14/13

Working Paper

Implicit Cooperation? The Northeast Atlantic Mackerel Fishery

Rögnvaldur Hannesson

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by

Rögnvaldur Hannesson

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Abstract

This paper presents a quarterly, game-theoretic model of the Northeast Atlantic mackerel to study the fishing strategies of five players, the EU, Norway, the Faeroe Islands, Iceland, and the international fishery on the high seas. Data on the spatial distribution of fish catches 1977-2011 are used to model changes in the distribution of the mackerel stock. The Nash equilibrium solutions predict a severe decimation of the stock through overfishing, either by parties (Iceland, the Faeroe Islands) that refuse to cooperate, or by a general absence of cooperation. There is a wide discrepancy between this prediction and reality, as the stock seems only moderately overexploited or not at all, despite non-cooperation by Iceland and the Faeroe Islands. It is conjectured that these parties, and others, may have a degree of implicit cooperation that falls somewhat short of full cooperation but avoids the extreme destruction of the Nash equilibrium. This implicit cooperation can be seen as being maintained by a mutually assured destruction of the fisheries of all parties in case they go to the logical extremes of non-cooperation.

April 2013

1. INTRODUCTION

Over the last few years there have been dramatic changes in the mackerel fishery in the Northeast Atlantic. In 2007 the mackerel apparently changed its migratory habits and appeared in large quantities in the Icelandic economic zone. This prompted the Icelanders to fish the mackerel within their economic zone, which they previously had been unable to do. Prior to this the main mackerel fishing nations, Norway and the European Union (EU), had established a management regime where they set an overall catch quota and divided it among themselves, with some of it set aside for fishing in the high seas part of the Norwegian Sea and administered by the Northeast Atlantic Fisheries Commission. The Faeroe Islands later joined this arrangement.

The Icelandic fishery undermined the mackerel agreement. The Icelanders were dissatisfied with the offers made by Norway and the EU after the change in migrations was recognized, considering them too small compared with the amount of fish present in their zone. Subsequently the Faeroe Islands broke out of the agreement, finding the offer made to them unacceptable, compared with what the Icelanders were taking.

It goes without saying that no one will enter into cooperation unless he gains compared to what he gets if he acts on his own. But fisheries agreements are necessary because the outcome for one party depends on what the others do. When the Icelanders consider how they fare when fishing the mackerel as they like, they had better take into account how the other parties might respond to their actions. This gets us into the subject of game theory, which studies such interdependence. The bottom line for cooperation is what the parties would obtain if each takes action unilaterally, guessing as best it can what the other parties will do. This solution, under full information and certainty, is the outcome where the actions one player assumes the others will take are their best responses to what he will do. Such mutually consistent solutions form the benchmark which any viable cooperative solution must improve upon.

From theoretical studies of fisheries games (Hannesson, 2007; Clark, 1985) we know that such non-cooperative equilibria can be extremely destructive. There is some reason to believe that this is the case in the mackerel fishery. The destructive non-cooperative equilibria in fisheries games are due to insensitivity of the unit cost of fish to the size of the fish stock, giving players maximizing their individual profit an incentive to drive down the stock to a low and perhaps unviable level. The technology applied in the mackerel fishery (mainly purse seining and midwater trawling) is of a kind suspected to produce such stock-independent unit costs. Yet, when we contrast the present situation in the mackerel fishery with the predictions by the game-theoretic approach it stands out as surprisingly moderate. A possible reason is that unit costs might, after all, be stock-dependent, making it unprofitable for any single player to reduce the stock to a very low level.

Another possible reason why we have not seen the mackerel stock reduced to an unproductive and perhaps unviable level is that the parties could implicitly recognize the destructive character of a Nash-Cournot non-cooperative equilibrium. This could act as an implicit threat of mutual destruction of the fisheries of all parties, enticing them to tacitly apply a moderate fishing strategy, even if not fully cooperative.

In this paper we investigate this issue with a game-theoretic model of the mackerel fishery and contrast the outcome of that model with the situation as it has been recently (mainly with reference to 2011). This is an improvement on a recent paper on this issue (Hannesson, 2013) in that we have been able to use data on the quarterly distribution of mackerel catches among the various economic zones for the period 1977-2011. This has made it possible to formulate a quarterly model of the mackerel fishery, taking into account how the distribution of the stock changes from one quarter to another and how the quarterly distribution may change over time. Hence our migration model is better grounded in reality, but it is still unclear what causes the changes in migrations, in particular whether they depend on the size of the stock or on environmental factors unrelated to the stock itself.

Fisheries biologists and oceanographers have devoted considerable effort to investigating the said change in the migrations of the mackerel. Astthorsson et al. (2012) point out that the waters around Iceland have been relatively warm since the mid-1990s. This warming did, however, precede the appearance of the mackerel in Icelandic waters by about ten years, and it is difficult to identify any dramatic shift in temperature in 2007 or shortly before that would explain the sudden appearance of the mackerel in Icelandic waters at that time (see Astthorsson et al., 2012, Figure 3).

Nøttestad et al. (2013) report on a detailed investigation on the distribution of the mackerel stock 2007-12 and mention both the size of the stock and relatively high surface sea temperature as possible reasons for the extended migrations of the mackerel not just to Icelandic waters but also to the northern parts of the Norwegian Sea. The area of distribution increased, as did the stock, from 2007 to 2010. They also mention that the amount of zooplankton available has been relatively low in recent years. This, together with the increase in the stock, could explain why the mackerel migrated further and wider in these years in search for food. They do not offer a definite conclusion as to what caused the change in the migrations of the mackerel, but conjecture that it probably was the result of the coincidence of the two factors, a larger stock and warmer surface waters around Iceland and in the northern part of the Norwegian Sea.

This uncertainty about the causes of the changes in migrations is so much more deplorable as the outcome of a competition for the mackerel depends critically on what exactly the cause is (see Hannesson, 2013). Given this uncertainly, there is little we can do except explore the implications of different causes. In this paper we shall investigate (i) stock-dependent migrations and (ii) random changes in migrations, as in Hannesson (2013). As will be shown, the results of the quarterly model essentially confirm the results of that paper.

2. THE SPATIAL DISTRIBUTION OF CATCHES

Data on the spatial distribution of mackerel catches have been made available by the International Council for the Exploration of the Sea (ICES). The fish catches are attributed to rectangles of one degree longitude by half a degree latitude, shown in Figure 1 (see also

Figure 3). The data cover the period 1977-2011 and the bulk of the catches each year, from 78 percent of total catches in 1983 to 100 percent in 1994 (to calculate these percentages we have used the data on total catches in ICES, 2012, Table 2.3.1.1). Figure 1 also shows the borders of the national economic zones and how we have assigned the rectangles to these zones. Each rectangle has been assigned to one zone, without any attempt to divide the catches between zones for the rectangles that cover more than one economic zone. The assignment of catches to economic zones, which is the focus of our analysis, thus is not perfect but probably fairly accurate.

Figure 2 shows the quarterly division of fish catches between national economic zones. In the first quarter virtually all catches of mackerel are taken in the EU zone, from west of the Iberian peninsula to the waters west of Ireland. In the second quarter over 80 percent of the mackerel used to be caught in EU waters, mainly in the spawning area west of Ireland. In recent years (from 2008 onwards) this has changed radically, with more than 70 percent of the catches in 2010 being taken in the Icelandic zone. A similar change but on a smaller scale occurred in 1993, with more than 20 percent being taken in the Faeroese zone and 10 percent in the high seas part of the Norwegian Sea, and in 2005 almost 20 percent of the catches in the second quarter were taken in the latter area. It is possible that these changes are due to an unusually early post-spawning migration in the said years.

