The stability and resilience of management agreements on climate-sensitive straddling fishery resources: the blue whiting (*Micromesistius poutassou*) coastal state agreement

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Abstract: How would the formation, stability, and success of an agreement on cooperative management between neighbouring coastal states for a climate-sensitive fishery resource be affected by changes in the distribution and accessibility of the resource within the exclusive economic zones (EEZs)? In scenario 1, the blue whiting (*Micromesistius poutassou*) is harvestable in the EEZs of Norway, Iceland, the Faroe Islands, and the European Union (EU), as well as in the international waters of the Northeast Atlantic and the Norwegian Sea. The Barents Sea is a fringe area for the species, and there are no fisheries for blue whiting there. Hence, Russia is not regarded as a coastal state with respect to the blue whiting fishery. This severely weakens the stability of the coastal state agreement. In scenario 2, the area of distribution of the harvestable stock expands into the Russian EEZ, giving it status as a coastal state with respect to the resource and, thus, a partner in the management agreement. This secures the coastal state coalition the maximum attainable cooperative value and increases the likelihood of a stable coastal state agreement.

Résumé : Comment l'établissement, la stabilité et le succès d'un accord sur la gestion en commun par des états côtiers limitrophes d'une ressource halieutique sensible au climat sont-ils affectés par les changements dans la répartition et l'accessibilité de la ressource dans les zones économiques exclusives (EZZ)? Dans un premier scénario, le poutassou (*Micromesistius poutassou*) est récoltable dans les EZZ de Norvège, d'Islande, des îles Féroé et de l'Union Européenne (EU), de même que dans les eaux internationales du nord-est de l'Atlantique et de la mer de Norvège. La mer de Barents représente une zone marginale pour l'espèce et il ne s'y fait pas de pêche de poutassous. La Russie n'est donc pas considérée comme état côtier en ce qui concerne la pêche aux poutassous. Ce scénario affaiblit considérablement la stabilité de l'accord entre les états côtiers. Dans le second scénario, l'aire de répartition du stock récoltable s'étend dans la EZZ russe, ce qui donne à la Russie le statut d'état côtier en ce qui a trait à cette ressource et en fait un des partenaires de l'accord de gestion. Ce scénario procure à la coalition d'états côtiers les conditions maximales possibles de coopération et augmente la probabilité d'un accord stable entre les états côtiers.

[Traduit par la Rédaction]

Introduction

How would the formation, stability, and success of an agreement on cooperative management between neighbouring coastal states for a climate-sensitive fishery resource be affected by changes in the distribution and accessibility of the resource within the exclusive economic zones (EEZs) of these states? A shift in the climate regime could have two types of effects on a climate-sensitive fishery resource: (*i*) changed biomass and (*ii*) changed area of distribution and (or) migration pattern. Of course, both are possible and closely linked. If the stock decreases in numbers, this will have a corresponding effect on distribution. Abundance changes may also have a density-dependent effect on catchability. For the purpose of this paper, it is the distribution and accessibility changes that are important, not necessarily what causes them.

Though it is a challenging task to achieve efficient management of a fishery that is confined to a single jurisdiction (Gordon 1954), further complications emerge when the targeted fish population migrates across international boundaries or straddles the boundary between a national jurisdiction and the international waters of the high seas (e.g., Munro 1979, 1987). In the case of a fish population that migrates across international boundaries, harvesting in each jurisdiction affects the availability of fish in the other

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jurisdiction (Criddle 1996; McKelvey 1997). If these nations harvest the shared stock competitively, they will tend to waste its potential value. Recognising that possibility, they may attempt to work out a cooperative division of the harvest, but maintaining cooperation is difficult, and many international agreements have degenerated into mutually destructive fish wars. This instability appears to result from changes over time in the parties' incentives to cooperate (Miller 1996; McKelvey 1997). Uncertainty regarding the magnitude and sources of variations in fish stocks is another stumbling block to cooperative harvest management. The parties may have different information or beliefs about how the stock is changing, and they may have a strategic interest in concealing that information from one another, or in promoting a particular interest-laden interpretation of the biological facts (Miller 2000).

The key questions in this literature have been the distribution of benefits arising from cooperative versus noncooperative management and stability of cooperative arrangements (Sandberg 2005). The latter typically demands analysis of incentives of individual players to defect from cooperation, as well as credible punishment of defectors by remaining players. When expected costs of a credible punishment are higher than expected benefits of defecting from a cooperative agreement, the agreement is self-enforcing, and vice versa. Lindroos and Kaitala (2001) provide an overview of this literature.

The likelihood of reaching a cooperative management of transboundary fishery resources thus depends on numerous factors. Munro (1979) was among the first to recognise that when fish stocks are transboundary, different regulatory bodies may have diverging social rates of discount, fishing effort costs, or consumer tastes. In the absence of side payments, such differences will imply that the various parties' views on optimal management will differ. Kaitala and Lindroos (2004) showed that timing may be important for whether or not to cooperate.

Hannesson (1997) analysed which factors tend to sustain cooperative management and found that a low (high) discount rate, a small (large) number of parties and a high (low) cost of fishing would make cooperative management more (less) likely. Several papers have dealt with how (limited) access may influence incentives to cooperate among the parties harvesting a fish stock. Assuming a uniformly distributed stock, Hannesson (1997) illustrates two different cases. In one of these, each identical player has sole access to a share of the area where the stock is distributed. This condition reflects a stock that is distributed across the EEZs of more than one nation, where each nation has exclusive access to harvest the resource in its own zone. Assuming limited migration of the stock between areas, he finds such designated access rights to increase the likelihood of cooperation relative to a stock where all players have access to the stock over its entire area of distribution. In the second case, a dominant agent has access to the largest area of stock distribution, whereas a competitive fringe controls the remaining area. In this case, he finds that the existence of a competitive fringe reduces the optimal stock level, as well as the corresponding net present value (NPV) of the fishery.

Arnason et al. (2000) discuss the benefit of cooperation through the use of a surplus production model in which prices are constant and harvest costs depend on the stock, harvest, and distance to the exploitable biomass. They investigate a number of different noncooperating coalitions that only have access to the stock on the high seas and in their own EEZs. In this way, limited access influences the incentives to cooperate via the cost function.

The inherent difficulty of managing such resources suggests that adaptation to the effects of climate variability and climate change is likely to be less complete and effective than might be the case for resources that are controlled by private property owners. Furthermore, climatic variations may destabilize efforts to cooperatively manage resources that are shared among multiple jurisdictions.

Work that has been done on the implications of climate regime shifts for fisheries management has largely been on fisheries confined within the EEZ of one, or at most two, coastal states (Hannesson et al. 2006). Miller and Munro (2004) (see also Miller (2000) and Miller et al. (2001)) presents evidence for the significance of climatic regime shifts and draws on the history of conflict between Canada and the United States over Pacific salmon (*Oncorhynchus* spp.) management to illustrate the dangers that unpredicted, unanticipated environmental regime shifts pose for the efforts to maintain international cooperation (Hannesson 2007). Another, well-documented example of this is the coastal state agreement on the management of the Norwegian spring-spawning herring (*Clupea harengus*) that was suspended for two years (2003 and 2004) (Hannesson 2006) when the stock failed to resume its expected migration pattern by spending the winter in Norwegian coastal waters rather than out in the open Norwegian Sea. The Norwegian fishermen, in particular, were not content with their share of the catches as the stock spent most of its time within the Norwegian EEZ (Sissener and Bjørndal 2005). Further, Miller (2007) examined the effects of climate variability on a small number of economically important shared and highly migratory marine fish resources and outlined the results of previous case studies that highlight the disruptive effects of climate variability on international harvest management efforts. In these cases, limited understanding and poor predictability of the biological impacts of climate variability contributed to the dysfunction or breakdown of existing cooperative management arrangements. Changing patterns of abundance and availability also led to shifts in power relationships among the competing harvesting entities. Furthermore, Miller (2007) then explored the potential management challenges posed by the effects of climatic variability on tropical tuna stocks in the western and central Pacific and western Indian oceans in light of the rapid development of commercial fisheries for tropical tuna in those regions over the past two decades. The fact that coastal states' EEZs encompass only part of the migratory range of the target fish, as well as the significant role of distant water fishing nations (DWFNs) in harvesting these stocks, creates an incentive structure that is quite different from the previously described cases.

