Mika Rahikainen
Marko Lindroos &
Veijo Kaitala

Stability of international fisheries agreements using precautionary bioeconomic harvesting strategies

University of Helsinki
Department of Economics and Management
Discussion Papers n:o 27
Environmental Economics
Helsinki 2008

Stability of international fisheries agreements using precautionary bioeconomic harvesting strategies

Running title: Impacts of harvesting rule on fisheries agreements

JEL Classification Codes Q22, Q57, C72.

Abstract

Open access drives fisheries to inefficient harvest rates and ultimately to stock collapses. International agreements are often necessary for exclusion of open access because many fish resources are spread across national boundaries and international waters. In fisheries economics, game theory is a common tool for analysing the strategic interactions of different countries. The main point is that all countries should be better off by cooperating, i.e. by complying with the agreement, than non-cooperating. We parameterized an age-structured bioeconomic model for the North Sea herring fishery to analyse the economic impact of harvest control rule (HCR) on this fishery. The trigger points of the current HCR are developed from spawning stock biomass and fishing mortality rate ceiling. They can be regarded as strategic bioeconomic reference points which operationalize the precautionary approach. Applying precautionary approach by the grand coalition through current harvest control rule adds net present value of the fishery compared to the case without the HCR. However, it does not pay off for a partial coalition to apply harvest control rule if the outside player does not comply with it and harvests using an optimal fixed fishing mortality rate. The coalition structure and the fishing costs have a strong impact on the optimal fishing strategies of the countries. The grand coalition is stable only when low fishing costs are low for two of the countries. If fishing costs are identical among countries, there will be incentive for free riding and multinational fishing agreement is never stable. However, HCR has potential of stabilizing multilateral fishing agreements if fishing costs are, on the applied relative scale, high.

Keywords: risk management, harvest control rule, precautionary approach, game theory, fisheries agreement, North Sea herring

Introduction

Herring stocks have contributed economic wealth in the past as well in the present day. Since the 1950s herring fisheries have expanded to a level at which they have a major impact on the harvested stocks revealing that clupeoid populations have a general tendency to collapse under heavy fishing pressure (Murphy 1977, Saville 1980, Hay et al. 2001). Obviously, stock collapse creates social, political, and ecological problems and dissipates large amounts of economic rent (Garcia and de Leiva Moreno 2003). Excessive fishing pressure on any stock may result from the practice of ignoring or underestimating uncertainty in stock assessment and fisheries management (Hilborn and Walters 1992, Walters and Maguire 1996, Hildén 1997) or from lack of national or international regulations (Bjørndal et al. 2000).

Exclusion of open access is a prerequisite to prevent economic overfishing (Gordon 1954) and international agreements have been established to reduce the undesirable effects due to common property exploitation. The UN has provided a platform to develop and agree upon international treaty laws such as the Extended Fisheries Jurisdiction (EFJ) with introduction of 200-mile Exclusive Economic Zones (EEZs) in 1977 (UN 1982). The EEZ's do not completely resolve the problem of open access to harvesting of the resources because many fish resources migrate or are spread across national boundaries and international waters (Kaitala and Munro 1997). Cooperation in the framework of bi- and multilateral agreements are therefore necessary to solve management problems by assigning property rights to international fish stocks or by regulating fisheries by other means such as national quotas, technical restrictions, spatial or temporal closures. Coalition game theory has been applied in real world fisheries to analyze the expected benefits of cooperation among the fishing countries and to predict the possibilities of reaching stable agreements among them (Arnason et al. 2000, Brasão et al. 2000, Lindroos and Kaitala 2000, Pintassilgo 2003, Lindroos 2004).

In addition to the lack of jurisdiction and property rights, assessment and management failures have also contributed to the inefficient use of marine resources globally. The apparent decline of fisheries has catalyzed more risk averse harvesting policies and management goals (FAO 1995). Consequently, a concept of precautionary approach (PA) has been launched to promote prudent management and to decrease probability of recruitment overfishing and subsequent stock collapse (FAO 1995; 1996; 1997). Biological reference points (BRP) are used as signposts in implementing the precautionary approach and pragmatic fisheries management has been based on a variety of them. The rules to calculate biological reference points are typically based on the perception of risk of stock collapse or of "safe" harvest level (ICES 2001). Biological reference points are usually expressed as fishing mortality rates (e.g. F_{med}, $F_{x\%SPR}$, $F_{0.1}$, F_{msy}) or as critical levels of spawning or recruited biomass (e.g., B_{loss}, B_{mbal}, $B_{20\%\ b\text{-}virg}$) (, Maguire and Mace 1993, ICES 1997; 2001). The precautionary levels of mortality and spawning biomass (F_{pa}, B_{pa}) are usually developed from the estimated overfishing thresholds (F_{lim}, B_{lim}).

Biological reference points, e.g., biomass and fishing mortality limits, targets and trigger points, are commonly applied to develop harvesting strategies. They are intended as robust plans stating how the catch from the stock will be adjusted to the changes in the stock abundance and to unpredictable or uncontrolled biological, economic, and social fluctuations (Hilborn & Walters 1992). Harvest control rules are explicit expressions of harvesting strategies and include proportional and threshold strategies. Additionally, a combination of these has been applied, namely proportional threshold strategies. Here, we analyse explicitly the economic consequences of these (proportional versus proportional threshold) strategies and their influence on likely success of international fisheries agreements. We parameterize the analysis for the autumn-spawning North Sea herring fishery.

Fish stock and the current management scheme

We consider autumn-spawning North Sea herring stock in the ICES subarea IV, division VIId, and division IIIa (autumn spawners). The North Sea herring stock was severely depleted in the late 1960s and 1970s due to excessive harvests under an open access regime. The stock was close to extinction in 1977, when a moratorium on fishing was introduced (Bjørndal 1988). Severe regulations in concert with a few abundant year-classes allowed the stock to recover, and the fishery was reopened in 1984 (Bjørndal and Lindroos 2004, Simmonds 2007). The second period of major decline was in the mid-1990s resulting in an EU/Norway agreement on management actions. The stock recovered again and the biomass was within the safe biological limits by 2002 (Simmonds 2007). The second recovery was obtained without temporal fishing closures. The recovery was initialized by reduction in by-catch limits for juveniles and abundant 1998 and 2000 year-classes.

