = Danish trawlers, O. = other fleets (Danish gillnetters and Swedish vessels); SE = Standard Error.
[a] Selection parameters for lemon sole.
[b] Basic setup to which all other gear configurations are compared. The same selection parameters are used for the model runs with 100 mm and 120 mm mesh sizes.
[c] Preliminary estimates.
[d] Fitted, but within the range given in the literature (FISH BASE, http://www.fishbase.org/search.php) (see Section 2.1.2).
[e] Estimated (see Section 2.1.2).
[f] ICES, 2006a,b (see Section 2.1.2).
[g] Discard parameters obtained from the DTU-Aqua discard database (see Section 2.1.2).
[h] (Necessity, 2008).

therefore, the 2004 values estimated in 2006 were used (ICES, 2006a,b). Consequently, the influence of higher uncertainty from the terminal assessment year was eliminated.

The parameters for the gear with a standard 90 mm codend (baseline) and a 90 mm codend with a 120 mm mesh panel (scenario 1) are given in Table 1. For the selectivity for Norway lobster in scenario 2 (90 mm trawl with grid) based on experimental hauls, it was not possible to calculate the selection parameters L_{50} and SR, as there is both selection at the grid (right hand side of the selectivity curve) and also at the codend (left hand side of the selectivity curve), i.e., two opposite directed selection ogives in the same gear. The two curves have opposite directions as the grid sorts out the larger individuals while the codend sorts out the smaller individuals. Accordingly, the overall resulting selection in this gear has been shown graphically (Necessity, 2008), and from this, the overall retention by length group of the gear has been directly estimated from this curve and inserted into the biological model, where the retention values of the gear correspond to the estimated mean length at age for given species/stock (Table 2). From this experiment, the selectivity for plaice has also been used for sole (but with length at age data for sole) as no observations exist for sole or lemon sole for this experiment.

For scenarios 3 and 4, using 100 mm and 120 mm codend respectively, the selection parameters for the 90 mm standard codend have been used under assumption of constant selection by use of the same gear with only a change in mesh size. Consequently, the selection parameters used for these scenarios are theoretically based.

2.2. The economic model

The basic foundation in CBA is a financial statement of the changes in the flow of income and cost that the new regulation brings for the consumers and producers, i.e., the consumer and producer surpluses are determined. Therefore, as part of the CBA, the single producer's income and cost can be calculated, making it possible to make an individual profit balance. This is relevant because changes in profit influence the producer's incentives and reaction to policy changes. The financial statement, however, has to be corrected in many important ways, so the statement is seen from a social point of view. It can then be determined whether the regulation—when compared to the current situation—will increase the economic welfare (the social surplus) in the society as a whole. The full social benefit analysis includes changes in producer, consumer and state surpluses. If the changes in landings are non-marginal, i.e., the prices will change, knowledge about the price elasticity would be needed to assess the resulting changes in consumer and producer surplus. In this model, it is assumed that there are no price changes in the full competitive market for fresh fish since this trawl fishery is only a small part of the overall Danish fish market and landings changes are marginal, i.e., the consumers' surplus is therefore ignored. The state surplus for the policy interventions in question primarily consists of changes in management costs incurred in enforcing the regulations on the different technical restrictions. The changes in management costs are ignored in this paper since it is assumed that the different gear sets are equally difficult to enforce. To sum up, what is relevant here is the changes in producers' surplus.

An important issue in CBA is the time perspective, because often the cost will be high in the short-term due to initial investment cost, while the benefits tend to be higher in the medium to longer term. Therefore, in order to be able to compare these changes, benefits and costs are discounted back to the present period. The weighting of these flows at different time periods is possible by using the price of holding money, the discount rate.

The changes in benefits in the mixed trawl fishery from the introduction of new gear types are attached to changing value of catches. The modelling takes into account the fact that some part of the catch is discarded. However, if the discard is reduced the future catches will—all things being equal—be higher via the stock effect

Table 2
Overall retention by age and mean length (ML) at age per species for the gear with 90 mm codend and grid.

