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Abstract

This paper studies the distributional effects of the implementation of a marine protected area (MPA) for the North-East Atlantic cod stock. A bioeconomic cohort model with two agents targeting different age groups is used to examine how the establishment of an MPA may affect the payoffs to the two main vessel types used to exploit cod, namely, trawlers and coastal vessels. Cooperative and non-cooperative behaviour between the management of the two vessel groups are used to describe the existence or non-existence of efficient management in the fishable area. The model includes a shock in the form of a recruitment failure. A key result that emerges from this contribution is that depending on the *ex ante* status quo and *ex post* management, we may observe win-win, lose-lose or win-lose situations as a result of an MPA implementation. For instance, when the *ex post* management is cooperation, both agents in our model gain, while *ex post* non-cooperative behaviour results in gains only to the coastal fleet with the implementation of MPAs. The study also shows that even without cooperation outside the MPA, both groups would prefer a 50% reserve to the non cooperative outcome in the absence of an MPA. This is an indication that a reserve may well be preferred to a badly managed non-reserve fishery even when management outside the reserve is non-existent.

Introduction

This paper studies the distributional effects of implementing marine protected areas (MPA) in a fishery, namely, the North-East Atlantic cod fishery in the Barents Sea. Recent work on MPAs has focussed on the biological and economic efficiency of implementing this form of management (see for instance, Polacheck, 1990, and Sanchirico and Wilen 1999). However, when MPAs are introduced in areas where there exists extensive and varied use of the marine resources, then clearly this management measure may have distributional effects, which could cause resistance to its implementation. Bohnsack (1993) argues that marine reserves reduce conflict between user groups, via physical separation of fishery and non-fishery interests. We show that implementation of marine reserves may cause conflict *within* diverse fishery interests. In the biological enthusiasm and perhaps more critical economic focus upon MPAs, issues regarding distributional effects have been afforded little attention. Holland (2000) shows some distributional effects due to dislocation. We demonstrate that even without actually forcing some agents to move their activity, the age structure of a stock and the selectivity patterns of the harvest when combined with an MPA may result in distributionally skewed effects.

Studies have shown that under certain conditions less harvest of fish is obtained with the implementation of MPAs (for example, Hannesson, 1998). Other work has also indicated that harvest may in fact increase compared to a no-MPA scenario in a patchy system (Sanchirico and Wilen, 2001) or if the marine ecosystem is likely to face a sudden shock due to true uncertainty (Clark, 1996 and Sumaila 1998). However, it is not inconceivable that there may exist some winning and/or losing groups of fishers with the implementation of MPAs, something we show to be the case. Furthermore, we show that some management systems combined with MPAs may ensure that the more efficient vessels gain increased access to harvesting, resulting in an increase in the total benefits from the resource. In the case of fisheries with complex agent and stock interactions (as we will present here), the implementation of an MPA may have *implicit* distributional effects where, for instance, a quota management system is more *explicit*.

In this paper, we abstract from physical location, and focus upon how the size of an MPA may affect different vessel groups through their gear selectivity patterns . In the case of increases in harvests resulting from the implementation of an MPA, these may not be distributed in an acceptably equitable fashion amongst the agents in a fishery. In a situation where an MPA results in a loss in total benefits, we may nonetheless find some groups enjoying increases in their own private benefits. In some cases there may be clear winners and losers, or just big and small winners (or losers). In many cases, the different agents in the fishery will be aware of how they may be affected by the implementation of a marine reserve, resulting in substantial lobbying against such a management regime. In other cases the resulting effects may be more uncertain, and the inequity of the regime may not appear prior to the regime being instituted. The costs and political tensions in both situations are apparent.

This paper undertakes a case study of a single species fishery, namely, the North-East Atlantic cod fishery. This fishery involves mainly two different fisher groups, trawler and coastal vessel fishers. We study a non-cooperative and a cooperative solution to the harvesting of the cod stock. Several studies of MPAs have discussed the issue of what management regime should exist outside the MPA, and the importance of this to the expected outcome (see for instance, Hannesson, 1998, Holland and Brazee, 1996). The presence of open access or un-managed common property outside the boundaries of the MPA will naturally not maximise the economic rents. As an illustration of a non-managed fishery, we use the non-cooperative case[1], while the cooperative case illustrates a managed fishery. Furthermore, a shock to the biological system is included in the model. Sumaila (1998) illustrates how an MPA can function as a hedge against shocks or natural fluctuations in a stock. We present the shock as a deterministic recruitment failure over a ten-year period, which may introduce different distributional effects for vessels targeting different age groups within a stock.[2]

Key results from our analysis include, (i) depending on the *ex ante* status quo and *ex post* management, we may observe win-win, lose-lose or win-lose situations with the implementation of an MPA, (ii) the two vessel groups may not prefer the same MPA sizes.