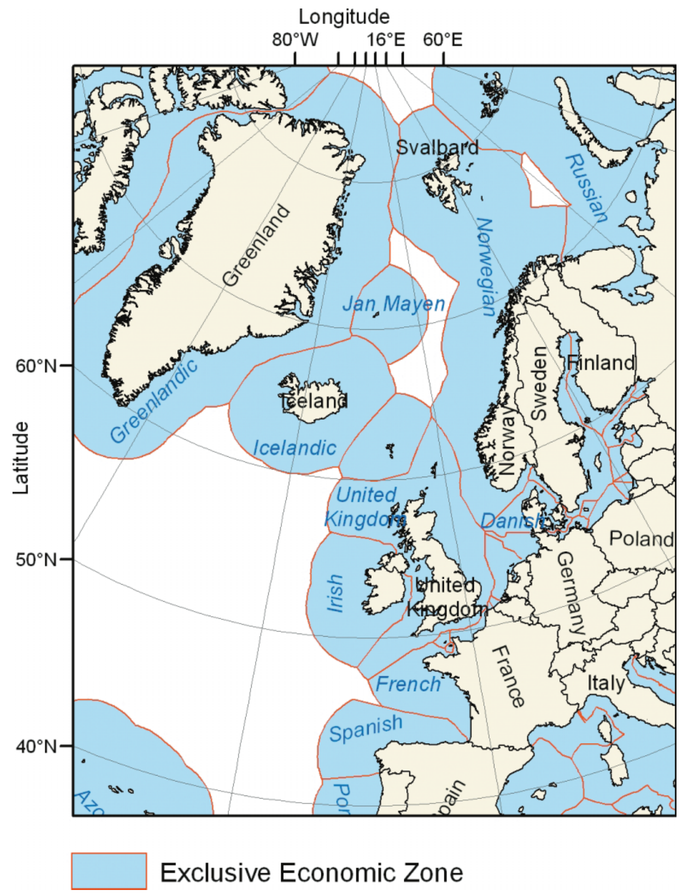
In this paper, we examine, within the framework of noncooperative, endogenous formation of coalitions and coalition structures (Pintassilgo 2003; Lindroos et al. 2007), the effects of distribution scenarios on a management agreement between the coastal states with EZZs in which the blue whiting stock (*Micromesistius poutassou* Risso) in the Northeast Atlantic is harvestable. In addition, the blue whiting stock is harvestable on the high seas (international waters), where it is accessible not only to the coastal states, but also to vessels from DWFNs. The analysis is conducted, drawing on the games and model described in Ekerhovd (2008), by changing the shares (quarterly zonal attachment) of the blue whiting stock available in the different EEZs and the high seas.

In the past and at present, the blue whiting is harvestable in the EEZs of Norway, Iceland, the Faroe Islands, and the European Union (EU), as well as in the international waters of the Northeast Atlantic and the Norwegian Sea, beyond national jurisdiction. The Barents Sea is a fringe area for the species, and there are no fisheries for blue whiting there (Bailey 1982; Monstad 2004; Heino et al. 2008). Hence, Russia, although a major participant in the blue whiting fishery, is not regarded as a coastal state with respect to the blue whiting fishery.

This outlines the basis for the game analysed in Ekerhovd (2008) and one of the distribution scenarios analysed in this paper in which the coastal states formed a coalition maximizing their cooperative value given Russia's harvest in international waters. The main finding in Ekerhovd (2008) was that the benefits of the coastal state coalition are not sufficiently large to cover all member states' profits, simultaneously, to keep them from unilaterally leaving the coalition while the other coastal states remain in the coalition. However, if the option is either full costal state cooperation or no cooperation at all, the prospects for achieving and maintaining a coastal state coalition is brighter.

Another distribution scenario analysed here is a climatic regime in which the ocean temperature becomes warmer and the area of distribution of the harvestable blue whiting stock expands into the Russian EEZ, which would give it status as coastal state with respect to the resource and, thus, a partner in the management agreement. The inclusion of Russia as a coastal state will secure the maximum attainable cooperative value for the coastal state coalition. Whether or not the coalition becomes more stable depends on the extent to which the increase in coalition value is sufficient to compensate unilaterally the free-rider values of both Russia and the other coastal states. By free-riding, we mean someone who reaps (some of) the benefits of a cooperative arrangement without participating in it.

Fig. 1. The exclusive economic zones (EEZs) and the high seas (North East Atlantic Fisheries Commission (NEAFC) regulatory area) in the Northeast Atlantic (NEAFC convention area). Source: Institute of Marine Research, P.O. Box 1870 Nordnes N-5817 Bergen, Norway, with EEZs from Flanders Marine Institute (Belgium).



The blue whiting fishery

The blue whiting stock migrates through the EEZs of the EU, the Faroe Islands, Iceland, and Norway (Fig. 1), considered as the coastal states with respect to the stock, and into the international waters beyond the EEZs (Fig. 1), where it can be harvested by vessels from any country, not just the coastal states. Besides the coastal states, Russia is an important player in the blue whiting fishery.

After 1991, the landings of blue whiting steadily increased, until they suddenly increased from about 650 thousand tonnes in 1996 to 1.1 million tonnes in the next year and continued increasing from then on more or less steadily to about 2.4 million tonnes in 2004 (International Council for the Exploration of the Sea (ICES) 2007). To be able to fish blue whiting in the waters of other countries, the nations have negotiated bilateral quotas within the various zones. Because of the lack of agreed sharing of the quota, the negotiations did not consider the recommended total allowable catch (TAC). In addition, each country allowed for unlimited landings from its own waters, as well as from international waters. As a result, the actual harvest in 2001 was in fact almost three times as large as recommended by ICES (2003).

As the landings of blue whiting grew to significant quantities, it became clear that an international agreement was needed on how to share this resource among the nations involved. The North East Atlantic Fisheries Commission (NEAFC) organized a series of meetings to this end, including workshops, discussions, and negotiations. However, despite two years of such meetings, in the early 1990s, when the matter was thoroughly dealt with, no agreement was reached on how to share the TAC, i.e., the quota recommended by NEAFC on the basis of advice from ICES (Monstad 2004; Bjørndal 2009).

NEAFC is a regional fisheries management organization with membership open to all parties with real interests in the fish stocks within the areas covered by the convention. NEAFC is intended to serve as a forum for consultation, the exchange of information on fish stocks, and the management of these and to advise on the fisheries in the high sea areas mentioned in the convention on which the commission is based. Because most of the fisheries take place within the jurisdiction of the coastal states, NEAFC has no real management responsibilities beyond the fraction of the fish stocks located within the high seas areas covered by the convention (Bjørndal 2009).

However, in December 2005, the coastal states consisting of the EU, the Faroe Islands, Iceland, and Norway signed an agreement (Appendix A). The agreement, starting in 2006, includes a long-term management strategy that implies annual reductions in the landings until the management goals are reached (Anonymous 2006). This arrangement provided for catches in 2006 of 2 million tonnes, allocated as follows: the EU, 30.5%; the Faroe Islands, 26.125%; Norway, 25.745%; and Iceland, 17.63%. Russia will be accommodated by quota transfers from some of the coastal states and additional catches in the NEAFC area (Appendix B).

Although it would be interesting to explicitly examine the possible role of the practice of bilateral quota swapping in maintaining cooperation when it would otherwise be difficult to sustain, we do not consider arrangements that allow foreign vessels to fish blue whiting inside other nations' EEZs. The quota-swapping bargaining involves exchanging quotas on several different fish species, and in a proper analysis of these practices, several fisheries should be considered simultaneously. While acknowledging the importance of bilateral arrangements, we stylize the blue whiting management and assume that the fleets fish in their respective EEZs and in the high seas areas, the NEAFC regulatory area (NEAFC RA).

Material and methods

Distribution of the blue whiting stock

The year (y) is divided into quarters, j, and i denotes the respective fleets (for a list of symbols, see Table 1). In the noncooperative case, the is are identical to the EEZs of the coastal states, and NEAFC RA (Bjørndal 2009) are the international waters (Fig. 1). Thus, $\theta_{i,j}$ denotes the shares of the blue whiting stock available for harvest in the different waters throughout the year. Harvest within a certain year is modelled sequentially. That is, the blue whiting stock migrates through different waters during a year (Fig. 2) and is available for harvest in different proportions in the EEZs and the high seas areas in the Northeast Atlantic, depending on the season. When the blue whiting is not present in a coastal state's EEZ, the fleet from that country can only fish blue whiting in international waters, if possible. This is a simplification that we make. In reality, bilateral agreements exist allowing foreign vessels access to the stock in national waters. Otherwise, they can harvest in their home waters, as well as on the high seas.

