

Management of Herring, Capelin and Cod in the Greater Barents Sea - Economic Optimal Management from a Norwegian point of view

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Abstract. In this paper the Norwegian economic gains / costs of rebuilding the Norwegian spring-spawning herring (*Clupea harrengus*) is analysed by including the effect of the herring stock on the cod (*Gadus morhua*) and capelin (*Mallotus villosus*) fishery in the Barents Sea. The herring stock collapsed in the late 1960's and went through a rebuilding period until mid 1990's. The size of the herring spawning stock affects the productivity of cod and capelin. The effects are analysed by combining the existing bioeconomic model for the Barents Sea (AGGMULT/ECONMULT) and a bioeconomic model for herring in the Norwegian Sea. Two management strategies for herring are studied under different levels of cod TAC: 1) The possible harvest control rule proposed by ICES (ICES), and 2) The herring stock is kept at a low level (Low). Present value of contribution margin in the cod fishery and especially capelin fishery increases when the herring stock is at a low level. The reduction of present value of the contribution margin in the herring fishery in the Low strategy causes the total contribution margin to decrease compared to a large herring stock (ICES). In the low herring stock simulations a large herring fishery takes place in the beginning to reduce the herring stock. If this fishery is not included, the difference in total contribution margin increases a lot. Simulation results show that it is not economic optimal for Norway to reduce the herring stock and by the increase the economic gains from cod and capelin fishery.

Keywords: Economic multispecies management, cod, herring, capelin.

1. INTRODUCTION

In this paper we analyse the economic effects of rebuilding the Norwegian spring spawning herring (*Clupea harrengus*) stock upon the fishery for Northeast Arctic Cod (*Gadhus morhua*), capelin (*Mallotus villosus*). We analyse the effect of the total economic yield to Norway, which has these fish stocks in its Exclusive Economic Zones in part of the year. The problem is analysed using a multispecies, multifleet bioeconomic model for the Norwegian – Barents Sea ecosystem. The yearly harvests of these three species have varied substantially in the last decades due to a combination of overfishing, changing environmental conditions and multispecies interactions.

The theory for optimal management of a renewable resource is well developed (see e.g. Munro (1985) for a review). The theory is expanded to include several species and analyse different types of interactions as 1) biological interactions, 2) harvest technological interactions, and 3) market interactions. In this paper the biological interaction and harvest technological interaction are most important. Flaaten (1998) gives a review of theory for predator-prey interactions. Theory for management having harvesting interactions is given in for example Clark (1985; 1990) and Lipton and Strand (1989).

Applied studies of interacting species are for example Conrad and Adu-Asamoah (1986) on competing species of tuna, Flaaten (1988) on plankton feeders-fish-sea mammals interaction, and (Flaaten and Stollery 1996) on predation cost from sea mammals. In this paper we analyse the

economical effects of a plankton feeder on two other species when the plankton feeder affect mortality and growth of two other species.

In Hamre (1988; 1994) theory for multispecies interaction between cod, herring and capelin are described, and based on this several biological models have been constructed for species in the Barents Sea and Norwegian Sea. Models presented in Rødseth (1998) that include herring, capelin and cod are MULTSPEC / AGGMULT (Tjelmeland and Bogstad 1998a), Systmod (Hamre and Hatlebakk 1998), STOCKFISH (Moxnes 1998) and SCENARIO BARENTS SEA (Hagen et al. 1998). Of those mentioned, only AGGMULT and STOCKFISH, have been used in bioeconomic analyses and none include the economics from fishing of all these three species at the same time. AGGMULT is the biological model used by Eide and Flaaten (1998). In this paper we expand the bioeconomic model in Eide and Flaaten (1998), ECONMULT, by adding a model for herring in the Norwegian Sea, SILD7.

This paper is an applied analysis that emphasises the economic side of species interaction, and the purpose of this paper is to analyse the total economic effect of two different management strategies for herring. One strategy is to use the harvest control rule proposed by the Advisory Committee on Fishery Management (ACFM) in the International Council for the Exploration of the Sea (ICES) in ICES (1998) (ICES-strategy). The other management strategy is to keep the herring stock at a low level, and by that minimise the multispecies effect of herring on cod and capelin in the Barents Sea. The profit from the cod, herring and capelin

fishery for the two herring management strategies are compared under different levels of total allowable catch of cod, and if capelin fishery takes place or not.

In searching for an optimal management strategy for a fish stock one must take into account both the ecological, economic and social effects of the management strategy. In this paper the biological and economic yield from the fishery is calculated from the simulations. The economical effects are emphasised in the discussion.

In part 2, the biology and fishery for the three fish stocks are described. The ICES-management strategy is also described here. The model is described in part 3 and parameter values used in the simulations in part 4. The different simulations we have done are presented in part 4. Part 5 contains the simulation results and a sensitivity analysis of some parameters. The simulation results are discussed in part 6. Part 7 is the conclusion.

2. THE NORWEGIAN SEA – BARENTS SEA ECOSYSTEM.

Hamre (1994) describes the area as one of high productivity, but of low biological diversity. Herring and capelin are pelagic species that feed on plankton, while cod is carnivorous, mostly feeding on different types of finfish and shrimps.

The fish stocks in the area spend different phases of their life span in different areas and the distribution pattern for the three fish stocks overlaps in parts of the year and the overlap is for certain ages of the fish.

The size of the fish stock biomass of herring, capelin and cod in the Norwegian Sea and the Barents Sea have varied a lot during the last decades. Figure 1 presents the size of the spawning stock for cod and herring, and total stock biomass for capelin in the period 1950-1998.

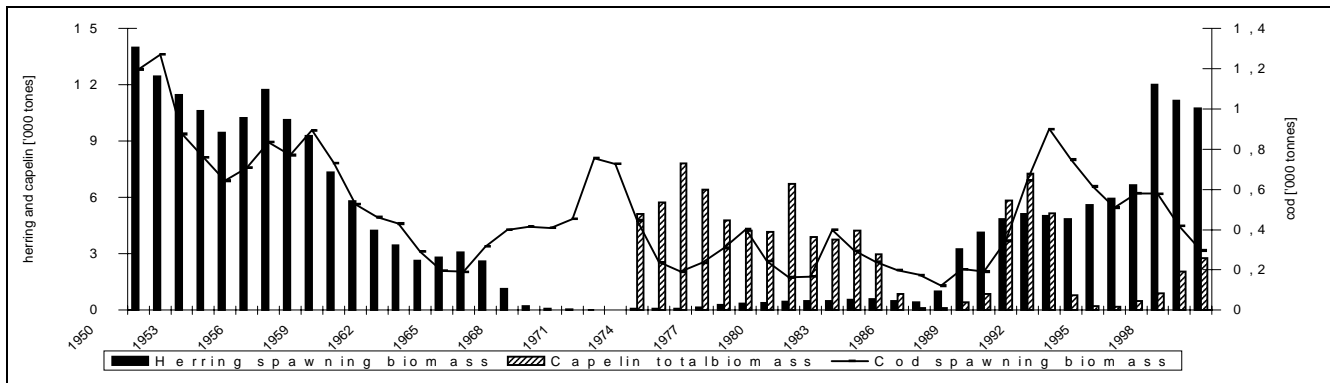


Figure 1: Total stock size for Barents Sea Capelin and spawning stock size for Norwegian Spring-Spawning Herring and North East Arctic Cod in the period 1950-1999. Source: (ICES 1999a).