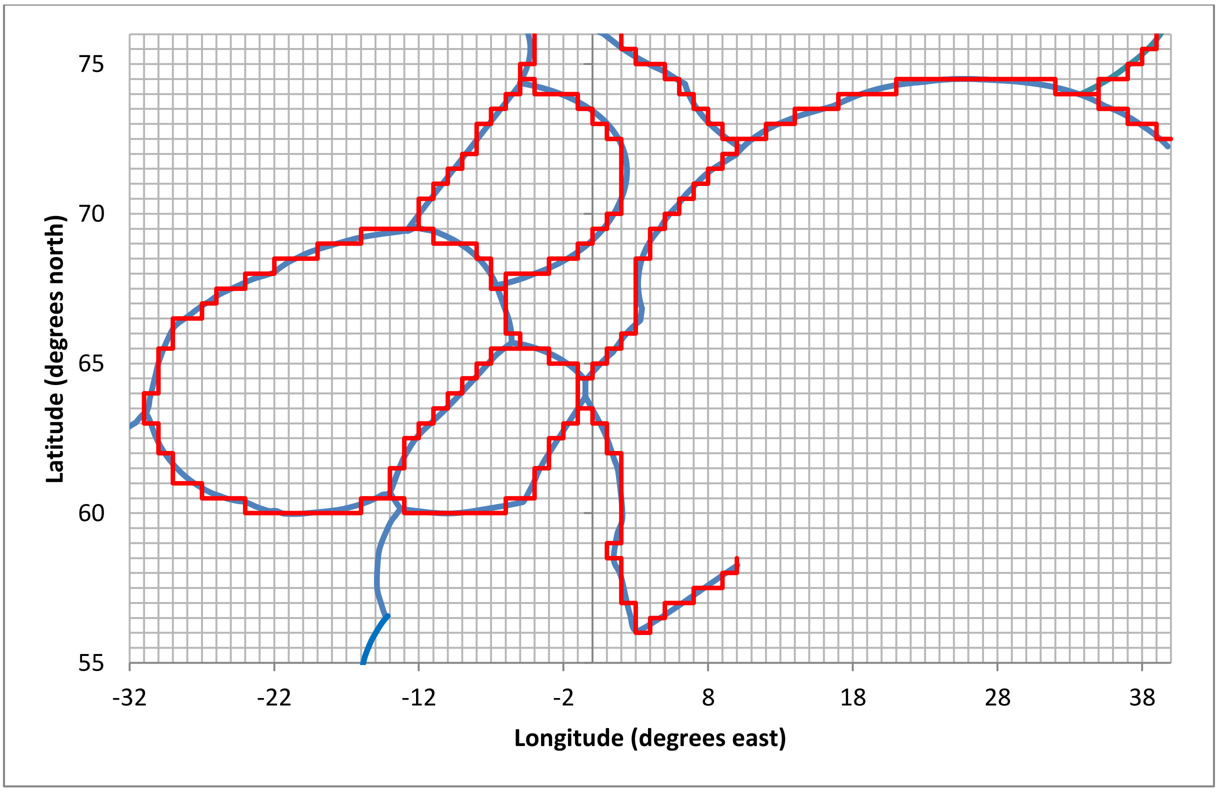

Figure 1: ICES statistical rectangles, borders of national economic zones, and how the rectangles have been divided among the national economic zones. The zones belong to the EU, the Faeroe Islands, Iceland, Greenland, Jan Mayen (Norway), Svalbard (Norway), Norway, and finally there is the area outside national economic zones (see also Figure 3).

In the third quarter, 60-80 percent of the catches used to be taken in the Norwegian zone. In the period 1978-1984, however, the share taken in the EU-zone was 60-80 percent and the share in the Norwegian zone correspondingly lower. The share taken in the high seas part of the Norwegian Sea has occasionally reached 20 percent. Before 2007 no mackerel was caught in the Icelandic zone, but from 2007 onwards the share taken in the Icelandic zone has varied between 20 and 40 percent.

In the fourth quarter the catches are concentrated to the EU and the Norwegian zones. Before 1990 almost all catches were taken in the EU zone, and again in 2010-11. In the years in between the catch shares in the two zones were a mirror image of one another, with about a half of the catches taken in each zone and virtually no catches elsewhere.

The said changes in the quarterly catch pattern indicate changes in migrations of the mackerel. Presumably the locations of the catches reflect the locations of the stock; not necessarily perfectly, but most likely to a high degree. The spawning area is known to be within the EU zone, and that is where the fish are available in the first quarter. The fish spawn in the second quarter, and most of them used to be caught in the EU zone then as well, but recently they have been captured in the Icelandic zone, presumably on their post-spawning migration. In the third quarter three “regimes” can be identified; (i) captures in the EU and the Norwegian zone, but primarily the first, before 1984; (ii) same as (i), but with most captures in the Norwegian zone; this lasted until 2006. (iii) From 2007 onwards, captures in all five zones (Icelandic, Faeroese, Norwegian and EU zones, and in the international part of the Norwegian Sea). Three but different regimes appear also in the fourth quarter; prior to 1990 virtually all catches were taken in the EU zone, and after 2008 in the Norwegian zone, with the two alternating in importance in the years between. We thus seem to have two regime shifts in the third and the fourth quarter. The latter regime shift happened at almost the same time in the third and the fourth quarter (2007-2009), but not the first one, which happened in the early 1980s in the third quarter and the late 1980s in the fourth quarter.