In the next section, the North-East Atlantic cod fishery is presented, followed by the model and data used in the analysis, and the results obtained. A sensitivity analysis is applied to ascertain the robustness of the results with respect to key biological and economic parameters of the model. The paper concludes with a discussion of the results.

The North-East Atlantic cod fishery

The North-East Atlantic cod fishery has a long history of boom and bust. Though never as dramatic as for pelagic fisheries, the variation in the cod stock size has over the last 50 years been substantial; from 4,000,000 to 300,000 tonnes (Anon, 2000). Regulation of the trawler fleet has been in place since the early 70s, while the coastal vessel fleet has only been effectively managed since the late 80s. Nonetheless, we still see large stock variation. The last serious decline was in 1989, when the fishery was reduced to less than 20 % of its highest levels. And again, the last few years have seen serious declines in both the stock and the biologists' recommended harvest levels. Hence despite TACs and harvests not substantially over the biologists recommendations, the cod stock still seems to vary to a certain degree (Anon, 2000). The reasons given for this variation have been illegal fishing and by-catch, cannibalism and predation, as well as atrophic changes in the environment. In this scenario of uncertainty, MPAs are a natural suggestion for remedy[3].

The North-East Atlantic cod stock is a highly migratory fish stock, spending periods of its' life cycle in Norwegian, Russian and international waters. The cod is harvested by both Russia and Norway as well as a group of other nations mostly allotted quotas by these two countries. Harvesting is carried out using a wide variety of different vessel types and gears. It is however not uncommon to divide these vessels into two distinct groups, namely trawlers and coastal vessels, which is the vessel group division we apply in this study. The trawler vessel group is a relatively homogeneous entity, while the coastal vessel group consists of a large diversity of vessel sizes and gear types. The two vessel groups harvest upon different age groups within the cod stock, as a large part of the trawler harvest is concentrated on the younger cod, while the coastal vessel harvests mainly consist of mature cod (Armstrong, 1999). This is both due to gear selectivity and the migration pattern of the cod stock, as the young grow up in the open sea, migrating in to the coast to spawn. The difference in catch configuration as well as different degrees of freshness and processing onboard, leads to markedly different prices obtained by the two vessel groups.

The model

Biological aspects

Allow recruitment of age 0 fish to the whole habitat in period t *(t=1..T)*, R_t, be represented by the following Beverton-Holt recruitment function.[4]

$$(1) \quad R_t(B_{t-1}) = \frac{\alpha B_{t-1}}{1+\gamma B_{t-1}}$$

where $B_{t-1} = \sum_{a=1}^{A} p_a w_{s,a} n_{a,t-1}$ represents the post-catch spawning biomass of fish; p_a is the proportion of mature fish of age a $(a=1..A)$; $w_{s,a}$ is the weight at spawning of fish of age a; $n_{a,t-1}$ is the post-catch number of age a fish in period t-1; and α and γ are constant biological parameters. The α and γ values determine the recruitment for a given spawning biomass, which again determines the pristine stock level.

Initially it is assumed that the stock and recruits are homogeneously distributed, and randomly dispersed at a constant density. The fish population is split into two distinct components, i = 1,2 where 1 and 2 denote the protected and unprotected areas, respectively. There is net movement from the protected to the unprotected area, due to fish density being high relative to the carrying capacity in the protected section of the habitat (see the Basin model, MacCall, 1990). This movement is captured by the *net migration rate* ψ, which, assumed to be constant here, tells us the net proportion of a given age group of fish that is transferred from the protected to the unprotected area in a given fishing period.