The size of the fisheries has varied from largest in the world to almost nil and figure 2 show the harvest of Northeast

Arctic cod, Barents Sea capelin, and Norwegian spring spawning herring in the period 1950-1998.

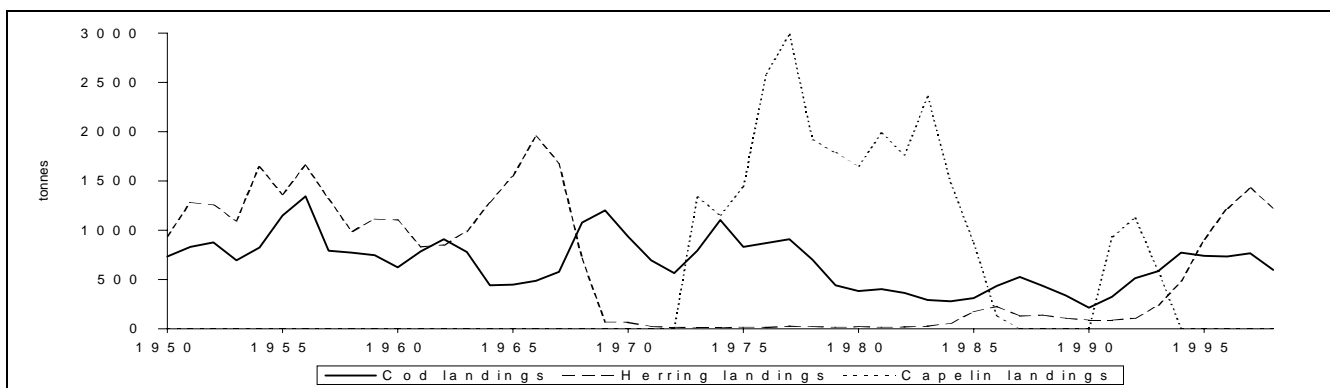


Figure 2: Landings per year in the period 1950-1998 of Barents Sea Cod, Barents Sea Capelin and Norwegian Spring Spawning Herring. Source: (ICES 1999a).

The herring stock was the largest fish stock in Europe prior to its collapse in the late 1960s and figure 2 show that the harvest was above 1.5 million tonnes in several years (ICES 1999a). The stock collapsed as a result of overexploitation (Hamre 1994), especially up on young herring (Dragesund et

al. 1980), and worsened environmental conditions in the adult herring feeding area (Jakobsson 1992). In 1970 the first regulations was introduced to limit the catch of herring and the fishery was strictly regulated during the 1970s and 1980s to rebuild the herring stock. It lasted until 1993 that

the total catch exceeded 200 thousand tonnes. The average harvest per year in the period 1950-1998 is 622 thousand tonnes and in year 2000 the TAC is 1250 thousand tonnes. The spawning biomass was calculated to be above the minimum biological acceptable level (MBAL) in 1994 (Havforskningsinstituttet 1994) set by ACFM, ICES. The migration pattern for adult herring has changed several times since the 1950s. During the 1950s and 1960s the adult herring was available for harvest during parts of the year in the Norwegian Sea. This changed after the stock collapse and in the period 1970-1993 the herring didn't migrate out of the Norwegian EEZ. Since 1994 the adults again have been available for harvest in the Faeroes and Icelandic EEZ, and in the High Seas area of the Norwegian Sea, during parts of the year.

Recruitment of herring is variable and very strong yearclasses relative to spawning stock size occurred in 1950, 1959-60, 1963, 1983 and 1991-92. Warm climate favour recruitment of herring, but in the warm period of the early 1970's the herring recruitment failed due to the depletion of the spawning stock (Hamre 1994). The Barents Sea is the most important nursery area for these yearclasses and the herring in the Barents Sea migrate out of the Barents Sea and into the Norwegian Sea at an age between 2 and 4 years.

ACFM, ICES (ICES 1998; 1999a) recommend a harvest control rule for herring where the fishing mortality decreases, if the spawning stock biomass (SSB) decreases. One possible harvest control rule is proposed in ICES (1998), recommending a fishing mortality (F) of 0.15 and a catch ceiling of 1.5 million tonnes, for a SSB higher than 5 million tonnes (B_{pa}). The fishing mortality decreases linearly from 0.15 to 0.05 for SSB between 5 and 2.5 million tonnes (B_{lim}) that is equal to the MBAL for herring. (ICES 1998) propose a fishing mortality of 0.05 when the SSB is less than B_{lim} . In the period 1985-1993 the fishing mortality was aimed to be restricted to 0.05 ICES (1999a) The ICES harvest control rule is presented in figure 3

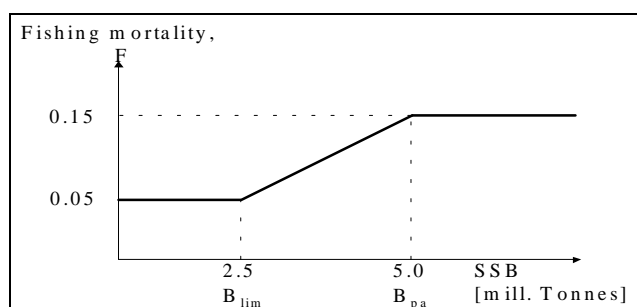


Figure 3: Fishing mortality, F, as function of SSB in the possible harvest control rule for Norwegian spring-spawning herring, proposed by ICES (1998)

The Barents Sea Cod stock is the potentially largest cod stock in the world (Jakobsson 1992), with capelin and herring being important as prey. The average harvest of cod in the period 1950-2000 is 670 thousand tonnes and in year 2000 the TAC for cod is 390 thousand tonnes. Bogstad and Mehl (1997) calculates the cod's consumption of herring and

capelin in the period 1984-1995, and show that the highest estimate of yearly herring consumption was only 10% of the highest estimate of capelin consumption. During the periods of reduced capelin stock, the cod-cannibalism increased (Mehl 1989; Bogstad and Mehl 1997). Norway and Russia regulate the cod fishery co-operatively, and give quotas to third countries such as EU, Faeroes, and Iceland.

The Barents Sea capelin is potentially one of the largest capelin stocks in the world (Gjøsæther 1995) and during the 1970s, the capelin fishery replaced the herring fishery as the largest in volume in Europe. In 1977 the catch was nearly 3 million tonnes (Hamre 1994). The average harvest of capelin in the period 1973-2000 is 1002 thousand tonnes and in year 2000 the TAC for capelin is 435 thousand tonnes. The capelin fishery has been closed in the periods 1987-1990 and 1994-1997 because of collapse in the fish stock biomass. Hopkins and Nilssen (1991) claim the main reason for the collapse in mid 1980s was overexploitation. Hamre (1988; 1991; 1994) states that the stock collapses were caused by predation from young herring on capelin larvae. Huse and Toresen (1995) presents evidence that young herring predate on capelin larvae and Gjøsæther and Bogstad (1998) show that the possibility for recruitment success for the capelin stock decreases dramatically if significant amounts of 1-year old and older herring is present in the Barents Sea.