The Norwegian Sea and the Barents Sea area is one of the world's richest, purest, and most productive marine areas and is one where the climate, in both the sea and the atmosphere, is expected to change in response to global warming (Arctic Climate Impact Assessment (ACIA) 2004; Stenevik and Sundby 2007; Ellingsen et al. 2008).

As the water temperature rises, the blue whiting's distribution boundaries will probably be extended to the north and east, and it is likely to occur in the area in higher concentrations and more regularly than in the past. Eventually, the blue whiting will possibly inhabit the southwestern parts of the present Arctic area on a permanent basis (ACIA 2004).

However, there is considerable uncertainty about the realisation of the above scenario, and the effects of climate change on the blue whiting in the Barents Sea might be small or insignificant. Simulations show that there will be no change in the decadal mean flow of water into the Barents Sea during the next 50 years, but the temperature of the water transported into the Barents Sea will become significantly higher (increase of about 1 °C during the period) (Ellingsen et al. 2008). Even though the simulation results show that the future climate will be warmer, there are also years when the climate is comparable to periods of the present climate. The position of the Polar Front in the Barents Sea, separating the warm Atlantic water from the cold Arctic water, is strongly governed by topography in the western part of the Barents Sea. In the east, where the topographic control is weak, changes of the position of the Polar Front towards the north and east are more likely (ACIA 2004).

The blue whiting stock increased from 1995 to 2004, when it started to decline. Simultaneously to the increased stock size, the stock expanded its horizontal distribution area towards north and west. When the stock started to decline again, it remained in the northern and western areas (K.R. Utne (Institute of Marine Research, Nordnesgt. 33, 5085 Bergen, Norway, kjell.rong.utne@imr.no), G. Huse, G. Ottersen, V. Zabavnikov, J.A. Jacobsen, G.J. Óskarsson, and L. Nøttestad, unpublished data).

Hátún et al. (2009*b*) documented a link between a weak subpolar gyre (Hátún et al. 2005) and strong blue whiting recruitment, along with a shift in spawning area, from south to north, i.e., from the Porcupine Bank southwest of Ireland to the Rockall Plateau west of the Hebrides (Salthaug 2009). Furthermore, Hátún et al. (2009*a*) showed that during the warm and saline condition, associated with a weak subpolar gyre index, the blue whiting fishery was more spatially distributed towards the western areas in Icelandic and Faroese waters than in colder and less saline periods. This indicates that under warmer climatic conditions, blue whiting distribution does not necessarily, or at least not only, expand its boundaries to the north and east in the Barents Sea, but rather to the north and west in the Norwegian Sea.

Here we present some potentially plausible relative shares (Tables 2 and 3) that we have postulated. It is difficult to determine the relative shares empirically, especially scenario 2, as a situation in which Russia is able to harvest blue whiting in its EEZ and is regarded as coastal state by the others has not been observed. Therefore, the shares are used illustratively and intended only to represent possible scenarios.

Scenario 1

Scenario 1 (Table 2) denotes the case of a more westerly distribution of the blue whiting stock in the Norwegian Sea. Spawning takes place in the waters between Iceland and the Faroe Islands, as well as in EU waters. The westerly distribution reduces the availability of the blue whiting in interna-

Table 1. List of symbols and abbreviations.

	Definition	Range	Unit	Subscript
Subscripts				
a	Age	$\{1, 2, \ldots, 10+\}$ years		
y	Time	Current year		
j	Quarter	$\{1, 2, 3, 4\}$		
i	Fleet index	n		
n	Number of fleets	Fleets		
Variables				
N	Abundance		Numbers	a, j, y
SSB	Spawning stock biomass		kg	y
R	Recruitment		Numbers	y
X	Fishing effort			i
Π	Profit		NOK	i,j,y
V	Value		NOK	i
P	Coalition value		NOK	i
F	Fishing mortality			a,j,i
Parameters				
m	Natural mortality		0.2	a
p	Price		0.8 NOK	
r	Discount rate		5%	
θ	Zonal attachment		cf. Tables 2 and 3	i,j
mo	Maturity ogive		cf. Table 4	a
q	Accessability		cf. Table 4	a,j
w	Weight		cf. Table 4	a
α	Recruitment parameter		cf. Table 5	
β	Recruitment parameter		cf. Table 5	
c	Cost parameters		cf. Table 6	i
Abbreviations				
ACIA	Arctic Climate Impact Assessment			
NEAFC	North East Atlantic Fisheries Commission			
RA	Regulatory area			
ICES	International Council for the Exploration of the Sea			
ACFM	Advisory Committee on Fisheries Management			
NOK	Norwegian kroner			
CS	Coastal states			
C	Coalition structure			
S	Coalition			
DWFN	Distant water fishing nation			
TAC	Total allowable catch			
EU	European Union			
FO	Faroe Islands			
IS	Iceland			
NO	Norway			
RU	Russia			
NPV	Net present value			

tional and Norwegian waters, and Russia is not regarded as a coastal state.

The blue whiting stock becomes more evenly distributed within the initial coastal states' EEZs, and between the EEZs and the high seas. Furthermore, Russia is excluded from participating in the coastal state coalition, as in Ekerhovd (2008).

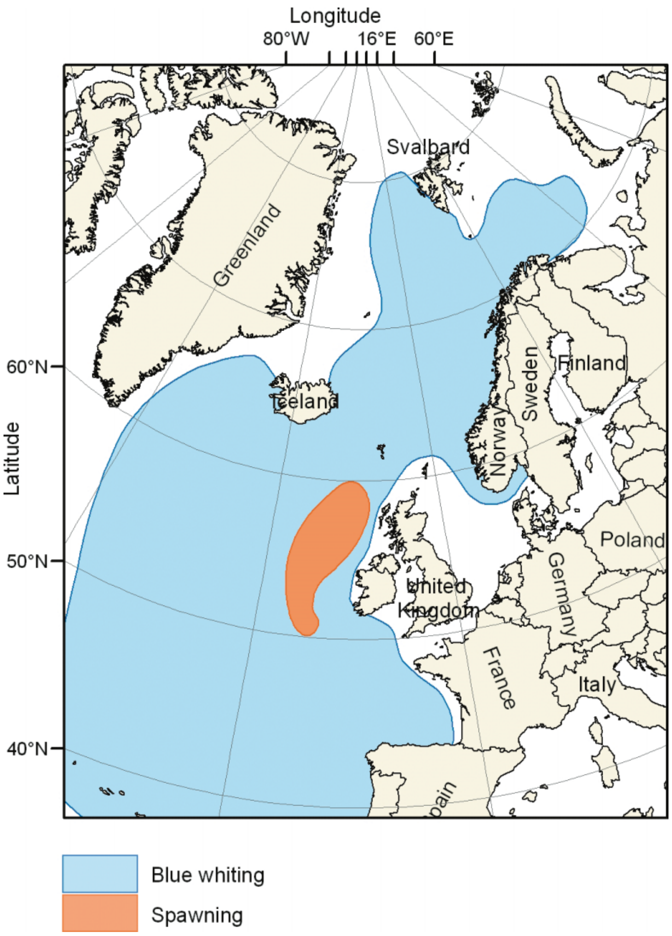
Scenario 2

Scenario 2 (Table 3) denotes the case in which the habitat of the blue whiting expands northeastward into the Barents Sea such that Russia becomes a coastal state and the blue whiting appears in Norwegian waters during the second quarter, in addition to EU and Faroese waters.

Biological submodel

Our model encompasses age groups 1 to 10+. The age groups are harvested simultaneously by applying a fleet-specific fishing mortality $F_{a,j,i}$ to all age groups. The catch rate for each fleet i is governed by two parameters, the effort, X_i, and the accessability coefficient, $q_{a,j}$, where a denotes the age group and j denotes the season. This is a

Fig. 2. Map summarizing the migration pattern and areas of concentration of adult blue whiting (*Micromesistius poutassou*). Source: Institute of Marine Research, P.O. Box 1870 Nordnes N-5817 Bergen, Norway.



version of the classical Schaefer (1957) production function, which assumes proportionality between effort and fishing mortality.

