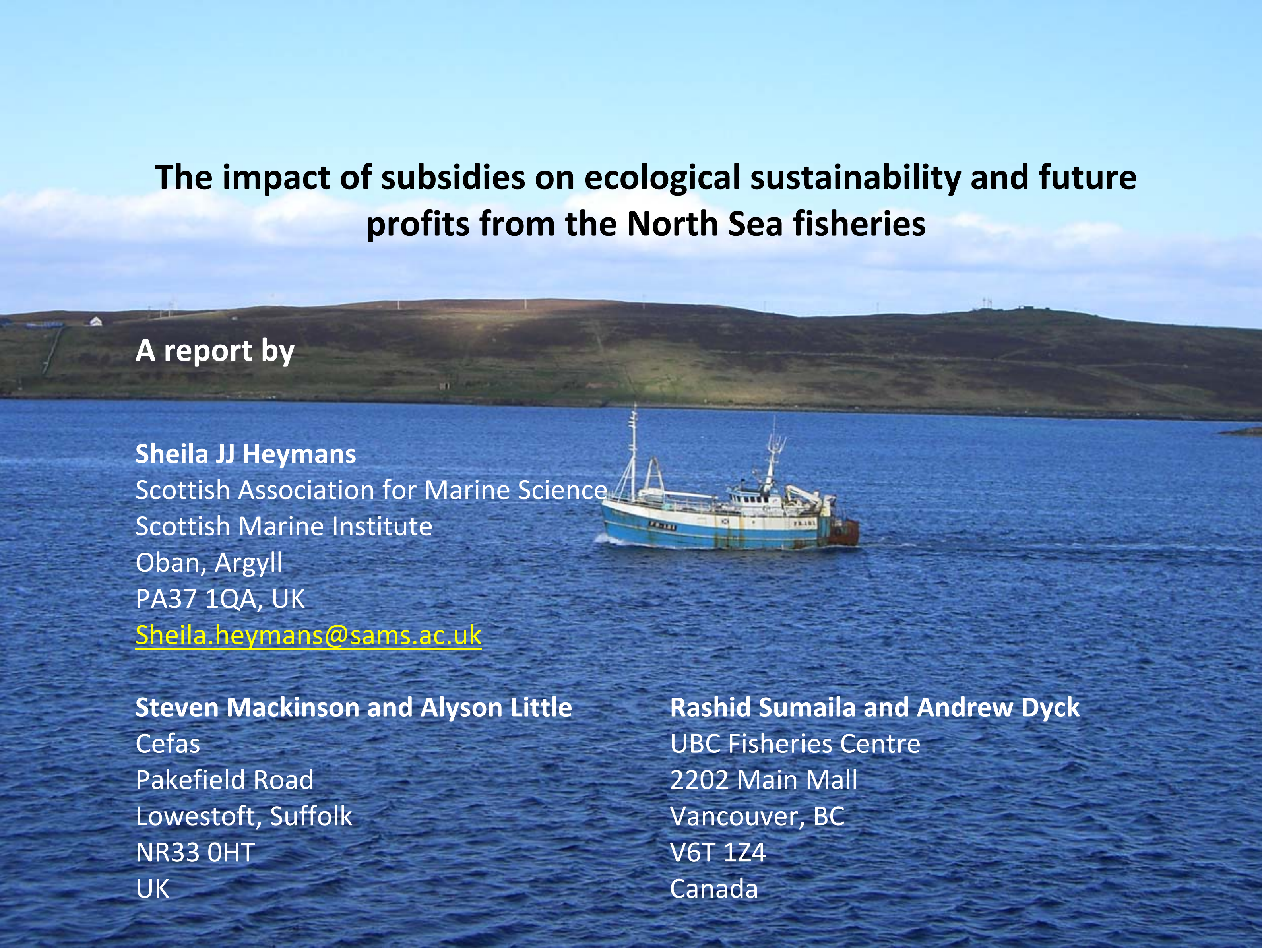

The impact of subsidies on ecological sustainability and future profits from the North Sea fisheries

A report by

Sheila JJ Heymans
Scottish Association for Marine Science
Scottish Marine Institute
Oban, Argyll
PA37 1QA, UK
Sheila.heymans@sams.ac.uk

Steven Mackinson and Alyson Little
Cefas
Pakefield Road
Lowestoft, Suffolk
NR33 0HT
UK

Rashid Sumaila and Andrew Dyck
UBC Fisheries Centre
2202 Main Mall
Vancouver, BC
V6T 1Z4
Canada

For the

Oak Foundation
Marine Conservation Programme
58 Avenue Louis Casaï
1216 Cointrin
Genève
Switzerland

SAMS report no. 266

The impact of subsidies on ecological sustainability and future profits from the North Sea fisheries

Sheila JJ Heymans[1], Steven Mackinson[2], Rashid Sumaila[3], Andrew Dyck[3], Alyson Little[2]

1. Executive summary

This study examines the impact that subsidies have had on the profitability and ecological stability of the North Sea fisheries over the past 20 years. The study uses a well known ecosystem model of the North Sea, includes the economic analysis of subsidies and look at the possible outcomes of each fishery if subsidies are removed. Two analyses were performed:

1) A hindcasting analysis of subsidies over the time period 1991-2003 which shows that subsidies reduced the profitability of the fishery although fisher's gross revenue might still be significant.

2) The second analysis optimised both the profit and ecological stability of the ecosystem through changes in the effort structure of the different fleets. This analysis shows that optimum profit can be achieved by increasing the effort of the Nephrops trawlers, the beam trawlers, and the pelagic trawl and seine fleet, while reducing the effort of demersal trawlers. By contrast, optimum ecological stability is only achieved by reducing the effort of the beam trawlers, Nephrops trawlers, pelagic- and demersal trawl-and-seine fleets. This analysis also shows that with subsidies included the effort will always be higher for all fleets, as it effectively reduces the cost of fishing.

Removing subsidies might reduce the total catch and revenue of the fisheries, but it does increase the overall profitability and the total biomass of commercially important species. Specifically, the biomass of cod, haddock, herring and plaice was increased by 1-3% over the simulation when optimising for profit and when optimizing for ecological stability the biomass for cod, plaice and sole increased by 0.3-1.2%. Although the most significant differences were obtained between optimising for profit and ecological stability, the results show the negative impact that subsidies have on both the biomass of important fish species and the profit that can be made from the fisheries.

[1] Scottish Association for Marine Science, Scottish Marine Institute, Oban, PA37 1QA, UK.
[2] Cefas, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK.
[3] UBC Fisheries Centre, 2202 Main Mall, Vancouver, V6T1Z4, Canada.

2. Introduction

The Common Fisheries Policy aims to ensure exploitation of living aquatic resources that provides sustainable economic, environmental and socially ethical fisheries (Cotter, 2009). However, fishing subsidies artificially keep too many commercial fishing boats in operation and drive the unsustainable exploitation of the world's depleted fish populations (Sumaila et al., 2007). Thus, EU Commissioner Joe Borg stated on 18 September 2008 that the EU fleet is at present capable of catching between two and three times the maximum sustainable yield (MSY) and that ecological sustainability must be placed before economic and social sustainability, since it is the precondition that makes the latter two possible.

The major fishing nations in the North Sea are Denmark, the UK, the Netherlands and Norway, with Germany, Belgium and France also active in the fishery. The principal fishing fleets are industrial and target several demersal and pelagic species. These fleets are subsidised by these countries to varying degrees. Some of the subsidies are harmful to fish stocks e.g., fuel subsidies) as they encourage overcapacity and overfishing of the fish stocks in the North Sea. Harmful fisheries subsidies affect the long-term sustainability of the ecosystem which is already under threat from climate change, invasive species and pollution (Clark et al., 2005). A crucial step to helping the EU to reduce harmful fisheries subsidies is to demonstrate, empirically, how harmful these subsidies are, not only to the health of the ecosystem but also to the economics and social wellbeing of the fishing sector in Europe. To date, most of the discussion on the effects of fisheries subsidies on sustainability are based on theoretical models (Milazzo, 1998, OECD, 2003, Sumaila et al., 2010).

The aim of this study is therefore to investigate the impacts of fisheries subsidies on the sustainability, resilience and stability of the North Sea ecosystem. This will be achieved by contrasting how policies on subsidies might influence fleet structure and therefore the economic and social contribution to the wellbeing of European fisheries. The project creates a framework for the empirical study of the ecosystem, economic and social effects of fisheries subsidies worldwide. The goal of the framework is to provide policy makers, civil society and the public in general with an empirically backed understanding of the impacts of fisheries subsidies on European fisheries in a broad and general sense.

The **objectives** of this report are therefore to:
1. Update the North Sea ecosystem model of Mackinson and Daskalov (2007) with current fisheries information;
2. Review subsidies available to fishers working in the North Sea;
3. Incorporate these subsidies into the North Sea model;
4. Make predictions of various possible fishing scenarios in order to examine the impact that subsidies would have upon the sustainability of the ecosystem and on the socio-economics of the dependent fisheries; and
5. Make the results available to a wider audience including non-governmental organisations (NGOs), fishermen, and civil society in general.

3. Materials and Methods

The ecosystem model of the North Sea, parameterised and validated using time series data of catch and biomass (Mackinson and Daskalov, 2007, Mackinson et al., 2009) was updated to reflect current information. Two main changes were made as explained in sections 3.1 and 3.2 below:

3.1 Catch profiles of the fisheries

The proportion of the landings and discards of each species aken by each fleet, as reported by STECF (Scientific, Technical and Economic Committee for Fisheries) from 2003 to 2007 (EU, 2008), was used to update the distribution of landings and discards among the 12 modelled fleets. The STECF does not resolve the catch information to different age groups. Thus, for functional groups split into adult and juvenile components in the model (cod, whiting, haddock, saithe and herring), the distribution of the catch to landings and discards was maintained as in the original 1991 model (Mackinson and Daskalov, 2007). This division is made based on data from discard sampling trips. The result of the re-profiling of the distribution of catches is that the model maintains the fishing mortalities of each species in 1991, and hence mass-balance, but is better suited to address the future policy questions addressed here as it reflects the present day fleet structure more accurately.