Based on the development in the fishery we are going to present the model used in the fishery.

3. THE MODEL

The problem is analysed by expanding the existing bioeconomic model for the Barents Sea, ECOMULT (Eide 1992; Eide and Flaaten 1994; 1998) / AGGMULT (Tjelmeland 1995; Tjelmeland and Bogstad 1998b) by including a bioeconomic model for herring in the Norwegian Sea, SILD7. ECONMULT is a multifleet economic model for cod and capelin fishing in the Barents Sea, while AGGMULT is an age structured multispecies biological model for plankton, cod, capelin, herring and sea mammals in the Barents Sea. AGGMULT is an aggregated model of the age, length and area structured model MULTSPEC (Tjelmeland and Bogstad 1989; Bogstad et al. 1997) developed at the Institute of Marine Research, Bergen.

SILD7 that model the biological processes, harvest, and economics for herring into the Norwegian Sea and along the Norwegian coast is based on the model in Helstad (1995) and Kristmannsson (1985).

The time step in the two models differs and in ECONMULT/AGGMULT the time step is 3 months and in the SILD7-model 1 month.

3.1 Biological model

AGGMULT and SILD7 are combined in the way that they run together like zipper. The models wait for each other output files every quarter of the year before starting the next simulation step.

The biological interaction between AGGMULT and SILD7 is that in some years, *herringyear*, a large number of young herring recruits to the herring stock and a given part of these yearclasses, *migrate*, drifts into the Barents Sea and are included in AGGMULT. The herring the Barents Sea in AGGMULT migrate into the Norwegian Sea in the summer at age 3 and are then included in the SILD7 model.

The version of the AGGMULT model used in this paper is the same as the one in Tjelmeland and Bogstad (1998a) except for recruitment of herring into the Barents Sea. Below are the most important equations presented and they are valid for an individual of given specie, (*j*), and age, (*a*), if nothing else is mentioned.

The multispecies interactions are included by using the feeding-level concept introduced by Andersen and Ursin (1977). The feeding level, *f* (φ), for an individual is a function of the amount of food available and suitability of the different types of food available.

$$f(\varphi) = \varphi / (P_3 + \varphi) \quad \text{where} \quad \varphi = P_{23} + \sum_{j,a} S_{j,a} B_{j,a} \quad (1)$$

φ - total perceived food abundance
 P_3 - feeding level half value
 P_{23} - Parameter for other food
 $B_{j,a}$ - biomass abundance of prey item *j* at age *a*
 $S_{j,a}$ - Suitability for prey item *j* at age *a*

The feeding level is multiplied with the maximum consumption for each predator and the number of predators to calculate the food consumption. This gives the total consumption, which is distributed on the prey species according to the proportion in the diet.

The individual growth in length, *l*, and weight, *w*, of the individuals is a function of the feeding level and age of the fish:

$$dl/dt = f(\varphi) * P_4(j,a) \quad (2)$$

$$dw/dt = f(\varphi) * P_8(j,a) \quad (3)$$

P_4, P_8 - parameters

The spawning stock biomass-recruitment relationship, *R*, for cod and capelin is expressed using a Beverton & Holt recruitment function. The mature part of a cohort is dependent of the individual length of the cohort.

$$R_j(SSB_j) = P_{13,j} * SSB_j / (P_{14,j} + SSB_j), \quad (4)$$

$$SSB_j = \sum_{a=0}^{\infty} B_j(a,l) * m_j(l) \quad (5)$$

$P_{13,j}$ - maximal recruitment

$P_{14,j}$ - halfvalue

B - biomass of the yearclass

m - maturation parameter

Recruitment of herring into the Barents Sea is modified in this paper compared to Tjelmeland and Bogstad (1998a) and is dependent of size of the recruiting year classes in the SILD7 model.

Mortality generated by other causes than predation from modelled species and catch, *M*(*a,j*), may be age and specie specific. 0-3 year old herring in the Barents Sea generates a

natural mortality on 0-group capelin according to the following equation.

$$M_{0, cap} = C_{15} N_{0, her} + C_{16} N_{1, her} + C_{17} N_{2, her} + C_{18} N_{3, her} \quad (6)$$

$C_{15}, C_{16}, C_{17}, C_{18}$ - parameters

These are the most important biological equations in the AGGMULT-model.

SILD7 is a modified age structured Beverton & Holt model consisting of the age groups 0-14 plus a group of herring 15 years and older (15+).

The individual length for an individual at age *a* in yearclass, *y*, *l*(*a,y*), is dependent of age and size of the yearclass, *y*, at recruitment to the fish stock. The dependence of the yearclass size is based on Toresen (1990) who showed that the individual growth rate for immature herring is dependent of the area that the herring spend it immature phase. The area where the herring spend is immature phase is dependent of the size of the yearclass.

$$l(a,y) = (1 - e^{-\sum_{i=0}^a k(a_i,y)}) \quad (7)$$

where

$$k(a) = k_0 * (1 - s(r-r_0) * (a_m - a)),$$

$$k_{min} \leq k \leq k_{max} \quad \text{when } a \leq a_m$$

$$k_m \quad \text{when } a > a_m$$

The individual weight is the product of the individual length at the age, *a*, and a length and month specific condition factor, *condition*_{*l,month*}, estimated from Holst (1997). It is assumed that the weight / length-ratio does not vary between years for a given length and month.

$$w_{a,y,month} = l_{a,y} * condition_{l,month} \quad (8)$$

The biomass of the yearclass, *b*_{*a,y,month*}, is the product of the number of individuals in the yearclass, *N*_{*a,y,month*}, and weight of the individuals. The total biomass, *B*_{*y,month*}, of the stock is the sum of all year classes.

$$B_{y,month} = \sum_{a=0}^{15+} w_{a,y,month} * N_{a,y,month} \quad (9)$$

The spawning biomass of a yearclass, *spbio*_{*a,y,month*}, is the product of the length dependent maturity coefficient, *m*_{*l*}, and the biomass the yearclass. The total spawning biomass, *SSB*_{*y,month*} is the sum of all yearclasses.

$$SSB_{y,month} = \sum_{a=0}^{15+} m_l * b_{a,y,month} \quad (10)$$

Herring recruits to the herring stock at age 0 in June and the size of the recruiting yearclass is a function of the size of the spawning stock biomass in February. The spawning stock biomass recruitment function, *R*(*SSB*), is the one used in Dommasnes and Hauge (1994) and Bogstad et al. (1997).

$$R(SSB) = H_{15} (1 - Exp[Exp\{-H_{16}H_{17}\} - Exp\{H_{16}(SSB - H_{17})\}]) \quad H_{15}, H_{16}, H_{17} - \text{parameters} \quad (11)$$

The value of the maximum recruitment parameter, H_{15} , varies between years of high recruitment success, *herringyear*, and years of low success, *non-herringyear*. In July in a *herringyear* a given part of the recruiting yearclass, *migrate*, drifts into the Barents Sea and are included in the AGGMULT-model. *Herringyear* happens with a periodicity of 8 years and it is two *herringyears* in a row. In a *herringyear* the part of the yearclass that drifts into the Barents Sea is *migrate*. Young herring migrate out of the Barents Sea (AGGMULT-model) in July at age 3, and the individuals are included into the SILD7-model. Bogstad et al. (1997) has a similar solution when modelling the herring stock.