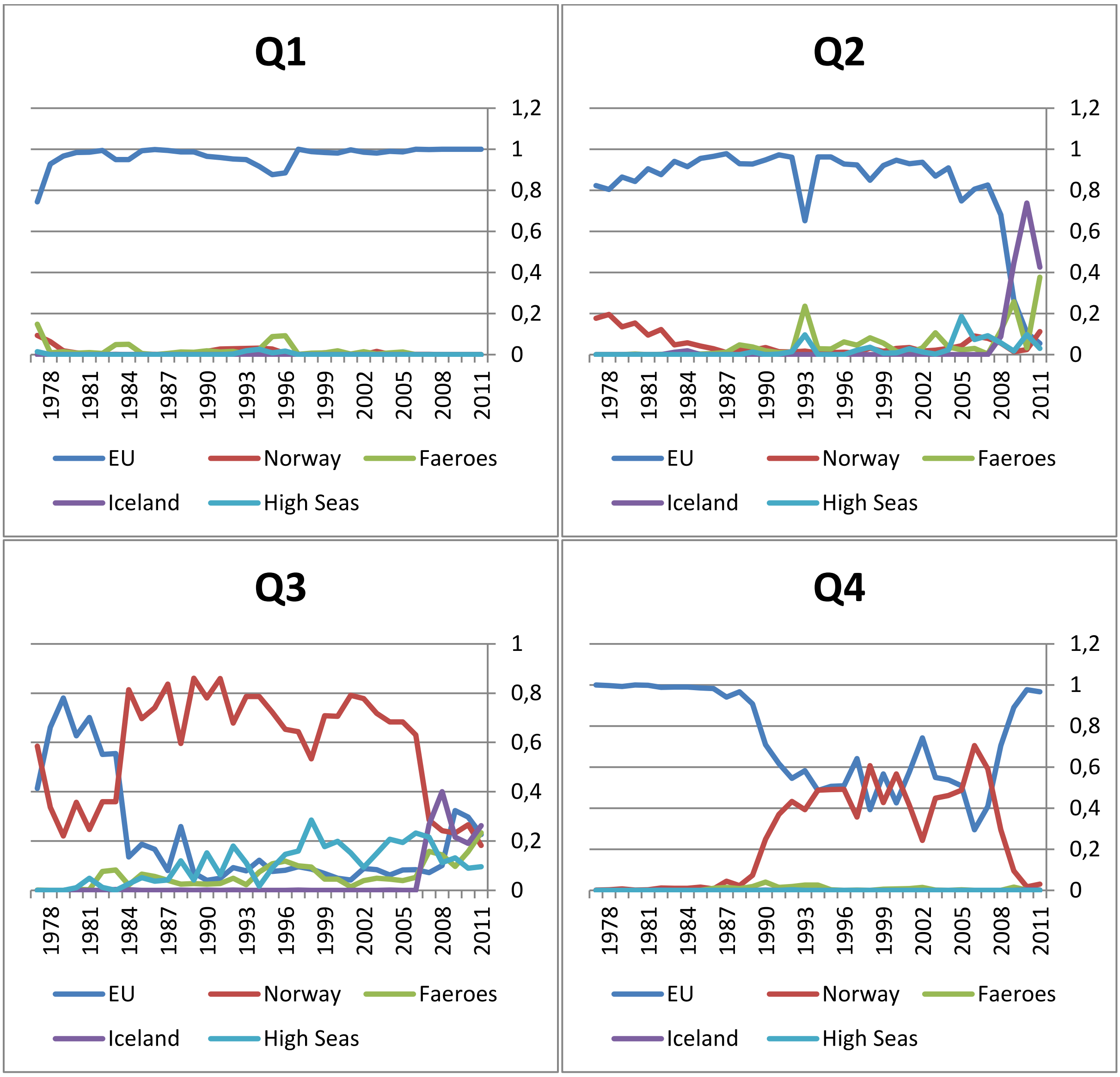

Figure 2: Quarterly distribution of mackerel catches between national economic zones 1977-2011.

3. GROWTH

In ICES (2012), Table 2.4.2.1, there are data on weight at age in 2011 in the ICES statistical areas (these are much larger than the statistical rectangles discussed above; cf. Figures 1 and 3). Figure 4 shows these data; note that by convention the age of the 0-group is 0.5 in the third quarter, even if they were spawned in the second quarter; the age groups are age 0, 1.0, 2.0, etc. in quarter 1. The weight at age is rather similar in the Norwegian Sea (Area II), the North Sea (Area IVa), at Iceland (Area Va), and around the Faeroe Islands (Area Vb). The weight at age in the Bay of Biscay (Area VIIIcE) and west of the Iberian peninsula (Area IXaN) is lower, except for the very youngest age groups, but what is surprising is that the weight at age in an adjacent area west of the Iberian peninsula (Area IXaCN) is quite similar to the weight at age in the North Sea (Area IVa). The weight at age in the Irish Sea and southwest of Ireland (Areas VIIa and VIIj) is also lower than it is in the North Sea and somewhat out of sync with the North Sea curve, which peaks one quarter later.

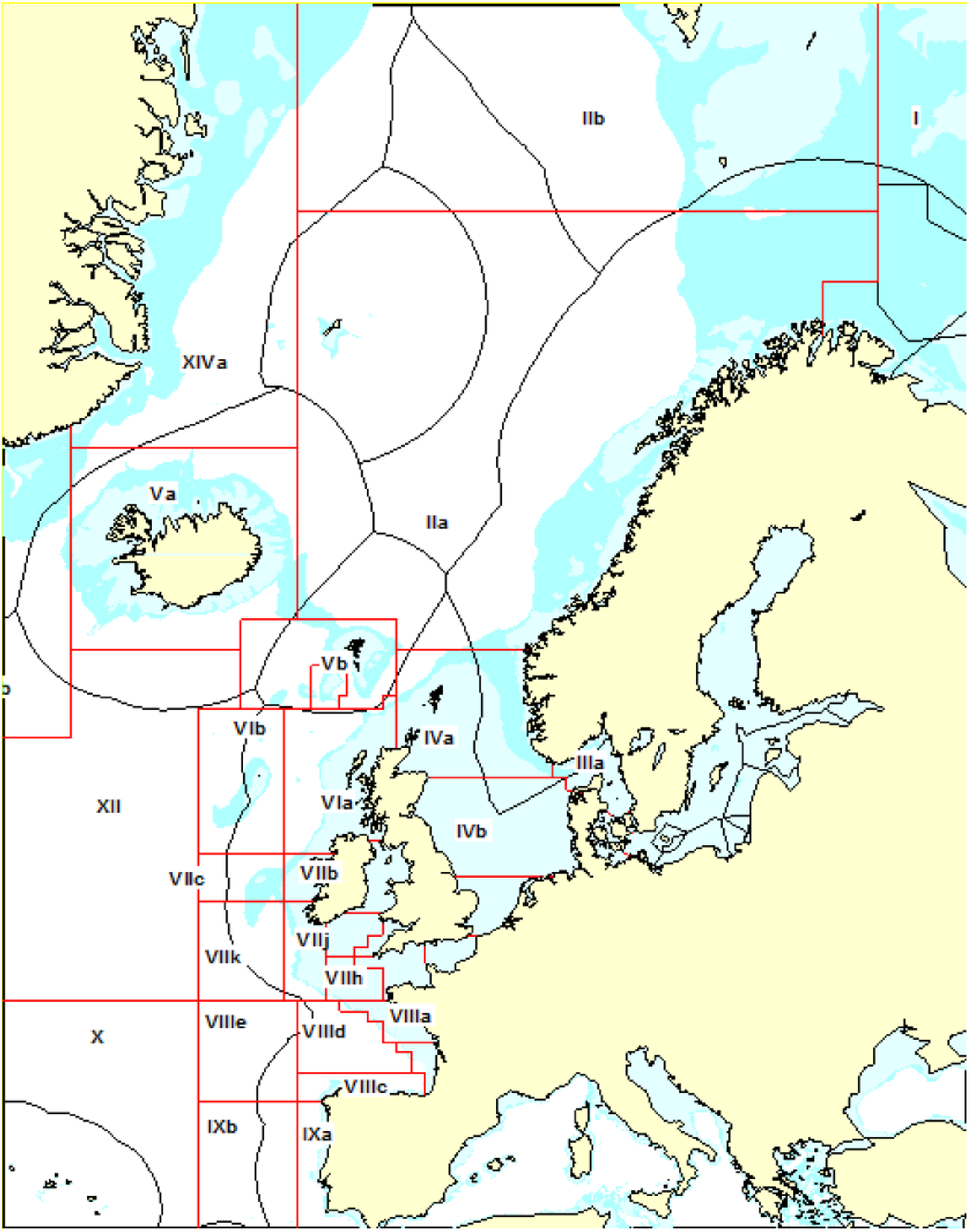

Figure 3: ICES statistical areas (from ICES, 2012).