3.2 Fisheries economics

Fish prices and fishing costs

Current information on the ex-vessel price (Euro/tonne) of each species to each fleet and economic performance of each fleet was obtained from the data reported in the 2008 Annual Economic Report (AER, EU, 2008)[4] and was used to define the cost and revenue of each modelled fleet and the differences in value of each species to each fleet. In preparing the data, each modelled fleet was mapped to its corresponding AER fleet (Appendix Table A1). The Data Collection Regulations (DCR) provide the basis for this mapping since it is used to define the fleet structures used in both the AER reports and ecosystem model (see Mackinson and Daskalov, 2007). The mapping is however, not a perfect one, with some differences in the fleet descriptions used by the AER, DCR and ecosystem model still remaining. Where AER fleets did not have a direct link to a fleet in the model, the associated catch compositions were examined and used to assign the AER fleet to its corresponding model fleet.

In assigning the prices of each species to each fleet, we found instances where there was no specific price information for a particular species fleet combination. Where other price information was available for the species, we assigned the minimum price to that combination; otherwise a nominal value of 1 was assigned. We also found a few instances (2% of the total) where price was reported, but there was no catch. These somewhat puzzling cases were confined to shellfish groups and reflect some of the differences in the sources of information arising from AER and STECF (EU, 2008). They have no consequence in the model because no catches occur.

Fixed- and effort-related costs reported for each fleet in the AER include the subsidies paid to the fleets. Costs in the AER report (EU, 2008) that are classified as fixed or capital costs are defined as fixed cost in Ecopath, while fuel, crew, repair and variable costs in the AER report are all classified as effort-related costs in the model.

Subsidies

Subsidies are defined as government financial transfers that help reduce the cost of fishing, e.g. fuel subsidies or artificially increased revenue to fishing enterprises, e.g. through price support subsidies. The new fleet structure was used to update the subsidies reported for each country in the *Sea Around Us* project and described in Sumaila et al. (2007) and Sumaila et al. (2008), where the fixed and variable cost subsidies for each fleet were assumed to be proportional to its share of landed value from the North Sea. For example, if Belgian beam trawlers operating in the North Sea take 1/5th of the value of Belgium's landings, the subsidies to their North Sea beam trawlers are assumed to be 1/5th of Belgium's fishing subsidies. Subsidy types reported in Sumaila et al. (2008) are assumed to be focused towards fixed or effort-related (variable) as described in Table 1 below.

[4] The AER report contains economic data from all EU Member States collected under the framework of the Data Collection Regulation (Council Regulation (EC) No. 1543/2000).

This share of subsidies data was used to estimate the proportion of the fixed and effort related costs of each fleet that were subsidized, by combining it with the AER cost data to calculate how the gross revenue of each fleet differed when subsidies were included and when they were not (Appendix Table A2). Using the information in Appendix Table A2, two scenarios of the ecosystem model were made, one with subsidies included in the costs of fishing, the other without. In the without subsidies parameterisation, the costs of fishing are higher, because the calculated proportion of the costs that are subsidised is added to the costs given in the AER data. During simulations, the fixed costs remain constant for the duration of the model simulations (see below). Effort-related costs vary during the simulation depending on the effort of each fleet.

Table 1: Fixed cost and effort-related subsidies by subsidy type.

Subsidy type	Predicted effect of subsidy	Effort-related or fixed cost subsidy
Boat construction & modernization	Capacity enhancing	Fixed cost
Development projects	Capacity enhancing	Fixed cost
Port construction	Capacity enhancing	Fixed cost
Marketing & storage support	Capacity enhancing	Effort-related
Tax exemptions	Capacity enhancing	Effort-related
Fuel subsidy	Capacity enhancing	Effort-related
Fisher assistance programs	Ambiguous	Effort-related
Vessel buyback programs	Ambiguous	Fixed cost
Rural development programs	Ambiguous	Fixed cost

Economic analyses

Economic indicators such as landed values or gross revenues and profits were examined and analysed to see how they are impacted with and without subsidies. Reducing total fishing costs with subsidies will induce additional effort to enter the fishery, putting extra pressure on the resource and causing biomass to decline as described graphically in Figure 1. Frame two of the figure below displays the effect of cost-reducing subsidies, which shift total effort higher and decrease total revenue in the fishery.

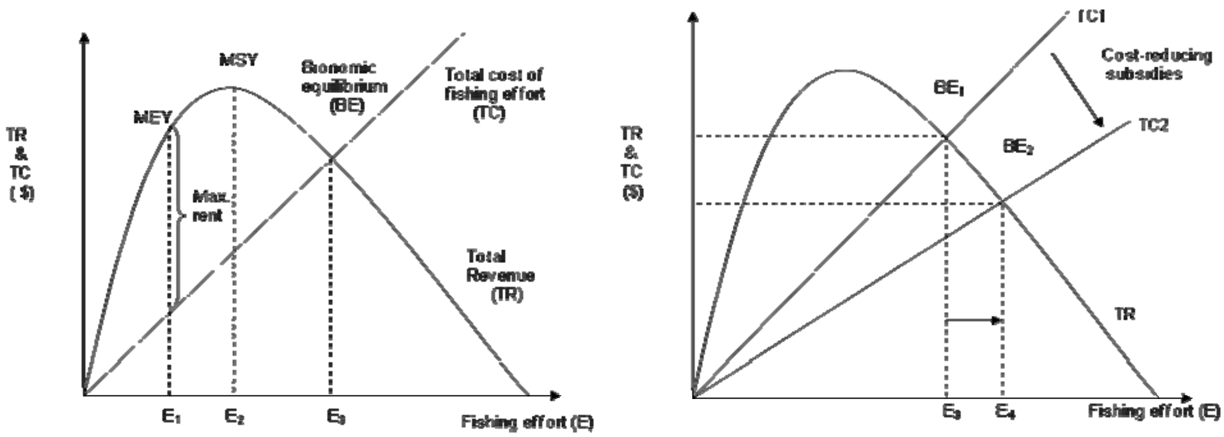

Figure 1: Theoretical effect of subsidies in a fishery. TR and TC is total revenue and total cost, MSY = maximum sustainable yield, MEY = maximum economic yield, BE1 and BE2 are biomass at effort 1 and 2 respectively and TC1 and TC2 are total cost before and after subsidies.

Fishing profit vs. revenue

Our simulation analysed economic profit in the North Sea fisheries with and without subsidies. It is necessary to distinguish the concept of fisheries profit from total revenue when contrasting the two scenarios, as revenue with subsidies cannot be accurately compared with revenue in the non-subsidy cases. In the case of scenarios with subsidy, the total revenue generated by a given fishery is augmented by subsidy, while this does not occur in the non-subsidy case. Since subsidy represents a government transfer it is not considered as profit generated in a fishery and, as such, subsidies and total costs are subtracted from total revenue to produce an estimate of fishery profit. This measure can then be compared to profit in the non-subsidy scenarios in our simulations. It is therefore expected that the removal of subsidies in the economic optimisation simulations will result in higher profit for North Sea fisheries.

Thus, when subsidies are included:
Profit = Value-Costs-Subsidies (1)
where the subsidy costs are calculated as:
Subsidies cost = (Fixed cost * subsidized proportion of fixed cost) + (Variable cost * subsidized proportion of variable cost) (2)

In the model where subsidies are not included,
Profit = Value - Costs (3)
As subsidies in this case are zero.

Note that in Ecosim, the value of landings is calculated simply as landed weight*price. In this case the units for value (and profits) are Value = Landed weight (t/km^2)*Price (Euro/kg) = 1000 Euro/km^2.

3.3 Scenarios

The effects of including or excluding fishing subsidies were evaluated by performing two types of simulation, namely Hindcast simulation and Optimisations (3.3.1 and 3.3.2).

3.3.1 Hindcast simulation

The hindcast simulation predicts changes in the relative biomass of each functional group in the model when driven by changes in the fishing effort, and mortality and trends in primary productivity during the period 1991-2003. The simulation has been calibrated to time series data from fish stock assessments and biological surveys by estimating the parameters that influence the strength of the predator-prey interactions. Full details are given in Mackinson et al. (2009).

During the simulation, changes in the relative effort of the various fishing fleets was combine to determine the total mortality of the given species. The mortality of a species caused by a particular gear is known as the partial fishing mortality (F), and is calculated as:

Partial F species A caused by fleet 1 = Catch of species by fleet 1/ Biomass of species A (4)

Because the variable costs of fishing are linked to the amount of fishing effort expended, it is important to have knowledge of how the effort patterns of each fleet changes during the simulation. Trends in effort for each fleet (Figure 2) were obtained from ICES WG assessment reports defined in Table 2, and are consistent with that recently published in STECF SGRST report (STECF, 2009).

Table 2: Sources for effort data used in the hindcast simulations.

Fleet	Period available	Source and notes
Demersal trawl & seine	1978-2008	(WGNNSK08, 2008), including fleets SCOSEI_IV, SCOLTR_IV, ENGTRL_IV, ENGSEI_IV, FRATRB_IV, FRATRO_IV, NORTRL_IV, GER_OTB_IV
Beam trawl	1979-2007	(WGNNSK08, 2008), including fleets NL_BT_EFF,UK_BT_EFF
Pelagic trawl & seine	1987-2006	(WGNNSK08, 2008) fleet NOR_DEN_NPOUT_EFF
Nephrops trawl	1981-2004	(WGNSSK06, 2006), summed over Nephrops functional units
Shrimp trawl	1984-2003	(WGPAN, 2005), Pandulus – total international effort in ICES div IV.