Mortality for herring consists of natural mortality and fishing mortality. The natural mortality, $M_{her}(a)$, is age dependent and higher for herring below 3 years of age M_s , than older, M_l . ICES (1999b) have higher M for herring below 3 year than older.

The number of a yearclass harvested during a period is dependent of the yearclass' availability for harvest, size of the yearclass and total harvest.

The calculated stock size is used in the economic models to calculate the harvest in the period.

3.2 Economic Model

Structure of the two economic models, SILD7 and ECONMULT is shown in figure 4.

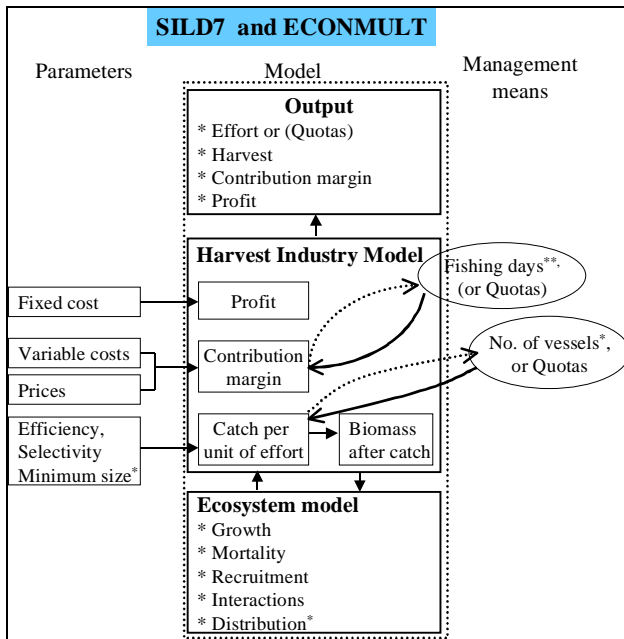


Figure 4: The economical structure of SILD7 (*) and ECONMULT (**). Based on Eide and Flaaten (1994).

A Cobb-Douglas harvest equation is used to calculate the harvest, H , for vessel group in a period. The harvest is a function of biomass available for harvest, X , and total fishing effort in the vessel group, E . The catchability parameter, q ,

effort-output elasticity, α , and stock-output elasticity, β , is specie and fishing gear specific.

$$H_{j,v}(E_{j,v}, X_j) = q_{j,v} * E_{j,v}^{\alpha} * X_{j,v}^{\beta} \quad (12)$$

Each vessels harvest, h , when the effort of the vessel is e and n vessels participate is

$$h_{j,v}(e_{j,v}, X_j) = q_{j,v} * e_{j,v}^{\alpha} * n^{\alpha-1}_{j,v} * X_{j,v}^{\beta} \quad (13)$$

In ECONMULT the harvest is calculated for each cohort of the cod stock and the total harvest is the sum of the harvest of the cohorts.

In SILD7 the biomass used to calculate the harvest, $X_{v,month}$, is the sum of the biomass available for harvest for all cohorts. The biomass of a cohort available for harvest, $x_{herring,a,v}$, is dependent of the availability coefficient, $S_{a,j,month}$ that is age and month specific and biomass of the cohort, $B_{herring,a}$.

$$X_{y,month} = \sum_{a=0}^{15+} S_{a,month} * b_{a,y,month} \quad (14)$$

A yearclass are not available for harvest if the length are below the legal minimum size, l_{min} .

ECONMULT and SILD7 calculate the contribution margin and the total profitability for the vessel. The crew's wages are not included in the profit calculated and this is because the crew salary is a percentage of the harvest value. In ECONMULT the price of the harvest may be independent or dependent of the size of the harvest of cod or capelin. In this paper we assume that the price, p_j , is independent of the harvest size as Eide and Flaaten (1998) assumed.

A vessel's total revenue from fishing up on specie j , $tr_{j,v}$, is:

$$tr_{j,v} = p_j * h_{j,v} \quad (15)$$

The harvesting costs, $tc_{j,v}$, for the vessel consist of fixed costs, $fc_{j,v}$, mainly capital costs, and variable costs, $vc_{j,v}$, the later being proportional to the number of fishing days, $e_{j,v}$. Total costs, $tc_{j,v}$, are.

$$tc_{j,v} = fc_{j,v} + vc_{j,v} * e_{j,v} \quad (16)$$

When the ex-vessel prices of fish are independent of harvest size, the contribution margin per vessel, $cm_{j,v}$, is:

$$cm_{j,v} = p_j * H_{j,v} - vc_{j,v} * e_{j,v} \quad (17)$$

The profit from the fishery $\pi_{j,v}$, is:

$$\pi_{j,v} = cm_{j,v} - fc_{j,v} \quad (18)$$

The total profit from the fishery for the n vessels in vessel group v , $\Pi_{j,v}$, is:

$$\Pi_{j,v} = n_{j,v} * \pi_{j,v} \quad (19)$$

The present value of the fishery for a simulation period of length t , $PV_{j,v}$, is

$$PV_{j,v} = e^{-\delta * t} \Pi_{j,v}(t) dt \quad (20)$$

These are the important equations in the ECONMULT-model and the economic equations in the SILD7 model are similar to these, except for having the price of herring as a

function of the use of the harvest and amount landed. Herring have two main uses, human consumption and destruction into fishmeal and oil, and generally herring delivered for human consumption is higher priced than herring delivered for destruction (Bjørndal et al. 1998). In the model the amount of herring used for human consumption is limited both per month and year, while the amount of herring used for destruction is unlimited. This is based on the description of use of herring for the two purposes for in Bogstad et al. (1994) and letters from the Norwegian Fishermen's Sales Organisation for Pelagic Fish in Fiskeridirektoratet (1995; 1996). The variation in price of herring used for human consumption is larger than for herring used for destruction in the period 1987-1997 (Bjørndal et al. 1998).

Generally the quality criteria's are higher for herring used for human consumption than destruction and this is included in the model that in way that the vessel group fish either for human consumption or destruction. The harvest capacity per month for a vessel is higher for if the harvest is used for fishmeal production compared to human consumption. It is restriction in the amount of herring that can be delivered for human consumption per month, $H^{max, month}$, and year, $H^{max, year}$. If the harvest landed for human consumption, $H^{consumption}$, exceed these limits, the exceeding harvest is delivered for reduction. The variable and fixed costs for a vessel per month are independent of the actual use of the harvest.

3.3 Using the model

The different management means that can be used to simulate the cod fishery in the ECONMULT-model are described in Eide and Flaaten (1998). The management mean used in this paper to simulate the cod fishery is the number of vessels, (n), and maximum total catch, (H), in a year. In the capelin fishery the management mean is the number of vessels. The contribution margin has to be positive before a vessel participates in the cod or capelin fishery.