Age	Cod		Plaice		Norway lobster	
	ML	Retention	ML	Retention	ML	Retention
0	7.9	0.0306	4.59	0.0000002	4.99	0.0017
1	21.9	0.4508	12.93	0.0525	13.90	0.0999
2	33.9	0.0320	20.26	0.2461	21.58	0.3584
3	44.2	0.0009	26.69	0.1724	28.18	0.6804
4	53.0	0.0001	32.33	0.0602	33.87	0.8661
5	60.5	0.0001	37.29	0.0205	38.76	0.8585
6	66.9	0.0001	41.64	0.0059	42.97	0.7465
7	72.4	0.0001	45.46	0.0018	46.60	0.6393
8	77.1	0.0001	48.82	0.0006	49.72	0.5310
9	81.1	0.0001	51.77	0.0003	52.40	0.4508
10	84.6	0.0001	54.36	0.0001	54.72	0.3790

and may induce higher landings in the future. Therefore, effects in the current period on the stock are—indirectly and via the biological model—evaluated in future periods. Our model handles this important and crucial aspect of the problem.

The changes in costs associated with the investment costs of new gear and the fishing costs of using a gear with another selectivity.

2.2.1. Central economic parameters

One of the more important results from the biological part of the model is that the more selective gear changes the composition of the year classes in the catches and in the stocks. For the economic analysis, it is therefore of great importance to recognise that prices of fish often are closely connected to the size of the fish. The quality attributes are, however, not available and therefore, are ignored in the model. This is, according to Nielsen et al. (2005), not a critical assumption since their study shows that it is primarily the size and not the quality of the fish, which is the driving factor for price difference. The prices are based on the Danish auctions statistics from Skagen and Strandby auctions in 2004.[8] The different size categories follow the Council Regulation on common marketing standards for fishery products (Council Regulation, 1996). The calculated von Bertalanffy average weights give the nominal catch in live weight. This has to be converted into landed weight, which is defined as the nominal weight subtracting the waste from the gutting and icing process on the vessel before landing. For this purpose, the conversion factors from the Yearbook of Fishery Statistics (Directorate of Fisheries, 2004) have been applied. Table 3 summarises the applied prices for the different species. Different prices for different commercial grades of Norway lobster are not available. The consequences of not differentiating the price for commercial grades are discussed further in Section 3.

Note that there is a tendency towards increasing unit prices when the size of the landed fish increases. The Table also reveals that there is a large difference in the unit price across species.

The changes in costs of the trawl vessels consist, as mentioned, of the gear investments and fishing costs of the new gear. The gear investment costs are assumed to take place in the first period. The variable cost in the model is linked to fishing days, and it is assumed that the variable cost per fishing day is unchanged for all gear. This does not mean constant variable costs per output, as changes in landings will lead to changes in the variable cost per output unit. Further, in order to isolate the effects of changing gear, it is assumed that the number of fishing days is constant; this can be justified by the input restriction on the days at sea. This means that the total

[8] Auction statistics, Danish Directorate of Fisheries: http://webfd.fd.dk/stat/aukintro.htm (April, 2009).

Table 3
Prices and size categories for the economically relevant species for trawlers in Kattegat and Skagerrak.

European plaice			Atlantic cod			Common sole			Norway lobster	
Size	DKK/kg	kg/fish	Size	DKK/kg	kg/fish	Size	DKK/kg	kg/fish	Size	DKK/kg
1	20.31	>0.6	1	28.18	>7	1	81.82	>0.5	n.a.	51.42
2	21.46	0.4–0.6	2	25.67	4–7	2	58.06	0.35–0.5		
3	15.86	0.3–0.4	3	23.20	2–4	3	47.84	0.25–0.35		
4	12.46	0.15–0.3	4	19.59	1–2	4	53.86	0.2–0.25		
			5	12.23	0.3–1					

Source: Directorate of Fisheries Account Register (2004), Council Regulation (1996), Directorate of Fisheries (2004) and our own calculations.

variable costs as a function of inputs are unchanged compared to the baseline scenario and, therefore, that the costs of implementing a more selective gear set are connected only to the direct costs of obtaining the different gear. The direct costs of obtaining the selective gear types are based on interviews with the Danish Fishermen's Association and are summarised in Table 4. The common procedure in the Danish trawl fishery is that each vessel harvest with a double trawl, and since the costs in Table 4 are per Trawl, they are doubled to get the additional costs per vessel of gear switch.