Hindcast simulations were run with the fixed and variable costs of fishing subsidised and not subsidised. The differences in gross revenue and profit were recorded. In addition, subsidies were also removed from the profits calculated by the model post simulation, and these were compared with the scenarios where the subsidies were removed from the value of the fishery as an input variable in the model.

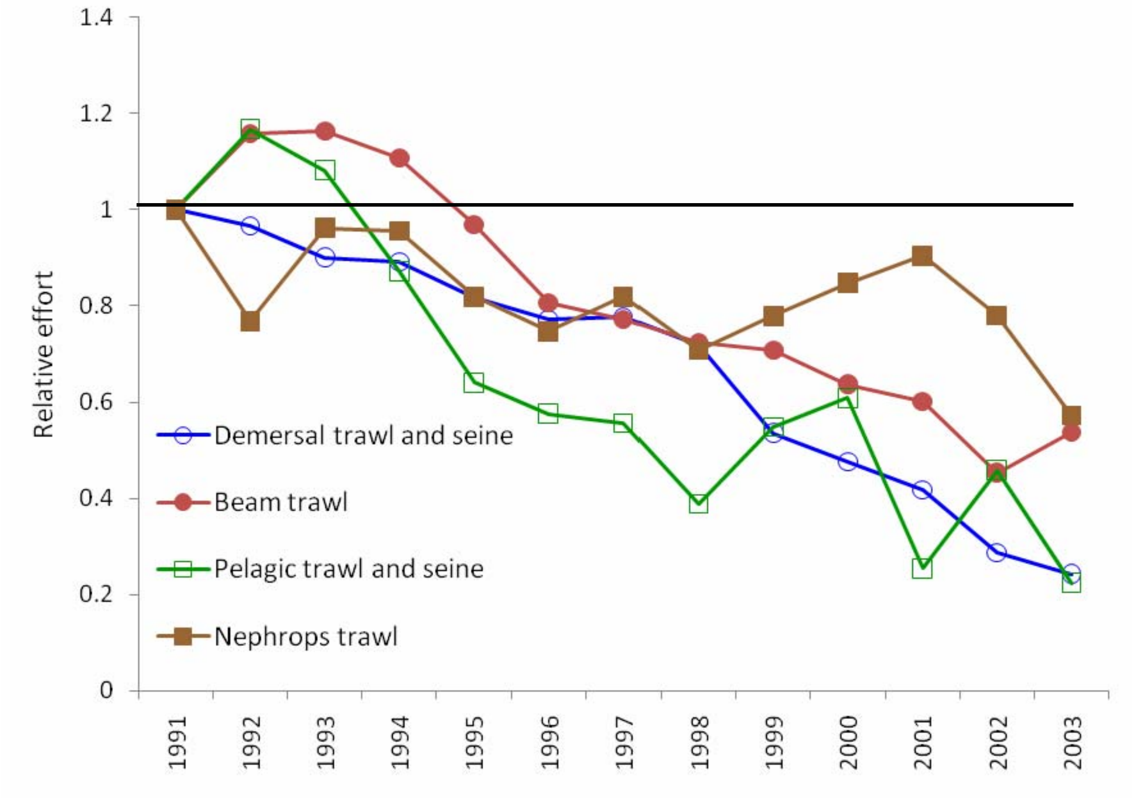

Figure 2: Trends in relative effort of the modelled fishing fleet, standardized to 1 in initial year of data.

3.3.2 Optimisation

Two future policy optimisation scenarios were performed by optimising the effort of the demersal, beam, pelagic and Nephrops trawls only. The effort of the remaining modelled fleets, represent principally inshore fisheries and were not optimised for, but held constant over the duration of the simulation. The rationale for this is that fisheries policies are aimed at making changes in the main commercial fleets prosecuting fisheries in the central North Sea, whereas, local and regional management decisions are the tools used to affect change in the inshore fisheries. The two policy optimisation scenarios were:

a) maximising economic return, and by contrast;
b) maximising the ecological stability of the ecosystem.

The economic optimisation scenario aims to maximise the total profit (net economic value, i.e. value - fixed and effort related costs), over all fleets even if this means operating some fleets unprofitably to act as controls on less valued species that compete/predate on more valued ones (Christensen et al., 2005). The ecological stability scenario maximises the longevity-weighted summed biomass over all the ecosystem groups. This index is calculated from the inverse of the production/biomass ratio and the biomass calculated for each group (Christensen and Walters, 2004).

In addition, future scenarios were run with- and without subsidies. The fitted model was run forward for 7 years from 2003 to 2010 with constant forcing functions and optimising for profit or ecological stability in the last 7 years using 2003 as the base year. Thus the optimisation begins at the end of the period of declines in effort.

The optimisations were examined to identify:

1) The changes in fleet structure for the main fleets by running 10 optimisations starting from random fishing mortalities for each run to see if the effort distribution is stable;
2) What profit can be made from the four different fleets when optimising for a) profit or b) ecological stability;
3) The impact that the optimised run would have on the ecosystem, specifically:
    i. What changes there would be on the landings and biomass of the principle species (cod, haddock, whiting, Nephrops, plaice, sole, herring, Norway pout); and
    ii. What changes there would be to ecosystem stability, size, structure and resilience?

Fishery stability is defined by the FiB index (Pauly et al., 2000), the size of the ecosystem is defined by the total systems throughput (TST), the structure of the system by the Finn Cycling Index (FCI), and the resilience by the Redundancy index. The total systems throughput shows the sum of all the flows through the ecosystem and was developed from input-output analysis by Finn (1976). The TST is used to calculate the Finn Cycling Index (FCI) which is an indication of stress and structural differences either among models or through time (Finn, 1976). The ecosystem redundancy (R) is an index based on information theory, first estimated by Ulanowicz (1986) and defined in Ulanowicz (2004) as an indicator of the change in degrees of freedom of the system. It is also an indicator of the distribution of energy flow among the pathways in the ecosystem. These indices and the methodology of getting them from Ecosim are further described in Heymans et al. (2007) and the formulas for calculation of these indices are shown in Appendix B.

4. Results

4.1 Hindcasting

The variable costs of each fleet change with changes in effort, and as such only those fleets with changes in effort will show changes in variable cost over time. These changes in effort cause changes in the profit made by each fleet, with the pelagic fleet starting off with the biggest profit, and also the largest difference between subsidised and non-subsidised profit (Figure 3). Figure 3 shows the profit (left) as well as the cumulative profit (right) for each fleet over time. Figure 3 also shows the profit (when subsidies are removed from the profit calculated by Ecosim, pink) and the gross revenue that the fishers have taken home over time (blue). Finally, in the model where subsidies were removed from the value of the fishery as an input variable into the Ecopath model, the estimated profit is also shown (red). The initial difference for demersal and beam fleets seem large but that is due to the scale of their profits compared to that of the pelagic fleet.

From Figure 3, it seems that the differences between gross revenue (blue) and profit in the model without subsidies (red) diminish over the 12 years of the simulation. This is due to the fact that the effort for all these fleets decline over time (Figure 1), which reduces the variable (effort related) cost in the Ecopath model without subsidies. The beam trawlers became profitable (Figure 3) only when effort declined substantially, i.e. 1996 and 2002 (Figure 1) because the reduction in effort reduces the variable costs in those two years.

