Improving the exploitation pattern in the fishery for Northeast Arctic Saithe (*Pollachius virens*).

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Abstract:
Fisheries affect fish stocks through their exploitation rate and exploitation pattern. Both influence the economic yield from the fish stock. In regulated fisheries, the exploitation rate is determined either by the acceptable level of fishing effort or catch, whereas the exploitation pattern is determined by selectivity of gears and/or regulatory measures like closed areas, closed seasons and minimum catch and/or landing sizes. This paper describes the process of improving the exploitation pattern in the fishery for Northeast Arctic Saithe in Norway. The process was started in 1996 when the Norwegian Ministry of Fisheries requested the Directorate of Fisheries and the Institute of Marine Research to calculate the biological and economic consequences of increasing the minimum catch size in the fishery. Data on the biological characteristics of the fish stock, the selectivity of the various fishing gears and cost and earnings from the various fleet segments were collected. Using these data, the biological and economic consequences of increasing the minimum catch size on spawning stock biomass, catch and net economic revenue during a 10-year period were calculated. Regional consequences for the fishermen were also described. The calculated consequences were written in a report sent to various interested parties. Comments to the report were treated and in cooperation with the fishing industry, new minimum catch sizes were advocated in 1997 and formally established in 1999. Since then, the spawning stock has grown and it is debated whether this growth has been caused by a modest exploitation rate or by an improved exploitation pattern. This underlines the mutual dependency between the exploitation rate and exploitation pattern when managing a fishery.

Keywords: Fisheries management, Exploitation Pattern, Northeast Arctic Saithe, Bioeconomic Modelling, Consultative Management

1 INTRODUCTION

The economic yield that the stock of Northeast Arctic Saithe may sustain depends on natural conditions regulating its stock size as well as the fishery. In this article we will first give a description of the Saithe stock, its fisheries and how it has been managed. Thereafter we will describe the methods used to analyse the consequences of changing the exploitation pattern through a change in the minimum catch size (which size of specimen to fish) and report on the process of changing the regulation accordingly. Finally, we will point out how the Saithe stock has developed during the last years and which factors can be expected to be the main reasons for this growth.

2 THE STOCK, ITS FISHERIES AND MANAGEMENT

2.1 Stock characteristics

Norwegian fishermen utilise two stocks of Saithe (*Pollachius virens)(ICES, 1995)*. These are the North Sea Saithe, which yield is shared between Norway and the European Union, and the Northeast Arctic Saithe. Figure 1 shows he distribution of catches taken from the Northeast Arctic Saithe in 2001.

Northeast Arctic Saithe has its main distribution within the Exclusive Economic Zone (EEZ) of Norway. The spawning grounds are found off the coast from the archipelago of Lofoten and south to 62°N, and to a lesser extent, also in the northern North Sea. Juvenile fish are normally found close to shore and even within the many fjords of Norway. As the saithe grow larger, the fish migrate out from the inshore areas to the near coastal banks. This migration starts at an earlier age and shorter length in the south (mainly age 2-3) than in the north (mainly age 3-5). As long as the trawlers are not allowed to fish close to shore, the purse seine fishery is mainly an inshore fishery, and the gill-netters prefer to target mature fish gathering and migrating for spawning, the size of the saithe available to the different fleets will vary along the coast accordingly. The Northeast Arctic Saithe spawns at the age of 5-6 years, has a schooling behaviour and may in rare cases reach an age of 30 years, a weight of 20 kg and a length of 1.2 meter (Mehl, 2002, Godø, 1995, Reinsch, 1976). The stock has traditionally been fluctuating and since the 1960s the spawning stock is assessed to have varied between 90.000 tonnes and 650.000 tonnes (ICES, 2002).

2.2 The Saithe fisheries

During the period 1960-2001 the annual landings have ranged from 70.000 tonnes to 274.000 tonnes (ICES, 2002). The Northeast Arctic Saithe stock is primarily utilised by Norwegian fishermen (above 90%), and during the last four years the annual value of the catch to Norwegian vessels has varied between 70 and 100 million Euro.