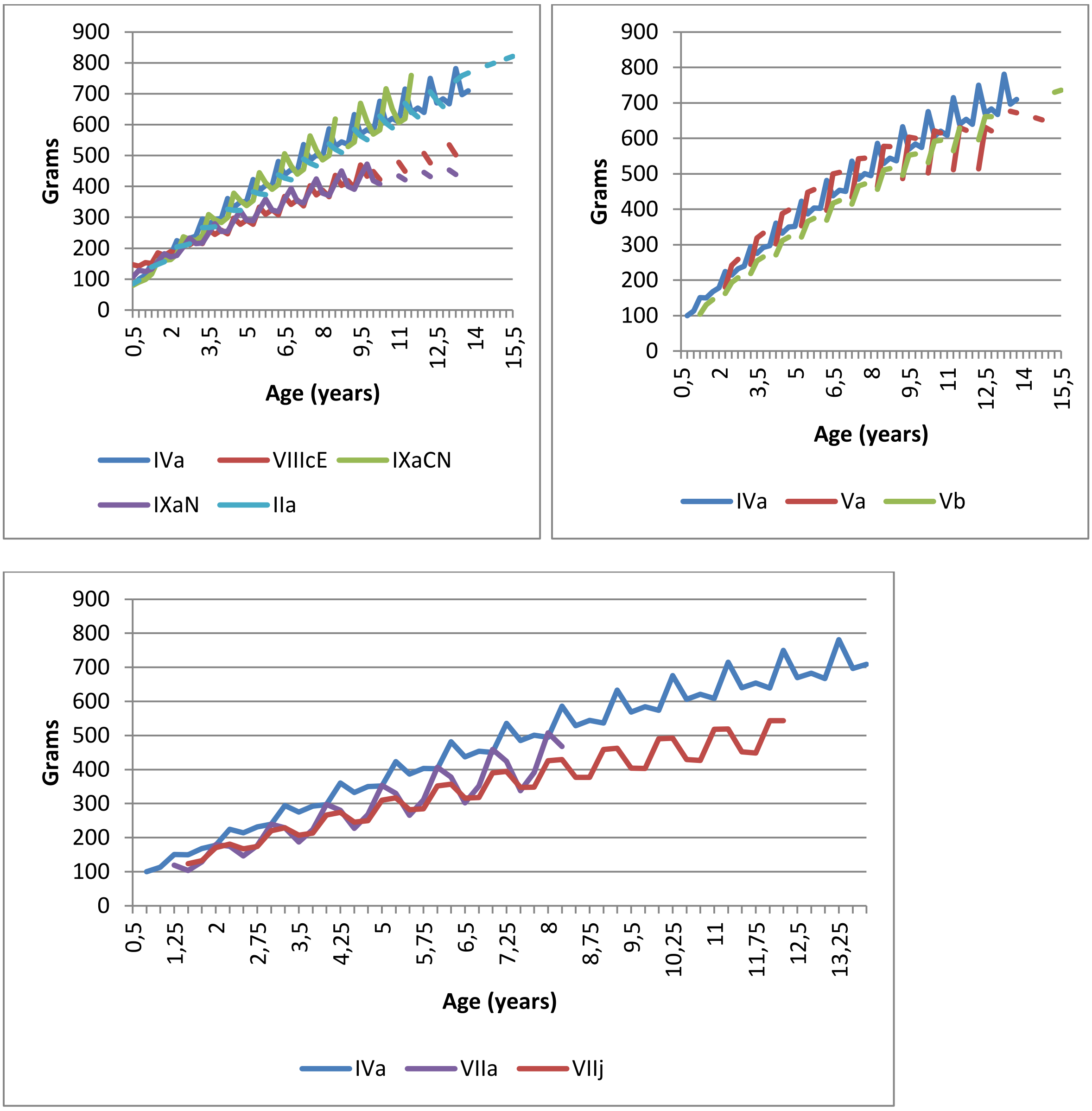

Figure 4: Weight at age of mackerel in various statistical areas (from ICES, 2012).

These apparent differences in growth indicate that the mackerel migrations depend on size, with the fastest growing fish migrating further and the slow growers perhaps remaining in the spawning grounds south and west of Ireland or further south (Nøttestad et al. (2013) report that the largest individuals are the ones that migrate farthest). This would be an argument for individual-based size-selective modeling of migrations, an aspect we shall not pursue further here and for which the factual basis still probably is too incomplete. Instead we shall model the growth on the North Sea data, pretending that all fish follow that growth curve in whatever zone they might be found. For comparison, the weight at age curve for the North Sea (Area IVa) is shown in all the panels of Figure 4. Clearly the growth is seasonal, with the weight at age peaking in the second quarter, but in some other areas the peaks occur in other quarters; southwest of Ireland (Area VIIa) they occur in the first quarter, but west of the Iberian peninsula (Area IXaCN), at Iceland (Area Va) and around the Faeroe Islands (Area

Vb) in the third quarter. The growth is fairly well described by the following quadratic curve with quarterly dummy variables:

(1) $$w_h = \left(a + bh - ch^2\right)\left(1 + k_2 d_2 + k_3 d_3 + k_4 d_4\right)$$

where h is age measured in years (1 for one year old fish in the first quarter, 1.25 in the second quarter, etc.), d_2, d_3 and d_4 are dummy variables for quarters 2 to 4, and a, b, c and the k's are parameters. Figure 5 shows the growth curve and the actual observations for the North Sea (Area IVa), the parameters are a = 45.45, b = 69.5555, c = 1.6715, k_2 = 0.1595, k_3 = 0.0246, and k_4 = 0.0341, estimated by minimizing the sum of squared differences between the curve and the observations.

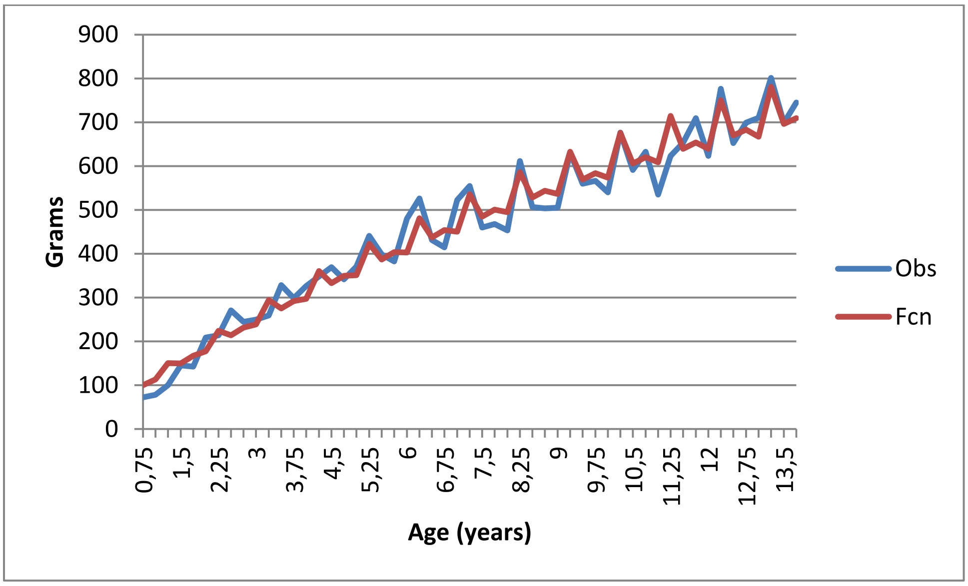

Figure 5: Observed weight at age and estimated growth curve for mackerel in the North Sea (Area IVa).

4. A QUARTERLY MODEL OF THE FISHERY

The quarterly model of the mackerel fishery is a standard Beverton-Holt model:

(2) $$C_{hiq} = \frac{s_h F_{iq}}{s_h F_i + M} X_h r_{iq} \left(1 - e^{-(s_h F_{iq} + M)/4}\right) w_h$$

where C_{hiq} is catch of fish of age h by "player" i in quarter q. The selectivity parameter s is taken from ICES (2012), Table 2.6.13, and changes only when the fish "turn year", that is, when they reach age 1, 2, etc., in the first quarter of every year. The 0-group fish, which are spawned in the second quarter, are available from the third quarter onwards.

The fishing mortality (F) is specific for each quarter and "player". We identify each "player" with each economic zone, and so we have the EU, Norway, Iceland and the Faeroe Islands as players. In addition we have the high seas, and we also treat the fishery in this area as associated with one player, even if all countries that fish the mackerel fish in this zone. Russia is, however, the most significant one in this area. The other players mostly fish in their own zone, but there are agreements between them about rights to fish in each other's zones. If, however, there is no agreement on the mackerel fishery the dissenting parties will be confined to their own economic zone and the high seas. This is what has happened to Iceland and the Faeroe Islands since they refused to agree with Norway and the EU, the dominant players in the mackerel fishery, and would also hold for all parties in the absence of any agreement on the mackerel fishery.