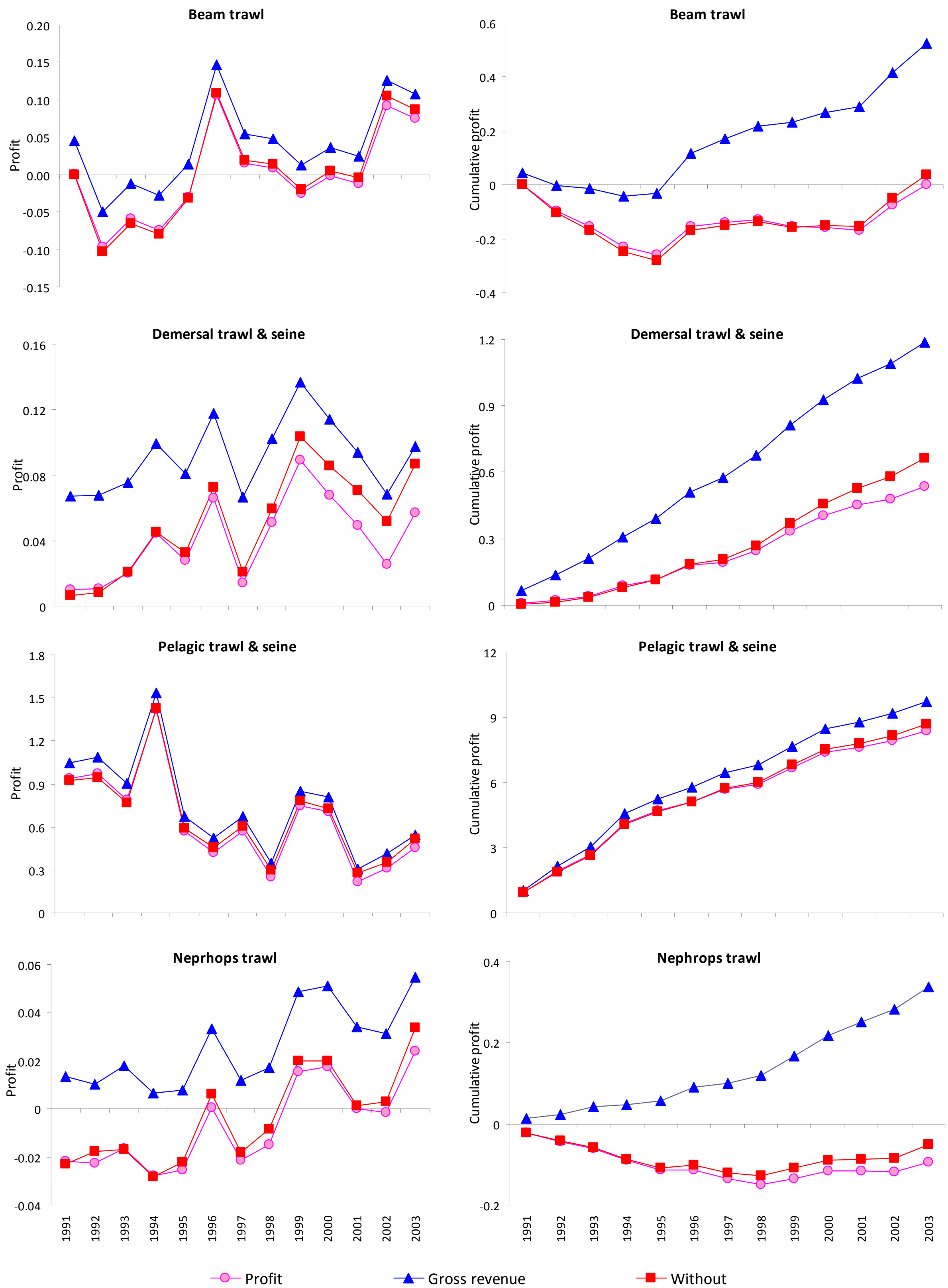

Figure 3: Profits (pink) and total revenue (blue) obtained from four different fleets with subsidies and profit in the model where subsidies were removed (red), in 1000 Euro/km^2.

However, the fleet quickly became unprofitable again. The beam trawlers start off at a loss in 1991 and cumulatively make a loss for the whole simulation, except for the last year, although their gross revenue was above zero from 1995 onwards (blue). Similarly, the cumulative profits of Nephrops trawlers are also never positive (i.e. both these fleets are working at a loss) over the 12 years from 1991 to 2003, but the gross revenue was positive for all of the simulation. Without subsidies, the Nephrops fleet makes losses year on year until 1998, when the effort decreased substantially. After 1998 the effort increases again and the cumulative profit starts to increase, although the fleet was still losing money by the end of the simulation (2003).

In all cases the gross revenue is higher than the profit because costs are subsidized. However, the profit of the demersal and pelagic trawls and seines are minimised with the reduction in effort, while that of the beam trawl increases over the time period of the simulation and the Nephrops trawl profit declines.

4.2 Optimisation

The profit optimisation runs showed that after 2003 the effort of the demersal fleets declined significantly regardless of whether subsidies were applied or not, while beam, pelagic and Nephrops fleets increased (Figure 4A). This is because the profit that can be made given the prices of the species caught by these fleets is much lower for the demersal fleets than for the Nephrops fleets. Nephrops command a high ex-vessel price (Appendix Table A3), so it is unsurprising that the optimisation seeks to maximise the effort and yield from this fleet. From Figure 4A, it is also obvious that for all fleets effort was higher when subsidies were included. This is because the cost of fishing is lower when subsidies are included, and so more effort can be expended for the same cost. Figure 4B shows that when optimising for ecological stability the relative effort will have to decrease significantly from that of 2003, and that effort with subsidies will be marginally higher than without.

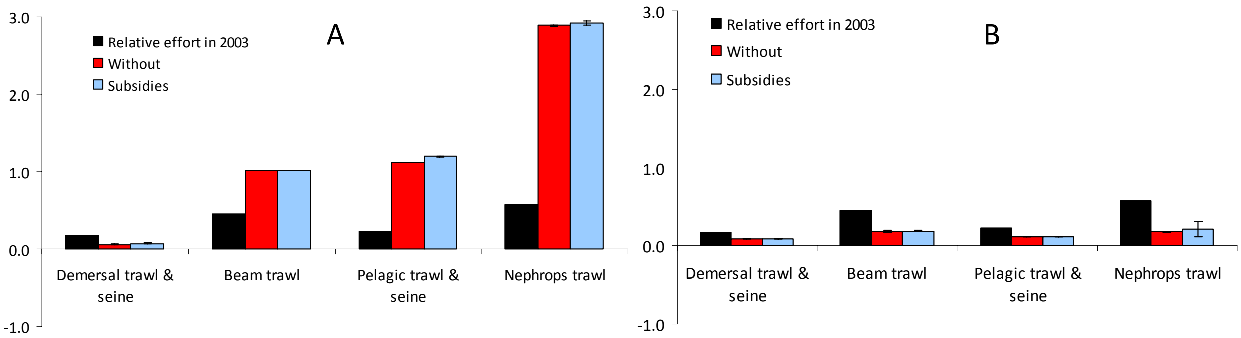

Figure 4: Relative effort (and standard deviation) estimated from policy optimisations run from random fishing mortalities and starting from the relative effort in 2003, when optimising for A) profit and B) ecological stability.

Interestingly, the Nephrops fleet is the most profitable fleet in the system. Despite the increased effort (increased 3 times, Figure 4), profits are not sustained over the period simulated, and the fleet goes into a loss in the last 4 years even with subsidies (Figure 5). This is because profits to the Nephrops fleet does not only come from Nephrops catches, but also from other species caught and sold by that fleet (see catch composition in Appendix Table A3). The declines observed are due to loss of catch for whiting, haddock and plaice, all of which are also caught by the Nephrops trawl. This demonstrates the tradeoffs among fleets as all three species are targeted by other fleets (demersal and beam trawlers). The increase in Nephrops fleet effort increases the fishing mortality on Nephrops and therefore their landings (Figure 6). However, it also increases the fishing mortality on other species that are caught by the Nephrops trawl, such as whiting, haddock and plaice (Appendix Table A3). Specifically the landings of whiting and haddock increase significantly in the first year of the policy optimisation, but both species are not able to sustain the higher fishing mortality from the Nephrops trawl. Therefore the biomass ob both species decline (Figure 7), causing their total landings to decline and thus the total value of the Nephrops trawl declines. By contrast the landings of herring and sole both increase (for herring rather dramatically) but their biomass are not substantially depleted, while the biomass of sole increase over the simulation period. The herring biomass will be dependent on changes in primary production as they feed lower down the food web, and as all the environmental drivers are kept constant this result has to be taken with that caveat in mind.

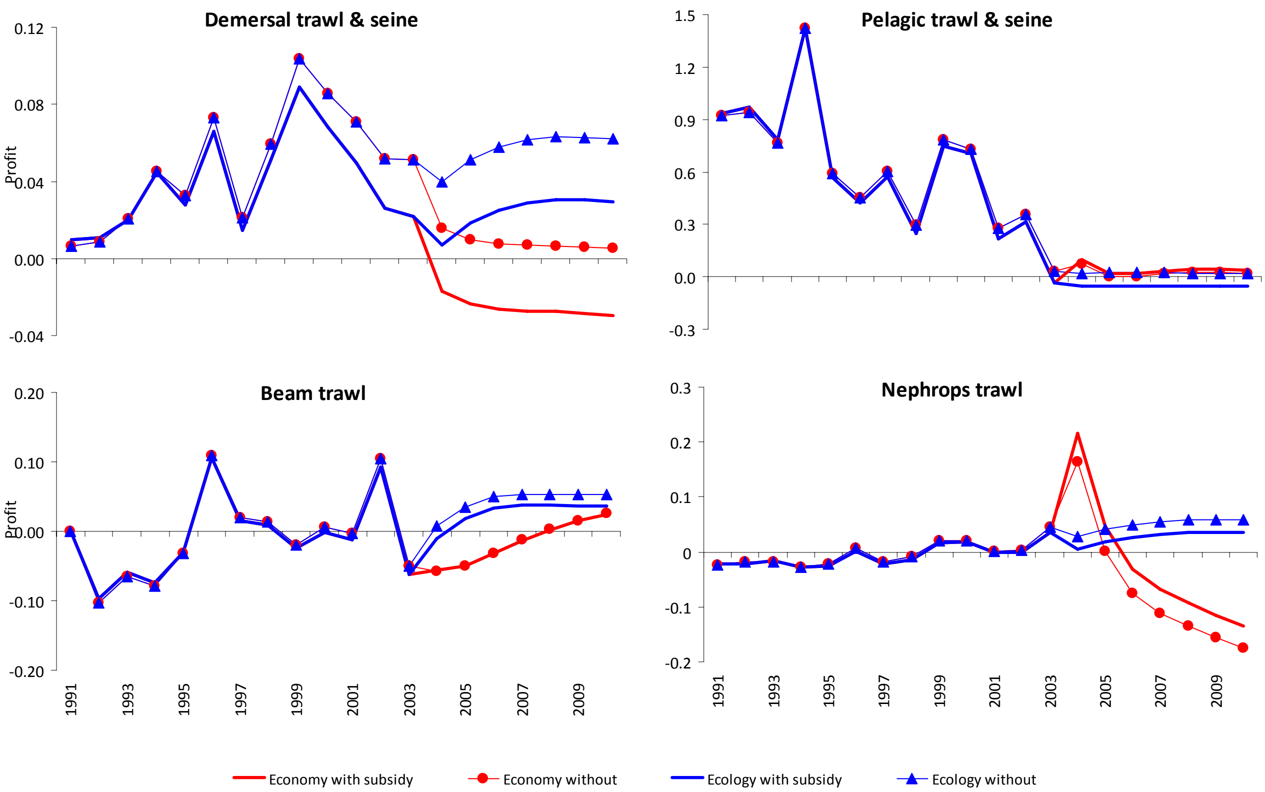

Figure 5: Profits (in 1000 Euro/km^2) obtained from the different fleets with and without subsidies when optimising for profit (Economy, red) and ecological stability (Ecology, blue).