The stock reached a peak of 3.3 million tonnes in 1989. It was reduced to a level of about 2–2.5 million tonnes during 1993–1996. Subsequently, due to stricter regulations, the stock increased to an estimated level of 3.6 million tonnes in 2001 (Bjørndal and Lindroos 2004). Since the second collapse in the mid-1990s the spawning stock biomass (SSB) has increased from 0.5 million tonnes to 1.8 million tonnes. The lowest estimated SSB was only 0.05 million tonnes in 1977. Catch has varied within the range 0.25 - 0.70 million tonnes since 1987 (ICES Advice 2006). Since the late 1990s Norway's share of the total allowable quota (TAC) has been about 30% while the European Union member countries have received the rest of the TAC.

Harvest control was agreed between the EU and Norway in 1997 (Patterson et al. 1997). Currently, the harvest control rule applies proportional threshold strategy using a limit and a trigger reference point (ICES Advice 2006). According the EU-Norway agreement on management of North Sea "Every effort shall be made to maintain a level of spawning stock biomass (SSB) greater than the 0.8 million tonnes (B_{lim})." If the SSB is estimated to be below 0.8 million tonnes, the quotas are set to reflect a fishing mortality rate of less than 0.1 for 2 ringers and older and less than 0.04 for 0-1 ringers. Consequently, the HCR does not automatically impose a moratorium if SSB falls below the B_{lim}. When spawning stock biomass is estimated to be below 1.3 million tonnes but above 0.8 million tonnes, i.e. between the limit and the trigger reference point, quotas are set to reflect a fishing mortality rate equal to:

$$F_{2 \text{ and older}} = 0.25 - (0.15*(1.3\text{-SSB})/0.5), \tag{1}$$

$$F_{0\text{-}1} = 0.12 - (0.08*(1.3\text{-SSB})/0.5), \tag{2}$$

which defines the proportional threshold strategy and subscripts refer to age groups.

The rule also specifies fishing mortalities for juveniles ($F_{0\text{-}1}$) and for adults ($F_{2\text{-}6}$) not to be exceeded, at 0.12 and 0.25 respectively, for the situation where the SSB is above 1.3 million tonnes. Moreover, the current agreement has a constraint on change in a TAC that is no more than 15% greater or 15% less than the TAC of the preceding year, but allows for a stronger reduction in TAC if necessary (ICES 2007).

This HCR regulates fishing activities of Norway and seven EU countries. The allocation of TAC for the directed fishery for herring shall be 29% to Norway and 71% to the Community. Bjørndal and Lindroos (2004) have analyzed the optimal sharing rule of the North Sea herring quota and concluded that according to the Nash bargaining solution, the current sharing allocates a too large fraction to the EU.

Four fleet segments have been identified in the North Sea herring fishery (Dickey-Collas, M., pers. comm.):

1) Globally operating freezer trawlers from the Netherlands, Germany, France, and England (under Dutch ownership)

2) "Standard" trawlers from Scotland, Denmark, and Sweden harvesting for human consumption and typically containing refrigerated sea water tanks.

3) The Norwegian fleet being a mixture of trawlers and purse seiners catching both adults and juveniles in the Norwegian Sea.

4) Industrial fleet catching herring solely as a by-catch in the sprat fishery, vessels being Danish and deploying dominantly small-meshed gears.

These segments 1-4 match to classification A-D used by the Herring Assessment Working Group (HAWG). Segments 1-3 do essentially constitute fleet A, fleet B matches the industrial fleet (4 above), and fleets C and D operate in the Skagerrak and Kattegat harvesting for human consumption or industrial use. The current harvest control rule is limiting fishing mortality of 0-1 ringers to about 50% of F of 2-ringers and older. It is enforced by a by-catch ceiling of the industrial fishery. The catch of the industrial fishery has been about 50% of that allowed for the last 10 years.

The model

We begin by presenting the biological model of the herring fishery. We then describe the economic model, which will then be used in the game-theoretic analysis.

Biological model

Population dynamics of herring are simulated using an age-structured model describing recruitment, mortality, and life history attributes in discrete time. The mature component of the stock first spawn and produces new recruits in the youngest age class. Spawning stock biomass is adjusted to beginning of September when spawning mostly takes place. Beverton-Holt stock-recruitment function is fitted in maximum likelihood using stock and recruitment estimates by ICES (2006a). The deterministic model is:

$$R_y = \frac{\alpha S_{y-1}}{\beta + S_{y-1}}, \tag{3}$$

where *R* is recruitment to the stock and *S* is spawning stock biomass in year y, and α and β are parameters (Table 1).

All parameter values for life history are adopted from the ICES working group report (ICES 2006a).The number of fish of each age class is assumed to be known in 2006 (Table 2), which is the initialization year for the analysis. The age-classes are then subject to natural and fishing mortality *F*, which reduces the number of fish when they grow older. Natural mortality *M* is constant over the years but vary by age. Selectivity *S* of the fishing gear is estimated using the average fishing mortality profile at age during 1996-2005. Herring are partially recruited at ages 0-3 and are assumed fully recruited at ages 4+.

Population biomass at year y is given as the sum of the number of fish over all age classes multiplied by the stock weights as follows:

$$B_y = \sum_{a=0}^{a=9} W_a^S N_{a,y} \,, \qquad (4)$$

where W_a^S is weight at age in the stock (Table 2) and $N_{a,y}$ is number of fish at age a in the beginning of year y. Spawning stock biomass is given by the population abundance at the beginning of the year, total mortality between the beginning of the year and the spawning period, and by the maturation schedule:

$$SSB_y = \sum_{a=0}^{a=9} W_a^{SSB} MO_a N_{a,y} e^{0.67(-(S_a F_y + M_a))} \,, \qquad (5)$$

where W_a^{SSB} is weight at age in the spawning stock, MO_a is maturity at age. It is assumed that age groups 0 and 1 are immature, ages 2 and 3 partially mature, and older component is fully mature (Table 2). Population dynamics is simulated for 20 years period in 2006-2025.