The fleets can be separated in three major categories according to gear. These are the trawlers fishing for whitefish (Cod, Haddock, Saithe, redfish and Greenland halibut, the purse-seiners fishing for Herring, Mackerel and Saithe and finally the vessels fishing whitefish with gillnets, hand line, long line or Danish seine. In the following these groups will be referred to as trawlers, purse-seiners and gill-netters respectively.

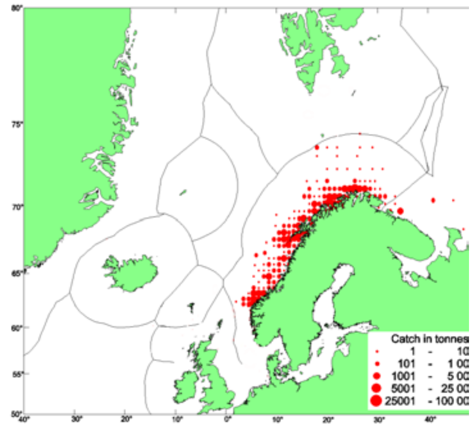

Figure 1. Distribution of Norwegian catches of Northeast Arctic Saithe, 2001.

All vessel groups target several species and the fishery for Saithe represents a limited source of income. According to statistics from 1994, the catch of Northeast Arctic Saithe constituted on average between 2 and 20% of total catches (in tonnes) for the various groups. Limited as this may seem, Saithe is considered an important element in the fishery of all vessel groups. This can be appreciated when taking into account the existence of overcapacity in the fishing fleet in relation to its available resources. For many vessels, the surplus generated in the Saithe fishery may be what is needed to generate a cash flow large enough to cover fixed costs and avoid bankruptcy.

Most of the catch is delivered to processing industry along the coast. The main products are frozen fillets and block of fillets exported to the European Union. In addition, a variety of products are exported to countries all over the world (Norwegian Seafood Export Council, 2001).

2.3 Management of the fishery

The fishery has been regulated for years. Norwegian law that specifies that only active fishermen are allowed to own and operate fishing vessels and as such, conduct a fishery for Saithe regulates participation in the fishery. To operate a trawler there is also a need to hold a specific license. Regardless of these instruments to monitor fishing effort, overcapacity in the fleet stresses the need for additional regulatory measures. After advice from the International Council for the Exploration of the Seas (ICES) a total allowable catch (TAC) is therefore determined each year. Taking account of the need foreign fishing fleets will have for by-catch of Saithe in cod-fisheries (generally less than 10% of the quota), the Norwegian share of the TAC is divided between trawlers, purse-seiners and gill-netters. Within these groups, individual non-transferable vessel quotas are established.

As mentioned above, the size of the Saithe available for the different fleets varies along the coast. To accommodate the need for local fishing communities to fish Saithe close to their ports, technical regulations like minimum mesh size and landing size have been different in various regions along the coast. The minimum catch size varied from 35 cm in the south to 40 cm in the north. Correspondingly, the minimum mesh size allowed in the trawl fishery varied from 135 mm north of 64° latitude to 100 mm south of this latitude. The regulations further stated that until 10% of the catch could be below the minimum catch size. These regulations implied that the fishery for Saithe had completely different exploitation pattern (how the fishery targets various sizes of fish) along the coast.

3. THE MODEL AND DATA

The prime objective for our work was to analyse the biological and economic consequences of increasing the minimum catch size of Saithe. As the fishery policy of Norway is multi-faceted, focussing on efficiency, distributional aspects and stock conservation, the analysis should try to answer how such an increase would be expected to affect:

- The spawning stock of Saithe
- The catch of Saithe for various vessel groups
- The change in net present value from the fishery during a given transitional period

The problem to be solved was quite similar to Thunberg et al (1998) who analysed a change in the exploitation pattern in the Atlantic Silver Hake fishery. However, due to different regulations, especially the existence of individual vessel quotas in our study, the method for calculating economic consequences differed.