The net present value (NPV) of changes in benefits and changes in costs is found by discounting according to the following formula:

$$NPV = \sum_{t=0}^{10} \frac{\Delta B_t - \Delta C_t}{(1-d)^t},$$

where ΔB_t = the changes in benefits at time t = change in value of harvest compared to the baseline at time t; ΔC_t = the changes in costs at time t = changes in the private fishing costs; d is the discount rate = 3%.

We find the present value of the changes in costs and changes in benefits of more selective gear in the Kattegat–Skagerrak Norway lobster fishery by applying a discount rate of 3%, as recommended by Weitzman (2001) for projects with life between 6 and 25 years.

Sensitivity analyses are made for higher levels of discount rate. If net present value is positive then change in gear adds to the economic welfare compared to the baseline situation.

3. Results

Running the dynamic biological model, we estimate the relative changes in the stocks, the changes in catches and discards within the four different scenarios with the application of the different gear technologies. Fig. 3 illustrates the relative changes in the biomass compared to the baseline on a yearly basis over the simulation period for all four species in all four scenarios.

From scenario 1 (90/120 mm), there is a growth in the biomass of cod of almost 10% compared to continuous fishing with 90 mm (the baseline). For the other three species, there is a reduction in biomass compared to the baseline. For scenario 2 (grid), there is an increase in the biomass for all species except for the stock of Norway lobster, which is more or less status quo. In this scenario, sole and cod will have the largest relative increase in biomasses, up to almost 30%, which is due to the very selective gear technology. In scenario 3 (100 mm), all species will experience a moderate increase in biomass and in scenario 4 (120 mm), all species will experience a large relative increase in biomass.

Based on the output from the dynamic biological model and the defined economic parameters, the net cash flow over the simulation period is determined. Not surprisingly, the net cash flow follows the changes in the landing weights and catch composition

Table 4
Costs per trawl of obtaining the selective gear.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
90 mm codend with mesh panel	90 mm codend with grid	100 mm codend	120 mm codend
5000 DKK	13 500 DKK	12 500 DKK	12 500 DKK

Source: Interview with the Danish Fishermen's Association.

of the different species. Changes in the net cash flow from the four different sets of gear technology on an aggregated level are illustrated in Fig. 4.

For all four scenarios, the initial investments in the more selective gear result in a negative net cash flow in 2003, this is the year before the more selective tool is actually applied. In scenario 1 (90/120 mm), there is, in initial years, a positive net cash flow compared to the baseline. This is explained by the increment in landings in initial years. This results in a degradation of the stocks in future periods and therefore, negative net cash flow in the future. When implementing scenario 2 (grid), there is a significant loss for all the years in consideration. This is because the gear is so selective that the gear sorts out even the mature cohorts of the different species. For scenarios 3 and 4 (100 mm and 120 mm), the initial landings are reduced compared to the baseline. This can be considered an investment in the stocks that returns a positive net cash flow after some 2–3 years compared to the baseline. The size of the investment and the returns are 3–4 doubled for the 120 mm compared to the 100 mm scenario.

The biological part of the model yields results on changes in catches for the different species. Since one of the aims of economic analysis is to evaluate the consequences for the single vessel category, the catch shares are relevant. The catch shares are used for dividing the changes in catches among the vessel length categories. They are determined by the single category's landing of a specific species in relation to the aggregated landings from the area by trawl vessels in 2004. It is assumed that these catch shares are unchanged over a ten-year period and that changes in gear also do not change the catch shares.[9] The net present value of the changes in cash flow is summarised in Table 5. The results are illustrated as changes relative to the baseline revenues for the species.