The herring fishery in SILD7 can be simulated using one of the following management means:

- i) number of vessels
- ii) maximum total catch
- iii) fishing mortality as function of spawning stock size
- iv) maximum spawning stock size

The ICES management strategy used in this paper is a combination of management mean ii) and iii), while the low strategy is management mean iv).

The model used in the simulations has been described and we will present the parameter values used and the simulations done in the following part.

4. SIMULATIONS

In this part of the paper we describe the parameter values used and simulations done.

In the simulations, existing rules for sharing TAC for cod and capelin between Norway and Russia are used. Russia and Norway share the cod-TAC equally, while the sharing rule for capelin is 40-60 in the favour of Norway. It is disregarded that other countries get about 10 percent of the TAC of cod. We assume that the two countries have the mutually interest and apply the same means.

ECONMULT calculate the economic results from the Norwegian fishery for cod and capelin, and in the simulations 24 types of vessels participate in the cod fishery and 5 types of vessels participate in the capelin fishery. The different vessel groups are presented in and number of vessel participating are identical the one used in Eide and Flaaten (1998) used. In the simulations the Norwegian quota of cod is distributed between the bottom trawl and the other gears according to the recommendations from Norges Fiskarlag¹.

In the herring fishery we assume that the Norwegian share of the TAC of herring is 57%. This is similar to the share of the TAC that Norway got in the agreement between Norway, Faeroes, Iceland, Russia and EU for the period 1997-2000 (Toresen et al. 2000). In the SILD7 four types of vessels participate in the herring fishery and vessel group 1, 2 and 3 is assumed to represents the Norwegian vessels while the last one represent the other nations.

The distribution of the Norwegian TAC between the vessel groups 1-3 is set according to the recommendation from Norges Fiskarlag² if the Norwegian TAC is 750 thousand tonnes. They recommend that coastal vessels (group 1) get 32% of the TAC. It is assumed that vessel group 2 and 3, (small and large purse seiners), get respectively 1/3 and 2/3 of the remaining Norwegian TAC. The relative part of the TAC for the vessel groups 1 - 4 are then 18,24%, 12,92%, 25,84% and 43,00%.

The economic result from the Norwegian fishery for a simulation period is present value of contribution margin for Norwegian vessels. Eide and Flaaten (1998) used contribution margin to describe profit in the fishery.

4.1 Parameter values

The biological parameters for cod, capelin, and herring in the Barents Sea are based on data from the period 1973-92 and the values of the parameters are constant except for the recruitment parameters (Eide and Flaaten 1998). The price and cost parameters in ECONMULT are from 1989 that Eide and Flaaten (1998) used, adjusted for inflation until January 1, 2000. The maximum number of vessels

1 For reference see e.g. Hallenstvedt and Søvik (1996), p. 21.

2 For reference see e.g. Hallenstvedt and Søvik (1996), p. 19.

participating in the fishery is same as Eide and Flaaten (1998) used.

The biological parameter values in SILD7 are based on different sources as Bogstad et al. (1997), Holst (1997), Helstad (1995) and Toresen (1990). The parameter values are identical to the one used in Helstad (2000).

It is assumed that herring larvae drift into the Barents sea (*herringyears*) occurs with a periodicity of 8 years, *herring cycle*. In the *herringyears* we assumed that 90 % of the yearclass migrates into the Barents Sea. Holst and Slotte (1998) show that the Barents Sea component portion of a yearclass varies between 80% and close to 100% in most of the year in the period 1930-1989. In years of low spawning stock as 1970s and early 1980s (except 1983), the Barents Sea proportion of the yearclass was below 40%.

The parameters used in to describe the herring fishery are data for total harvest of herring during the year and harvest per vessel for different types of Norwegian vessels in 1992. The cost data are for Norwegian vessels for 1992 and the value of the herring are based on herring landed in Norway or landed by Norwegian vessels in the period 1992-1998. The cost parameters are adjusted for inflation until January 1, 2000. The harvest and economic parameters are identical to the one used in Helstad (2000). The stock output elasticity in the herring fishery, $\beta_{herring}$, is zero and effort output elasticity, $\alpha_{herring}$, 1.0, based on Ulltang (1976; 1980) who estimated the stock output elasticity to be close to zero when effort output elasticity was one.

A discount rate, i , of 5% p.a. is used in the simulations

4.2 Number of vessels actually participating in the fishery in a period.

In ECONMULT a vessel does not participate in the fishery in a period if the calculated contribution margin is negative. For positive contribution margin, the number of vessels participating is dependent of time of year, but constant between years.

In the herring fishery in SILD7, the number of vessels participating in the fishery is dependent of the TAC. Because a vessels catch is independent of stock, the quota may vary between years, the number has to vary to catch the TAC.

4.3 Initial values and simulations

The simulations start by using actual biomass of the dtocks by January 1 1994. Initial number of herring individuals is from ICES (1998). In the period 1/1-1994 to 31/12-2000, the TAC for cod and herring in the simulations have been identical to the actual ones, and capelin fishery takes place in 1999 and 2000. From 1/1-2001 until 31/12-2030 we have simulated the cod, herring and capelin fishery under different assumptions about management strategy for cod and herring.

10 simulations have been done for different combinations of herring management regime, TAC for cod. The same simulations have been done without capelin fishery and the

results from these simulations for the cod and herring fishery was almost identical to those having capelin fishery.

Two herring management regimes have been simulated, one similar to the possible harvest control rule ACFM, ICES (1998), proposed and that is described in part two of the paper (ICES-strategy). The other strategy is a harvest control rule where the herring stock is kept at a low level, (Low). This is based on an assumption that a low herring spawning stock reduces the possibility of young herring drifting into the Barents Sea, based on the history from the 1970's where no strong *herringyear* classes recruited to the herring. The maximum allowable spawning stock size of herring in this management regime is the average spawning stock size in the period 1970-1979 of 143 thousand tonnes. The TAC for herring in a year is the difference between the calculated spawning stock January 1 and 143 thousand tonnes. If the spawning stock is below 143 thousand tonnes, the TAC is calculated using a fishing mortality of 0.05.

Based on the TAC, the number of vessels participating in the fishery in the coming year is calculated.

In the cod fishery, 5 levels of TAC for cod have been used, 300, 350, 375, 400 and 500 thousand tonnes. The reason for using different cod TAC was to analyse the effect of cod fishery on the herring and capelin fishery.

The different simulations are described in table 1.

Table 1: Simulated management strategies for cod, herring and capelin in the Greater Barents Sea.

Simulation no.	Total TAC cod	Herring Management Regime	Capelin Fishery
6	300	ICES	Yes
7	350	ICES	Yes
8	375	ICES	Yes
9	400	ICES	Yes
10	500	ICES	Yes
16	300	Low	Yes
17	350	Low	Yes
18	375	Low	Yes
19	400	Low	Yes
20	500	Low	Yes

The simulation results are presented in the following part.

5. SIMULATION RESULTS

In this part the simulation results for the three fish stocks are presented.