As weight at age (w_h) we use the estimated weight function for the North Sea, discussed above. The fishing mortality and the natural mortality (M) are expressed on an annual basis, so in the quarterly model we divide them by 4. X_h is the number of fish of age h in the stock, and a share r_{iq} is present in player i's zone in quarter q. This share is the same for all age groups but changes from quarter to quarter, due to the migrations of the fish. The model treats the stock present within each player's zone as staying there for the entire quarter, but changing places from quarter to quarter according to the parameter r_{iq}. The number of fish in each age group is updated with the equations

$$\text{(3a)} \qquad X_{j,q+1} = \sum_{i=1}^{5} r_{iq} X_{jq} e^{-(s_j F_{iq}+M)/4} \quad \text{for } q < 4 \text{ and } j > 0, \text{ and } j = 0 \text{ if } q = 3,$$

$$\text{(3b)} \qquad X_{j+1,1} = \sum_{i=1}^{5} r_{i,4} X_{j,4} e^{-(s_j F_{i,4}+M)/4}$$

$$\text{(3c)} \qquad X_{0,3} = R$$

with j being an integer index for the age of the fish. The number of 0-aged fish coming into the stock in quarter 3, alias recruitment (R), will be modeled below in two alternative ways; either as a constant and equal to the average 1972-2011 (ICES, 2012, Table 2.6.9), or as a random variable with a mean and variance as in the said period. A regression of the number of recruits on the spawning stock biomass produces a negative but not significant correlation. The reason why no significant positive correlation turns up could be that the spawning stock biomass has never been close to a perilously small level; the smallest spawning stock in the period 1972-2011 was 1.7 million tonnes.

5. THE FISHERY IN 2011

As a reference solution we set the r_{iq}'s equal to the share of catches taken in each zone in 2011. If this were true the fishing mortalities would have to be the same in all zones in each quarter. They might well have been different, but as we shall see the catches produced by the model on this assumption are indeed quite close to the actual catches. As Figure 6 shows, the quarterly share of mackerel catches has always been lowest in the second quarter. The last two years there have been dramatic changes in the other quarterly shares, with more than a half of the annual catch being taken in the third quarter, while the shares taken in the first and the fourth quarter have declined precipitously. To replicate the fishery in 2011 we use the initial stock size estimated for 2011 as reported in ICES (2012), Table 2.6.11, and set the quarterly mortalities to $F_{i1} = 0.2$, $F_{i2} = 0.06$, $F_{i3} = 0.61$ and $F_{i4} = 0.2$, same for all players.

Figure 7 shows the catches in 2011 produced by the model and compares them with the actual catches. There is good agreement between model and reality. The fishing mortalities mentioned above sum to 0.2675 for five year old fish, the age group with the selection parameter *s* = 1. The estimated fishing mortality for this age group according to the estimates in ICES (2012) was the same, 0.268. One implication of this is that the actual fishing mortalities applied by the players in the mackerel fishery in 2011 were in fact quite moderate, despite the fact that no agreement was reached between them and mutual accusations about overfishing were made.

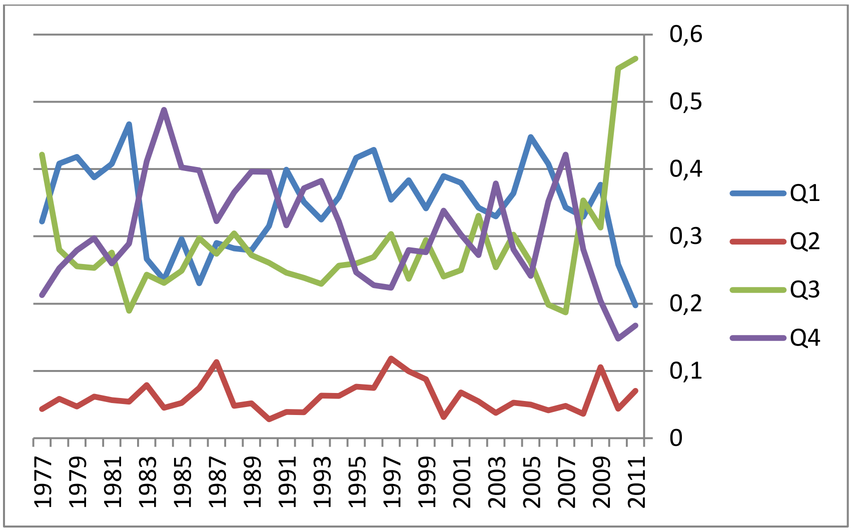

Figure 6: Shares of mackerel catches taken in different quarters of the year 1977-2011.

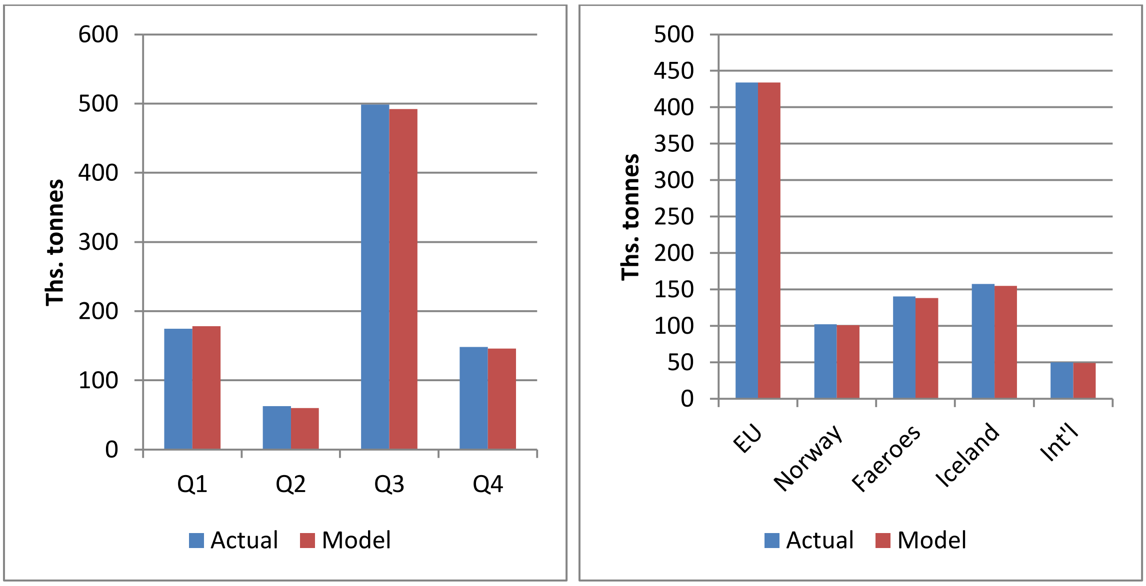

Figure 7: Actual and modeled catches in 2011, quarterly and by area.

What would a cooperative solution look like? This obviously depends on the objectives the players would agree on. Any such agreement would presumably be governed by economic parameters such as costs and discount rates. The objectives of the players are stated in very general terms such as "sustainable fishing"; the disagreement between them seems to be more about the division of the total catch than how that target should be set. If the cost per tonne of fish is unrelated to the size of the fish stock and the price is insensitive to the volume of landings, and furthermore if the discount rate is set to zero, maximizing sustainable yield would be an appropriate overall goal. It turns out that the maximum sustainable yield requires more than twice the fishing mortality of 2011, or $F = 0.615$. The annual catch in a steady state and the stock remaining after fishing with these two mortality rates are compared in Figure 8. The fish catch would be about five percent higher than in 2011, but the stock left after fishing would be much lower, or 2.9 million tonnes versus 4 million tonnes. A stock of 2.9 million tonnes is close to its lowest level in the period 1972-2011; in only four years in this period has it been lower than that.