In Table 5, the figures in bold in the lower-right corner for each scenario summarise the total net-benefits to society with regard to the four species in the baseline. The overall results indicate a slight reduction in net-benefits from implementing the 90/120 mm setup (scenario 1), a larger reduction in net-benefits from implementing scenario 2. Scenarios 3 and 4 indicate an increase in net-benefits over the ten-year period, relative to the baseline. From the Table, it is also possible to find the relative changes in net-benefit of the single species divided into different vessel categories. Based on the table, we can conclude that despite slightly different catch compositions for the different vessel categories, the tendency for the different scenarios is the same for all vessel categories, the most outlying category being 24–40 m.

The bio-economic model indicates that implementing scenario 1 implies additional landings of cod combined with an increment in the stock and reduced discards of cod. Overall there is, however, a socio-economic loss around 100 mill. DKK in net present value over a ten-year period. This loss is primarily due to the reduced

[9] This might seem a strict assumption, but it allows us to see the direct changes in revenues as the result of gear changes. The assumption only has effects on the net-benefits for the single vessel categories, not on the overall cost–benefit analysis.

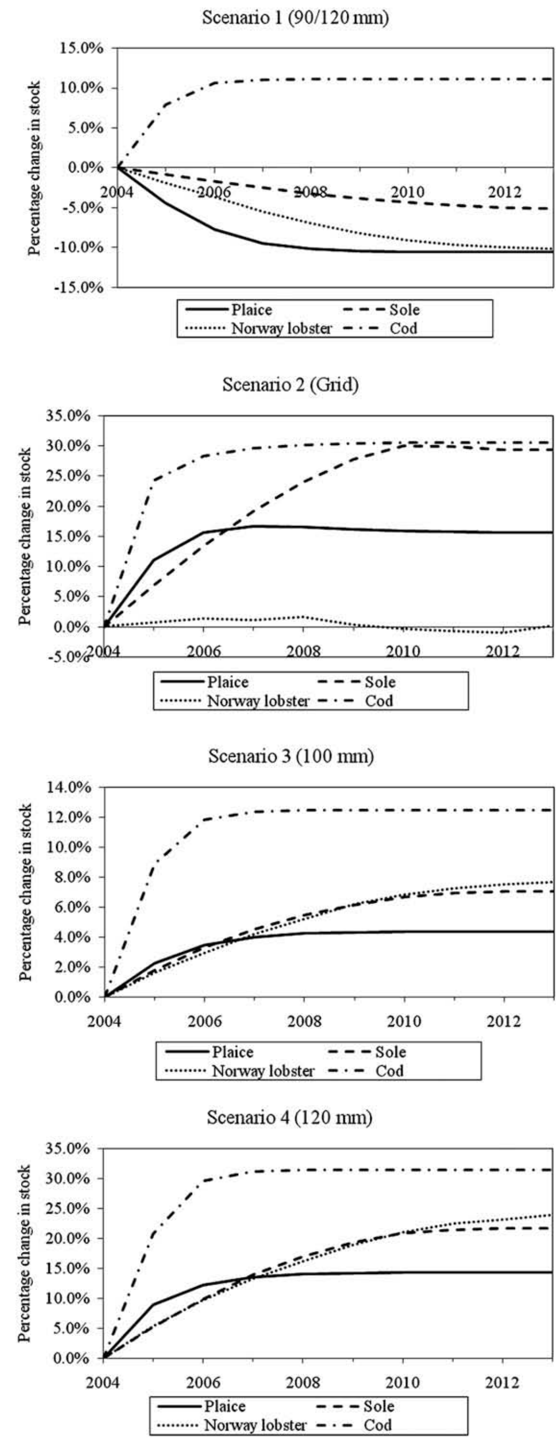

Fig. 3. The relative changes in biomass in the four scenarios for plaice, sole, Norway lobster and cod compared to the baseline.

landings of Norway lobster. It is assumed that catches of undersized fish and Norway lobster are discarded and do not survive. In scenario 1, the discard of Norway lobster (in particular, the two- and three-year-olds) increases significantly, which induces the reduction in the stock. Fig. 5 illustrates the changes in the harvest, landings and discards for Norway lobster when comparing scenario 1 (90/120 mm) to the baseline (90 mm).