Our hypothesis was that an increase in minimum catch size would improve the exploitation pattern (i.e. the size and age distribution of the fish in the catches relative to similar distribution in the stock) which would lead to an increase of the spawning stock and the long term economic yield of the fisheries, but that there would be a short term loss (of economic yield). In addition, we assumed that a certain vessel group (purse-seiners) would also be a long-term looser and not be able to gain from the change in the management measure due to specific fleet characteristics.

3.1 The model

The biological model used to answer our questions was the same as used by ICES when giving advice on the TAC for the stock. This is a model that breaks down the stock in various age groups and where, at a specific point of time, each age group consists of a specific number of individuals (N) at a given weight (W). The biomass of a year class is then modelled as the product of N and W and the biomass of the stock as the sum of the biomasses of the year-classes. The spawning stock is determined as the part of the year classes where the individuals are classified as mature. The modelled stock grows through recruitment and individual growth and is reduced through the effect of natural mortality and fishery. Concerning fishery, both exploitation rate and exploitation pattern influences the long-term development of the stock (e.g., Beverton and Holt 1957, Jakobsen 1993).

The economic model was simply mimicking the economics of the various fleets utilising the stock in a directed fishery. Overcapacity in the fishing fleet and a limited market for second-hand tonnage indicated that fixed costs could be treated as “sunk”. Taking account of the limited share that the Saithe fisheries constitute of the total fisheries for the fleets further supports this approach. Price less variable harvesting costs, labelled the contribution margin, was chosen as the key economic indicator. An average price for each fleet group was utilised, and as the various fleets have distinctive exploitation pattern, and the price obtained varies along with the size of the fish, this average price differed between the fleet groups. As the general price level Norwegian fishermen obtain for their catch is influenced by a variety of factors, no attempt was made to calculate how price might respond to changes in quantity. The variable costs contained items expected to vary with catch level of which the two most important items were fuel and remuneration to labour.

As mentioned, all vessel groups participate in various fisheries, and the annual accounts reflect the vessels total activity in all these fisheries. All variable cost items other than labour costs were set equal to the average costs per unit catch for the entire catch of the vessel group. In contrast to Thunberg et al (1998), costs were specified per unit catch and not per day since the regulatory tool applied in the Norwegian Saithe fisheries are quotas and not fishing days. The earnings for the fishermen are fixed as a certain percentage of the value of the catch less some variable cost items. Labour costs per unit catch in the Saithe fishery was therefore specifically computed as a percentage of the value of a unit catch less these variable cost items. This method gave a good estimate of the costs for the vessel-owners. However, as market prices on labour may deviate from their social opportunity costs, our results cannot be taken as proxies for the economics of Saithe fisheries relevant for the Norwegian society.

The connection between the economic and the biological model was set through the exploitation rate and pattern. No measures of uncertainty within the data were available, so analyses of consequences were run on a pure deterministic model. Possible sources of uncertainty were described qualitatively.

Appendix A gives a detailed description of the biological and economic models.

3.2 The data

To run the model, biological data on the Northeast Arctic Saithe stock, the economics of the fleet and the fishery was needed.

3.2.1 Biological data

The biological data were drawn from ICES (1996). The initial stock was set equal to the stock assessed by ICES at 1 January 1995. Three natural processes determine the development of the fish stock (recruitment, growth and natural mortality). Recruitment at age 2 was set equal to the average experienced during the 30-year period 1965-1994. Growth is determined by the change in individual weight when the age of the individual increases with one year. The data on weight at age in catch was set equal to the average 1990-1994. Natural mortality was set equal to 0.2 per year.

As our biological model was disaggregated with respect to age, it was necessary to establish a link between age and length of the fish. This is, of course, not easy as fish of the same age may have different length. For our analyses we assumed that there was a unique relationship where a minimum catch size of 40 cm prevented the catch of all fish at the age of 3 years and younger, a minimum catch size of 45 cm prevented the catch below 4 years and a minimum catch size of 50 cm prevented the catch of Saithe below 5 years. These minimum catch sizes therefore corresponds to minimum landing ages of 3 – 5 years.

3.2.2 Fishery data

The fishery data show how the fishery influences the fish stock, i.e. levels of the exploitation rate and the exploitation pattern.