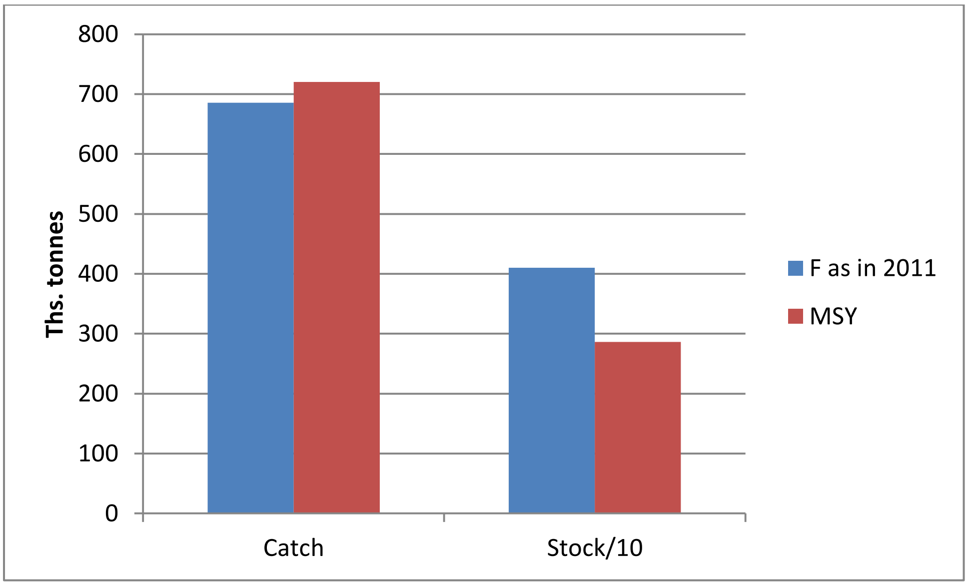

Figure 8: Annual catch and stock after fishing with fishing mortality as in 2011 versus one that maximizes sustainable yield.

Given that the fishing mortality producing the maximum sustainable yield is considerably higher than the one that appears to have been applied for the last ten years or so (ranging from 0.23 to 0.4), this objective and the assumptions that lead to it seem none too likely. Nevertheless, we can ask what the situation would be like if all five players tried to individually maximize their own fish catch in long run equilibrium. The answer to that question is discouraging; each would scoop up all the fish available in his own zone, so that the stock would be sustained only with the assumed constant recruitment of fish arriving each year. Since virtually no fish would survive to spawning age this is none too likely, but serves as a reminder that an equilibrium when everyone fights against everyone else could be very destructive. We could get a more credible solution by extending the model with a recruitment function where the number of 0-aged fish depends on the size of the spawning stock, but shall not pursue that matter here, partly because there is little or no empirical evidence on which to base such a recruitment function.

Instead we shall pursue a different question. What if the cost per tonne of fish depends on the size of the fish stock? If the fish are always evenly distributed over a given area, a unit of fishing effort (a measure of the activity of the fishing fleet aimed at removing fish) will always remove the same share of the fish stock (produce the same fishing mortality), and a cost proportional to fishing effort would translate into a cost proportional to fishing mortality while the cost per tonne of fish would be inversely related to the size (density) of the fish stock. In that case an increase in fishing mortality beyond a certain limit would be unattractive, because the increase in fish catches would not be on par with the increase in costs. We shall ask two questions: first, what would the cost per unit of fishing mortality have to be in order to make the fishing mortality as it was in 2011 the optimal one? Second, given this cost, what would the outcome look like if all five players maximized their individual benefit irrespective of others? It is the latter solution one may expect to see in case there is no cooperation between the players.

Assuming a fixed price of mackerel and setting it equal to unity and accounting for the fish catch in thousands of tonnes, we find that a cost per unit of fishing mortality of 100 would produce an optimal fishing mortality of 0.2568 for five year old fish, close to the actual value estimated for 2011 (0.268). This is in fact a very low cost; it would produce a rent in the long term equilibrium equal to 84 percent of the catch value. When calculating the optimal fishing mortality we have used the same quarterly pattern of fishing mortalities as when calculating the catches in 2011, an assumption which we also maintain below.

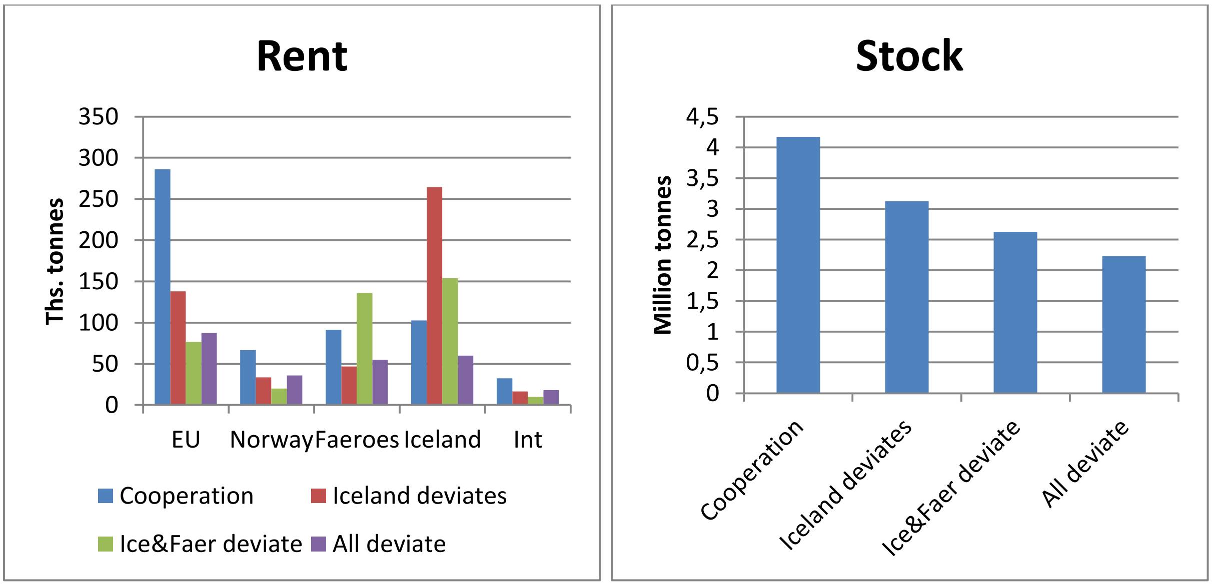

Figure 9: Rent and stock left after fishing under (i) full cooperation; (ii) if Iceland deviates; (iii) if both Iceland and the Faeroes deviate, and (iv) if there is no cooperation.

We shall consider (i) full cooperation, (ii) deviation from cooperation by Iceland but cooperation among the rest, (iii) deviation from cooperation by Iceland and the Faeroe Islands but no cooperation between those two, and (iv) everyone plays against everyone else. The results in terms of rent and stock left after fishing in equilibrium are shown in Figure 9. If Iceland breaks out of cooperation it would cut the rent of the remaining players by about a half but more than double its own. If the Faeroe Islands also deviate they would reduce the rent of the others by a further quarter of the cooperative rent. Finally, in the absence of any cooperation the rent of all would be cut by one half or more, somewhat differently for different players. The stock left after fishing would be reduced from 4.2 million tonnes to 3.1 if Iceland deviates, further to 2.6 if the Faeroese also deviate, and finally to 2.2 in the absence of any cooperation. Note that the actual catches would not be less in the non-cooperative than in the cooperative equilibrium, but profits would be lower, the fishing mortality higher, and the stock left after fishing smaller. The latter would be smaller than it has ever been in the period 1972-2011 and the fishing mortality much higher.

The fishing mortality applied by Iceland if she breaks out of cooperation would be extremely high, or 2.5, but applied only for two quarters of the year when the fish is in the Icelandic zone. Her fish catches would be about 400,000 tonnes in equilibrium. Both are way above what has been occurring in recent years and thus contradicting the notion that she has been playing an aggressive non-cooperative game. The Faeroese fishing mortality would be of a similar magnitude if they played non-cooperatively and the Icelandic and Faeroese catches would be about 250,000 tonnes for each in the long term equilibrium, but also this is inconsistent with the recent situation in the mackerel fishery.