From Fig. 5, it appears that the total harvest in 2004 for scenario 1 (90/120 mm) is around 500 tonnes higher than the harvest in the

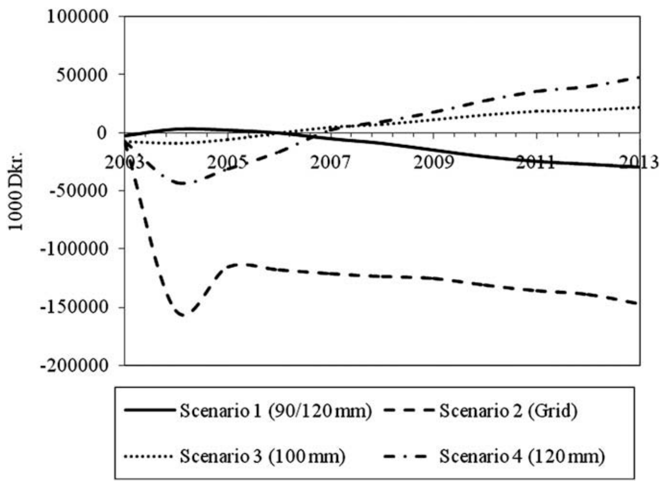

Fig. 4. Changes in net cash flow for the trawl fleet compared to baseline of the four scenarios in 1000 DKK (1000 DKK is app. 130 Euro).

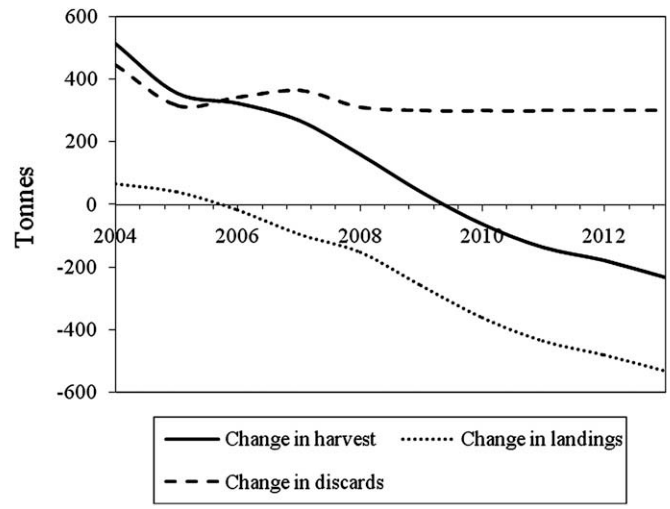

Fig. 5. Changes in harvest, discards and landings for Norway lobster in scenario 1 (90/120 mm) compared to baseline (90 mm).

baseline (90 mm). This corresponds to around 10% of the total harvest with 90 mm in 2004. The changes in landings decrease over the period, and from 2006, the landings are smaller in scenario 1 compared to the baseline, while discards will still be higher. Between 2009 and 2010 the total harvest tips from being higher in scenario 1 to being lower in this scenario compared to baseline. The discards are, however, still positive in scenario 1 and therefore landings are now much smaller in scenario 1 compared to the baseline.

If scenario 2 is implemented, the calculations show huge reductions in landings of plaice, sole and cod to a level close to zero, and the value of landings of Norway lobster is reduced by some 30%. Jointly, this implies a significantly loss in revenues to the trawlers. The selectivity of the gear also implies that discards are reduced. The decreased catches imply increased stocks that might be valuable for other fleets, but it is not within the scope of this article to analyse the effects outside the trawl fishery. The overall conclusion is a significant reduction in the net-benefits for trawlers by implementing scenario 2.

Table 5
Relative changes in net present cash flows separated into species, vessels segments and total over a 10-year period.