<u>Exploitation rate</u>
The exploitation rate was represented by a fishing mortality for the age groups 3-6 ($F_{3\text{-}6}$). This was set equal to 0,37, a level close to the biological reference point F_{med}, which indicate a fishing mortality that balance the number of fish recruiting to the stock and the number of fish removed from the stock at the existing level of spawning stock biomass. By other words, it is the fishing mortality that enables the current spawning stock to reproduce itself through recruitment. The fishing mortality was allocated to the trawlers, purse-seiners and gill-netters with 0.20, 0.08 and 0.09 respectively. The allocation was the same as used by ICES in their annual assessment during the period 1990-1994, and reflects the various vessel groups historical catch records.

<u>Exploitation pattern</u>
The various vessel groups exhibit specific exploitation patterns. Data describing these exploitation patterns were collected by sampling of catch from the various vessel groups in 1990-1994, and is printed in Table 5.11 in ICES (1996) and reprinted in Appendix B.

Biological data on length, weight and age were sampled from commercial landings at landing ports by technicians from the Institute of Marine Research during a six week travel every quarter covering the area from the Russian border in the east to the Lofoten islands in the (south)west. Representative samples (80-100 fish per sample) were collected on an area, gear and quarterly basis. The samples collected from each area and gear should reflect the fishing activity going on along the coast. Most of the samples comes from the near coastal fishery, less from trawlers, and very few (if any) from freezer vessels and vessels producing fillets on board. The degree of representativity may therefore not be complete, and in general, more but smaller samples would have reduced the variation and increased the precision.

These data shows that the purse seiners in particular have an exploitation pattern where a high degree of their effort is targeting Saithe at the age of 3-5 years whereas the exploitation pattern of trawl and gill-netters is targeting older Saithe.

3.2.3 Data on fishery economics

Data on fishery economics were drawn from the databases on landings and cost and earnings in the Directorate of Fisheries (Directorate of Fisheries, 1995). As the minimum catch size varied along the coast (35, 37 and 40 cm) and it would be of interest to see the consequences for the trawlers, purse-seiners and the gill-netters in each of these areas, profitability analyses of each fleet in each of the areas were calculated (9 groups). In the analyses, the profitability figures for the vessels operating under a minimum catch size of 35 cm were used.

A discount rate of 5% was established in order to calculate net present value (NPV) of the contribution margin of the various increases in the minimum catch sizes. The level corresponded to the then real interest rate for bonds issued by the Norwegian Government in 1995.

All data are shown in detail in Appendix B.

3.3 Simulation

With the models and data described above and in the Appendixes, prognoses of spawning stock biomass, net present value of the catch and distribution of catch between fleets were calculated. Several simulations were run, and simulation with the following three minimum catch sizes are shown here:

- 40 cm
- 45 cm
- 50 cm

An increase in the minimum catch size will lead to a short-term loss and a long-term gain. The length of the period had to cover both the loss and the gain. To reflect this a length of 10 years was used.

4. RESULTS OF THE ANALYSIS

The table below shows how biological and economic indicators vary with varying exploitation patterns. In the scenario "Basis" the exploitation pattern with the existing minimum catch sizes were used. In the remaining three scenarios the consequences of changing the minimum catch sizes to 40, 45 and 50 cm are shown.

Table 1. Consequences of various exploitation patterns. The Net Present Value (NPV) refers to the 10-year period, whereas the catch and the spawning stock biomass (SSB) refers to Year 10 in the analysis.

Scenarios	**Net Present Value (MNOK)**	**Catch Gill netters (tonnes)**	**Catch Purse seiners (tonnes)**	**Catch Trawlers (tonnes)**	**Catch All fleets (tonnes)**	**Spawning Stock Biomass (tonnes)**
Basis	850	48.900	34.300	69.570	152.760	210.000
Min L = 40 cm	870	64.000	25.540	81.680	171.230	280.000
Min L = 45 cm	898	84.050	16.760	90.440	191.250	389.000
Min L = 50 cm	866	103.360	12.150	84.270	199.780	536.000

Table 1 shows that the NPV during a 10-year period would be highest by increasing the minimum catch size to 45 cm. An increase of the minimum catch size beyond 45 cm would reduce the NPV as the short-term loss would outweigh the long-term gains within the period. It is, however, an interesting feature that the difference in NPV between the various scenarios is not large. Inclusion of the gains from an improved exploitation pattern in a longer period would however have resulted in larger difference between the NPV of the various strategies.