6. IMPLICATIONS OF A VARIABLE STOCK DISTRIBUTION

The results just discussed are predicated on the distribution of the stock as it was in 2011 and a constant recruitment of fish. The distribution of the fish stock between the different economic zones has, however, been very variable, as shown above. A critical factor is whether the distribution of the fish stock depends on its size or on environmental factors unrelated to the size of the stock. Since the stock has been unusually large in recent years (Figure 10), it is tempting to conclude that its appearance in the Icelandic zone is size-dependent; it is not unlikely that a larger stock will migrate farther in search of food. The fact that the stock was just as large in the 1970s would seem to contradict that hypothesis, but could be due to a component residing in the North Sea that now appears extinct or nearly so (Iversen, 2002); the mackerel fishery in the North Sea in later years depends on migrations of “western” mackerel into the North Sea. There also appears to be some but much less clear relationship between the size of the stock and the share in the Faeroese zone.

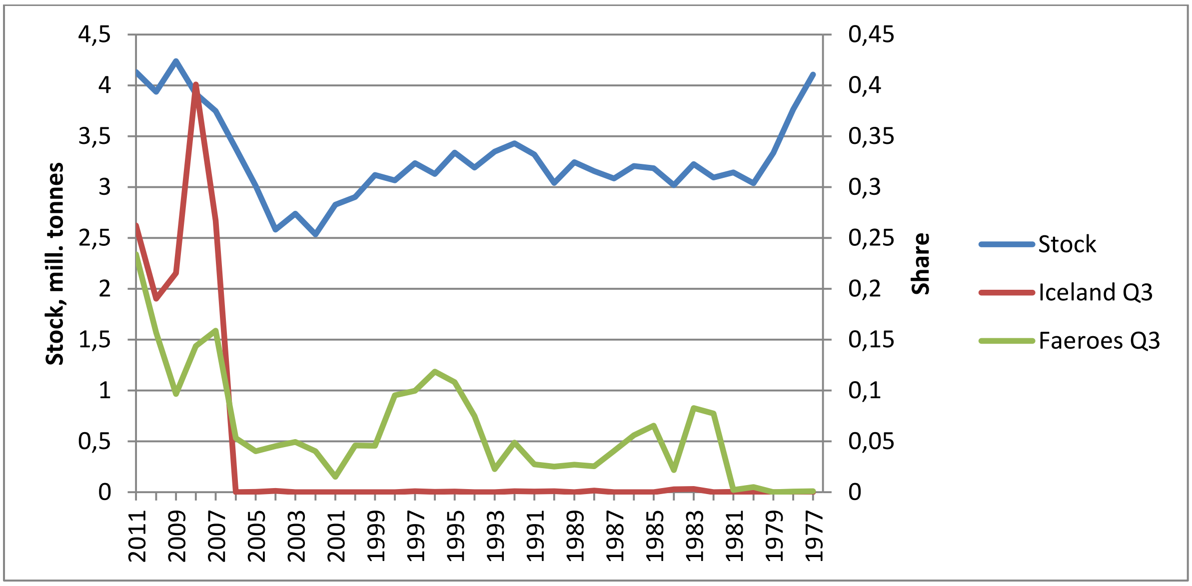

Figure 10: Size of the mackerel stock 1977-2011 and share of catches (third quarter) taken in the Icelandic and the Faeroese zones.

Here we shall explore two hypotheses; first, that the migrations into the Icelandic zone depend on the size of the stock and, second, that the distribution of the mackerel between economic zones is random. We model this as follows. With size-dependent migrations we consider two alternative distributions: (i) a distribution as in 2011, and (ii) a distribution as in 1998, such that when the mackerel stock is over 3.5 million tonnes the 2011-distribution prevails, but otherwise the one in 1998. The main difference is, as can be seen from Figure 2, that in 1998 there were no catches taken in the Icelandic zone, and the share of catches taken in the Faeroese zone was much smaller than in 2011. With the random distribution we assume that all distributions observed in the period 1977-2011 are equally likely. This ignores the persistence there appears to be in distribution profiles, as discussed above, but captures the apparent fact that the distribution can change abruptly over a relatively short period of time (there is insufficient evidence to determine the length of these distribution regimes). In this investigation we have treated recruitment as a random, normally distributed variable with the same mean and variance as observed for the period 1972-2011, running 10000 simulations over a 50-year time horizon each and an initial stock as in 2011.

Figure 11 shows the average annual rent from fishing in the four different economic zones and the international area under four different strategies; cooperation, a unilateral deviation by Iceland, a deviation by Iceland and the Faeroe Islands simultaneously but no cooperation between them, and with no cooperation whatever. Iceland would gain handsomely by a unilateral deviation, but those gains would be more than reversed if the Faeroe Islands also deviate. In the absence of cooperation the outcome for the Faeroe Islands and especially Iceland would be much worse than with cooperation. Iceland's rent in fact comes only from the first year, due to the large initial stock as of 2011. The high fishing mortalities applied by the other players would prevent the stock from exceeding the benchmark of 3.5 million tonnes where it begins to spill into the Icelandic zone. The rents of Norway and especially the EU are substantially lower than in the cooperative solution. The rents in the high seas fishery are almost the same in the non-cooperative solution as in the cooperative solution.

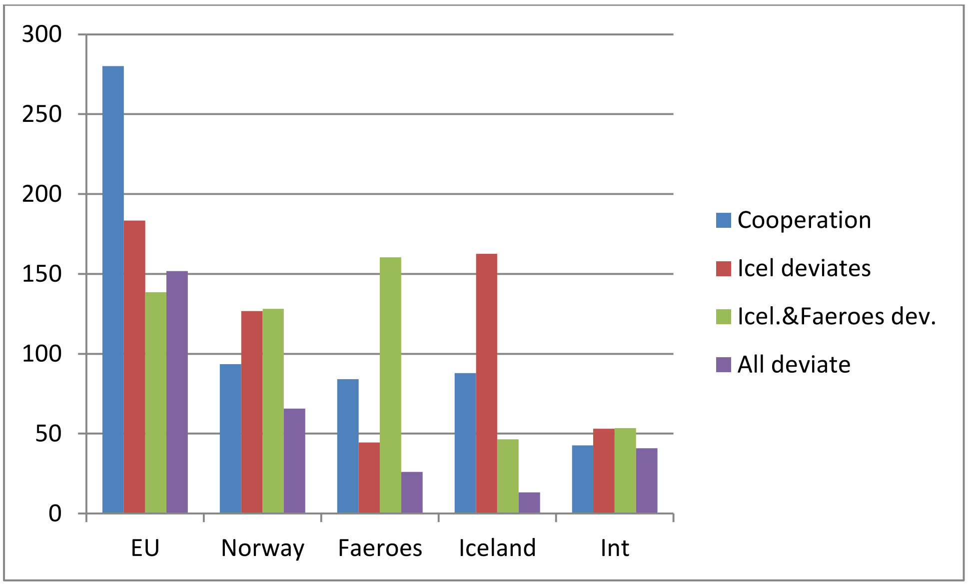

Figure 11: Rent from fishing within the four exclusive economic zones and the international area under four different strategies. Distribution among zones size-dependent.

It bears noting that what happens to the fish captures is quite different from what happens to the rent, because of the stock-dependent unit cost of fish. The fish catches taken by Norway would in fact be considerably larger in the non-cooperative solution and those taken by the EU almost the same. The catches taken by the Faeroe Islands and especially those taken by Iceland would be less; Iceland would be effectively shut out of the fishery, as already mentioned. If the costs per unit of fish were less sensitive to the size of the fish stock the players would apply a much higher fishing mortality and the catches in the non-cooperative solution would become quite small and the stock possibly threatened.

The outcome in the case where the distribution of the stock is random is shown in Figure 12. It is in some respects quite different from the case of a size-dependent distribution. The rent of the Faeroe Islands and Iceland is slightly higher in the non-cooperative than the cooperative solution, underlining the strong bargaining position a small player can have in games of this kind and discussed in Hannesson (2013). For Iceland the difference compared with the size-dependent distribution is substantial; she is no longer shut out of the fishery by the relatively high fishing mortality. The rent of the EU and especially Norway is now much lower in the non-cooperative solution and their incentives and ability to entice the two small players to accept the cooperative solution much stronger. The fish catches taken by the small players (Iceland, the Faeroe Islands) are in fact greater in the non-cooperative solution than in the cooperative one.