Table 1 around here

Table 2 around here

Economic model

We apply a constant unit price of herring/kg and a linear cost function for exercised fishing mortality. Data of the Norwegian purse seine herring fishery is applied to derive the cost function. That fleet typically accounts for approximately 85% of the Norwegian landings of North Sea herring. The annual variable costs of the Norwegian purse seine fleet targeting on herring (Nøstbakken 2006) were related with fishing mortality rate contrived by the Norwegian fleet annually in 1996-2000. The fishing mortality rate of the Norwegian fleet (F_y^N) in year y was estimated by:

$$F_y^N = F_y \frac{Y_y^N}{Y_y} , \tag{6}$$

where F_y denotes the overall fishing mortality rate, Y_y total catch, and Y_y^N Norwegian catch in year y (ICES 2006a).

The variable costs Q^i of harvesting by country i is defined by:

$$Q^i = \varphi \theta F_y^i , \tag{7}$$

where φ is a scaling term, and θ is a parameter. There may be significant differences in fishing costs among countries. This is due to varying vessel attributes, crew shares, and different distances to fishing grounds. We apply a scaling term, φ, to characterize different fishing costs. The cost per unit of instantaneous fishing mortality is used instead of the conventional usage of the cost of fishing effort because there are no estimates available about effort or catchability for the North Sea herring fishery.

The actual number of vessels in each country is unknown and is excluded from the analysis framework. It is implicitly assumed that vessels are identical with respect to variable fishing costs within a national fleet. The impact of relaxing the assumption of identical costs among countries is tested by scaling the costs by the term φ. It is thus assumed that all economic differences among countries are captured by the cost function differences (Table 3).

Table 3 around here

Norway is designated as country 1, and EU countries harvesting the North Sea herring stock form countries 2 and 3. These countries are United Kingdom, the Netherlands, Denmark, Germany, Sweden, Belgium, and France. Because of lacking data of the national fleet sizes and fishing cost, it is neither necessary nor helpful to assign any particular EU nation as country 2 or country 3.

The catch (harvest) for country *i* is calculated in terms of the fleet specific fishing mortality and natural mortality rate of the stock:

$$C_y^i = \sum_{a=0}^{a=9} W_a^C N_{a,y} \frac{S_a F_y^i}{M_a + S_a F_y^i} (1 - e^{-M_a - S_a F_y^i}), \tag{8}$$

where W_a^C is mean weight in catch at age a.

The total annual harvest is the sum of national harvest:

$$C_y = \sum_{i=1}^{i=3} C_y^i \, , \tag{9}$$

Table 4 around here

Game theory framework

The coalition game under certainty is described by Nash equilibrium solution. The net present values of countries as functions of the control variables, derived from the harvest control rule, are given by:

$$J^i(F, F^\wedge, B_{pa}) = \sum_y \pi_y^i = \sum_y \frac{pC_y^i - Q_y^i}{\rho_y} \quad , \tag{10}$$

s.t. (1-9) and s.t. $F_y \geq 0.1$. Here, p is the unit price per kg, $\rho_y=(1+r)^{y-y_1}$ is the discount rate, $\hat{F}$ is the upper limit of the fishing mortality, and B_{pa} is precautionary spawning stock biomass. According the current harvest control rule coalitions engage in harvesting activities every year, even if it was not profitable for them. Year-to-year change in a TAC is not limited to 15% of the TAC in the previous year.

In the first version of the characteristic function game the decision variable of the players is simply the players' fishing mortality, F_i. The values of the coalitions in the game can be defined as follows

GAME 1

$$v(i) = \max_{F_i} J^i(F_i, F_j, F_k), \quad i = 1, 2, 3, i \neq j, k, \ j \neq k,$$

s.t. (1-9) for singletons

$$v(i, j) = \max_{F_i, F_j} \sum_{s=i,j} J^j(F_i, F_j, F_k), \quad i = 1, 2, 3, i \neq j, k, \ j \neq k,$$

s.t. (1-9) for two-palyer coaltions, and

$$v(M) = \max_{F_1, F_2, F_3} \sum_{i=1}^{3} J^i(F_1, F_2, F_3).$$

s.t. (1-9) for the grand coalition (GM).

In the second version we assume that the grand coalition applies HCR. It this case the revenue of the grand coalition is given as

GAME 2

$$v(M) = \max_{F_1, F_2, F_3, F_1+F_2+F_3 \leq \hat{F}, \hat{F}, B_{pa},} \sum_{i=1}^{3} J^i(F_1, F_2, F_3, \hat{F}, B_{pa}).$$

s.t. (1-9), where $\hat{F}$ is the maximum fishing mortality and B_{pa} is .

In the third game version we assume that even two player coalitions are able to apply HCR. Then, for the two-player coalitions we have,

GAME 3

$$v(i, j) = \max_{F_i, F_j, F_i + F_j \leq \hat{F}, \hat{F}, B_{pa},} \sum_{s=i, j} J^s(F_1, F_2, F_3, \hat{F}, B_{pa}), \quad i = 1, 2, 3, i \neq j, k, \; j \neq k,$$

s.t. (1-9).

where v(i) is the value of a single-player coalition, and v(i,j) is the value of a two-player coalition. The value of grand coalition v(M) contains all cooperatively acting players. The characteristic functions imply singletons optimizing static fishing mortality rate without implementing any harvest control rule based on trigger points. The grand coalition can either apply harvest control rule or adjust only the fishing mortality rate. The same alternatives apply also to partial coalitions. Because costs are assumed to be linear, only the most effective country in a coalition is active.