The next columns show catch for the various fleets after 10 years. The "winner" of increasing the minimum catch size are the gill-netters and to some extent the trawlers whereas the "losers" are the purse-seiners. However, the total catch would increase with minimum catch size up to 50cm. This implies that the increased catch for the gill-netters and the trawlers far outweigh the loss of the purse-seiners.

The last column in the table shows the Spawning Stock Biomass at year 10. It can be seen that the spawning stock increase dramatically as a consequence of increasing the minimum catch size up to 50 cm (and would probably increase even further following a further increase in minimum catch size). It should be noted that in the analysis, exploitation rate were kept constant, i.e. with an exploitation pattern of F=0.37. The remaining spawning stock could have been calculated in economic terms as the net present value of the sustainable catch derived from such a stock. This was not done. However, the spawning stock is an indicator of the biological status of the resource, relevant for the objective of securing the marine resources, and represents the degree of freedom for the managers to increase the exploitation rate if deemed to be necessary.

As mentioned, the results were derived from a pure deterministic model. The major sources of uncertainty in the biological parameters were identified as the stock-recruitment relationship and possible density dependent growth. As the young Saithe also grow by 5-10 cm per year, the knife-edged age-length relationship used in the analysis is a rough approximation. The way this knife-edged relationship was set in our model, the results may be correct relatively speaking when comparing the options/alternatives in the model, but too optimistic when comparing with the actual fishery which is spread throughout a year while the saithe is growing. In addition to these, economic parameters like the future price for Saithe and variable costs dependence upon the size of the biomass can be expected to be important. Data were not available to estimate the quantitative importance of these uncertainties, but they were identified and discussed qualitatively in the report.

5. DECISION PROCEDURE AND PRELIMINARY CONSEQUENCES OF ESTABLISHING NEW MINIMUM CATCH SIZE.

The model, data and analysis of consequences of changing the minimum size of Saithe were described in a report (Directorate of Fisheries, 1996). The report were given a wide distribution and specific organisations representing the fishermen, the buyers of Saithe and the various fishing communities were asked to present their view on the report and on the question of whether or not they found it instrumental to increase the minimum catch size of Saithe. The majority of those responding to these questions advocated the increase of the minimum catch size to 45 cm.

Thereafter the report and the point of view of the various organisations were discussed between the Director General of Fisheries and the industry at a meeting in the Regulatory Board of Fisheries. This was done in June 1997. The Regulatory Board gave their general approval to increase the minimum catch size to 45 cm with several qualifications regarding the purse-seiners (Directorate of Fisheries, 1997). The Board advocated that the purse-seiners should be allowed to conduct a Saithe fishery with minimum catch sizes ranging from 35 cm to 42 cm in specific areas. For those areas where the minimum catch size was set to 40 and 42 cm, the Board advocated that the legal intermixture of Saithe below minimum size should be increased from 10% to 20% (in weight). The Ministry of Fisheries implemented the new minimum catch sizes during the spring of 1999.

The final decision concerning the minimum catch size reflect objectives of securing the resource base and increasing the NPV in the fishery on the one hand and on the other hand to limit the losses of specific fleet segments. The SSB and NPV could have been higher and the regulations less complicated with a uniform minimum catch size, but distributional effects modified such a solution.

5.1 Preliminary consequences

The new minimum catch size has been in force for three years now. Inspection of data on the overall exploitation pattern in the fishery do however not suggest that this has been improved since the change of minimum catch size. Regardless of this, the SSB has grown sharply. From a level of approximately 280.000 tonnes in 1995, the SSB is recently estimated to 360.000 tonnes (ICES, 2002), caused by the following;

First, in accordance with the philosophy around the Precautionary Approach (PA), the recommended (F=0.26), and agreed, exploitation rate for a number of years has been lower than used in our report.