The profit obtained when subsidies are included are dramatically less for the demersal trawlers than when no subsidies are given (Figure 5), while the profit for the Nephrops trawlers seem to increase when subsidies are included. By contrast, when optimising for ecosystem stability (blue lines in Figure 5), all fisheries would do better if no subsidies are given. When optimising for ecosystem stability, the profit for the demersal, beam and Nephrops trawls increase marginally and stabilise over time at values similar to that of the early 2000s (Figure 5). These profits are obtained by reducing the effort of most fleets (Figure 4), and therefore the landings of most species specifically in the first year of the simulation (2004). Some of the landings increase over time, specifically for cod, whiting, plaice and sole (Figure 6) as their biomasses recover (Figure 7).

Conversely the landings of Nephrops, herring and Norway pout stays low (Figure 6), and only the biomass of herring seems to be recovering in this simulation (Figure 7). Norway pout and Nephrops are important in the diet of many species, thus any optimisation that increases the biomass of their predators would be detrimental to the biomass of these two species.

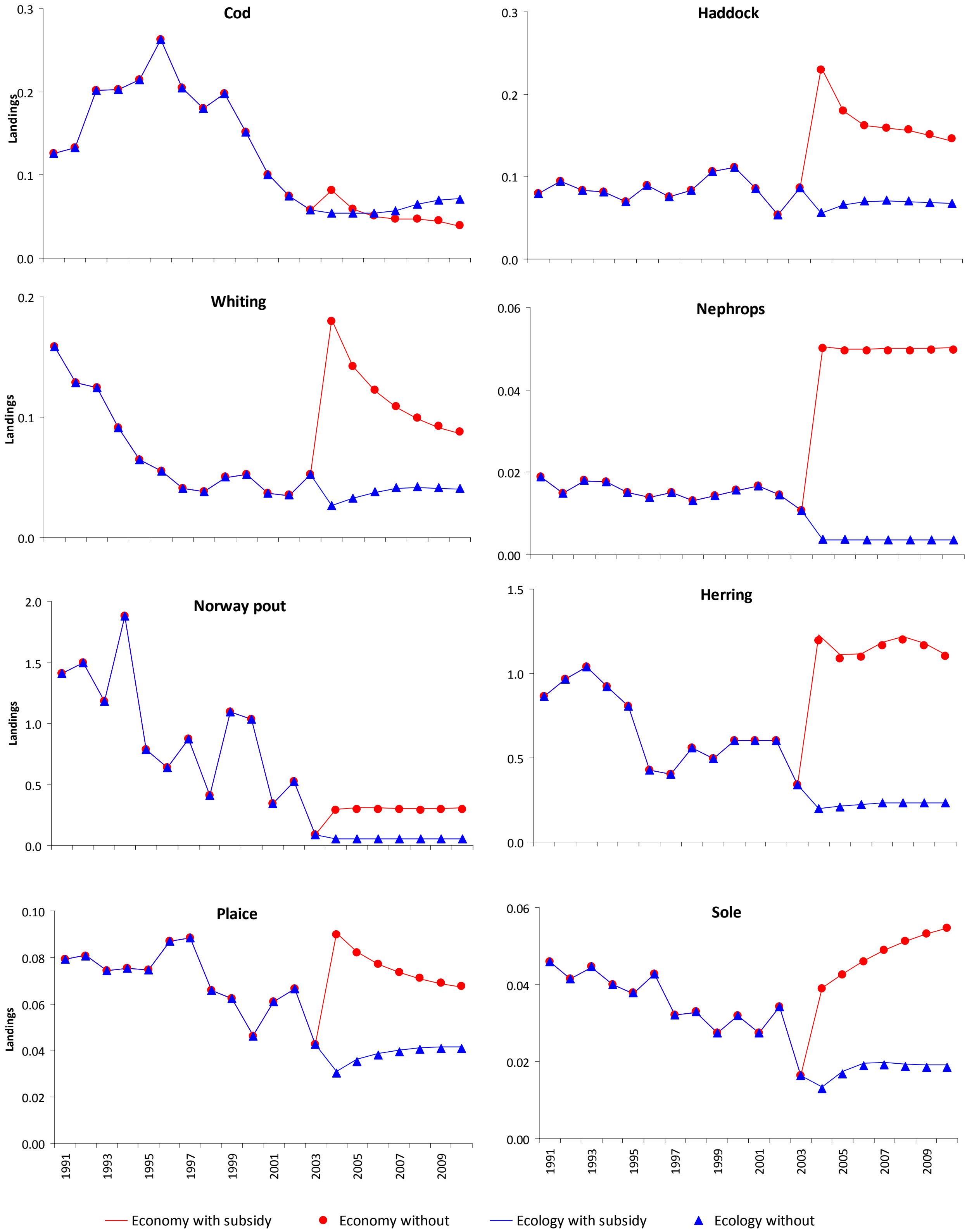

Figure 6: Landings (t.km^{-2}.year^{-1}) of different species with and without subsidies when optimising for profit.

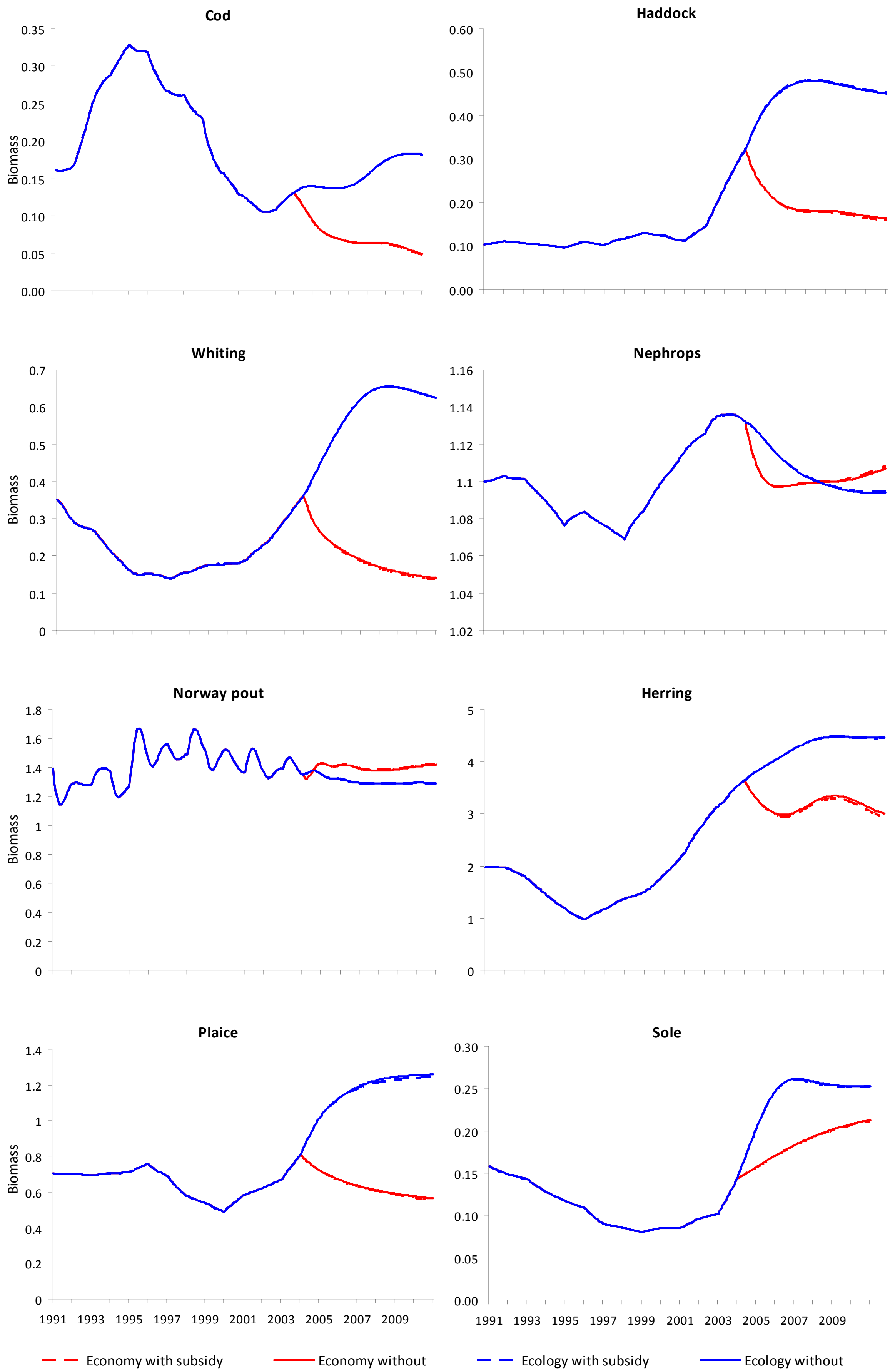

Figure 7: Changes in biomass (t.km^{-2}) of important species due to optimising for profit (Economy, red) or ecosystem stability (Ecology, blue).