	Species	Vessel segments				Total
		12–15 m	15–18 m	18–24 m	24–40 m	
90/120 mm (Sc. 1)	Norway lobster	−1.53%	−1.53%	−1.69%	−0.27%	−5.69%
	Cod	3.47%	4.11%	2.75%	0.21%	11.51%
	Sole	−0.80%	−0.74%	−0.73%	−0.15%	−2.69%
	Plaice	−2.26%	−2.25%	−2.85%	−1.47%	−9.34%
	Total	−1.10%	−1.17%	−1.17%	−0.33%	**−4.37%**
Grid (Sc. 2)	Norway lobster	−7.87%	−8.84%	−8.67%	−1.40%	−30.36%
	Cod	−25.32%	−30.00%	−20.06%	−1.53%	−84.05%
	Sole	−26.06%	−24.08%	−23.77%	−4.81%	−80.27%
	Plaice	−20.94%	−20.89%	−26.40%	−13.67%	−86.58%
	Total	−13.21%	−13.94%	−13.53%	−3.11%	**−48.05%**
100 mm (Sc. 3)	Norway lobster	1.02%	1.15%	1.13%	0.18%	5.74%
	Cod	3.02%	3.58%	2.39%	0.18%	10.02%
	Sole	−1.56%	−1.44%	−1.42%	−0.29%	−4.79%
	Plaice	0.46%	0.46%	0.58%	0.30%	1.89%
	Total	0.74%	0.89%	0.79%	0.12%	**2.46%**
120 mm (Sc. 4)	Norway lobster	2.03%	2.28%	2.23%	0.36%	13.63%
	Cod	8.86%	10.49%	7.02%	0.54%	29.40%
	Sole	−8.11%	−7.50%	−7.40%	−1.50%	−24.98%
	Plaice	−2.34%	−2.34%	−2.95%	−1.53%	−9.68%
	Total	0.63%	1.02%	0.67%	−0.09%	**2.13%**

The last two scenarios involve an increment of the mesh size. In both these scenarios, the biological part of the model shows that the biomass for the four species will increase over the ten-year period. The landings of Norway lobster and cod will increase while the landings of sole will decrease. The landings of plaice will increase in scenario 3 but decrease in scenario 4. In addition, there are reductions in discards for all four species. The economic part of the model shows that in the first 3–4 years after implementing the larger mesh size, there are negative net-benefits compared to the baseline, but this serves as an investment in the stocks and results in a gain in revenues after the first 3–4 years and throughout the rest of the ten-year period. All together the bio-economic model shows a gain in revenues in net present value for the ten-year period between 100 mill. DKK and 150 mill. DKK by applying mesh sizes 100 mm and 120 mm, respectively.

The economic results do not distinguish the prices of Norway lobster between commercial grades, since these prices are not available on the relevant auctions for the period in question, but it could be reasonable to imagine that prices would increase with the size of the landed Norway lobster. If different prices for Norway lobster are included in the model, it would strengthen the economic loss seen for scenario 1 (90/120 mm) compared to the baseline scenario (90 mm), since more small lobster are caught in scenario 1 (90/120 mm) compared to the baseline scenario (90 mm).

4. Robustness and uncertainties

This Section discusses the robustness of the results from the bio-economic model. The reason for conducting a sensitivity analysis on our results is that there is general uncertainty about forecasting the future. In particular, there might be some parameters of special uncertainty because the lack of a solid and reliable data foundation. Here it is particular important to underline that the experimental trawl hauls remain uncertain and as a consequence, the following estimation of selection parameters is uncertain. To address this issue, a sensitivity analysis of the selection parameter, discount rate and prices is undertaken.

The selection factor was changed +/−10% and +/−50% in order to test the biological model's sensitivity to changes in the selection parameters. Generally speaking, the model showed little sensitivity to changes in the selection parameters on +/−10% for all four species, and the changes were less than the differences between the different scenarios. When the selection parameters were changed +/−50%, the changes in the outcome of the model generally were in the same order of magnitude as the differences between the different scenarios. This implies that there has to be very large uncertainty on the estimation of the selection parameters to explain the observed differences between the different scenarios.

The applied discount rate may seem low from a private perspective. The sensitivity of the results was therefore tested by applying a higher discount rate of 5% and 7%, respectively. With a higher discount rate the results remained with the same signs and magnitude.