5.1 Simulated development in biomass and catch

Development in the stock biomass for cod, herring and capelin in the period 1994-2030 for simulation 6, 10, 16 and 20 are presented in figure5, 6 and 7. The simulations are for the two herring management regimes (6 and 10 versus 16 and 20) and a cod TAC of 300 thousand tonnes (6 and 16) versus a cod TAC of 500 thousand tonnes.

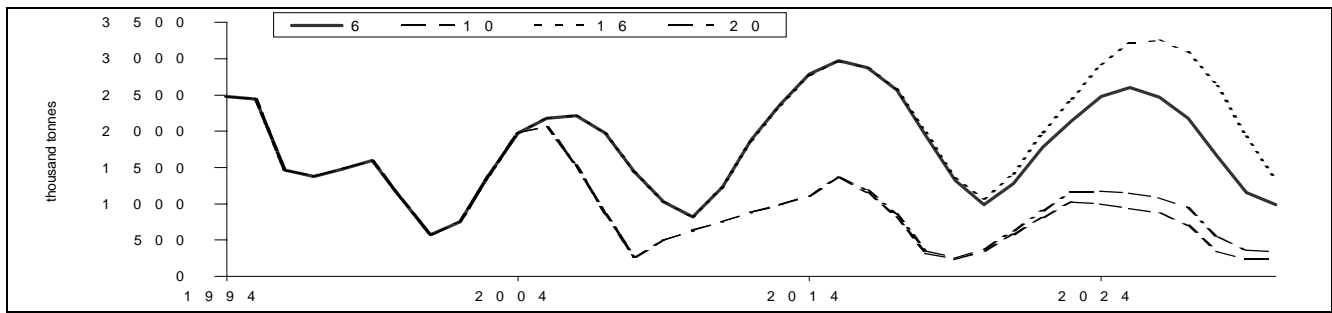


Figure 5: Development in the total biomass of cod age 3 and above in thousand tonnes, simulation 6, 10, 16 and 20.

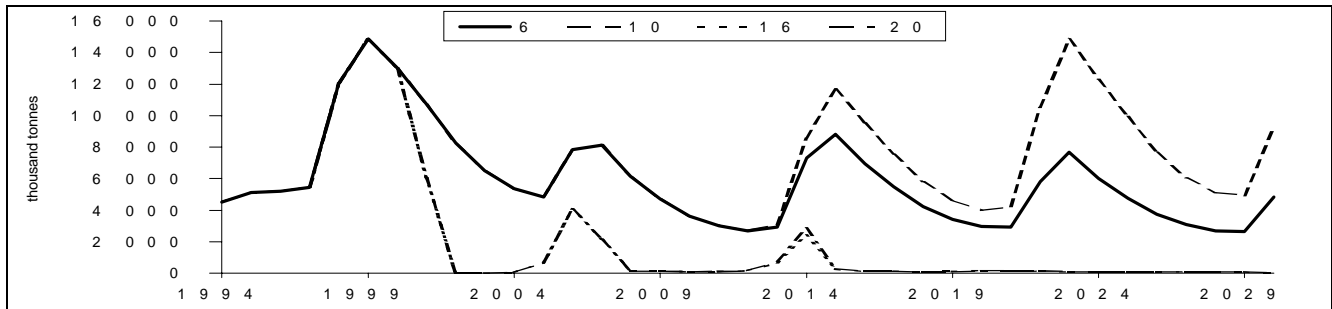


Figure 6: Development in herring spawning biomass in thousand tonnes, simulation 6, 10, 16 and 20.

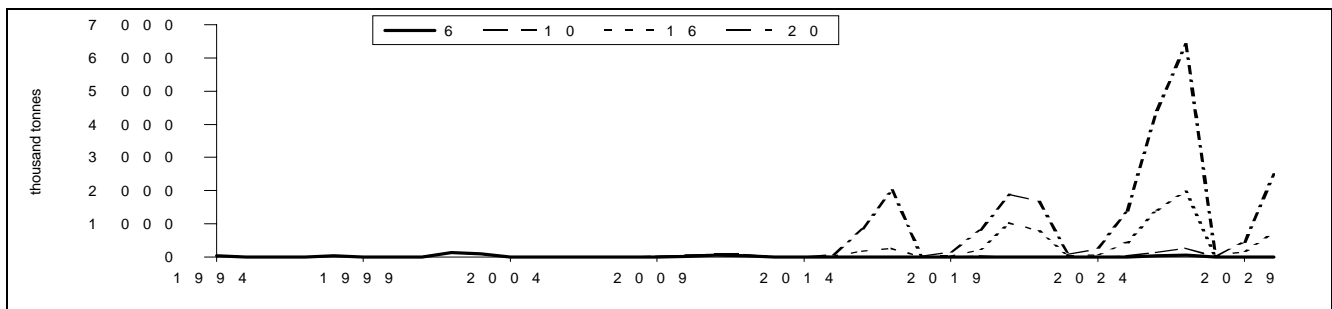


Figure 7: Development in capelin biomass in thousand tonnes, simulation 6, 10, 16 and 20.

Figure 5 shows that the cod biomass is mostly dependent of size of the cod TAC (6 and 16 versus 10 and 20). The effect of different herring management regimes increases in the simulation period. The effect of the two management regimes on the cod-biomass increases as the time goes (6 and 16, versus 10 and 20). The average stock biomass is maximised for a cod TAC of 300 thousand tonnes and low herring stock

Figure 6 shows that the herring spawning biomass varies as a function of the management regime for the herring stock (6 and 10, versus 16 and 20). Effect of cod management regime increases over time (6 versus 10). The herring stock almost collapses in the Low regime. The average herring biomass is maximised if the ICES strategy used and a large cod TAC of 500 thousand tonnes is present.

Figure 7 show how the capelin biomass is dependent upon management regime for cod and herring. This resulting in the largest capelin stock size when the cod and herring stocks are lowest. The capelin stock collapses several times in both herring management regimes, but in some period in the Low regime the capelin stock is large. The capelin biomass is maximised if the cod TAC is 500 thousand tonnes and the herring stock is low.

The developments in catch of the three species develop in a similar pattern as the biomass. The fishery of herring are absent in some years when the herring stock is kept at a low level, while the herring fishery is absent in some years in all simulations.

Average harvest, variation in harvest, and harvest in year 2030 for the 10 simulations are presented in table 2.

Table 2: Harvest of cod, herring and capelin in the period 2001-2030 for the simulations.

No.	Cod harvest ('000 tonnes)					Herring harvest ('000 tonnes)					Capelin harvest ('000 tonnes)				
	Average	st.dev.	min	max	Harvest 2030	Average	st.dev.	min	Max	Harvest 2030	average	st.dev.	min	max	Harvest 2030
6	278	41	162	300	286	729	411	171	1 500	732	6	23	0	110	0
7	296	77	146	350	161	793	417	181	1 500	1 019	11	29	0	110	0
8	280	99	103	375	171	850	422	181	1 500	1 174	15	32	0	110	0
9	273	111	99	400	142	901	428	181	1 500	1 371	16	34	0	110	0
10	251	128	73	500	73	989	424	182	1 500	1 395	178	37	0	125	0
16	279	40	162	300	295	894	2 475	0	11 790	3	173	194	0	558	528
17	312	66	146	350	285	899	2 481	0	11 790	3	242	258	0	751	636
18	296	88	131	375	236	904	2 486	0	11 790	3	286	290	0	859	687
19	287	104	99	400	189	906	2 489	0	11 790	3	304	3069	0	923	710
20	265	126	85	500	91	926	2 515	0	11 790	3	328	322	0	963	721

Table 2 shows that the average cod harvest is maximised having a cod TAC of 350 thousand tonnes. The variation in yearly cod harvest increases as the TAC increases and average cod harvest is higher having a cod TAC of 300 thousand tonnes compared to 500 thousand tonnes. Herring management regime has minor effect on average cod harvest.