The division of the habitat is done by first; dividing the initial stock size between the protected and unprotected areas in proportion to these areas' respective sizes. Hence, an MPA consisting of 30% of the habitat, results in a split of the initial stock size into a 3:7 ratio in favour of the unprotected area. Secondly, it is assumed that recruitment takes place separately in the two areas defined as in equation 1 above, each area with its own B_{t-1}^{i} and γ^{i}, i=1,2. The α parameter, being an intrinsic element of the stock under consideration, is kept equal for fish both in the reserve and in the fished area. Finally, the respective γ parameters are set such that (i) the sum of recruitment from both areas satisfies

(2)

$$R_t^1 + R_t^2 = R_t \quad \text{for} \quad B_{t-1}^1 + B_{t-1}^2 = B_{t-1}$$

and (ii) the recruitment into the protected and unprotected areas are directly related to the quantity of the total biomass in them. These conditions are enforced by giving γ^{i} values from 1 to 10 depending on the MPA size, with a value of 1 depicting a large MPA and a value of 10 depicting small MPA.[5]

For the protected area, the stock dynamics in numbers, $n_{a,t}^{1}$, is described by

(3)

$$n_{0,t}^1 = R_t^1,$$

$$n_{a,t}^1 + \psi n_{a,t}^1 = sn_{a-1,t-1}^1, \qquad \text{for } 0 < a < A,$$

$$n_{A,t}^1 + \psi n_{A,t}^1 = s\left(n_{A-1,t-1}^1 + n_{A,t-1}^1\right), \quad n_{a,0}^1 \quad \textit{given.}$$

where the parameter *s* is the age independent natural survival probability of cod; $\psi n_{a,t}^1$ is the net migration of age *a* (where A is the last age group) cod from the protected to the unprotected area in period *t*, and ψ is the net migration rate; $n_{a,0}^1$ denotes the initial number of age *a* cod in the protected area. Recollect that there is no harvesting in the protected area.

The stock dynamics in the unprotected area are expressed as

(4)

$$n_{0,t}^2 = R_t^2,$$

$$n_{a,t}^2 + h_{a,t} = sn_{a-1,t-1}^2 + \psi n_{a,t}^1, \qquad \text{for } 0 < a < A,$$

$$n_{A,t}^2 + h_{A,t} = s\left(n_{A-1,t-1}^2 + n_{A,t-1}^2\right) + \psi n_{A,t}^1, \quad n_{a,0}^2 \quad \textit{given.}$$

where $\mathrm{h}_{\mathrm{a,t}}$ is the total harvest function.

The total harvest is defined in the traditional way as

$$h_{a,t} = q_a n_{a,t}^2 e_t$$

where q_a is the age dependent catchability coefficient, e_t, is the effort employed in the harvesting of cod in period t.

One of the central justifications for implementing MPAs is hedging against uncertainty (see Clark 1996). In order to illustrate the effect of uncertainty upon the distributional effects of an MPA, we introduce a sudden shock in the natural system (see Sumaila, 1998) by incorporating a recruitment failure (zero recruitment) that occurs in each of the years 5 to 15 of the 28 year-time horizon model. It is important to note that the shock is assumed to occur only in the fished area, an assumption which follows Lauck et al. (1998), where it is assumed that true uncertainty occurs due to human intervention in the natural environment, leading to over-fishing and habitat degradation. Sensitivity analysis is performed to study the effects to the system of differing shocks and migration rates.

Economic aspects

A dynamic game theoretic model is applied to describe the cooperative and non-cooperative management of the Northeast Atlantic cod fishery in which there are two participants, namely, the coastal vessel group (*cf*) and the trawler gear group (*tf*). These are the two main vessel types used to harvest cod (see Armstrong and Sumaila, 2000). The single period profit from harvesting fish, $\Pi_m(.)$, is defined as

(5)

$$\Pi_m(n^2, e) = v\sum_{a=0}^{A} w_a q_a n_{a,t}^2 e_t - \frac{k}{1+b}(e_t)^{1+b}$$

where m= cf, tf (cf stands for coastal fleet, and tf is the trawler fleet)[6]. The variable e_t (t = 1,2,..,T=28) denotes the profile of effort levels employed by the particular player; n^2 is the age and time dependent stock size matrix in the fished area; v is the price per unit weight of cod; w_a is the average weight of age a cod; k is a cost parameter, and $b>0$ is a parameter introduced to ensure strict concavity in the model, which is required to ensure convergence (see Flåm, 1993, and Sumaila, 1997).