Influence of HCR on profitability of coalition

The characteristic functions identify that grand coalition is always more profitable than any partial coalition or singletons (Table 5). When grand coalition applies the harvest control rule, it adds about 2% to NPV of profits in 2006-2025 compared to situation when grand coalition optimises only fishing mortality rate (the two bottom rows in the table). Importantly, applying precautionary approach through biomass trigger point and fishing mortality rate ceiling adds NPV, at least when the reference points are optimal. Fisheries stakeholders commonly argue that precautionary approach is an economic disaster for fisheries.

However, it does not pay off for a partial coalition to apply harvest control rule if the outside player does not apply HCR. Compared to situation where the partial coalition does not apply HCR, the losses of that coalition are 82-97 million € (NPV) if the unit costs are identical among countries, or if they are "high". The range of economic losses of the partial coalitions increase if the unit costs of fishing are "low", being 79-167 million € (Table 5). Also the outside player will be negatively impacted if the partial coalition applies HCR.

Table 5 around here

The Shapley value (1953) measures the marginal contributions (averaged sums) of countries to each coalition. It is a single point solution with intuitive interpretations: each player is treated equally, and all benefits are shared among players. The Shapley value measures the sum of dividends that each coalition pays to its members. The most effective country would harvest as a sole owner and give away the rest to the two other players.

$$Z_i = \sum_{K \subset M} \left[v(K) - v(K - \{i\}) \right] \frac{(k-1)!(l-k)!}{l!} , \tag{11}$$

where k denotes the number of elements in coalition K and l is the number of players in the game (Shapley 1953).

The Shapley values give a share of the total cooperative benefits which are equal to 732 million € (Table 6) when grand coalition applies HCR. If fishing costs are identical among countries, each country will receive identical share of the benefits regardless of whether the partial coalitions apply or do not apply HCR. Depending whether HCR is applied or not, the shares change when costs are not identical. However, total benefits deviate only when fishing costs are "low". This is because only the most effective country would harvest as a sole owner and the most effective player is country 1 in both of the cases.

Table 6 around here

Stability of agreements

The core conditions (cooperative stability) are given for all coalitions K as:

$$\sum_{i \in K} Z_i - \upsilon(K) > 0 \tag{12}$$

The core conditions state that each country should be satisfied with their Shapley values (Table 7). The core exists in all the games and the Shapley lies in the core. This means that each coalition receives more than it would gain by harvesting as a singleton. The result holds for all tested fishing costs and applications of harvest control rule by the partial coalition and the grand coalition.

Table 7 around here

The stability conditions (non-cooperative stability) are given as:

$$\upsilon(M) - \sum_{i \in M} \upsilon i > 0 \ , \tag{13}$$

where υi is the free-rider value for country i. The stability conditions state that there should be enough cooperative benefits to be shared in order to make staying in the full cooperative mode optimal. If the sum of free-rider values υi of the countries is smaller than the value of the grand coalition *M* then the grand coalition is stable.

The grand coalition is stable only when "low" fishing costs are assumed, regardless of whether harvest control rule is applied or not (Table 8). This means that only in this case no single country would benefit from free-riding, that is, by leaving the grand coalition. If fishing costs are identical among countries, there will be incentive for free riding and, consequently, multinational fishing agreement is never stable. We can identify one case when application of optimal harvest control rule by a partial and grand coalition will make fishing agreement stable, that is under assumption of "high" fishing costs. Harvest control rule, operationalized through strategic bioeconomic reference points, has thus potential of stabilizing multilateral fishing agreements.

Table 8 around here

Fishing mortality rate trajectories under harvest control rule

The optimal parameter values of the decision variables (F, maxF, SSB_{pa}) are impacted by the fishing costs, coalition structure, and application of harvest control rule versus optimizing a fixed fishing mortality rate (Table 9). Optimization of harvesting strategy under combination of "low" variable fishing costs and application of HCR will lead to very low SSB_{pa} and high maxF for the partial coalition. The precautionary element of the HCR will therefore be vanished, and the trigger point will approach the minimum acceptable biomass, B_{lim} (Fig. 1). In this game, the partial coalition will apply either the minimum of maximum F except in the rare instances when SSB is estimated to between B_{lim} and SSB_{pa}, and F will be scaled accordingly.

Table 9 around here

Figure 1 around here

In this game, the harvests of the partial coalition will fluctuate between rare high yield state while low yields will dominate. This pattern is caused by the trigger points in HCR, which let the coalition to exercise high fishing mortality whenever the stock biomass exceeds SSB_{pa}. The biomass will, consequently, be reduced below B_{lim} during one time step (year), and F of the coalition will stay at the minimum level until "recovery" takes place. The harvests of the outside player will exhibit considerably less variability due to fixed F strategy (Fig. 2).

Figure 2 around here

The optimal bioeconomic HCR is estimated to be reasonably close to the currently applied HCR with respect to maximum allowed fishing mortality rate (Table 10). Biomass trigger point is estimated to considerably higher than the current SSB_{pa}.

Table 10 around here

Discussion/ Conclusions

We analysed what are the international consequences of harvest control rules where the trigger points can be regarded as strategic bioeconomic reference points. Non-cooperative equilibria (Nash) were compared to the partial (subcoalition) and full cooperative (grand coalition) outcomes. The shares that each country will receive were determined by cooperative solution concepts (Shapley value). We solved reaction functions for the countries in a case study to find the optimal fishing mortality rate of a country as a function of fishing mortality rate of other countries harvesting the same fish stock. The results of our study will help to understand the dynamics of international fisheries negotiations. Indicating the key obstacles to stable international arrangements is a key issue in international risk management. In some cases risks may increase cooperation and in some cases decrease it.