Second, the stock of Saithe has grown more rapidly than expected by ICES. The result is that the realised exploitation rate has been even lower than the agreed rate. The main reason for this has been that the analytical assessment method has overestimated the fishing mortality and underestimated the stock size in the assessment year.

These effects have resulted in a more conservative exploitation rate than what the stock could have sustained, and the availability of fish far above the minimum catch size has been abundant. Due to the realised exploitation rate, the annual catches have been moderate. In addition, prices on Saithe have dropped slightly so the income from the Saithe fishery has not increased during these years.

6. CONCLUSIONS AND RECOMMENDATIONS

The management problem discussed in this paper is whether an improvement of the exploitation pattern could be obtained by an increase in the minimum catch size. The method we applied when analysing the problem takes care of the stock dynamics and how various exploitation patterns influence the stock and the economics in the fishery. Our method does however suppose that fishermen change behaviour and alters their exploitation pattern when a new landing size is introduced.

Preliminary findings indicate that the exploitation pattern has not changed significantly. However, the assessment of the youngest year-classes of Saithe is considered to be uncertain. Consequently, and since relative little fishing is harvesting 2- and 3-year olds, reliable estimates of exploitation pattern on these young year-classes are difficult to obtain until they have better manifested their strength in the fishery and surveys, making it difficult to conclude only after 3 years that the increase in minimum catch size has not had an effect on the exploitation pattern.

However, if the preliminary findings are verified later, the following reasons may explain why:
First, the reluctance to increase the minimum catch size for the purse seiners as much as for the trawlers and gill-netters as well as the acceptance to increase the legal bycatch of undersized fish in their fishery from 10 to 20% (in weight) may effectively have reduced the expected improvement in exploitation level. Second, a change of minimum catch size alone may not be enough for fishermen to change existing fishing practices. Pinhorn and Halliday (2001) identified the last reason (among others) as a possible explanation why they, in a survey of 26 cod, haddock and saithe (Pollock) stocks in the North Atlantic, did not find any correlation between expected and realised consequences of regulations aimed at an improved exploitation pattern when comparing the time periods before and after the introduction of exclusive economic zones (EEZs) in 1977.

Although our method seems instrumental to calculate the consequences of an improvement in the exploitation pattern in a fishery, it may be too simple concerning modelling unavoidable bycatch and fishermen behaviour when changing the minimum catch size. To get a better understanding of how increased minimum catch sizes affects the fishery, more attention should be given to these factors, see Gezelius (2002). In addition, it would be interesting to evaluate whether other regulatory tools like closed areas, closed seasons or gear modifications should have been applied simultaneously with an increase in the minimum catch size to achieve better results.

If changing the exploitation pattern in a fishery is difficult to implement for various reasons, a traditional change of exploitation rate may be the obvious alternative. The management of the stock of Northeast Arctic Saithe indicates that this indeed has been an effective regulatory tool in the latter part of the 1990s.

REFERENCES

Beverton, R.J.H. and Holt, S.J. 1957. On the dynamics of exploited fish populations. U.K. Ministry of Agriculture, Fisheries and Food, Fishery Investigations (Ser. 2) 19. 533 pp.

Directorate of Fisheries, 1995: Register of landings of fish and profitability analysis for the Norwegian fishing fleet, Bergen, Norway.

Directorate of Fisheries, 1996: An evaluation of the minimum catch sizes of Saithe (En vurdering av minstemålene for sei [in Norwegian].) Fiskeridirektoratets rapporter og meldinger nr 6, 1996. Bergen, Norway

Directorate of Fisheries, 1997: Minutes from the Regulatory Board of Fisheries (Referat fra Reguleringsrådets møte i juni 1997 [in Norwegian].) Fiskeridirektoratet 1997. Bergen, Norway

Gezelius, S.S. 2002. Legitimacy, Compliance, Survival. Natural Resource Harvesters and the State. Doctoral Thesis, Department of Sociology and Human Geography, University of Oslo, 2001. 379pp. ISBN 82-570-0163-5

Godø, O.R. 1995. Sei nord for 62ºN. Pp. 139-144 *In* Torsvik, N., Mortensen, S and Nedreaas, K. (eds.) *Fiskeribiologi*. Landbruksforlaget. Norway. ISBN 82-529-1720-8. (In Norwegian)

ICES, 1995. Report of the Saithe Study Group. Aberdeen, 30 May-2 June 1995. ICES C.M. 1995/G:2. 53 pp.