We assume that under cooperation, the objective of the participants in the fishery is to find a sequence of total effort levels, e_t (t = 1,2,..,T=28) that maximizes their weighted joint discounted market value, that is, the discounted economic rent from the resource for given MPA sizes, as a function of the net migration rate. Thus, using the effort level as the control variable, the vessel groups jointly maximize their present value of profit, *Prof*

(6)

$$\mathrm{Pr}\,of = \sum_{t=1}^{T} \delta^t (\beta \prod_{cf} + (1-\beta) \prod_{tf})$$

where $\delta = (1+r)^{-1}$ is the discount factor, β is the weighting of the preferences of the coastal fleet and (1-β) is that of the trawler vessels with respect to the use of the fish (see Munro, 1979), and r denotes the interest rate. Hence β=1 describes management preferred by the coastal vessels winning the day, while the trawler preferences are not taken into account, and vice versa with β=0. The optimization is carried out for different sizes of the MPA, subject to equation (2), (3) and (4), and the obvious nonnegativity constraints, giving a resulting optimal β value as well as reserve size. It should be noted that cooperative solutions can be with side payments in which a player can be bought out of the fishery if such an action will lead to an increase in the overall payoff, and those without side payments, where it is not allowed to buy out a player. Most of the results presented in this paper are for a cooperative solution with side payments because this produces the *optimum optimorum* (Munro, 1979).

Similarly, under non-cooperation we assume each agent wishes to maximize own profits, that is Π_{cf} and Π_{tf}, respectively, for the coastal and trawler fleets. The non-cooperating agents must therefore choose their own effort levels in each fishing period in order to maximize own discounted profit, given that the other agent does the same. This is done without regard to the consequences of their own actions on the other agent's payoff. For the coastal fleet this translates into choosing own effort level to maximize

(7)

$$\Pr of_{cf} = \sum_{t=1}^{T} \delta_{cf}^{t} \Pi_{cf,t}$$

We resort to a computational procedure to solve the model because it is generally difficult to solve a multicohort model such as the current one analytically (see Conrad and Clark 1987).

The solution procedure (algorithm) is based on non-smooth convex optimisation, in particular, subgradient projection and proximal-point procedures (see Flåm, 1993). These class of algorithms are intuitive because they are of a "behaviouristic" type; they model out-of-equilibrium behaviour as a gradient system driven by quite natural incentives. It should be noted that the solutions we compute in this paper do not subscribe fully to the customary open loop solution concept derived from control theory. Unlike here where agents impact on their rivals' stock indirectly through their choice of effort level, in the customary open loop solutions, agents are expected to directly control their rival's stock once the rival has committed to a given profile of actions.

The data

Model data is mostly taken from Sumaila (1997, 2002). The parameters α and γ are set equal to 3 and 1 per billion kilograms, respectively, to give a billion age zero fish (assuming negligible weight at age zero) when the spawning biomass is half a million tons.[7] Based on the survival rate of cod, s is given a value of 0.81 for all a. The price, v= NOK[8] 6.78 and 7.46 per kilogram of cod landed by trawlers and coastal vessels, respectively. The cost parameter k_m, which denotes the cost of engaging a fleet of vessels (10 and 150, respectively for tf and cf) for one year, is calculated to be NOK 210 and 230 million, respectively, and b is set equal to 0.01. The discount factor is given a value of 0.935 to reflect the current low level of real interest rates. The initial number of cod of age groups 1 to 8 are obtained by taking the average of the initial numbers from 1984 to 1991 reported in Table 3.12 of the ICES (1992). For the other age groups, we assume the same number as for age group 8. This gives (460,337,298,223,117,61,33,9,9,9,9,9,9,9,9) for $a=1..15$. This gives an estimated initial stock size of 2.24 million tons, which is close to the reported biomass of cod in the beginning of the 90s (Anon, 2000). The parameter p_a=0 for $a<7$ and 1 otherwise; $q_{a,tf}$=0 for $a<5$ and 0.074 otherwise, and $q_{a,cf}$=0 for $a<7$ and 0.0593 otherwise, w_a =

(0.1, 0.3, 0.6, 1.0, 1.4, 1.83, 2.26, 3.27, 4.27, 5.78, 7.96, 9.79, 11.53, 13.84, 15.24, 16.34) for *a=0..15;* and weight at spawning w_{sa} is assumed to be 90% of w_a (see Sumaila, 1995).

The Results

An overview of the results of the analysis relating to stock size and the distribution of profit to the two vessel groups for the different scenarios is presented in Table 1. Table 2 illustrates the different distributional effects that may result from the implementation of an optimal MPA, depending on the management regime originally in place and the management regime applied to the now reduced fishable area. The results show that win-win, win-lose and lose-lose outcomes may emerge depending on whether there exists cooperation or not.