The selectivity of the pelagic trawls used in the blue whiting fishery is, at least in principle, uniform for all age groups, meaning that the gear catches fish indiscriminately of size or age. The reason for this lack of age-specific escapement from the gear is that in the opening of the trawl, which covers a huge area of water (Standal 2006), the mesh size is quite large, several metres in fact (Bailey 1982), and at the other end, where the fish finally end up, the mesh size is much smaller, about 50 mm. Furthermore, there are one or two extra nets outside the fish end to prevent it from breaking as a result of the increased pressure generated when the swim bladder expands as the fish is forced to the surface (Monstad 2004).

The abundance of each age group in landings from specific areas varies over time and is governed by many factors. The age distribution of the landings is not uniform across the age groups. Instead, we stylize the accessibility coefficients based on assumptions about the age distribution for each area that seems reasonable (Table 4). In the first two quarters of the year, the stock is either migrating towards or already in the spawning areas (Fig. 2). Therefore, the accessibility coefficients for quarters 1 and 2 are set equal to the age-specific proportion of the maturity ogive, that is, the age distribution of the harvest is equal to the age distribution in the spawning stock biomass (SSB). In quarter 3, the stock

Table 2. Scenario 1 — quarterly zonal attachment, $\theta_{i,j}$, of the blue whiting (*Micromesistius poutassou*) stock.

	Quarter			
	1	2	3	4
Scenario 1*a*				
NEAFC RA	1/2	0	1/6	1/6
EU	1/2	1/2	0	0
FO	0	1/4	1/3	1/3
IS	0	1/4	1/3	1/3
NO	0	0	1/6	1/6
RU	0	0	0	0
Scenario 1*b*				
NEAFC RA	1/2	0	1/4	1/4
EU	1/2	1/2	0	0
FO	0	1/4	9/32	9/32
IS	0	1/4	9/32	9/32
NO	0	0	3/16	3/16
RU	0	0	0	0
Scenario 1*c*				
NEAFC RA	1/2	0	1/4	1/4
EU	1/2	1/4	0	0
FO	0	1/4	1/4	1/4
IS	0	1/4	1/4	1/4
NO	0	1/4	1/4	1/4
RU	0	0	0	0

Note: See Table 1 for abbreviations.

Table 3. Scenario 2 — quarterly zonal attachment, $\theta_{i,j}$, of the blue whiting (*Micromesistius poutassou*) stock.

	Quarter			
	1	2	3	4
Scenario 2*a*				
NEAFC RA	1/3	0	1/3	1/3
EU	1/3	1/3	0	0
FO	1/9	1/3	1/9	1/9
IS	1/9	0	1/9	1/9
NO	1/9	1/3	1/3	1/3
RU	0	0	1/9	1/9
Scenario 2*b*				
NEAFC RA	1/2	0	1/4	1/4
EU	1/8	1/3	0	0
FO	1/8	1/3	1/6	1/6
IS	1/8	0	1/6	1/6
NO	1/8	1/3	1/4	1/4
RU	0	0	1/6	1/6
Scenario 2*c*				
NEAFC RA	1/4	0	1/5	1/5
EU	1/4	1/4	0	0
FO	1/6	1/4	1/5	1/5
IS	1/6	1/4	1/5	1/5
NO	1/6	1/4	1/5	1/5
RU	0	0	1/5	1/5

Note: See Table 1 for abbreviations.

Table 4. Blue whiting (*Micromesistius poutassou*): proportion of maturation, accessibility, weight at age (kg·individual^{-1}), and numbers at age (in millions) in 2000 and 2006.

	Accessibility coefficients				Numbers at age	
Age group	mo_a*	$q_{a,3}$	$q_{a,4}$	Weight at age	2000	2006
1	0.11	1.00	1.00	0.049	39 743.1	1 1141.0
2	0.40	1.00	1.00	0.075	16 963.6	18 435.0
3	0.82	1.00	1.00	0.102	16 123.1	18 369.9
4	0.86	1.00	1.00	0.125	12 150.7	15 955.9
5	0.91	0.50	1.00	0.147	3 813.6	7 862.8
6	0.94	0.25	1.00	0.168	909.8	5 220.1
7	1.00	0.10	1.00	0.185	435.0	1 440.2
8	1.00	0.10	1.00	0.200	207.4	337.0
9	1.00	0.10	1.00	0.222	138.7	209.3
10+	1.00	0.10	1.00	0.254	384.3	171.1

*Maturity ogive, used as an age-specific accessability coefficient in catches of the first and second quarters, $q_{a,1}$ and $q_{a,2}$, respectively.

has finished spawning and has migrated to the feeding areas in the Norwegian Sea. As the older individuals start the migration earlier and travel farther than the younger ones (Bailey 1982), they are too widely dispersed on their migration to be caught. Moreover, younger individuals are reported as being over-represented in the landings from the Norwegian Sea during summer (Heino 2006). Furthermore, the accessibility coefficients of quarter 3 are set to unity for the younger age groups, while being held at a lower level for the older ones. In quarter 4, we assume that the entire stock congregates before starting the migration back to the spawning grounds. This results in a uniform age distribution. Note that the $q_{a,j}$s distribute the overall fishing effort across the different age groups (Table 4).

All age classes are subject to natural mortality, m, set to 0.2 for all age groups, which appears to be a common assumption and used for stock assessment (ICES 2007). It is assumed that only the older component of the population (from age class 7 on) is fully mature, whereas the younger age classes are only partially mature. The values for the maturity ogive (Table 3) were estimated by the 1994 Blue Whiting Working Group (ICES 1995). The estimate of the maturity ogive defines the proportion of the mature individuals in the age class as constant average, mo_a, for each age class. The annual SSB is then given by

$$(1) \qquad \mathrm{SSB}_y = \sum_{a=1}^{10+} mo_a w_a N_{a,y}$$

where w is the individual weight (in kilograms; Table 4; ICES 2007), and N is the number of fish.

The stock in the beginning of the first quarter of each year is equal to the recruitment to the youngest cohort plus the fish that survived the last quarter of the previous year.

To determine a possible stock–recruitment relationship, we try to fit the well-known stock–recruitment models of Beverton and Holt (1957) and Ricker (1954) to data on the SSB and recruitment. However, we failed to obtain any satisfactory fit between the data and the models (Ekerhovd 2008). Instead, a serially correlated recruitment relationship, estimated on the recruitment from 1981 to 2006, reported in ICES (2007), was used in linking the number of recruits, R_y, to the previous year's recruitment, R_{y-1}. An explanation for this relationship is that the recruitment is mainly dependent on various environmental factors such that a possible stock–recruitment relationship drowns in the noise (Ekerhovd 2008). In addition, the serial correlation that we found indicates that good or bad environmental conditions occur at least two years in a row (Fig. 3).

When running this serially correlated recruitment process, starting from any initial recruitment level, the recruitment will converge to a certain recruitment level given the parameter values, and this level is independent of the fishing effort applied. This means that the steady-state recruitment of the serially correlated recruitment process (Table 5) will be about 21.5 billion individuals entering the fishable stock in steady state (Fig. 4). This recruitment level is relatively strong if we compare it with the average recruitment of the period 1981–1995, which was less than 10 billion recruits, but moderate if we compare it with the average recruitment of about 36 billion for the years 1996–2005. Such a strong and reliable recruitment would lead to an unrealistic and overoptimistic valuation of the stock and leave us with the impression that the stock can sustain a very high fishing effort indefinitely. To compensate for this and in spite of the fact that we were unable to establish any stock–recruitment relationship, we let the recruitment process be dependent on the SSB, as follows.

In 1998, ICES's Advisory Committee on Fisheries Management (ACFM) defined limit (lim) and precautionary (pa) reference points for this stock as follows: B_{lim} (1.5 million tonnes), B_{pa} (2.25 million tonnes), F_{lim} (0.51), and F_{pa} (0.32) (ICES 1998). The advice of ACFM in the following years has been given within a framework defined by these reference points (ICES 2003).

Note that we do not treat the reference points as something that the countries have agreed upon (Lindroos 2004), but rather as a biological feature of the stock, and that fishing could continue even when the spawning stock is below B_{lim}.

As long as SSB is greater than or equal to B_{pa}, we let the recruitment follow the serially correlated process $R_y = \alpha +$

Fig. 3. Blue whiting (*Micromesistius poutassou*) recruitment (in millions) observed (◆) and estimated (□) using the serial recruitment relationship $R_y = \alpha + \beta \times R_{y-1}$, plotted over time, 1981–2006 (ICES 2007).