The average size of the fish stock declines substantially as we move from the cooperative outcome to the non-cooperative ones. Under cooperation it is just below 4 million tonnes. It drops to 3.5 or less if Iceland does not cooperate, to just above 3 if the Faeroese join them in not cooperating, and to just above 2 if there is no cooperation. The minimum stock in any particular year can be lot lower and probably perilously low; less than half a million tonnes. That would be unprecedented (cf. Figure 10).

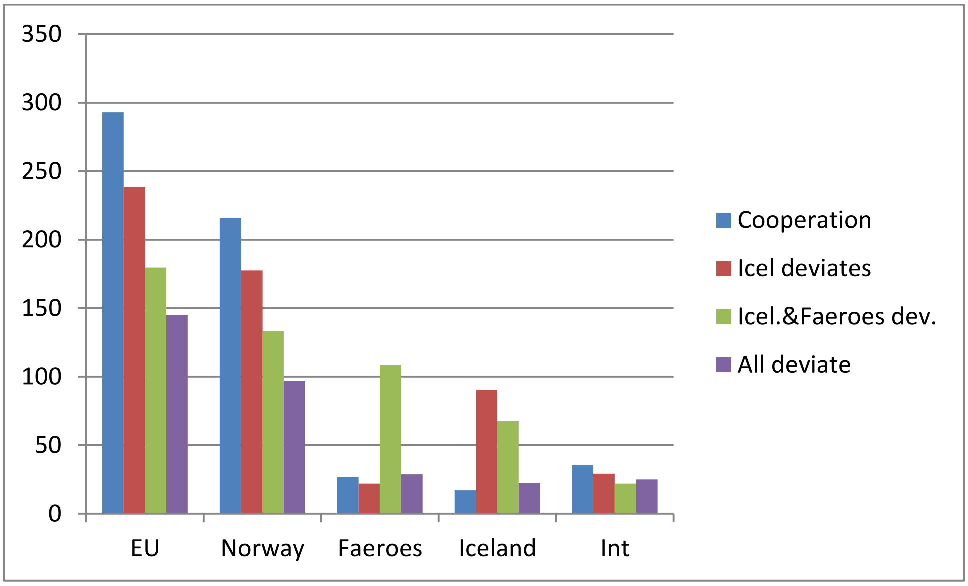

Figure 12: Rent for fishing within the four exclusive economic zones and the high seas under four different strategies. Random distribution of fish among zones.

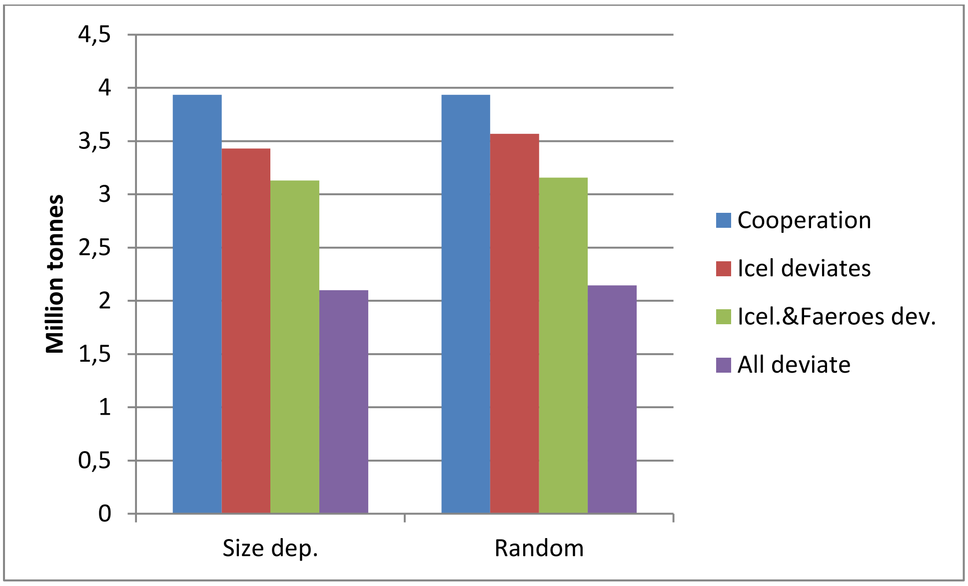

Figure 13: Average size of the fish stock under different strategies. Stock distribution random versus size-dependent.

7. CONCLUSION

The sequence of events in the mackerel fishery over the last few years has been similar to the ones presented above; the Icelanders suddenly emerged as a player and have not thus far found it attractive to cooperate with the EU and Norway. Soon after the Faeroese abandoned their cooperation with Norway and the EU. The reality does not, however, correspond to the model outcomes above. In the above solutions the Icelanders and the Faeroese, acting on their own, would apply a very high fishing mortality, catch about a million tonnes each in the first year of deviation and severely decimate the stock. Nothing remotely like that has happened; in 2007-2011 Iceland has gradually increased its catches to 160,000 tonnes and the Faeroese to 120,000 tonnes. The mackerel stock has not been depleted to the level where it was before the migrations into the Icelandic zone occurred. It thus appears that both the Icelanders and the Faeroese are playing much less aggressively than the game-setting above predicts. Neither do the two remaining parties, the EU and Norway, play as aggressively as the game setting predicts, they appear to be applying a fairly moderate fishing mortality and not driving down the stock below the level that might possibly exclude the Icelanders; in 2011 the stock was still above 4 million tonnes.

One possible reason why the fishing mortalities currently applied by all parties are much lower than the model results is that the cost per unit of fishing mortality is much higher than assumed here. But if that were the case we would have seen a much lower fishing mortality applied in the years of cooperation between the EU, Norway and the Faeroe Islands. The opposite is in fact the case; according to ICES (2012) the fishing mortality before 2006 was higher than in 2007-2011. The only way to reconcile the years 2007-2011 with non-cooperation is that Norway, the EU and the Faeroe Islands were in fact not taking advantage of cooperation in the years prior to 2006 and exploiting the stock more heavily than warranted. This is unlikely.

What could be the reason why the players in the mackerel game are playing more cautiously than the game model predicts? One possibility is capacity constraints; they simply cannot take more fish than they currently do. This is unlikely; all parties have set themselves catch quotas; in the case of Iceland and the Faeroe Islands these have been set unilaterally on the basis of what they consider themselves entitled to. Another reason could be that these players are in fact playing cautiously, albeit not cooperatively, in the knowledge that an unfettered competition among all players would be their common ruin. The fact that the Icelanders and the Faeroese set their own quotas supports that hypothesis. These quotas may still be greater than warranted by full cooperation, and they are certainly not to the two other players' liking, but still probably not nearly as excessive as they could be. To use an analogy from international politics, a degree of cooperation seems to be maintained by the mutually assured destruction of the fisheries of all parties in case they take non-cooperation to its logical extreme.

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This paper presents a quarterly, game-theoretic model of the Northeast Atlantic mackerel to study the fishing strategies of five players, the EU, Norway, the Faeroe Islands, Iceland, and the international fishery on the high seas. Data on the spatial distribution of fish catches 1977-2011 are used to model changes in the distribution of the mackerel stock. The Nash equilibrium solutions predict a severe decimation of the stock through overfishing, either by parties (Iceland, the Faeroe Islands) that refuse to cooperate, or by a general absence of cooperation. There is a wide discrepancy between this prediction and reality, as the stock seems only moderately overexploited or not at all, despite non-cooperation by Iceland and the Faeroe Islands. It is conjectured that these parties, and others, may have a degree of implicit cooperation that falls somewhat short of full cooperation but avoids the extreme destruction of the Nash equilibrium. This implicit cooperation can be seen as being maintained by a mutually assured destruction of the fisheries of all parties in case they go to the logical extremes of non-cooperation.

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