Table 1 and Table 2 about here

Economic results

From Table 2, we observe that for cooperation in the *ex post* management, an MPA results in both vessel groups receiving more discounted profits. As in Sumaila (1998) the total profit increases when an MPA is established in the presence of a shock, but what is new is that this study also shows that all agents involved gain from the MPA. This is however not necessarily the case when the *ex post* management is non-cooperative. In this case, only the coastal vessels gain from the introduction of an MPA, and this only when the *ex ante* management is also non-cooperative.

Furthermore, both vessel groups lose when an MPA is introduced, if the *ex post* management is non-cooperative, while the *ex ante* management was cooperative. On the quantitative side, we observe that the coastal vessel group enjoys the highest gain, both under cooperation and non-cooperation.

What payoffs accrue to the vessel groups for every management choice made by the managers, and which management choice is preferred by each vessel group given that an MPA is going to be implemented? To explore these questions, we develop Figures 1 and 2, which portray the discounted profits of the two vessel groups for a spectre of MPA sizes. As we see from the two figures, cooperation outside the MPA results in a higher optimal MPA size than when there is non-cooperation. In the cooperative case both vessel groups prefer an MPA size of 70%. In the non-cooperative case the trawlers prefer an MPA size of 50%, while the coastal vessels prefer 80%.

The stock size when management is both *ex ante* and *ex post* non-cooperative is more than 50% larger under an MPA regime, than when an MPA is absent (see Table 1). This is partly because fish within the MPA are assumed to be fully protected from fishing, hence, the negative conservation effect of non-cooperative behaviour is avoided in the portion of the habitat which is protected. In the case of *ex ante* and *ex post* cooperative management, the implementation of an MPA leads to a 40% increase in the stock. Here, the key reason for the higher standing biomass is the fact that the ecological shock to the system is assumed to occur only in the fished area. This also accounts for some of the conservation games we see under non-cooperation. It is worth noting that a large enough MPA combined with non-cooperative management gives a higher stock size than a purely cooperative management without an MPA.

Figure 1-2 about here

Effort levels

The total average effort employed when an MPA is implemented is lower regardless of management choice (see Table 3). Furthermore, the effort taken out to fish in the cooperative case is lower than the non-cooperative case. However, the effort level used when there is cooperation *without* an MPA, exceeds the effort used when there is non-cooperation combined with an MPA. This is because most of the fish are assumed to be well protected within the MPA. Note also that in the cooperative case it is optimal to have no trawl effort, that is, it is optimal to buy out the trawlers.

Table 3 about here

Sensitivity analysis

A sensitivity analysis is carried out with regards to the degree of the recruitment failure, the discount rate, and the rate of migration. We see from Table 4 that relatively large changes in these parameters do not affect the optimal MPA sizes, except when the degree of shock is reduced. In this case, however, only the non-cooperative MPA size is changed, and then only reduced from 60% to 50%. The sensitivity analysis shows that effects upon the average stock biomass are also limited. It is only when the discount factor increases that the magnitudes of the discounted profits change significantly. When comparing discounted profits for different *ex ante* and *ex post* management, we do however observe some differences compared to the results reported in the base case (see Table 1). When studying the case of increased discount factor, we observe that for *ex ante* and *ex post* non-cooperation, the preferences of the two vessel groups are different when compared to the base case. Here, the coastal group loses out, while the trawlers gain. Furthermore, both groups now lose out in the case of *ex ante* and *ex post* cooperative management. This latter result also occurs when migration is reduced. In the case of a milder recruitment failure, we observe new tendencies when the *ex ante* and *ex post* management regimes differ; the trawlers now lose out, while the coastal group gains. These results indicate that depending on what the real world actually looks like, different winners and losers will emerge with the implementation of MPAs.

Table 4 about here

Discussion

The results in this paper show that the implementation of MPAs may give varying distributional effects, depending on the management regime in place before and after the MPA is implemented. In a situation with a shock to the system, and cooperative interaction between the agents after the implementation of an MPA, we see *both* vessel groups gaining from the change. However, if an MPA is introduced in combination with non-cooperation, this may not ensure gains to all agents involved. The results show further that the advantageous character of MPAs (in economic terms) in the presence of shocks or true uncertainty may be diminished when the management outside the MPA is non-cooperative. Yet, there may be overall gains (see the move from non-cooperation *without* an MPA to non-cooperation *with* an MPA in Table 2), while still leaving one agent worse off.