The simulations for the North Sea herring stock indicate that using precautionary bioeconomic harvesting strategies may increase stability of international fishery agreements. Stability of agreements depends crucially on costs of harvesting. The grand coalition is always stable only when low fishing costs for two of the players are assumed (Table 8). In this case, it would be beneficial for all countries to cooperate in the grand coalition. If fishing costs are identical among countries, there will be incentive for free riding and multinational fishing agreement is never stable so that at least one of the countries will have incentives not to sign in the agreement or to sign out from the grand coalition. However, HCR has potential of stabilizing multilateral fishing agreements if fishing costs for two of the players are high. In this case, acceptance of the precautionary approach as the baseline of management will induce stability of the grand coalition.

These findings are partly in line with a recent article by Finus et al. (2008) where the stability and success of fisheries coalitions under different levels of asymmetry in fishing costs was analyzed. They conclude that the success of coalition formation is positively correlated with the of the cost asymmetry among fishing states. The explanation suggests that the gains of cooperation increase in concert with the cost asymmetries (Weikart 2005, Finus et al. 2008). These findings are supported by our study. Finus et al. (2008) conclude also that the higher is the overall efficiency of the fishing states, the lower is the probability of success of coalition formation. We did not observe this tendency, most likely because the set up of these two studies are not completely comparable. First, Finus et al. (2008) apply a probabilistic approach while our approach in deterministic. Therefore, the difference in the results concerning the low cost case may be a product by pure chance. Additionally, the production function used (age-structured population model using Ricker stock-recruitment function versus classical Gordon-Schaefer model), and the treatment of fishing costs (multiplier φ versus inverse efficiency parameter b (Masterton 1993)) are obvious differences. The different approaches (coalition game theory versus partition function approach) also may be the cause for deviations in the results.

Whether a harvest control rule is applied or not impacts also profits of the partial and grand coalitions. As predicted by the theory (Pintassilgo 2003), a grand coalition is always more profitable than any partial coalition or singletons. Applying precautionary approach by the grand coalition through HCR adds net present value of the fishery compared to case when fixed F is optimized. The fixed F is inelastic by definition, but the harvest control rule allows for changes in the fishing mortality rate - determined by trigger reference points - according to changes in biomass allowing more elasticity in the harvest rate.

The biological benefits of precautionary threshold strategy have been confirmed earlier (Enberg 2005) but our results support the use them also on economic grounds. This result is significant for two reasons. First, the fixed F strategy has a reputation of performing reasonably well through large fluctuations in life history parameters and equilibrium abundance (Clark 1991). A precautionary threshold strategy now seems to be an useful alternative to a fixed exploitation rate strategy. Secondly, fisheries industry often blames precautionary harvest strategies as causing severe negative economic impact on their business. Our result falsifies that argument and proves that a precautionary approach can be a profitable long term management strategy.

An earlier study (Kaitala et al. 2003), considering a sole owner case, suggests that increase in the threshold value (B_{pa}) in the proportional threshold strategy will increase the variability in the yield. This pattern changes when competition is present. Now, the lower is the threshold, the higher is variability in the catches (Fig. 2).

A partial coalition applying a precautionary harvest control rule will suffer substantial economic loss, ranging 79-169 million € NPV during the simulation period, if the outside player applies a fixed exploitation rate strategy. The losses will be largest when costs are low. Therefore, a partial coalition would be better off by switching to a fixed F strategy as well. Also the outside player will be negatively impacted if the partial coalition applies HCR, but losses are considerably smaller. The total losses of such behaviour ranges between 89-244 million €. In the relative terms profits are 16%-43% lower compared to a case where also the partial coalition applies fixed F strategy.

The constraint on change in a TAC that is no more than 15% greater or 15% less than the TAC of the preceding year, which is included in the current harvest control rule for the North Sea herring, is omitted from the analysis because our primary aim is to evaluate the influence of precautionary (bioeconomic) reference points on stability of fishery agreements. Where both the quota increase and decrease per year are severely limited, the optimum average quota is somewhat reduced. Optimally, the quota should be decreased or increased as rapidly as possible (Walters and Martell 2004). The 15 % constraint is instead closely linked to practical management procedure about how to adjust TAC according to the scientific advice (STECF 2008). However, the constraint of maximum change in the consecutive TACs obviously influence on the optimal bioeconomic reference points. For instance, the pattern in catches of a partial coalition (Fig. 2) would have been impossible.

Many of the biological reference points essentially rely on a reliable stock-recruitment function. For various fish stocks, including the North Sea herring (ICES 2008), derived stock-recruitment scatterplots are uninformative (noisy). We apply deterministic stock-recruitment function which largely drive the stock dynamics in the simulations, especially the recovery of the stock. Currently there are hypotheses put forward about a regime shift in the recruitment, and uncertainty about recruitment process has not been considered in our analysis. In such cases, alternative criteria or information sources may be considered to determine threshold of sustainable harvesting. For instance, spawning per recruit (SPR) analysis has received some attention in establishing thresholds for recruitment overfishing (Sissenwine and Shepherd 1987, Mace and Sissenwine 1993, Caddy and Mahon 1995).

References

Arnason, R., Magnuson, G. and Agnarsson, S. 2001. The Norwegian spring-spawning herring fishery: a stylized game model. Marine Resource Economics, 15: 293-319.

Bjørndal T. (1988), ‘The Optimal Management of North Sea Herring’, Journal of Environmental Economics and Management, 15: 9–29.

Bjørndal, T. and Gordon, D. 1998. Cost functions for the Norwegian spring-spawning fishery. Centre for Fisheries Economics, Discussion Paper No. 10/1998, Bergen.

Bjørndal, T., Kaitala, V., Lindroos, M. and Munro, G. R. 2000. The management of high seas fisheries. Annals of Operations Research, 94: 183–196.

Bjørndal, T. and Lindroos, M. 2004. International management of North Sea herring Environmental & Resource Economics, 29: 83–96.

Brasão, A., Duarte, C. C. and Cunha-E-Sá, M. A. 2000. Managing the Northern Atlantic Bluefin Tuna Fisheries: The Stability of the UN Fish Stock Agreement Solution. Marine Resource Economics, 15: 341–360.

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Canadian Journal of Fisheries and Aquatic Sciences, 48: 734-750.