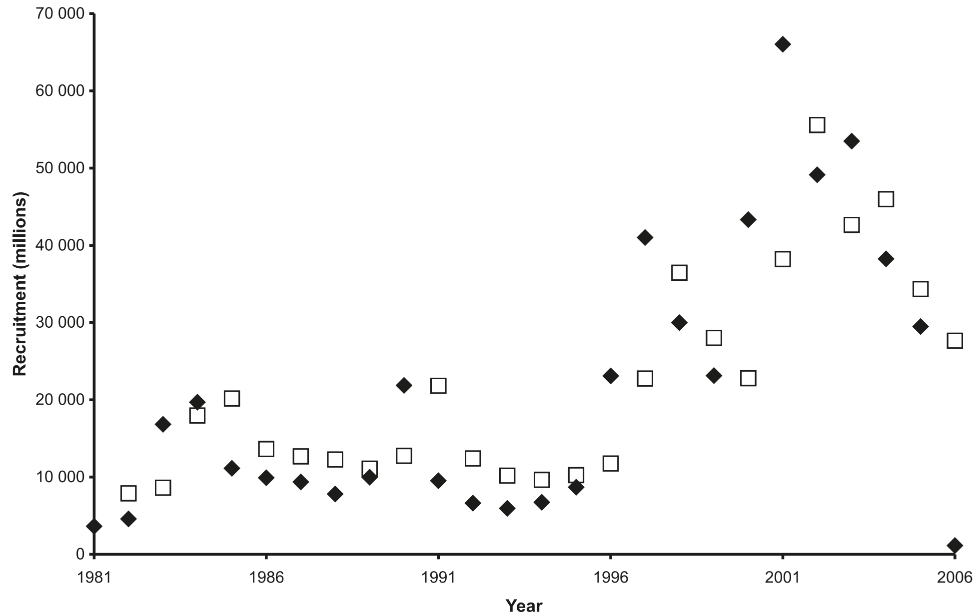


Table 5. Estimated serially recruitment relationship fitted to data from 1981–2006 (ICES 2007).

Parameters			
α	β	R^2_{adjusted}	Durbin–Watson test statistic
5113.6 (3790.4)	0.76 (0.14)	0.56	1.51

Note: Standard errors in parentheses.

$\beta \times R_{y-1}$. If SSB falls below B_{pa} but stays above B_{lim}, the recruitment is fixed at α and 5113.6 million individuals are recruited annually. Further reduction of SSB below B_{lim} leads to partial recruitment failure, with recruitment dropping to only 500 million recruits annually. Hence,

$$(2) \qquad R_y = \begin{cases} 500 & \text{if } \mathrm{SSB}_{y-1} < B_{\mathrm{lim}} \\ \alpha & \text{if } B_{\mathrm{lim}} \leq \mathrm{SSB}_{y-1} < B_{\mathrm{pa}} \\ \alpha + \beta \times R_{y-1} & \text{otherwise} \end{cases}$$

The empirical foundation for what will happen to the recruitment if the SSB is severely reduced is weak. Over the period from 1981 to 2006 (Fig. 5), a SSB below B_{lim} has hardly been observed, was reported to be less than B_{pa} only a few times, and certainly did not collapse. Moreover, the period from 1996–2005 can be regarded as extraordinary. In hindsight, and in spite of the high and increasing fishing mortality of this period, the SSB is estimated to have been about 4.3 million tonnes in 2000, about 4.6 million tonnes in 2001, and increasing until at least 2003 (Fig. 5). However, evidence from other heavily exploited fish stocks suggests that sustained harvesting outside what is considered safe biological limits will eventually lead to recruitment failure and stock collapse, although under favourable environmental conditions, it may take some time for this to become evident. Hence, we have decided to follow the biologists in assuming that low SSB and high fishing mortality indicate that the stock is harvested outside safe biological limits that will eventually end in a recruitment failure.

The numbers of fish at the beginning of a season that have survived previous quarter's harvest and avoided death by natural causes are given as follows (dropping the year subscript y):

$$(3) \qquad N_{a,j} = N_{a,j-1}\left\{\sum_i \theta_{i,j-1}\, \mathrm{e}^{-[m/4+q_{a,j-1}X_i]} + \theta_{\mathrm{NEAFC},j-1}\, \mathrm{e}^{-[m/4+q_{a,j-1}\sum_i X_i]}\right\}$$

Game theory

Before we continue with the economic model, we discuss equilibrium concepts and solution methods.

To predict the outcome of the game, we focus on the possible strategy profiles, as it is the interaction of the different players' strategies that determines what happens. The distinction between strategy profiles, which are sets of strategies, and outcomes, which are sets of values of whichever variables are considered interesting, is a common source of confusion (Rasmusen 2007). Often different strategy profiles lead to the same outcome.

Predicting what happens consists of selecting one or more strategy profiles as being the most rational behaviour by the players acting to maximize their payoffs.

Fig. 4. Development of the serially correlated recruitment relationship $R_y = \alpha + \beta \times R_{y-1}$ over time from a high 2001 (×) and a low 2006 (○) initial recruitment level, respectively.

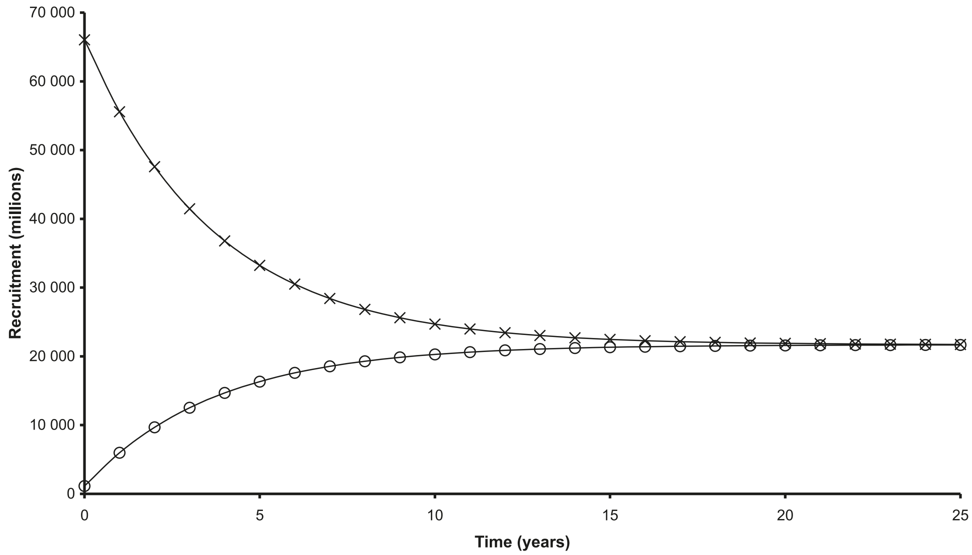
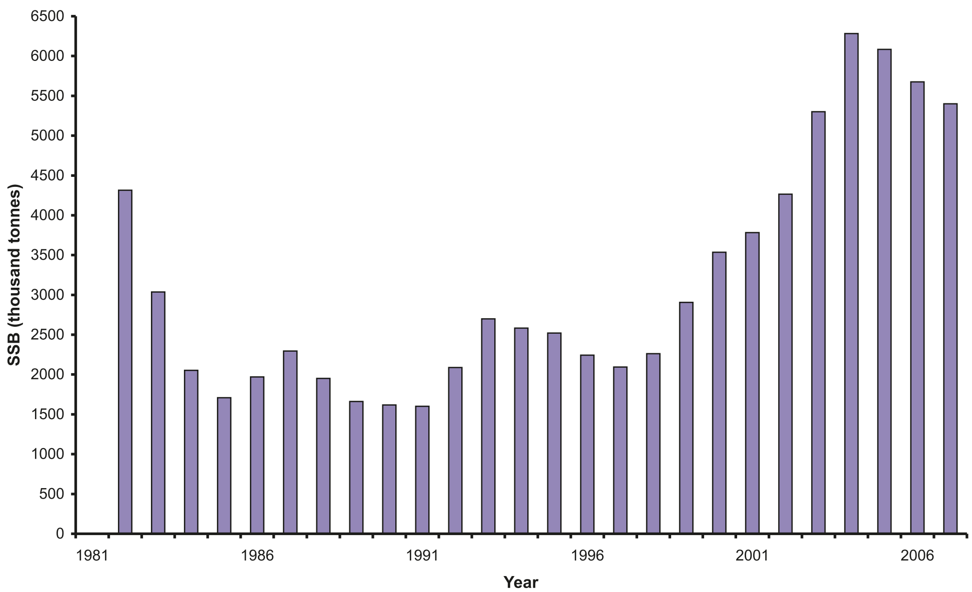


Fig. 5. Blue whiting (*Micromesistius poutassou*) spawning stock biomass (SSB), 1981–2006 (ICES 2007).