The impact of MPAs on the average biomass is significant. This is especially so in the case of non-cooperation, where the biomass is increased by more than 50% when an (optimal) MPA consisting of 60% of the total habitat is introduced. The reason for this is that in the non-cooperative situation without an MPA, the stock is heavily fished down. Hence, even a small MPA increases the biological wellbeing of the stock substantially. In light of the discussion around open access and MPAs (Hannesson, 1998), it is worth noting that an MPA with non-cooperative management gives a substantially higher stock size than purely cooperative management without an MPA. Hence, despite sub optimal management outside the marine reserve, the protection of the stock is higher than under optimal management without a reserve. This illustrates the biological attractiveness of MPAs.

In the presence of shocks, we would expect to find that MPAs of some size to be preferred by both vessel groups. This is due to the fact that the shock incorporated in the model is a recruitment failure, the impact of which is mitigated by the introduction of an MPA. With the possibility of shocks to the system, we also see winners and losers relative to their optimal possibilities. For instance, under non-cooperation, the coastal vessels lose out the most when the optimal MPA size of 60% is chosen, compared to their optimal choice of MPA size. The overall trend shows that the trawlers would prefer smaller MPAs than the coastal vessels. This is due to the two vessels' harvesting strategies, where the trawlers harvest immature cod, which if left in an MPA yield mature cod, which again can migrate and be harvested by the coastal vessels. This would, however, not be the case if, for instance, a breeding ground such as the Lofoten Islands in Norway was closed to fishing. It appears that the assumption of homogeneous distribution is a prerequisite for the above result.

The large impact that MPAs without cooperation have upon coastal vessel interests comes out clearly in the results. In a situation of recruitment failure non-cooperation makes relatively large MPAs more attractive to the coastal vessels, as this keeps some of the immature cod from being harvested by the trawlers, allowing them to reach maturity, and finally migrating into the fishable area. Under cooperation a large MPA is not equally beneficial to the coastal vessels.

Comparing our results to the actual harvest of North-East Atlantic cod, the existing management is probably most correctly portrayed by the non-MPA cooperative scenario without side payments. That is, the trawlers are not bought out. Hence, the only overall acceptable management option would be a cooperative MPA, as this increases both the trawler's and the coastal vessel profits. If we assume that buying out one vessel group is politically unacceptable, we must study the optimal case without side payments. In the case of no side payments, both vessels lose some revenues as compared to the optimal case, but are still compensated compared to the non-MPA case with cooperation. The optimal MPA size is however unchanged at 70%, and the optimal stock sizes are almost identical. Harvest is shared such that the trawlers obtain 55% of the harvest, with the coastal vessels harvesting the remainder. However, the real world harvest shares to the coastal vessels are lower than what this analysis prescribes to be optimal, as the actual trawler versus coastal vessel ratio is approximately 7:3.[9] Hence, a move to an optimal MPA in the cooperative setting would presumably be a hard pill for the trawlers to swallow, even if side payments were not implemented.

The fact that it is optimal to have zero trawl harvesting in the cooperative case is most probably because complex biological interactions such as cannibalism are not incorporated in the model. Armstrong and Sumaila (2000) have shown that when cannibalism is introduced to this fishery, it is not optimal for only one vessel group to harvest. Hence more complex intra-stock relations than used in this model, may show that it is optimal for both fleet groups to exploit the resource, rather than to effectively create a reserve of the whole off-shore area.

The fact that both vessel groups prefer cooperation with a 10% MPA to non-cooperation without an MPA is an interesting observation. This indicates the potential of even a small MPA if there is *ex ante* non-cooperation. Even without cooperation outside the MPA, both groups would prefer a 50% reserve to the threat point. This illustrates the potential of marine reserves in poorly managed fisheries. Even when management outside the reserve is hard to implement, a reserve may well be preferred to a badly managed non-reserve fishery. However, the North East Atlantic cod fishery is highly regulated, hence such a possible improvement in actual life is hard to imagine. The result does however present some hope for unmanaged fisheries. It is also of interest to note that the discounted total profits in the cooperative situation without an MPA do not exceed the discounted total profits in the non-cooperative situation with an MPA by much. In light of satellite tracking, rather than alternative costly control, an MPA combined with non-cooperation may involve lower enforcement costs than a cooperatively managed resource without an MPA. Thus, once management costs are added to the equation, we may find different optimal management systems than those presented here (see Armstrong and Reithe, 2001, for a discussion of this).[10] This is however left to future research.