4.3 Ecosystem impacts

The fishery stability (described by the fisheries in balance index, or FiB), ecosystem size (defined by the total systems throughput), structure (defined by the Finn cycling index, or FCI) and ecosystem redundancy are described in Figure 8. The ecosystem indices do not seem to show any significant differences between the scenario with and without subsidies, but do show the impact of the large change in the different fleets in year 14. The different impacts of optimising for profit vs. ecological stability are also shown (Figure 8), with the total throughput increasing marginally when optimising for profit. There is, however very little change when optimising for ecological stability. The redundancy of the system is affected by optimising for profit, while it is improved by optimising for the ecosystem. Similarly the system structure is affected with the FCI declining in year 14. The large increase in the Nephrops trawl effort significantly reduces the redundancy and the structure of the ecosystem in year 14 and the ecosystem does not regain its resilience in the remaining 6 years of the simulation, although the structure (FCI) seems to recover quite quickly. The FiB show a large jump with the much larger catch of Nephrops, which is quite a low trophic level species, but it is reduced when optimising for ecological stability.

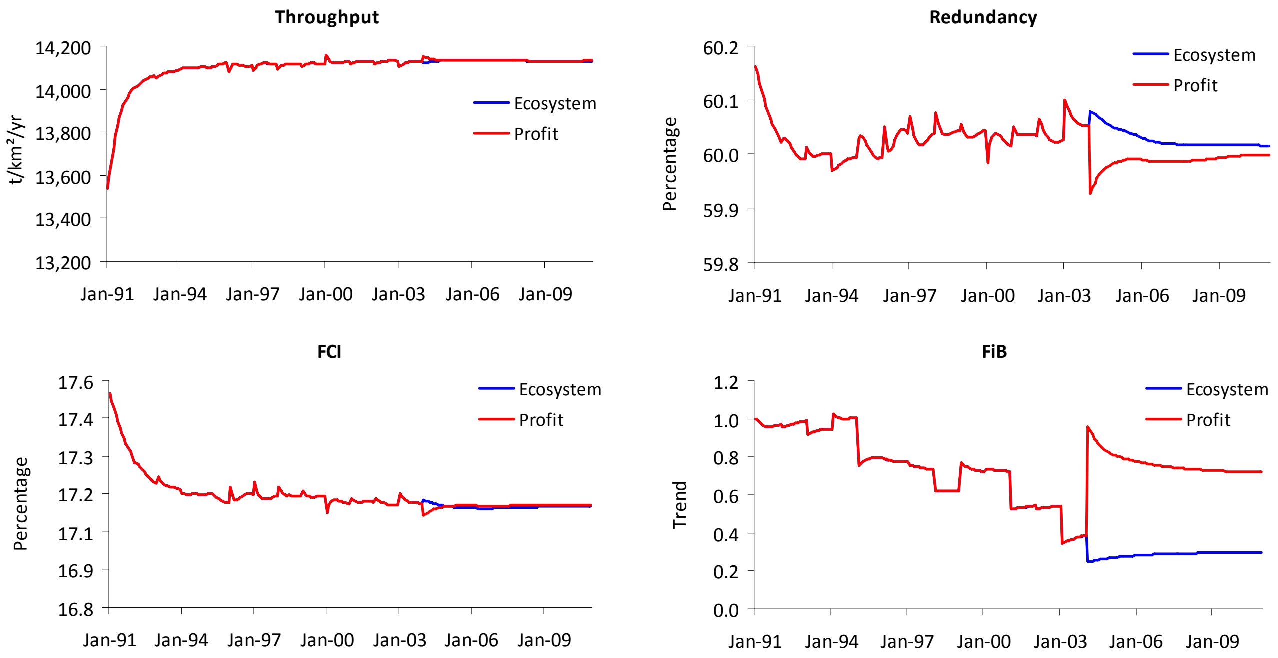

Figure 8: Throughput, Finn Cycling Indices (FCI), redundancy and FIB index estimates over time when optimising for profit or ecosystem stability.

5. Discussion

At the EU seminar on financial policy in the future Common Fisheries Policy in Brussels on the 13th of April 2010, Magnus Eckeskog of the Fisheries Secretariat of Sweden concluded that “In order to be able to assess which EU subsidies are good for the environment, we need a full assessment of all EU fisheries subsidies and their impacts on the environment.” This report is a first step towards that end in the North Sea. The hindcasting shows that most fisheries have not become much more profitable over time, and that both the beam trawlers and Nephrops trawlers were sometimes producing negative profit even if gross revenue to the fishers were positive. This is because a more than appropriate level of fishing effort is employed resulting in high cost of fishing. When comparing the hindcasting simulations with real profit (Figure 9) obtained from the AER reports (AER, 2006), it is clear that the general trend in the profit for the demersal trawl and seine fleet and the beam trawl were quite similar from 1999-2003. Unfortunately, the data for all profits of all fleets and years were not available to enable a more extensive comparison of the model outputs and the empirical data.

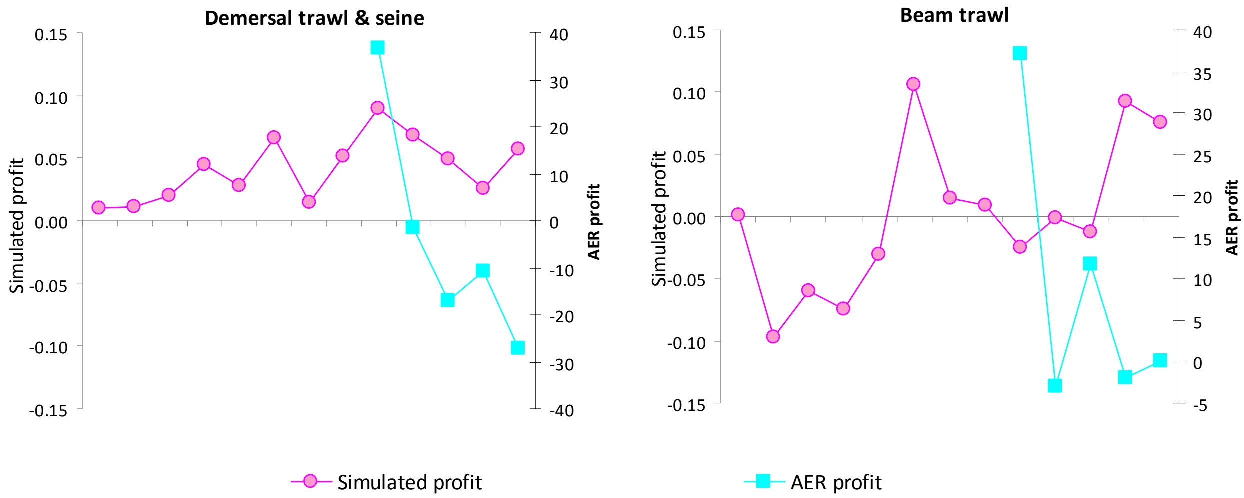

Figure 9: Comparison between the profit obtained from simulations of the Ecosim model (in 1000 Euro/km²) and compared to that obtained from the AER reports (millions of Euro).

It is clear from Figures 6 and 7 that the largest difference in the landings and biomass of important species are seen when you optimise for either profit or ecological stability. However, the summarised results from the optimisations (Table 3) show that in spite of higher landed values and catches with subsidies, the cumulative profit that the fisheries could make if no subsidies are given is larger than with subsidies regardless of what optimisations are run, i.e. if you wanted to maximise profit the best option would be not to subside the fisheries.

Table 3: North Sea fisheries simulation results (2010 estimates). All economic indicators are cumulative while ecological indicators are the result for the end of the simulation (2010).

	Optimisation	Profit		Ecology	
		With subsidies	No subsidies	With subsidies	No subsidies
Economic Indicators (1991-2010)	Landed Value	122.82	122.52	102.31	102.26
	Cumulative Profit	20.9	21.4	18.8	20.4
	Catch	99.2	97.8	80.59	80.57
Ecological indicators (2010 only)	Biomass* (t/km^2)	6.58	6.66	9.6	9.61
	Stability (FiB)	0.923	0.719	0.296	0.304
	Throughput ($t/km^2/yr$)	14132	14132	14130	14130
	Redundancy (%)	59.99	59.99	60.02	60.02
	Cycling (%)	17.1473	17.1459	17.1407	17.1407

*Biomass is final biomass for cod, haddock, whiting, Nephrops, Norway pout, plaice and sole combined.

Removing subsidies does not make a significant difference on the overall ecosystem indices such as throughput, redundancy or cycling in the system, as most of these indices are very dependent on changes in the lower trophic levels (phytoplankton and zooplankton) which are mainly influenced by changes in the environment (Heymans et al., 2007). These changes were not included in the optimisation routine, and therefore the secondary production, and throughput, redundancy and cycling did not change much over the last 7 years of the simulation.

However, removing subsidies does change the structure of the fleet, leading to lower effort for most fleets regardless of which function was optimised (profit or ecological stability). The reduction in effort causes increases in biomass of most species (Figure 7) when subsidies are removed. Specifically, the removal of subsidies increased the biomass of cod, haddock, herring and plaice by 1-3% by the end of the simulation (2010) when optimising for profit and for cod, plaice and sole by between 0.3-1.2% when optimising for ecological stability. These changes are not as significant as the difference between optimising for ecological stability, but they do show the negative impact that subsidies have on the biomass of important fish species, and the profit that can be made from the fisheries.

Finally, our simulations indicate that rather than forcing those involved in the fishery into the red, fisheries become more profitable when subsidies are removed. Despite increasing profitability when subsidies are removed, total revenue to the fishery decrease since they are no longer receiving financial transfers from the government. This will require some re-distribution of effort among the North Sea fisheries or redistribution to the wider economy. In this situation it would be best to avoid removing subsidies completely at first but to re-direct the funds to ease the transition for those affected by reduced subsidies.

6. References

AER. 2006. Economic performance of selected European fishing fleets. Annual Economic Report, 2005.