> An equilibrium $X^* = (X_1^*, ..., X_n^*)$ is a strategy profile consisting of a best strategy for each of the n players in the game. (Rasmusen 2007, p. 18)

The equilibrium strategies are the strategies that players pick in trying to maximize their individual payoffs, as distinct from the many possible strategy profiles obtainable by arbitrarily choosing one strategy per player. In game theory, the set of payoffs would be an equilibrium outcome, but the equilibrium itself would be the strategy profile that generated the outcome.

To find the equilibrium, it is not enough to specify the players, strategies, and payoffs, because we must also decide what "best strategy" means. We do this by defining an equilibrium concept.

> An equilibrium concept or solution concept $H(X_1, \ldots, X_n, V_1, \ldots, V_n) \rightarrow X^*$ is a rule that defines an equilibrium based on the possible strategy profiles and the payoff functions. (Rasmusen 2007, p. 18)

Accepted solution concepts do not guarantee uniqueness, and lack of a unique equilibrium is a major problem in game theory. Often the solution concept employed leads us to believe that the players will pick one of the two strategies A or B, but we cannot say whether A or B is more likely.

A model with no equilibrium or multiple equilibria is underspecified. The modeller has failed to provide a full and precise prediction for what will happen. One option is to admit that the theory is incomplete. Or perhaps the situation being modelled really is unpredictable, in which case to make a prediction would be wrong. Another option is to renew the attack by changing the game's description or the solution concept (Rasmusen 2007).

In discussing equilibrium concepts, it is useful to have a shorthand for "all other fleets' fishing efforts." For any vector $I = (I_1, \ldots, I_n)$, denote by I_{-i} the vector $(I_1, I_{i-1}, I_{i+1}, \ldots, I_n)$, which is the portion of I not associated with fleet i.

Using this notation, X_{-i} is the profile of fishing effort strategies for every fleet except for fleet i. That profile is of great interest to i, because it uses it to help choose its own fishing effort, and the new notation helps define its best response. Fleet i's best response to the fishing efforts X_{-i} chosen by the other fleets is the fishing effort X_i^* that yields it the greatest NPV, that is,

$$(4) \qquad V_i(X_i^*, X_{-i}) \geq V_i(X'_i, X_{-i}) \quad \forall \quad X'_i \neq X_i^*$$

The best response is strongly best if no other fishing efforts are equally good, and weakly best otherwise.

Nash (1951) equilibrium is the standard equilibrium concept in economics. Nash equilibrium is so widely accepted that the reader can assume that if a model does not specify which equilibrium concept is being used, it is Nash or some refinement of Nash.

> The fishing effort (strategy) profile is a Nash equilibrium if no fleet (player) has incentives to deviate from its fishing effort given that the other fleets do not deviate. (Rasmusen 2007, p. 26)

Formally,

$$(5) \qquad \forall i, \quad V_i(X_i^*, X_{-i}^*) \geq V_i(X_i', X_{-i}^*), \quad \forall X_i'$$

A straddling stock fishery usually involves many countries and fleets. The analysis of games in which the number of players exceeds two requires analysis of coalitions (Sumaila 1999). A coalition means a subset of the set of players. Two or more countries are considered to form a coalition if they ratify (or sign) a mutual agreement on the particular fishery. Three types of coalition scenarios may result. If all parties concerned sign the agreement, the situation is denoted full cooperation, and a grand coalition is said to be formed. If some countries are left outside the agreement, the situation is denoted partial cooperation, and the outsiders may act as free riders (Lindroos et al. 2007). Finally, in the case of noncooperation, there are no agreements between the countries, and each is only interested in maximizing individual net present value from the fishery. The value for coalition members depends on the particular behaviour of nonmembers. The assumption made in this paper is that nonmembers of the coastal state coalition act as single fleets (singletons) and adopt individually best-response fish efforts (strategies) against other fleets. This results in a Nash equilibrium between the fleets.

In a second stage, it is assumed that the members of the coalition act cooperatively, forming a single common fleet, by choosing a fishing strategy that maximizes the net present value for the coalition, given the strategies of the outsiders. The outsiders, or all players in the case of noncooperation, choose the strategy that maximizes their own individual net present values given the behaviour of the other players. This noncooperative behaviour leads to a noncooperative solution for each coalition structure (Lindroos et al. 2007).

The game is solved backwards. The result will be a Nash equilibrium of the game where it is not profitable for any of the coalitions or players to unilaterally deviate from the equilibrium strategies. The procedure for solving the game has to be repeated for each possible coalition structure. Having solved all these games allows us to proceed to stage 1 to find the equilibrium coalition structure. Of course, there may exist several equilibrium coalition structures, one equilibrium, or none at all.

In the blue whiting fishery game, each player simultaneously announces a list of players (including itself) with whom it is willing to form a coalition. The players that announce exactly the same list of nations belong to the same coalition. Given the players' announcements, the resulting coalition structure is one in which the players belong to the same coalition if and only if they choose exactly the same list of players (Yi 2003). Coalition structures C can be characterized as follows.

Let us assume the coastal states in scenario 1, consisting of the European Union (EU), the Faroe Islands (FO), Iceland (IS), and Norway (NO), with Russia (RU) as a DWFN. If the coastal states find it beneficial to form a coalition (EU,FO,IS,NO), while (RU) formulates its own unilateral fishing effort strategy, the coalition structure is (EU,FO,IS,NO),(RU). Clearly, the benefits of the coastal state coalition must depend on the fishing effort decision of Russia because externalities are present in fisheries (Pintassilgo 2003).

In scenario 2, on the other hand, the coastal states, now consisting of the European Union (EU), the Faroe Islands (FO), Iceland (IS), Norway (NO), and Russia (RU), find it beneficial to form a coalition (EU,FO,IS,NO,RU). Thus, the coastal states act as a cooperative unit, full cooperation is achieved, and (EU,FO,IS,NO,RU) is the resulting coalition structure.

If we compare the NPVs of the coastal state coalitions, we will typically find that it is larger in scenario 2 when all countries cooperate than in scenario 1, when Russia is outside the coalition, unilaterally maximizing its own NPV.

We can calculate the net present values for the coalition game setting. We do not, however, calculate the NPVs for every possible coalition structure of the game but restrict our analysis to calculate the NPVs of the coastal state coalition and the NPVs accruing to its members from unilateral free-rider behaviour. In addition, we calculate the individual NPV to players when all act noncooperatively.

For the singletons, we assume that the countries play a noncooperative game. This means that when a country does not belong to any coalition, it does not cooperate, and all that it can do is maximize its own profit, taking into account the strategies of the other players.

The countries outside the coalition will play noncooperatively against the coalition members. Thus, the members of the coalition will try to do their best, taking into account the actions of the outside countries and vice versa.

Under full cooperation, the value of the grand coalition, where all players are cooperating, is given by maximizing the sum of net revenues of the countries.

A coalition is said to be stable if there is no player that finds it optimal to join the coalition (external stability) and if no player within the coalition finds it optimal to leave the coalition (internal stability) (Lindroos et al. 2007).

When determining the stability properties of the coastal state coalition, it is sufficient to check for internal stability. To verify this, we can apply the criterion of stand-alone stability (Yi 1997), which states that a coalition is stand-alone stable if and only if no player finds it profitable to leave its coalition to form a singleton coalition, holding the rest of the coalition structure constant (including its former coalition). In the case of the coastal state coalition, this occurs when no coastal state is interested in leaving the coastal state coalition to adopt a free-rider behaviour.

In the management of shared and straddling fish stocks, positive externalities are expected to be present. In fact, as the members of a coastal state agreement tend to adopt strategies conserving the stock, a nonmember state is typically better off the greater the number of states that join the agreement. Pintassilgo (2003) established that the existence of externalities is a necessary, but not sufficient, condition for a coalition structure not to be stand-alone stable. To do so we define the coalition value.