Enberg K. 2005. Benefits of threshold strategies and age-selective harvesting in a fluctuating fish stock of Norwegian spring spawning herring *Clupea harengus*. Marine Ecology-Progress Series 298: 277-286.

FAO 1995. Code of conduct for responsible fisheries. Food and agriculture organization of the United Nations. Rome, 1995. 41 pp.

FAO 1996. Technical Guidelines for Responsible Fisheries. Precautionary Approach to Capture Fisheries and Species Introductions. No. 2. FAO, Rome. 54 pp.

FAO 1997. Technical Guidelines for Responsible Fisheries. Fisheries Management. No. 4. FAO, Rome. 82 pp.

Finus, M., Pintassilgo, P., Lindroos, M. and Munro, G. 2008. Stability and success of regional fisheries management organizations. Fondazione Eni Enrico Mattei Working Papers, 182. 31 pp. + appendixes. http://www.bepress.com/feem/paper182

Garcia, S.M. and de Leiva Moreno, I. 2003. Global overview of marine fisheries. In: Sinclair, M. and Valdimarsson, G. (*Eds.*). Responsible Fisheries in the Marine Ecosystem. FAO and CABI Publishing, Wallingford. pp. 1-24.

Hay, D.E. et al. 2001. Taking stock: an inventory and review of world herring stocks in 2000. In: Funk, F., Blackburn, J., Hay, D., Paul, A.J., Stephenson, R., Toresen, R. and Witherell., D. (*Eds*.). Herring: Expectations for a New Millennium University of Alaska Sea Grant, AK–SG–01–04. pp. 381–454.

Hilborn, R. and Walters, C.J. 1992. Quantitative fisheries stock assessment. Choice, dynamics & uncertainty. Chapman & Hall, New York. 570 pp.

Hildén, M. 1997. Risk, uncertainty, indeterminacy and ignorance in fisheries management – an analysis of management advice. Monographs of the Boreal Env. Res. 5. 61 pp.

ICES. 1997. Report of the Study Group on the Precautionary Approach to Fisheries Management. ICES CM 1997/Assess: 7, 41 pp.

ICES 2001. Report of the Study Group on the Further Development of the Precautionary Approach to Fishery Management. ICES CM 2001/ACFM: 11, 48pp.

ICES Advice 2006. Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2006. Book 6, North Sea. 314 pp.

ICES 2006a. Report of the Herring Assessment Working Group South of 62º N (HAWG). ICES CM 2006/ACFM:20. 647 pp.

ICES 2006b. Report of the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy (WGMHSA). ICES CM 2006/ACFM:36. 601 pp.

Kaitala, V., Jonzén, N. and Enberg, K. 2003. Harvesting Strategies in a Fish Stock Dominated by Low-frequency Variability: The Norwegian Spring-spawning Herring (*Clupea harengus*). Marine Resource Economics, 18: 263–274.

Kaitala, V. and Munro, G.R. 1997. The conservation and management of high seas fishery resources under the new law of the sea. Natural Resource Modeling, 10: 87–108.

Lindroos, M. 2004. Sharing the benefits of cooperation in the Norwegian spring-spawning herring fishery. International Game Theory Review, 6: 35-53.

Lindroos, M. and Kaitala, V. 2000. Nash equilibria in a coalition game of the Norwegian spring-spawning herring fishery. Marine Resource Economics, 15: 321–339.

Maguire, J.-J. and Mace, P. 1993. Biological reference points for Canadian Atlantic gadoid stocks. In: Smith. S.J., Hunt, J.J. and Rivard, D. (*Eds*.). Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120. pp. 321-331.

Murphy, G.I. 1977. Clupeids. In: Gulland, J. Fish population dynamics (*Ed*.). Wiley-Interscience, New York. pp. 283-308.

Nøstbakken, L. 2006. Cost structure and capacity in the Norwegian pelagic fisheries. Applied Economics, 38: 1877-1887.

Nøstbakken, L. and Bjørndal, T. 2003. Supply functions for North Sea herring. Marine Resource Economics, 18: 345-361.

Patterson, K. R., Skagen, D., Pastoors, M., and Lassen, H. 1997. Harvest Control Rules for North Sea herring. Working Document for the ICES ACFM November Meeting 1997.

Pintassilgo, P. 2003. A coalition approach to the management of high seas fisheries in the presence of externalities. Natural Resource Modeling, 16: 175-197.

Saville, A. (*Ed.*) 1980. The assessment and management of pelagic fish stocks. Cons. Int. Expl. Mer, Rapp. et Proc.-Verb. des Reunions 177.

Shapley, K. 1953. A value for *n*-person games. In *The Shapley Value - Essays in Honor of Lloyd S. Shapley*, Ed. A. Roth. Cambridge University Press, Cambridge. pp. 31-40.

Simmonds, E. J. 2007. Comparison of two periods of North Sea herring stock management: success, failure, and monetary value. – ICES Journal of Marine Science, 64: 686–692.

STECF 2008. Harvest Control Rules (SGRST-08-02). Commission of the European Communities. 104 pp.

United Nations Convention of the Law of the Sea of 10 December 1982, UN Doc. A/Conf. 61/122, 1982.

United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks. Agreement for the implementation of the provisions of the United Nations Convention of the Law of the Sea of 10 December 1982 relating the conservation and management of straddling fish stocks and highly migratory fish stocks, Sixth session, New York, 24 July–4 August, 1995. United Nations, A/CONF. 164/37, 8 September 1995.

Walters, C. and Maguire, J.J. 1996. Lessons for stock assessment from the northern cod collapse. Rev. Fish Biol. Fish. 6: 125-137.

Walters, C. J. and Martell, J. D. 2004. Fisheries Ecology and Management. Princeton University Press, Princeton. 399 pp. ISBN 0-691-11545-1.

Weikart, H.-P. 2005. Cartel Stability under Optimal Sharing Rule. Fondazione Eni Enrico Mattei, Italy. Working Paper 77.