Christensen, V., Walters, C. and Pauly, D. 2005. Ecopath with Ecosim: A User's guide. 154 pp, Fisheries Centre, University of British Columbia, Vancouver, BC.

Christensen, V. and Walters, C. J. 2004. Trade-offs in Ecosystem-scale Optimization of Fisheries Management Policies. Bulletin of Marine Science, 74: 549-562.

Clark, C. W., Munro, G. R. and Sumaila, U. R. 2005. Subsidies, Buybacks and Sustainable Fisheries. Journal of Environmental Economics and Management, 50: 47-58.

Cotter, J. 2009. Reforming the European Common Fisheries Policy: a case for capacity and effort controls. Fish and Fisheries, 9999.

EU. 2008. SGECA 08-02 working group report. Preparation of annual economic report. 335 pp, Commission of the European Communities, Copenhagen.

Finn, J. T. 1976. Measures of ecosystem structure and function derived from analysis of flows. Journal of theoretical Biology, 56: 363-380.

Heymans, J. J., Guénette, S. and Christensen, V. 2007. Evaluating network analysis indicators of ecosystem status in the Gulf of Alaska. Ecosystems, 10: 488-502.

Mackinson, S. and Daskalov, G. 2007. An ecosystem model of the North Sea for use in research supporting the ecosystem approach to fisheries management: description and parameterisation. 200 pp, CEFAS, Lowestoft.

Mackinson, S., Deas, B., Beveridge, D. and Casey, J. 2009. Mixed-fishery or ecosystem conundrum? Multispecies considerations inform thinking on long-term management of North Sea demersal stocks. Canadian Journal of Fisheries and Aquatic Science, 66: 1107-1129.

Milazzo, M. 1998. Subsidies in World Fisheries: A Re-examination. Fisheries Series. World Bank Technical Paper No. 406, World Bank, Washington DC.

OECD. 2003. Liberalising Fisheries Markets: Scope and Effects., Organisation for Cooperation and Economic Development., Paris.

Pauly, D., Christensen, V. and Walters, C. 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impacts of fisheries. ICES Journal of Marine Science, 57: 697-706.

STECF. 2009. Scientific, Technical and Economic Committee for Fisheries (STECF) Report of SGRST-08-03 Working Group Fishing Effort Regime. JRC Scientific and Technical Reports, Ispra, Italy.

Sumaila, U. R., Khan, A., Watson, R., Munro, G., Zeller, D., Baron, N. and Pauly, D. 2007. The World Trade Organization and global fisheries sustainability. Fisheries Research, 88: 1-4.

Sumaila, U. R., Khan, A. J., Dyck, A., Watson, R., Munro, G., Tydemers, P. and Pauly, D. 2010. A bottom-up re-estimation of global fisheries subsidies. Journal of Bioeconomics, in press.

Sumaila, U. R., Teh, L., Watson, R., Tyedmers, P. and Pauly, D. 2008. Fuel price increase, subsidies, overcapacity and resource sustainability. ICES Journal of Marine Science, 65: 832-840.

Ulanowicz, R. E. 1986. Growth and Development: Ecosystems Phenomenology, toExcel Press, Lincoln, NE.

Ulanowicz, R. E. 2004. Quantitative methods for ecological network analysis. Computational Biology and Chemistry, 28: 321-339.

WGNNSK08 2008. Report of the working group on the assessment of demersal stocks in the North Sea and Skagerrak - combined spring and autumn (WGNSSK). ICES CM, 2008\ACOM:09.

WGNSSK06. 2006. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES CM 2006/ACFM:09, ICES Advisory Commitee on Fisheries Management.

WGPAN, I. 2005. Report on the Pandalus Assessment Working Group. ICES Advisory Committee on Fishery Management ICES CM 2005/ACFM:05.

Appendix Table A1: AER and Ecopath model fleet group.

Country	Fleets	Model Fleet group
Belgium	Beam trawl 12m - 24m	Beam trawl
Belgium	Beam trawl 24m - 40m	Beam trawl
Belgium	Demersal trawl and demersal seiner 24m - 40m	Demersal trawl & seine
Belgium	Drift nets and fixed nets 12m - 24m	Drift & fixed nets
Germany	Beam trawl 0m - 12m	Shrimp trawls
Germany	Beam trawl 12m - 24m	Shrimp trawls
Germany	Beam trawl 24m - 40m	Beam trawl
Germany	Demersal trawl and demersal seiner 0m - 12m	Demersal trawl & seine
Germany	Demersal trawl and demersal seiner 12m - 24m	Demersal trawl & seine
Germany	Demersal trawl and demersal seiner 24m - 40m	Demersal trawl & seine
Germany	Drift nets and fixed nets 12m - 24m	Drift & fixed nets
Germany	Non Active Vessels 0m - 12m	Non Active Vessels
Germany	Non Active Vessels 12m - 24m	Non Active Vessels
Germany	Non Active Vessels 24m - 40m	Non Active Vessels
Germany	Non Active Vessels over 40m	Non Active Vessels
Germany	Passive gears 0m - 12m	Drift & fixed nets
France	Beam trawl 0m - 12m	Beam trawl
France	Beam trawl 12m - 24m	Beam trawl
France	Beam trawl 24m - 40m	Beam trawl
France	Combining mobile and passive gears 0m - 12m	Dredges
France	Combining mobile and passive gears 12m - 24m	Dredges
France	Combining mobile and passive gears 24m - 40m	Other methods
France	Demersal trawl and demersal seiner 0m - 12m	Demersal trawl & seine
France	Demersal trawl and demersal seiner 12m - 24m	Nephrops trawls
France	Demersal trawl and demersal seiner 24m - 40m	Demersal trawl & seine
France	Demersal trawl and demersal seiner over 40m	Demersal trawl & seine
France	Dredges 0m - 12m	Dredges
France	Dredges 12m - 24m	Dredges
France	Dredges 24m - 40m	Dredges
France	Drift nets and fixed nets 0m - 12m	Drift & fixed nets
France	Drift nets and fixed nets 12m - 24m	Drift & fixed nets
France	Drift nets and fixed nets 24m - 40m	Drift & fixed nets
France	Drift nets and fixed nets over 40m	Drift & fixed nets
France	Gears using hooks 0m - 12m	Gears using hooks
France	Gears using hooks 12m - 24m	Gears using hooks
France	Gears using hooks 24m - 40m	Gears using hooks
France	Other mobile gears 0m - 12m	Other methods
France	Other mobile gears 12m - 24m	Other methods
France	Other passive gears 0m - 12m	Dredges
France	Other passive gears 12m - 24m	Other methods
France	Pelagic trawls and seiners 0m - 12m	Pelagic trawl & seine
France	Pelagic trawls and seiners 12m - 24m	Pelagic trawl & seine
France	Pelagic trawls and seiners 24m - 40m	Pelagic trawl & seine
France	Pelagic trawls and seiners over 40m	Pelagic trawl & seine

France	Polyvalent mobile gears 0m - 12m	Dredges
France	Polyvalent mobile gears 12m - 24m	Dredges
France	Polyvalent mobile gears 24m - 40m	Pelagic trawl & seine
France	Polyvalent passive gears 0m - 12m	Drift & fixed nets
France	Polyvalent passive gears 12m - 24m	Other methods
France	Pots and traps 0m - 12m	Pots
France	Pots and traps 12m - 24m	Pots
GBR	Beam trawl 0m - 12m	Beam trawl
GBR	Beam trawl 12m - 24m	Beam trawl
GBR	Beam trawl 24m - 40m	Beam trawl
GBR	Beam trawl over 40m	Beam trawl
GBR	Combining mobile and passive gears 0m - 12m	Other methods
GBR	Combining mobile and passive gears 12m - 24m	Other methods
GBR	Demersal trawl and demersal seiner 0m - 12m	Nephrops trawls
GBR	Demersal trawl and demersal seiner 12m - 24m	Nephrops trawls
GBR	Demersal trawl and demersal seiner 24m - 40m	Demersal trawl & seine
GBR	Demersal trawl and demersal seiner over 40m	Demersal trawl & seine
GBR	Dredges 0m - 12m	Dredges
GBR	Dredges 12m - 24m	Dredges
GBR	Dredges 24m - 40m	Dredges
GBR	Dredges over 40m	Dredges
GBR	Drift nets and fixed nets 0m - 12m	Drift & fixed nets
GBR	Drift nets and fixed nets 12m - 24m	Drift & fixed nets
GBR	Drift nets and fixed nets 24m - 40m	Drift & fixed nets
GBR	Drift nets and fixed nets over 40m	Drift & fixed nets
GBR	Gears using hooks 0m - 12m	Gears using hooks
GBR	Gears using hooks 12m - 24m	Gears using hooks
GBR	Gears using hooks 24m - 40m	Gears using hooks
GBR	Non Active Vessels 0m - 12m	Non Active Vessels
GBR	Non Active Vessels 12m - 24m	Non Active Vessels
GBR	Non Active Vessels 24m - 40m	Non Active Vessels
GBR	Non Active Vessels over 40m	Non Active Vessels
GBR	Pelagic trawls and seiners 0m - 12m	Pelagic trawl & seine
GBR	Pelagic trawls and seiners 12m - 24m	Pelagic trawl & seine
GBR	Pelagic trawls and seiners 24m - 40m	Pelagic trawl & seine
GBR	Pelagic trawls and seiners over 40m	Pelagic trawl & seine
GBR	Polyvalent mobile gears 0m - 12m	Other methods
GBR	Polyvalent mobile gears 12m - 24m	Other methods
GBR	Polyvalent mobile gears 24m - 40m	Other methods
GBR	Polyvalent mobile gears over 40m	Other methods
GBR	Polyvalent passive gears 0m - 12m	Other methods
GBR	Polyvalent passive gears 24m - 40m	Other methods
GBR	Pots and traps 0m - 12m	Pots
GBR	Pots and traps 12m - 24m	Pots
GBR	Pots and traps 24m - 40m	Pots
Netherlands	Beam trawl 0m - 12m	Beam trawl