> A game in partition function form specifies a coalition value $P(S, C)$ for every coalition structure and every coalition S that is an element of C. (Pintassilgo 2003, p. 179)

Formally, this can be written as:

$$P(S,C) = V(S,C) - \sum_{i \in S} V(S^i, C_T) \tag{6}$$

where $P(S, C)$ denotes the net value of coalition S under the coalition structure C; $V(S, C)$, the NPV of coalition S under coalition structure C; S^i, a singleton coalition formed only by player i; and C_T, the coalition structure in which all players act as singletons. Therefore, $V(S^i, C_T)$ is the threat point of player i.

A sufficient condition for a coalition structure not to be stand-alone stable is that the sum of the coalition value of the singleton coalitions, resulting from unilateral deviations from any of its coalitions, exceeds the value of that coalition (Pintassilgo 2003).

Economics

ICES's ACFM Northern Pelagic and Blue Whiting Working Group has conducted surveys and published reports on the development of the blue whiting stock. Data available on the economics of the blue whiting fishery, on the other hand, are scarce, not at all structured, dispersed, and not consistent. The exception is the Norwegian revenue surveys, collected by the Directorate of Fisheries 1991–2004, in which data from vessels targeting blue whiting along with several other important species are published (Ekerhovd 2007). Because of the severe data constraints, we build the model and determine intuitively those parameters that cannot be estimated for lack of data.

The profit earned by fleet i during a quarter of the year is as follows (dropping the year subscript y):

$$\Pi_{i,j} = pX_i \sum_{a=1}^{10+} q_{a,j} N_{a,j} w_a \left[\frac{\theta_{i,j}\left(1 - \mathrm{e}^{-[m/4 + q_{a,j}X_i]}\right)}{m/4 + q_{a,j}X_i} + \frac{\theta_{\mathrm{NEAFC},j}\left(1 - \mathrm{e}^{-[m/4 + q_{a,j}(X_i + X_{-i})]}\right)}{m/4 + q_{a,j}(X_i + X_{-i})} \right] - c_i X_i/4 \tag{7}$$

The first line of the right-hand side of eq. 7 is simply the price per unit, p (because most of the blue whiting landed is used for low-priced products such as fish meal and fish oil, the price is set equal to 0.8 NOK·kg^{-1}), multiplied by the weight of fleet i's quarterly harvest of all age groups, where w_a denotes the individual fish weight at age (Table 4). Again, note that X_i denotes fleet i's fishing effort, $q_{a,j}$, the quarterly age-specific accessibility coefficients, and $N_{a,j}$, the number of fish in age group a at the beginning of quarter j that have survived the previous quarter's harvest and avoided death by natural causes (cf. eq. 3). The first expression inside the brackets is the share of the total quarterly mortality from fishing in fleet i's EEZs, where $\theta_{i,j}$ denotes the shares of the total stock occupying the respective fleet's (coastal states) EEZs in quarter j, $m/4$ is the quarterly natural mortality, and $q_{a,j}X_i$ is the age-specific quarterly fishing mortality produced by fleet i's fishing effort only. Likewise for the second expression inside the brackets, but here $\theta_{\mathrm{NEAFC},j}$ denotes the share of the total stock occupying the high seas inside NEAFC convention area (Tables 2 and 3). In these waters (the NEAFC RA), fishing is open to all fleets. Therefore, the total age-specific quarterly fishing mortality here, $q_{a,j}(X_i + X_{-i})$, is a function of the sum of all fleets fishing effort (X_{-i} is the other fleet's fishing efforts). The expression on the second line is fleet i's total quarterly costs, where c_i is fleet i's cost parameter (Table 6), for every coalition structure and zonal attachment distribution in the game.

Here X is purely notational, and the only modes of cooperation observed are where the countries compete against each other, i.e., no cooperation at all, or full cooperation among the coastal states, with Russia as a nonmember. However, there are several possible ways in which the countries can engage in partial cooperation that are not observed in real life. Nevertheless, these intermediate and hypothetical levels of cooperation are important in finding the Nash equilibrium in a coalition game. Hence, to be able to proceed with this analysis, we need a consistent method of finding cost parameters for every coalition under every imaginable coalition structure. This method is as follows. Assume that all fleets apply an effort, X^{∞}, that results in a minimum recruitment such that the minimum stock level is reached after 35 years. The resulting cost parameters (Table 6) were set such that the present value of the revenues was absorbed by the costs. Our goal here is not to find the intramarginal profit of open access based on rational behaviour but intuitively determine those coefficients that cannot be estimated for lack of data.

The NPV of fleet i as a function of the control variable X_i is given by

Table 6. Coalition cost parameter (in million NOK).

	X^{∞}	CS	EU	FO	IS	NO	RU
Scenario 1*a*							
(EU,FO,IS,NO,RU)	0.1301	6735					
(EU,FO,IS,NO),(RU)	0.104	5776					1953
(EU,FO,IS,RU),(NO)	0.104	4416				3314	
(EU,FO,NO,RU),(IS)	0.104	5609			2121		
(EU,IS,NO,RU),(FO)	0.104	5178		2552			
(FO,IS,NO,RU),(EU)	0.104	5223	2507				
(EU),(FO),(IS),(NO),(RU)	0.0655		2387	2460	2054	3243	1894
Scenario 1*b*							
(EU,FO,IS,NO,RU)	0.1301	6735					
(EU,FO,IS,NO),(RU)	0.106	5540					2100
(EU,FO,IS,RU),(NO)	0.106	4645				2995	
(EU,FO,NO,RU),(IS)	0.106	5352			2288		
(EU,IS,NO,RU),(FO)	0.106	4929		2711			
(FO,IS,NO,RU),(EU)	0.106	5496	2144				
(EU),(FO),(IS),(NO),(RU)	0.0688		2009	2585	2198	2872	2021
Scenario 1*c*							
(EU,FO,IS,NO,RU)	0.1301	6735					
(EU,FO,IS,NO),(RU)	0.113	5453					1684
(EU,FO,IS,RU),(NO)	0.113	4882				2255	
(EU,FO,NO,RU),(IS)	0.113	4882			2255		
(EU,IS,NO,RU),(FO)	0.113	4882		2255			
(FO,IS,NO,RU),(EU)	0.113	5437	1701				
(EU),(FO),(IS),(NO),(RU)	0.0815		1584	2160	2160	2160	1627
Scenario 2*a*							
(EU,FO,IS,NO),(RU)	0.111	6071					1253
(EU,FO,IS),(NO),(RU)	0.0955	5716				1863	1272
(EU,FO,NO),(IS),(RU)	0.0955	5054			2925		1272
(EU,IS,NO),(FO),(RU)	0.0955	5054		2925			1272
(FO,IS,NO),(EU),(RU)	0.0955	4874	2705				1272
(EU),(FO),(IS),(NO),(RU)	0.0765		2537	2699	2699	1812	1219
Scenario 2*b*							
(EU,FO,IS,NO),(RU)	0.106	6107					1553
(EU,FO,IS),(NO),(RU)	0.0895	5435				2136	1495
(EU,FO,NO),(IS),(RU)	0.0895	4800			2772		1495
(EU,IS,NO),(FO),(RU)	0.0895	4800		2772			1495
(FO,IS,NO),(EU),(RU)	0.0895	4691	2881				1495
(EU),(FO),(IS),(NO),(RU)	0.0688		2734	2706	2706	2093	1446
Scenario 2*c*							
(EU,FO,IS,NO),(RU)	0.106	6107					1553
(EU,FO,IS),(NO),(RU)	0.0895	4907				2665	1495
(EU,FO,NO),(IS),(RU)	0.0895	4907			2665		1495
(EU,IS,NO),(FO),(RU)	0.0895	4907		2665			1495
(FO,IS,NO),(EU),(RU)	0.0895	5006	2566				1495
(EU),(FO),(IS),(NO),(RU)	0.0688		2444				1446

Note: See Table 1 for abbreviations.

$$(8)\qquad V_i(X_i, X_{-i}) = \sum_{y=0}^{\infty} \frac{\sum_{j=1}^{4} \Pi_{i,j,y}}{(1+r)^y}$$

where r is the rate of discount (a 5% discount rate is used throughout the calculations).

We can now use this (eq. 8) to find the best-response (eq. 4) Nash equilibria (eq. 5) for all coalitions and players in a given coalition structure. Then we can proceed with the analysis of the stability of the coastal state coalition.