Tables

Table 1. Parameters for stock recruitment function.

Parameter	Value	Unit
α	60.89	Numbers 10^9
β	0.456	Million tonnes

Table 2. Age dependent parameter values. Parameters by ICES (2006). MO as input for short term predictions, weight at age in the spawning stock as in the 3rd quarter reflecting weight just prior to the spawning period. All weights at age are averages in 2001-2005.

Age	M_a	MO_a	S	W_s^{SSB}	W_a^S	W_a^C	N_{2006}
0	1.0	0	0.11	-	0.006	0.013	26.98
1	1.0	0	0.25	-	0.043	0.040	7.57
2	0.3	0.73	0.53	0.129	0.123	0.107	2.57
3	0.2	0.95	0.83	0.170	0.166	0.149	1.37
4	0.1	1	1	0.200	0.200	0.173	1.49
5	0.1	1	1	0.223	0.226	0.198	2.77
6	0.1	1	1	0.242	0.247	0.214	0.82
7	0.1	1	1	0.258	0.265	0.231	0.93
8	0.1	1	1	0.278	0.283	0.251	0.26
9	0.1	1	1	0.290	0.281	0.264	0.21
Unit	Instantaneous rate	Percentage	Percentage	kg	kg	kg	Numbers 10^9
Source in ICES (2006)	Table 2.7.1	Table 2.7.1	Estimated from Table 2.6.12.2	Table 2.4.1.1	Table 2.6.12.2	Table 2.6.12.2	Table 2.7.1

Table 3. Interpretation of identical, high, and low unit costs in terms of the scaling term φ.

	Cost type		
country	identical	high	low
1	1	1	1
2	1	1.1	0.9
3	1	1.3	0.7

Table 4. Harvesting and economic parameters.

Parameter	Value	Unit
θ	116.1	M €
φ	0.7, 0.9, 1, 1.1, or 1.3	multiplier
r	0.05	percent
p (price)	0.184	€ / kg

Table 5. Profit by country or coalition (NPV in € 10^6) for three simulated unit cost cases. Partial coalitions and the grand coalition may or may not adopt harvest control rule.

		Partial coalition does not apply HCR			Partial coalition applies HCR		
		unit costs			unit costs		
		identical	high	Low	identical	high	low
Country/coalition	1	142	211	84	142	211	84
	2	142	153	144	142	153	144
	3	142	72	265	142	72	265
	12	285	360	254	187	278	176
	13	285	313	313	187	218	169
	23	285	254	422	187	169	256
Grand coalition applies HCR	123	732	732	850	732	732	850
Grand coalition does not apply HCR	123	714	714	834	714	714	834

Table 6. Shapley values by country (NPV in € 10^6) for three simulated unit cost cases. Grand coalition applies harvest control rule but partial coalitions may (right hand side of the table) or may not (left hand side of the table) apply HCR.

		Partial coalition does not apply HCR			Partial coalition applies HCR		
Z		unit costs			unit costs		
		identical	high	low	identical	high	low
Country	1	244	304	197	244	303	215
	2	244	246	281	244	250	289
	3	244	182	371	244	179	346
	v(M)	732	732	850	732	732	850

Table 7. The core conditions: stability of the core as cooperative stability concept.

	Partial coalition does not apply HCR			Partial coalition applies HCR		
	Unit costs			Unit costs		
	identical	high	low	identical	high	low
Grand coalition applies HCR	yes	yes	yes	yes	yes	yes
Grand coalition does not apply HCR	yes	yes	yes	yes	yes	yes

Table 8. Non-cooperative stability of the coalition.

	Partial coalition does not apply HCR			Partial coalition applies HCR		
	Unit costs			Unit costs		
	identical	high	low	identical	high	low
Grand coalition applies HCR	no	no	yes	no	**yes**	yes
Grand coalition does not apply HCR	no	no	yes	no	no	yes

Table 9. Optimal fixed fishing mortality rate (F) for singletons and optimal harvest control rule reference points, maxF and SSB_{pa}, in the "low" cost game. Partial coalitions apply HCR. Reference points maxF and SSB_{pa} are abbraviated here as F_m and B_{pa}, the units being instantaneous rate and million tonnes, respectively.

Coalition structure/ coalition								Range in actual F_y
	{1,2,3}	{1}	{2}	{3}	{1,2}	{1,3}	{2,3}	
Grand coalition	0.31							0.31
{1},{2},{3}		0.13	0.18	0.24				0.55
{1},{2,3}		0.34					B_{pa} 0.95 F_m 1.03	0.44-1.37
{2},{1,3}			0.45			B_{pa} 0.81 F_m 0.97		0.55-1.42
{3],{1,2}				0.47	B_{pa} 0.81 F_m 0.94			0.57-1.41

Table 10. Harvesting and economic parameters.

	Fishing costs			Current HCR
Reference point	identical	high	low	
maxF	0.27	0.27	0.31	0.25
SSB_{pa}	2.23	2.23	1.94	1.30