Herring harvest increases as the cod TAC increases and the average harvest does not differ very much between the management regimes. The harvest in the Low herring regime is very high in some years to keep the herring stock at a low level. There have not been restrictions in maximum harvest per year in this management regime.

Capelin harvest is maximised for a small herring stock and a large cod harvest. In all simulations capelin fishery do not take place in several years because of collapse in the stock size and in simulation 6 the harvest is almost absent.

5.2 Profit from the fishery in the simulations.

Present value of contribution margin from the three fisheries January 1 2000, for the simulation period January 1 2001 to January 1 2031 are presented in Table 3.

Table 3: Present value of contribution margin in million NOK January 1 2000 for the simulation period 1/1-2001 to 1/1-2030

Sim. no.	PV cont. margin cod	PV cont. margin herring	PV cont. margin capelin	PV cont. Margin total
6	12 520	9 289	22	21 831
7	13 276	9 657	26	22 959
8	12 562	9 923	27	22 512
9	12 080	10 145	30	22 255
10	10 932	10 629	35	21 597
16	12 703	8 598	410	21 712
17	13 848	8 628	620	23 096
18	13 068	8 656	763	22 486
19	12 564	8 667	831	22 062
20	11 326	8 771	909	21 006

Total contribution margin is maximised in simulation 7 having a cod TAC of 350 thousand tonnes in both herring management regimes, largest in the Low-regime. The ICES regime has highest total contribution margin for the other cod TAC's. Simulation 20 having a cod TAC of 500 thousand tonnes has the lowest total contribution margin.

The contribution margin in the herring fishery increases as the cod TAC increases and is highest under the ICES regime. The difference in contribution margin between the two management regimes for herring increases from 20% to 28% as the cod TAC increases. The ICES regime has a difference in contribution margin in the herring fishery for the different cod TAC of 9% compared to 2% in the Low herring regime.

The contribution margins in the cod fishery is maximised having a TAC of 350 thousand tonnes and is highest under the Low herring stock regime. Having equal TAC in both herring regimes, the difference in contribution margin in the cod fishery varies between 1,5% and 4,3% the different cod TAC. The difference in contribution margin for the different cod TAC are about the same, 22% in both herring regimes.

The contribution margin in the capelin fishery is highest under the Low herring regime and the difference in contribution margin between the two herring regimes for equal cod TAC increases from 20% to 44% as the cod TAC increases. In all simulations capelin fishery do not take place in several years because of collapse in the stock size. The Low herring regime has a difference in contribution margin in the capelin fishery from the different cod TAC of 21% compared to below 1% in the ICES regime.

The simulation period we analyses have a large herring stock at the start of the simulation period and a large herring fishery takes place from year 2001 to reduce the herring stock in the Low herring management regime. Table 4 show's the present value of the contribution margin for the simulations for the period January 1 2016 to January 1 2031. It shown to show profit in the three fisheries when the fish stocks have got their "equilibrium" size

Table 4: Present value of the contribution margin in mill.NOK for the last part of the simulation period, 1/1-2016 to 1/1-2031.

Sim. no.	PV cont. margin cod	PV cont. margin herring	PV cont. margin capelin
6	4 417	3 293	0
7	4 459	3 808	3
8	3 485	4 193	4
9	3 084	4 525	7
10	2 556	5 227	10
16	4 602	63	378
17	5 032	63	573
18	3 992	64	696
19	3 573	64	753
20	2 955	60	816

Figure 4 show that the present value of the contribution margin in the herring fishery in the Low herring management regime is almost zero and that this loss is not compensated by increased contribution margin in the cod and capelin fishery.

5.3 Sensitivity analysis

A sensitivity analysis has been done for a few parameters on simulation 7 and 17. The parameters changed are: a) reduce the effort in the cod and capelin fishery by 50% (*effort*), b) herring larvae enter the Barents Sea with a periodicity of 10 instead of 8 (*her.cycle.*), or c) maximum amount of herring used for human consumption reduced by 50% (*consump.*). We also made a simulation where the critical maximum size of the herring stock is increased to 1 million tonnes (*sildmin*) in the Low-regime.

The average cod biomass increases and the average mature capelin biomass decreases in the *effort*-simulations. The increase in cod stock size is lowest in the Low-regime (41%) compared to the ICES-regime (46%). The average capelin stock decreases by 29% in the ICES-regime and 46% in the Low-regime. The average herring stock decreases by 8% in the ICES regime and 4% in the Low-regime. A periodicity of 10 year between herring larvae entering the Barents Sea has minor effect on average cod stock, (increase is less than 2%). The effect on the average capelin stock is large, especially in ICES-regime (more than doubles) compared to an increase of 11% in the Low-regime. The herring stock decreases mostly in the ICES-regime (13%) compared to the Low regime (6%). Biomass is not affected in the *consump.*-simulations. Increased critical herring stock size, (*sildmin*), decreases the cod stock by 9% and the capelin stock by 69%. The average herring stock is more than doubled.

The average harvest decreases for all species in the *effort*-simulations. The cod fishery decreases mostly in the Low-regime (10%) compared to 7% in the ICES-regime. Herring and capelin fishery are reduced by respectively 10% and 73% in the ICES-regime compared to 5% and 64% in the Low regime. The effect on the average cod harvest is minimal (<1%) when the period between influx of herring

larvae in the Barents Sea increases (*her.cycle*). The average herring catches decreases by 15% and 7% in the ICES- and Low-regime. The average capelin catch increases a lot (from 11 thousand tonnes to 86 thousand tonnes) in the ICES-regime and by 16% in the Low-regime. Increased critical size of the herring stock increase the average herring stock by 112%, and reduces average cod and capelin stock by 4% and 61%.

The analysis showed that the capelin biomass and catch was mostly affected by changes in the herring parameter values, while the cod and herring stock and catch, was mostly affected by changes of effort in the cod and capelin fishery.

Present value the contribution margin from the fisheries in the sensitivity analysis is presented in table 5.

Table 5: Present value of contribution margin in mill.NOK for sensitivity analysis 1/1-2000 to 1/1-2031.

Sim. no.	Cod	Herring	Capelin	Total
7	13 276	11 150	26	24 452
7, half	19 453	10 460	1 015	30 928
7, cycle	13 320	11 090	150	24 560
7, cons.	13 276	10 127	26	23 429
17	13 848	10 763	620	25 232
17, half	19 788	10 108	1 213	31 109
17, cycle	13 975	9 168	736	23 878
17, cons.	13 848	9 526	620	23 994
17, sildmin	13 363	10 867	180	24 409

Table 5 show that the largest increase in contribution margin in the cod and capelin is for a reduction in the effort in these fisheries by 50%. The present value of the contribution margin in the cod fishery increases by respectively 47 % and 43 % in the ICES and Low herring management regime. The contribution margin in the capelin fishery increases by at least 96 %. Reduction of effort in the cod and capelin fishery reduces the contribution margin in the herring fishery of about 6 %.