ICES, 1996. Report of the Arctic Fisheries Working Group. ICES, Copenhagen, 23-31 August 1995. ICES C.M. 1996/Assess:4

ICES, 2002: Report of the Arctic Fisheries Working Group. ICES Headquarters, 16-25 April 2002. ICES CM 2002/ACFM:18

Jakobsen, T. 1993. Management of Northeast Arctic Cod: Past, Present - and Future? Pp. 321-338 *In* Kruse, G., Eggers, D.M., Marasco, R.J., Pautzke, C., and Quinn, T.J. (eds.). 1993. *Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations*. Alaska Sea Grant College Program Report No. 93-02, University of Alaska Fairbanks. ISBN 1-56612-021-7.

Mehl, S. 2002. Sei nord for 62ºN. Pp. 51-44 *In* Iversen, S, (ed.) *Havets ressurser 2002.* Fisken og havet, særnummer 1-2002. (In Norwegian) Institute of Marine Research, Norway, February 2002. ISSN 0802 0620.

Norwegian Export Council for Fish 2001: Monthly statistics on exports of fish products. November 2001. Tromsø, Norway. ISSN 0806 7651

Pinhorn, A.T. and Halliday, R.G. 2001: The regulation of exploitation pattern in North Atlantic groundfish stocks. *Fisheries Research, Volume 53*, Issue 1, September 2001, pp 25-37.

Reinsch, H.H. 1976. Köhler und Steinköhler. *Pollachius virens* und *P. pollachius*. A. Ziemsen Verlag, Wittenberg Lutherstadt. 158 pp. (In German)

Thunberg E.M., Helser T.E. and Mayo R.K (1998): Bioeconomic Analysis of Alternative Selection Patterns in the United States Atlantic Silver Hake Fishery. *Marine Resource Economics. Volume 13*, No 1, pp 51-74.

APPENDIX A:

Biological model

The usual VPA-type, age-structured population model was used:

$$N_{y+1,a+1} = N_{y,a}e^{-Z_{y,a}} \quad (1)$$

$$Z_{y,a} = F_{y,a} + M_{y,a} \quad (2)$$

$$C_{y,a} = \frac{F_{y,a}N_{y,a}(1-e^{-(F_{y,a}+M_{y,a})})}{F_{y,a}+M_{y,a}} \quad (3)$$

where

y: year

a: age (years)

$N_{y,a}$: Number of fish of age a at the start of year y.

$F_{y,a}$: Fishing mortality rate of age a in year y

$M_{y,a}$: Natural mortality rate of age a in year y

$Z_{y,a}$: Total mortality rate of age a in year y

$C_{y,a}$: Catch in numbers of age a in year y

Since three distinct vessel groups participate in the fishery, each with its specific exploitation and weight at age pattern, the total catch each year can be formulated as follows:

$$CATCH_y = \sum_{a,j} C_{y,a,j} WC_{y,a,j} \quad (4)$$

and Spawning stock biomass is given by:

$$SSB_y = \sum_a N_{y,a} WS_{y,a} O_{y,a} \quad (5)$$

where

$C_{y,a,j}$: Catch in numbers at age a by fleet j in year y

$WC_{y,a,j}$: Weight of fish at age a in the catch of fleet j in year y

$WS_{y,a}$: Weight of fish at age a in the stock in year y

$O_{y,a}$: Maturity ogive (proportion of fish at age a which is mature in year y)