The resulting optimal MPA sizes show a large degree of robustness to changes in key parameter values. Changes in the discount factor are, however, shown to have significant effects on the magnitude of the discounted profits. Furthermore, the distributional effects, i.e. who wins and who loses, are shown to vary with changes in parameter values. This illustrates the volatility of the implementation of MPAs, as the distributional effects will be largely unknown *ex ante*. The political problems surrounding MPA implementation become quite clear in this context. The claim that the implementation of MPAs will resolve conflicts amongst harvesters (Bohnsack, 1993) seems a vainly hopeful thought. On the contrary, the implementation of MPAs may have widely divergent distributional effects, and small changes in the surroundings, as well as management scenario in place may dramatically change who wins and who loses from the implementation of an MPA.

Let us conclude with some general observations: In the scenario of a habitat with the likelihood of facing shocks (which seems to be the case in reality), all agents in the fishery may well benefit from the establishment of MPAs. The size of the preferred MPA may however differ for the agents involved. The above results emanate from a model where agents specifically harvest either mature or immature fish, where the interaction between the two fished entities is recruitment. Similar distributional issues may be expected to arise in situations where the agents harvest in the presence of cannibalism in the single-species case, or in the presence of competition or predation in the multi-species case.

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Table 1. Total market values (discounted profits) in billion NOK totalled over the 28 year simulation period, average annual standing biomass in million tonnes, and MPA size as percentage of habitat. Migration rate = 0.8; Discount factor = 0.935

		Non-cooperative	Cooperative
Discounted profits (NoMPA)	Trawlers	13.93	18.15
	Coastal	12.60	16.82
	Total	26.53	34.97
Discounted profits (BestMPA)	Trawlers	13.77	23.70
	Coastal	16.50	22.37
	Total	30.27	46.06
Average stock biomass	NoMPA	1.15	1.81
	BestMPA	2.48	3.16
	MPA-size (%)	60	70

Table 2. Change in discounted profits depending on *ex ante* and *ex post* management. T= trawlers, C= coastal vessel group

	Ex post management w/MPAs	
Ex ante management w/out MPAs	Non Cooperation	Cooperation
Non cooperation	T↓ C↑	T↑ C↑
Cooperation	T↓ C↓	T↑ C↑

Table 3. Average effort use (over a 28 year period) in number of vessels.

	No MPA		**Best MPA**	
	Coastal	**Trawler**	**Coastal**	**Trawler**
Non-coop	651	36	479	23
Coop	924	0	740	0

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Table 4 Sensitivity analysis: The discount factor δ is increased to 0.98, the net migration rate ψ is decreased to 0.4, and the recruitment failure is reduced to year 5-9.

		δ=0.98		**ψ = 0.4**		**Shock; yr 5-9**	
		Non-coop	**Coop**	**Non-coop**	**Coop**	**Non-coop**	**Coop**
Discounted profits (NoMPA)	**Trawlers**	23.57	48.91	13.93	18.15	13.07	17.05
	Coastal	29.18	54.52	12.60	16.82	11.30	15.28
	Total	52.74	103.41	26.53	34.97	24.37	32.33
Discounted profits (BestMPA)	**Trawlers**	24.32	36.00	11.90	17.80	14.77	24.09
	Coastal	25.84	41.61	12.79	16.46	16.10	22.32
	Total	50.17	77.60	24.69	34.26	30.87	46.41
Average stock biomass	**NoMPA**	0.91	2.50	1.15	1.81	1.36	2.02
	BestMPA	2.12	2.91	2.79	3.43	2.50	3.17
	MPA-size (%)	60	70	60	70	50	70