The year 2004 served as a baseline for the model, but in this year the price of Norway lobster was exceptionally low. Because of the economic importance of Norway lobster, it was tested whether this low price could change the results. An average price for all species was calculated, by applying prices from 2004, 2005 and 2006 and adjusting the prices in 2005 and 2006 by the index for consumer prices. With the price adjustment, the results also remained with the same signs and magnitude.

The overall conclusion on the sensitivity of both biological and economic parameters is that the results are robust to minor changes in the central parameters.

5. Conclusions

If it were possible to harvest the different species and cohorts selectively and the prices, costs and regulations simultaneously made it economically beneficial to target single species and cohorts, then there would be no problems in the mixed fisheries with bycatches, discards and illegal landings. But in reality, the biological, technical and economic conditions make such fisheries impossible. In mixed fisheries, where some stocks are at low or critical levels, the issue is to change the fishing pattern such that catches of the threatened species are reduced while catches of less threatened species are possibly increased. In this context, the regulation plays a significant role since a regulation that does not supplement the biological and economic matters will hardly be successful. One possible type of regulation could be changes in technical measures. This paper has examined the effects of changes in the gear technology applied. The effects are divided into changes in biomass, catches, landings, discards, operating profit and net-benefits in the Danish trawl fishery in Kattegat and Skagerrak.

The paper sets up a bio-economic model designed to evaluate the consequences of changes in the gear technology. From an economic point of view, a gear change is an investment consideration since a change in the catch composition in the present, via changes in the stocks, may result in better catch composition in the future. The bio-economic model can handle these considerations and is calibrated according to year 2004. In the biological as well as the economic appraisals, what is important are the changes: therefore all the scenarios implemented are compared to the fishery as it was in year 2004. Additional values such as the value of having recovered stocks at the end of the simulation period being more robust to ecosystem changes or the existence value of the stocks, are not included in the applied bio-economic model.

It is important to note that there is some uncertainty about the parameters, both caused by lack of data and by uncertainty in the gear surveys. In particular, the selection parameter for Norway lobster in scenario 1 is uncertain as, from the surveys, it was not possible to calculate the standard deviation. Therefore, the preliminary estimate for the selection parameter is applied. In addition for, scenario 1, there are no selection parameters for Common sole, therefore the selection parameters for lemon sole, which is similar in shape to the Common sole, are applied.

The model includes changes in costs and benefits for the trawlers fleet, and therefore, other effects, like effects on the ecosystem and for other fleets, are not included. The scenario 1 gear type has, after 2004, become a common gear type. The implementation has not, according to a set of interviews with fishermen and fishing control authorities, implied increased control costs since the gear implementation is simple and easy to control. Implementing a larger mesh size will most likely not meet the same acceptance. This conclusion is based on interviews and the fact that it implies a reduction in revenues in the first years. If fishermen have a high discount rate they will primarily care about short run losses and gains.

Based on the CBA, it is difficult to conclude that implementing scenario 1 (compulsory use of 90 mm codend with 120 mm mesh panel) has an economic advantage compared to the use of a 90 mm codend. However, it is important to recognise that the biological simulations indicate an increment of about 12% in the cod biomass in year 10 by applying this gear type compared to the baseline. For scenario 2 (compulsory year-round use of 90 mm codend with a grid), it is concluded that the selectivity is extremely high, and based on the significant socio-economic loss by implementing this gear, it cannot be recommended. This result is also supported by the fact that the gear change has not already been implemented despite the fact that it gives an unlimited number of days at sea. Not surprisingly, the model shows, that the gear is particular efficient in rebuilding all stocks except the Norway lobster. The economic results can therefore be seen as the price of protecting and rebuilding the cod, sole and plaice stocks. Net present value is positive for scenarios 3 and 4 (compulsory use of 100 mm and 120 mm codend) due to long-run relative positive revenues. In these scenarios, all stocks are protected and rebuild to varying extents. However, the selection factors used in these scenarios are not experimentally documented yet.

This paper evaluates the ecological and economic consequences of selectivity by determining the changes in biomass for four different species. This is one step in the direction of assessing the impacts from fishing: the next step could be to consider the effects on the ecosystem in a broader context—i.e., habitat damages—or to include spatial aspects.

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