Figures

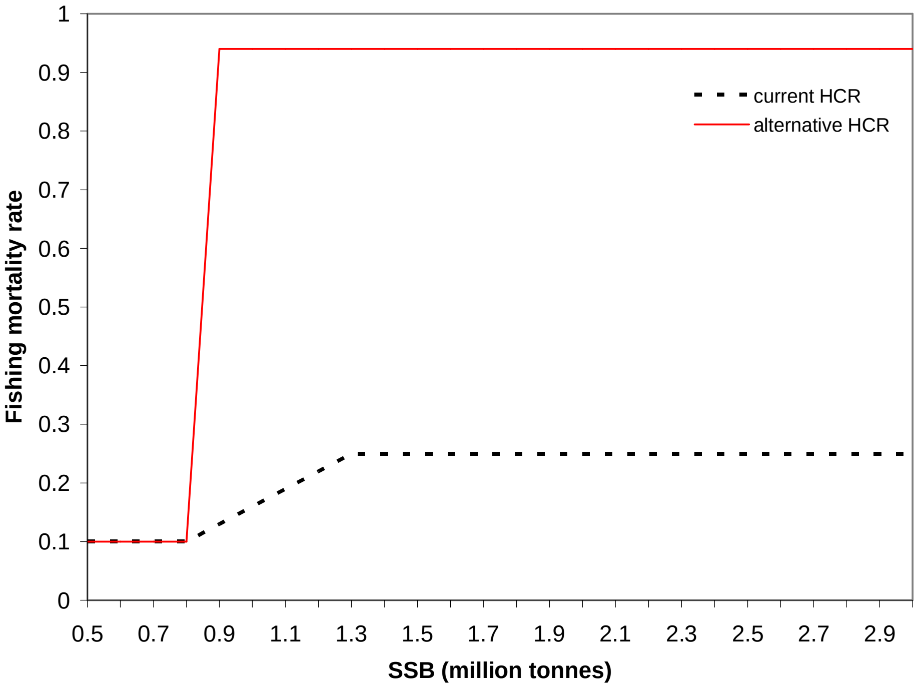

Fig. 1. The current harvest control rule (dashes line) and that of {1,3} with assumption of low variable costs. The coalition applies optimal HRC ($\hat{F}$ 0.97, Bpa 0.81 million tonnes).

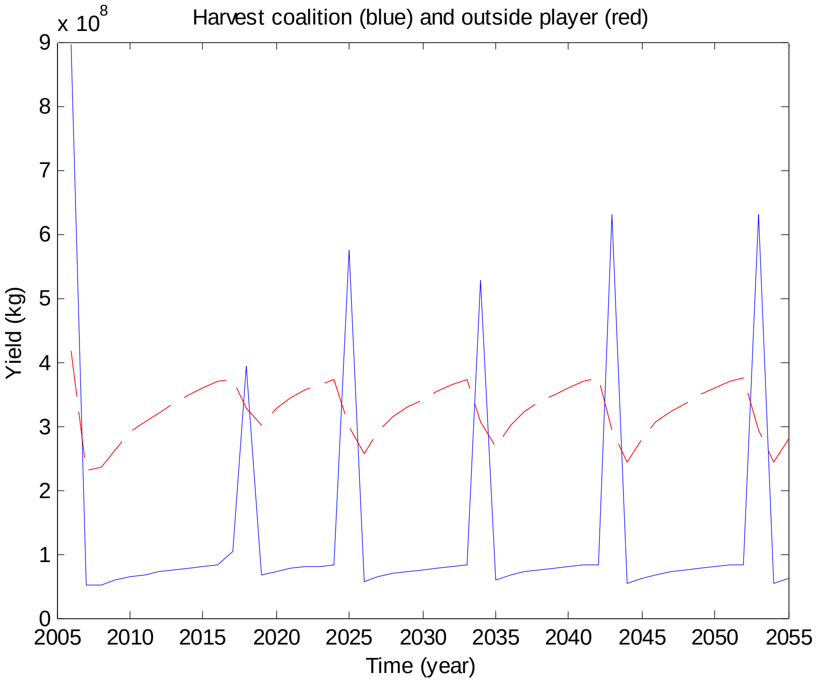

Figure 2. Harvest of {1,3}{2} with assumption of low variable fishing costs. Coalition (solid line) applies optimal HRC ($\hat{F}$ 0.97, B_{pa} 0.81 million tonnes) and the outside player (dashed line) uses optimal fixed F (F 0.45). Note that time frame is extended to 2055 for illustrative purpose.

UNIVERSITY OF HELSINKI

Discussion Papers:

No.

13. Chen Quizhen & John Sumelius (2006). Comparative Study on Chinese and Finnish Experts' Opinion of Multifunctional Agriculture. Agricultural Economics.
14. Hervé Guyomard, Jussi Lankoski & Markku Ollikainen (2006). Impacts of Agri-environmental Policies on Land Allocation and Land Prices. Environmental Economics.
15. Kyösti Arovuori & Jukka Kola (2006). Farmers' choice on multifunctionality targeted policy measures. Agricultural Economics.
16. Seppo Vehkamäki & Stefan Bäckman (2006).Evaluation of economic activities and poverty in the region close to the National Park of Río Abiseo in Peru.
17. Jussi Lankoski & Markku Ollikainen (2006). Bioenergy crop production and climate policies: A von Thunen model and case of reed canary grass in Finland. Environmental Economics.
18. Heini Ahtiainen (2007). The willingness to pay for reducing the harm from future oil spills in the Gulf of Finland – an application of the contingent valuation method. Environmental Economics
19. Andrea Cattaneo, Jussi Lankoski & Markku Ollikainen (2007). Green auctions with joint environmental benefits. Environmental Economics.
20. Chen Qiuzhen, Kyösti Arovuori & John Sumelius (2007). Evolution and Implementation of Multifunctionality-Related Policies in China and Finland. Agricultural Economics.
21. Antti Iho & Jaakko Heikkilä (2008). Has selling tickets in advance increased attendance in the Finnish football league? Environmental Economics.
22. Soile Kulmala, Polina Levontin, Marko Lindroos, Catherine Michielsens, Tapani Pakarinen & Sakari Kuikka (2008). International Management of the Atlantic Salmon Fishery in the Baltic Sea. Environmental Economics.
23. Stefan Hellstrand, John Sumelius & Stefan Bäckman (2008). Ekonomiska och miljöeffekter för olika åtgärder att begränsa Östersjöns övergödning - kan den gröna marknadskraften bidra? Agricultural Economics
24. Anna-Kaisa Kosenius (2008). Heterogeneous Preferences for Water Quality Attributes: the case of Eutrophication of the Gulf of Finland, Baltic Sea. Environmental Economics.
25. Antti Iho (2008). Spatially Optimal Steady State Phosphorus Policies in Crop Production. Environmental Economics.
26. Leena Lankoski (2008). Multiobjective firms and the management of trade-offs. Food Economics.

ISSN 1459-9996
Helsinki 2008