Netherlands	Beam trawl 12m - 24m	Beam trawl
Netherlands	Beam trawl 24m - 40m	Beam trawl
Netherlands	Beam trawl over 40m	Beam trawl
Netherlands	Demersal trawl and demersal seiner 0m - 12m	Demersal trawl & seine
Netherlands	Demersal trawl and demersal seiner 12m - 24m	Demersal trawl & seine
Netherlands	Demersal trawl and demersal seiner 24m - 40m	Demersal trawl & seine
Netherlands	Dredges 0m - 12m	Dredges
Netherlands	Dredges 24m - 40m	Dredges
Netherlands	Dredges over 40m	Dredges
Netherlands	Non Active Vessels 0m - 12m	Non Active Vessels
Netherlands	Non Active Vessels 12m - 24m	Non Active Vessels
Netherlands	Non Active Vessels 24m - 40m	Non Active Vessels
Netherlands	Non Active Vessels over 40m	Non Active Vessels
Netherlands	Other passive gears 0m - 12m	Other methods
Netherlands	Other passive gears 12m - 24m	Other methods
Netherlands	Other passive gears 24m - 40m	Other methods
Netherlands	Pelagic trawls and seiners 0m - 12m	Pelagic trawl & seine
Netherlands	Pelagic trawls and seiners 12m - 24m	Pelagic trawl & seine
Netherlands	Pelagic trawls and seiners over 40m	Pelagic trawl & seine
Netherlands	Polyvalent passive gears 0m - 12m	Drift & fixed nets
Netherlands	Polyvalent passive gears 12m - 24m	Other methods
Netherlands	Polyvalent passive gears 24m - 40m	Other methods
Sweden	Demersal trawl and demersal seiner 0m - 12m	Nephrops trawls
Sweden	Demersal trawl and demersal seiner 12m - 24m	Nephrops trawls
Sweden	Demersal trawl and demersal seiner 24m - 40m	Demersal trawl & seine
Sweden	Drift nets and fixed nets 12m - 24m	Drift & fixed nets
Sweden	Gears using hooks 12m - 24m	Gears using hooks
Sweden	Non Active Vessels 0m - 12m	Non Active Vessels
Sweden	Non Active Vessels 12m - 24m	Non Active Vessels
Sweden	Passive gears 0m - 12m	Other methods
Sweden	Pelagic trawls and seiners 12m - 24m	Pelagic trawl & seine
Sweden	Pelagic trawls and seiners 24m - 40m	Pelagic trawl & seine
Sweden	Pelagic trawls and seiners over 40m	Pelagic trawl & seine
Denmark	Beam trawl 12m - 24m	Shrimp trawls
Denmark	Beam trawl 24m - 40m	Beam trawl
Denmark	Demersal trawl and demersal seiner 0m - 12m	Demersal trawl & seine
Denmark	Demersal trawl and demersal seiner 12m - 24m	Nephrops trawls
Denmark	Pelagic trawls and seiners 12m - 24m	Pelagic trawl & seine
Denmark	Pelagic trawls and seiners 24m - 40m	Pelagic trawl & seine
Denmark	Pelagic trawls and seiners over 40m	Pelagic trawl & seine
Denmark	Dredges 0m - 12m	Dredges
Denmark	Dredges 12m - 24m	Dredges
Denmark	Polyvalent passive gears 0m - 12m	Other methods
Denmark	Polyvalent passive gears 12m - 24m	Other methods
Denmark	Combining mobile and passive gears 0m - 12m	Other methods
Denmark	Combining mobile and passive gears 12m - 24m	Other methods

Appendix Table A2: Revenues, costs and profits, with (a) and without (b) subsidies.

Fleet	Average of Total Income (million Euro)	(a) Subsidies included (%)				Subsidies				(b) Without subsidies (subsidies added back on to costs, %)			
		Total cost	Fixed cost	Variable cost	Reven ue	Average of Subsidized portion of fixed costs	Average of subsidized portion of variable costs	Fixed cost subsidy	Variable cost subsidy	Total cost	Fixed cost	Variable cost	Reven ue
Demersal trawl & seine	33.9	32.4	8.5	23.8	1.5	0.30	0.04	2.56	0.91	35.8	11.1	24.8	-2.0
Beam trawl	31.1	31.4	10.3	21.1	-0.4	0.15	0.03	1.57	0.73	33.7	11.9	21.9	-2.7
Sandeel trawl	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0
Pelagic trawl & seine	40.9	38.4	13.3	25.1	2.5	0.26	0.03	3.50	0.65	42.6	16.8	25.8	-1.7
Drift & fixed nets	17.2	16.7	3.3	13.3	0.6	0.52	0.02	1.74	0.29	18.7	5.1	13.6	-1.4
Nephrops trawls	101.1	98.3	24.6	73.7	2.8	0.32	0.03	7.89	1.93	108.1	32.5	75.6	-7.0
Gears using hooks	8.5	7.5	1.4	6.1	1.0	0.14	0.00	0.19	0.00	7.7	1.6	6.1	0.8
Shrimp trawls	20.2	20.4	7.4	13.0	-0.2	0.14	0.11	1.01	1.49	22.9	8.4	14.5	-2.7
Dredges	13.6	12.6	3.0	9.6	1.0	0.10	0.03	0.31	0.28	13.2	3.3	9.9	0.4
Shellfish picking	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0
Pots	25.9	22.2	5.5	16.7	3.7	0.14	0.00	0.79	0.01	23.0	6.3	16.7	2.9
Other methods	2.9	2.4	0.7	1.7	0.5	0.59	0.06	0.38	0.11	2.9	1.0	1.8	0.0

Appendix Table A3: Catch composition and price of the most important species.

Group Name	Proportion of catch				Price			
	Demersal	Beam	Pelagic	Nephrops	Demersal	Beam	Pelagic	Nephrops
Starry ray + others	0%	2%	0%	0%	1.81	1.81	1.81	0
Cod (adult)	5%	12%	0%	8%	1.97	1.49	1.94	1.84
Whiting (adult)	9%	5%	1%	37%	1.48	0.9	0.9	0.9
Haddock (adult)	9%	1%	0%	17%	1.38	1.17	1.17	1.17
Saithe (adult)	16%	0%	0%	4%	0.82	0.82	0.82	0.82
Blue whiting	2%	0%	3%	0%	0.15	0	0.15	0
Norway pout	1%	0%	13%	0%	1	0	1	0
Other gadoids (large)	3%	0%	0%	2%	2.3	2.14	4.07	2.14
Monkfish	1%	1%	0%	5%	4.07	3.23	3.23	4.07
Gurnards	0%	2%	0%	0%	1.25	1.25	1.25	1.25
Herring (adult)	40%	0%	33%	0%	0.2	0.2	0.28	0.25
Sprat	0%	1%	10%	0%	0.14	0.14	0.21	0.16
Mackerel	5%	0%	27%	0%	0.71	0.71	1.06	0.71
Horse mackerel	0%	0%	9%	0%	0.37	0.37	0.37	0.37
Plaice	1%	30%	0%	3%	1.9	1.92	1.79	1.82
Flounder	1%	20%	0%	0%	0.41	0.74	0.41	0
Sole	0%	19%	0%	0%	10.06	9.75	11.17	10.22
Lemon sole	0%	2%	0%	2%	4.01	4.01	6.34	4.01
Witch	1%	0%	0%	6%	3.8	3.8	3.8	3.8
Nephrops	0%	0%	0%	10%	6.63	3.1	9.17	7.2
	96%	**95%**	**97%**	**95%**				

Appendix B: Ecosystem stability indicator calculations.

The fishery stability is defined by the FiB index (Pauly et al., 2000) is calculated for a given year by the formula:

$$FiB = \log\left(Y_i \cdot \left(\frac{1}{TE}\right)^{TL_i}\right) - \log\left(Y_0 \cdot \left(\frac{1}{TE}\right)^{TL_0}\right) \qquad (1)$$

where Y is the catch, TL the mean trophic level in the catch, TE is the transfer efficiency and 0 is the baseline year.

The total systems throughput (TST) shows the sum of all the flows through the ecosystem and was developed from input-output analysis by Finn (1976). The TST is the sum of all flows in the model (Finn, 1976):

$$TST = \sum_{i=1,\, j=1}^{n} T_{ij} \qquad (2)$$

where T_{ij} is the flow between any two compartments. Finn (1976) used the TST index to calculate the Finn Cycling Index (FCI).

The FCI is defined as the proportion of matter in an ecosystem that is recycled versus the matter that flows through the ecosystem and is calculated as (Finn, 1976):

$$FCI = \frac{TST_c}{TST} \qquad (3)$$

where TST_C is the total flow that is recycled.

The ecosystem redundancy (R) is an index based on information theory, first estimated by Ulanowicz (1986). It is an indicator of the distribution of energy flow among the pathways in the ecosystem, and is calculated as:

$$R = -\sum_{i=1}^{n}\sum_{j=1}^{n}(T_{ij}) \cdot \log\left(\frac{T_{ij}^{\ 2}}{\sum_{j=1}^{n} T_{ij} \cdot \sum_{i=1}^{n} T_{ij}}\right) \qquad (4)$$

where T_{ij} is the flow between any two compartments. These indices and the methodology of getting them from Ecosim are further described in Heymans et al. (2007).