The contribution margin in the cod fishery increases by less than 1 % and the contribution margin in the capelin fishery by at least 18 % when the number of years between recruitment of herring into the Barents Sea increases by two years. The herring contribution margin then decreases less than 1 % in the ICES-regime and 15 % in the Low-regime. The contribution margin in the cod and capelin fishery decreases by 4 % and 71 % when increasing the maximum stock size in the Low herring. The contribution margin in the herring fishery increases by 1 %.

The contribution margin in the herring fishery is reduced by 9 % in the ICES regime and 12 % in the Low herring regime, if the amount of herring used for human consumption is reduced by 50 %.

The total present value of the contribution margin changes by 5 % or less for the parameters analysed, except for reduction in the effort in cod and capelin fishery where the change in total contribution margin is at least 23 %.

Based on this simulation result described above we are going to discuss the effect of the two herring management strategies for herring on the management of cod, herring and capelin in the greater Barents Sea.

6. DISCUSSION

In the simulations, 10 different combinations of the two herring management regimes and different levels of cod TAC's have been simulated.

The simulations show that the present value of the contribution margin for the Norwegian vessels are largest for the cod fishery, while the herring fishery has the second largest contribution margin. Contribution margin in the capelin fishery is less than 10 % of the present value of the two other fisheries in almost all simulations. The simulation results also show that the herring management regime has largest effect on the capelin fishery. This is according to the multispecies effect between the three species, that herring in the Barents Sea have direct effect on the capelin stock in the way that the recruitment collapses. The cod fishery is not that much affected, because the cod substitute partly the loss of capelin as food by predated on herring.

The simulations show that present value of the contribution margin in the herring and capelin fishery increases when the cod stock decreases (TAC increases). The simulations show that it is economic optimal having a rather large cod stock (TAC equal to 350 thousand tonnes) compared to a small cod stock and large stocks of herring and capelin. One reason is that cod have a higher value than herring and capelin.

The loss in contribution margin from the herring fishery by reducing the herring stock in the Low herring regime are in most of the simulations not compensated by increased profitability in the cod and capelin fishery. The loss would be greater if the discount rate is lower than 0.05, because the herring stock is almost wiped out in the end of the simulation period. This effect is shown in table 4 showing present value of the contribution margin for the last part of the simulation period. The situation can be compared to the herring stock conditions in the 1970's when they decided to rebuild the herring stock.

The present value of the contribution margin of the cod fishery in these simulations is slightly lower than the present value of contribution margin calculated in (Eide and Flaaten 1998). One reason may be that they start the simulations for 30 years in 1996 while we start in 2001 where the biomass is smaller than in 1996. Another reason may be the difference in recruitment function for herring and that may cause the cod growth to be lower for cod in this paper.

Total profitability for these simulations are calculated in Helstad (2000) and it is big differences in total profitability between the herring fishery and the cod and capelin fishery. The main reason for this is that the number of vessels participating in the cod and capelin fishery is constant, but varies in the herring fishery. The effect is shown in the sensitivity analysis when we reduce the number of vessels

participating in the cod and capelin fishery. The combination of herring management regime and cod TAC that maximises the present value of the total profit are the similar to the combinations in this paper.

We have not analysed the effect of the rules for sharing the herring TAC between the different countries. This is especially important for the Low herring management regime where the herring stock may be in the Norwegian / Russian EEZ year around, compared to present migration pattern. The present value of the contribution margin from the herring fishery would probably lower than the ICES regime. This based on the assumption that the other nations will participate in the large herring fishery in the first years when the stock is reduced, and that present value from the herring fishery when the stock is reduced as table 4 show is very low compared to the ICES regime.

The 10 simulations have been done without capelin fishery, but the effect on cod and herring fishery is negligible. This result is in a way according to the present management regime for capelin where the TAC recommendations from ICES is the leftover after the cod consumption is taken into account and a certain amount are allowed to spawn. Effect of capelin fishery has to be small because the capelin spawn once and the capelin allowed to spawn are large enough to give a large possibility for successful recruitment.

In the real world the same vessels participate in both the herring and capelin fishery. We would expect that the vessels would prefer to participate in the herring fishery compared to the capelin fishery, because the herring fishery takes place almost all year around while the capelin fishery is more limited. Because of this, the profit in the capelin fishery is higher than calculated because the vessels participate in other fisheries in years when the capelin fishery is absent.

The price of the harvest is assumed constant for the different vessel groups and this cause the total profit to differ more than if the price was dependent of the size of the harvest. It is reasonable to believe that the price of herring would be higher for small stock levels. The sensitivity analysis where the amount of herring used for human consumption was reduced showed that the present value in the herring fishery decreased, but reduction was greater for other parameters analysed. An increased price would have similar effect, but in opposite direction.

By using the Low herring regime, variation in the biomass of cod and capelin for different years do not decrease, as one should expect when an important predator of young capelin larvae has been removed. A reason for this not happening, is the variation in the environmental conditions in the area (and AGGMULT) that determine recruitment and growth for cod and capelin.

The total biomass for the herring stock is larger in our model compared to the total biomass in (ICES 1999a) and a reason for this difference is a more rapid growth of young herring in our model. The spawning stock size does not differ very much from the spawning stock size.

7. CONCLUSION

In this paper we have used a combination of the existing bioeconomic model AGGMULT/ECONMULT and the herring model SILD7 to investigate the economical effects for Norway by rebuilding the Norwegian Spring Spawning herring stock on the cod and capelin fishery in the Barents Sea. We compare economic effect of two management strategies for herring (ICES and Low) on the cod and capelin fishery under different assumptions about cod TAC.

The results from this simulation model show that the rebuilding of the herring stock after its collapse in the late 1960s has been optimal from an economic view, especially if we compare the present value of contribution margin for the last part of the simulation period. We then compare the management under two levels of the herring stock. Reducing the herring stock does not reduce the variability in the biomass of cod and capelin in the Barents Sea because the environmental conditions decide the recruitment success for cod and capelin. In reality having a Low herring stock does not guarantee that herring not entering the Barents Sea in some years and disturbing the recruitment of capelin. That happened in 1983 where a rather small spawning stock of herring recruited a large herring yearclass that affected the cod and capelin a lot in the last part of 1980's.

In reality, profitability in the capelin fishery would be higher because the vessels participate in different fisheries throughout the year, and participating in other fisheries may compensate absence of capelin fishery in some years.

Future improvements in the biological models, especially the herring model, should include refinements that contain differences in the herring growth and harvest, as a function of the migration pattern for herring. An another topic is to analyse the effect of reducing the minimum legal harvesting size of herring and analyse the effects of this on the profitability in the cod, herring and capelin fishery. The effect of using different vessel types in the fishery upon the profitability would also be an interesting topic.

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