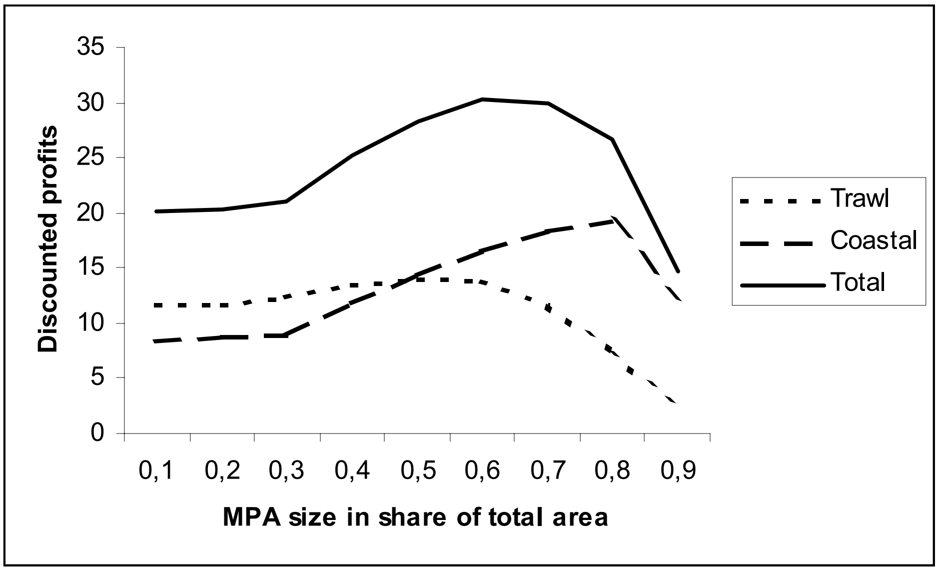

Figure 1. Discounted profits to trawlers and coastal vessels for different MPA sizes, in the case of non-cooperation.

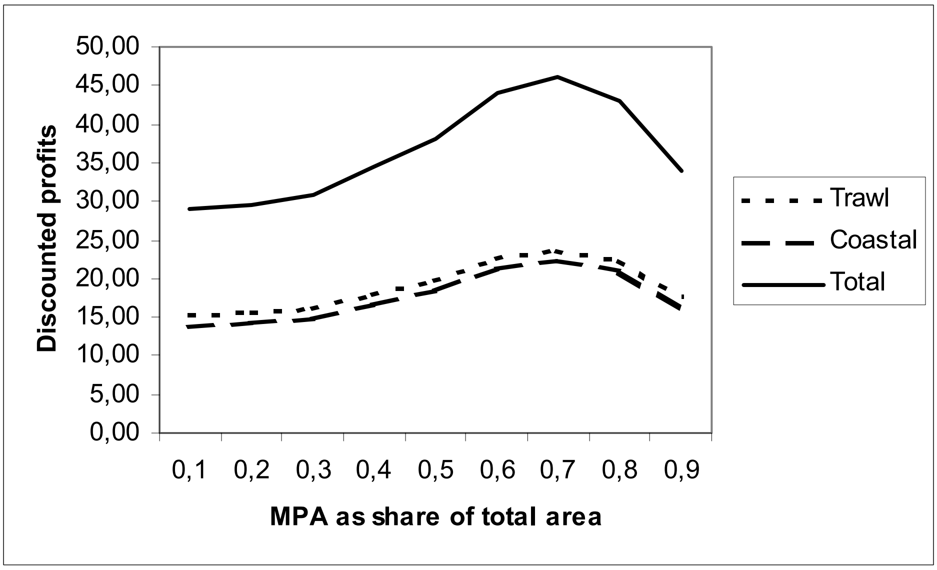

Figure 2**.** Discounted profits to trawlers and coastal vessels for different MPA sizes, in the case of cooperation.

[1] This is a more suitable model to use for the unmanaged scenario, than open access, as limited entry has for many years been practised in the North East Atlantic cod fishery.

[2] An interesting extension of the present paper would be to introduce some random shocks into the model

[3] Two of the northern Norwegian county's fishermen's organisations have suggested closing off sections of the Barents Sea, in order to protect juvenile cod.

[4] This function is chosen because recent biological studies have shown that it is more realistic than the Ricker recruitment function for species such as cod (Pitcher and Guénette, pers. comm.).

[5] We thank Daniel Pauly for helping us with this formulation.

[6] Harvest costs may be affected by the MPA size, making for longer travel distance. However, this would depend on structure and positioning of the MPA, as well as the fisher's alternatives, issues we will not study closer here.

[7] This is the spawning biomass seen as the long-term management goal for the North-east Atlantic cod (Anon, 2000).

[8] NOK=Norwegian Kroner

[9] This ratio consists of all harvesting on the North-East Atlantic cod stock; Russian, Norwegian and other countries' trawler harvesting versus the Norwegian coastal vessel harvesting.

[10] The broader effects of these two management options may however be very varying, as in the non-cooperative case with an MPA, the profits are distributed relatively equally, while in the cooperative case the trawlers have a much higher share of the total profits. If the trawlers have a high degree of onboard processing, this leaves less for the industry on land, resulting in large changes in the distribution of employment. The geographic distribution of trawlers versus coastal vessels is also different, as the latter are concentrated in northern Norway, while the former are owned by vessel owners further south, hence the cooperative solution may have a detrimental effect upon the distribution of populace in the scarcely populated north.