In order to separate the effect of the exploitation pattern from the effect of the overall fishing pressure, $F_{y,a}$ can be written as:

$$F_{y,a} = f_y \sum_{j=1}^{j=3} S_{j,a} \quad (6)$$

where

$S_{j,a}$: Exploitation pattern of fleet j for age a

f_y : reference fishing mortality

Economic model

The economic model is constructed in order to find the net present value of harvesting the Saithe stock using a fixed exploitation rate, but varying the exploitation pattern. The following model were used:

$$\text{NPV} = \sum_{y,j} ((P_j - VC_j) * X_{y,j} * (1+r)^{-y}) \quad (7)$$

Where;

NPV : Net present value of the catch

P_j : Average price of Saithe obtained by fleet j (NOK/kg)

VC_j : Average variable costs of Saithe by fleet j (NOK/kg)

$X_{y,j}$: Catch by fleet j in year y

$(1+r)^{-y}$: Discounting factor

and

$$X_{y,j} = \sum_a C_{y,a,j} * WC_{y,a,j} \quad (8)$$

$$VC_j = \text{Labour}_j + \text{Fuel}_j + \text{Other}_j \quad (9)$$

Where:

Labour_j = Average labour costs by fleet j (NOK/kg)

Fuel_j = Average fuel costs by fleet j (NOK/kg)

Other_j = Other variable costs (ice, salt, taxes and unspecified items) by fleet j (NOK/kg)

Note that:

$$\text{Labour}_j = (P_j - \text{Other}_j) * X_j \quad (10)$$

where X_j represents the share (in percent) allocated to the crew

Appendix B. Data

Biological data

Assessment of stock (SB) and spawning stock (SSB) of Northeast Arctic Saithe as of 1 January 1995:

Age (yrs)	Number (1000)	Ind. Weight (kilograms)	Maturity (percent)	SB (tonnes)	SSB (tonnes)
2	210 000	0,487	0 %	102 270	0
3	103 906	0,640	0 %	66 500	0
4	97 158	0,967	1 %	93 952	940
5	111 787	1,643	55 %	183 666	101 016
6	59 831	2,323	85 %	138 987	118 139
7	15 874	2,953	98 %	46 876	45 938
8	1 550	3,373	100 %	5 228	5 228
9	420	3,933	100 %	1 652	1 652
10	522	5,707	100 %	2 979	2 979
11+	541	7,050	100 %	3 814	3 814
Sum	**601 589**			**645 924**	**279 707**

Annual recruitment (as 2 years old, in 1000):	**210 000**
Annual instant natural mortality	**0,2**

Fishery data

Exploitation rate during the period	**F(3-6)**
Gill netters	0,09
Purse seiners	0,08
Trawlers	0,20
Total	**0,37**

Exploitation pattern (existing minimum landing size) and weighth at age for various fleets. Normalized to 1.0 for years 3-6.

	Gill netters		Purse seiners		Trawlers	
Age (yrs)	Expl.p.	Ind weight (kilograms)	Expl.p.	Ind weight (kilograms)	Expl.p.	Ind weight (kilograms)
2	0,01	0,52	0,28	0,48	0,06	0,44
3	0,09	0,68	1,51	0,63	0,44	0,63
4	0,28	1,18	1,33	0,93	0,85	0,90
5	0,93	2,00	0,61	1,67	1,32	1,54
6	2,70	2,50	0,54	2,50	1,39	2,16
7	3,40	3,04	0,34	2,91	1,50	2,85
8	3,72	3,25	0,09	3,36	1,44	3,57
9	4,67	3,72	0,09	3,83	1,07	4,38
10	4,18	4,58	0,09	3,84	1,07	5,77
11+	3,80	6,00	0,00	5,50	0,85	7,00

When simulating with higher minimum landing sizes, the exploitation pattern is 0 for following ages:

Min.land size	Age (yrs)
35cm	2
40cm	2-3
45cm	2-4
50cm	2-5

Economic data

Price and contribution margin (price less variable costs) per kilogram of saithe.

		Gill netters	Purse seiners	Trawlers
Price	**NOK/kg**	**3,81**	**2,19**	**3,24**
Contribution margin	**NOK/kg**	**0,68**	**0,67**	**0,61**
Discount rate per annum				**5 %**