Results

The best-response Nash equilibrium (cf. eqs. 4, 5, and 8) for each coalition structure in the game (Tables 7 and 9) are used to calculate the coalition values (Tables 8 and 10) of the coastal state coalition for scenario 1 and scenario 2, respectively, by subtracting the sum of the noncooperative payoffs to the individual coastal states from the payoff to the coastal state coalition (cf. eq. 6). The coastal states individual (coalition) values from unilateral deviation from the

Table 7. Scenario 1 — best-response Nash equilibria (net present values in million NOK).

	Total	CS	EU	FO	IS	NO	RU
Scenario 1*a*							
(EU,FO,IS,NO),(RU)	6934	3635					3299
(EU,FO,IS),(NO),(RU)	5640	2267				1712	1662
(EU,FO,NO),(IS),(RU)	5771	2252			1814		1704
(EU,IS,NO),(FO),(RU)	5771	2252		1814			1704
(FO,IS,NO),(EU),(RU)	5982	2017	2283				1682
(EU),(FO),(IS),(NO),(RU)							
Mean	4886	4055*	1228	961	961	905	831
Maximum			2546	2223	2223	1971	1820
Minimum			0	0	0	0	0
Scenario 1*b*							
(EU,FO,IS,NO),(RU)	6972	3699					3273
(EU,FO,IS),(NO),(RU)	6392	2947				2582	864
(EU,FO,NO),(IS),(RU)	6535	3115			2744		676
(EU,IS,NO),(FO),(RU)	6535	3115		2744			676
(FO,IS,NO),(EU),(RU)	6684	2808	3198				678
(EU),(FO),(IS),(NO),(RU)							
Mean	5124	4121*	1193	1003	1003	922	1003
Maximum			2955	2509	2509	2233	2298
Minimum			0	0	0	0	0
Scenario 1*c*							
(EU,FO,IS,NO),(RU)	6972	3699					3273
(EU,FO,IS),(NO),(RU)	5806	2017				2265	1524
(EU,FO,NO),(IS),(RU)	5806	2017			2265		1524
(EU,IS,NO),(FO),(RU)	5806	2017		2265			1524
(FO,IS,NO),(EU),(RU)	6420	2715	2841				865
(EU),(FO),(IS),(NO),(RU)							
Mean	5128	4120*	1056	1021	1021	1021	1008
Maximum			2494	2435	2435	2435	2357
Minimum			0	0	0	0	0

Note: See Table 1 for abbreviations.
*The sum of NPVs from the coastal states acting as singletons.

Table 8. Scenario 1 — coalition values (in million NOK).

Scenario	CS	EU	FO	IS	NO
1*a*	–420	1055	853	853	807
1*b*	–422	2005	1741	1741	1660
1*c*	–421	1785	1244	1244	1244

Note: See Table 1 for abbreviations.

coastal state coalition while the others remain in the coalition are found by subtracting the individual country's noncooperative payoff from the payoff from unilaterally deviating from the coastal state coalition (Tables 8 and 10).

Scenario 1

In scenario 1, the spawning takes place in the EEZs of the EU, the Faroe Islands, and Iceland, in scenario 1*c* in Norway's EEZ as well, and there is no blue whiting in Russia's EEZ (Table 2). Hence, Russia is not a partner in the blue whiting agreement and therefore always operates as a DWFN.

We see that the benefits provided in terms of coalition values when all of the coastal states cooperate in a coalition are negative (NOK –420 million, –422 million, and –421 million for scenarios 1*a*, 1*b*, and 1*c*, respectively; Table 8). For the coastal state coalition to be stand-alone stable, its value has to be greater than the sum of its members' individual coalition values. This is clearly not the case; the individual coalition values are all positive, whereas the coastal state coalition values are negative (Table 8). Thus, in the scenario in which a warmer climate leads to a more westerly distribution of the blue whiting stock, a coastal state coalition cannot be stable under any circumstances.

Scenario 2

We now continue with the scenario (Table 3) in which the distribution of the blue whiting expands eastward into the Barents Sea such that Russia will become a coastal state and the grand coalition, (EU,FO,IS,NO,RU) and the coastal state coalition are identical (Table 9).

We see that although the grand coalition's values (NOK 3504 million, 2666 million, and 2949 million for scenarios 2*a*, 2*b*, and 2*c*, respectively; Table 10) are all positive, they are not sufficiently large to compensate the coastal states for their individual values of free-riding the coalition while the others remain in the coalition. This is the criterion for a coalition not to be stand-alone stable (cf. the discussion of stand-alone stability under the game theory section). Therefore, in scenario 2, the grand coalition, in a strict sense, cannot be said to be a stable coalition structure.

Table 9. Scenario 2 — best-response Nash equilibria (net present value in million NOK).

	Total	CS	EU	FO	IS	NO	RU
Scenario 2*a*							
(EU,FO,IS,NO,RU)	7871						
(EU,FO,IS,NO),(RU)	7074	3852					3222
(EU,FO,IS,RU),(NO)	7170	3708				3462	
(EU,FO,NO,RU),(IS)	7102	3801			3302		
(EU,IS,NO,RU),(FO)	7481	6079		1402			
(FO,IS,NO,RU),(EU)	7417	5868	1549				
(EU),(FO),(IS),(NO),(RU)							
Mean	4367		1024	903	775	882	784
Maximum			2178	2072	1932	2066	1743
Minimum			0	0	0	0	0
Scenario 2*b*							
(EU,FO,IS,NO,RU)	7871						
(EU,FO,IS,NO),(RU)	7792	1935					5857
(EU,FO,IS,RU),(NO)	6901	3565				3337	
(EU,FO,NO,RU),(IS)	6887	3644			3243		
(EU,IS,NO,RU),(FO)	6934	3507		3427			
(FO,IS,NO,RU),(EU)	6977	3513	3464				
(EU),(FO),(IS),(NO),(RU)							
Mean	5205		1095	1077	1046	1039	947
Maximum			2590	2607	2482	2847	2556
Minimum			0	0	0	0	0
Scenario 2*c*							
(EU,FO,IS,NO,RU)	7871						
(EU,FO,IS,NO),(RU)	6774	3810					2964
(EU,FO,IS,RU),(NO)	6880	3621				3259	
(EU,FO,NO,RU),(IS)	6880	3621			3259		
(EU,IS,NO,RU),(FO)	6880	3621		3259			
(FO,IS,NO,RU),(EU)	6996	3592	3404				
(EU),(FO),(IS),(NO),(RU)							
Mean	4922		1068	1019	1019	1019	797
Maximum			2431	2335	2335	2335	2056
Minimum			0	0	0	0	0

Note: See Table 1 for abbreviations.

Table 10. Scenario 2 — coalition values (in million NOK).

Scenario	CS	EU	FO	IS	NO	RU
2*a*	3504	525	499	2527	2580	2438
2*b*	2666	2369	2350	2197	2298	4910
2*c*	2949	2336	2240	2240	2240	2167

Note: See Table 1 for abbreviations.

Let us now consider the stability of the coastal state coalition if unilateral deviation is not an option, but any deviation from the coastal state agreement breaks down any coalition, and all the players revert to noncooperative behaviour. As shown for scenario 2 (Table 7), there is no unique solution when all act as singletons. There are multiple strategy combinations that can be considered best response for all players. The maximum solutions are probably not feasible for all players simultaneously, because this would mean that all nations would have to fish with such high effort that the stock would collapse, and the minimum is zero for all players. However, if the average (mean) NPVs (Table 7) can be taken as an example of what the players can expect to gain by acting noncooperatively, the sum of all of the singleton NPVs is less than the NPV to the grand coalition. The sum of the NPVs of the coastal states when they all act noncooperatively (NOK 4367 million, 5205 million, and 4922 million for scenarios 2*a*, 2*b*, and 2*c*, respectively) are less than NOK 7871 million (Table 7), the NPV of the grand coalition. Thus, the coastal state agreement can be considered stable and the Nash equilibrium of the coalition game.

Note that this does not apply under scenario 1. Recall that coastal state coalition values were all negative (Table 8), and the formation of a coastal state coalition would not be rational.

It is important to note that in the presence of non-unique equilibrium, these results were based on the average of all the different possible solutions. If we had chosen one of the possible solutions, the cooperative solution could possibly be a better solution than the sum of the singleton's NPVs of the coastal states. However, because of the lack of a better equilibrium selection criteria, in the presence of multiple equilibria we decided use the average of the equilibria NPVs as a representation of the NPVs that the players could expect in the coalition structure where nonuniqueness occurs.

Discussion

This paper analysed how different blue whiting distribution scenarios might affect the formation, stability, and success of the coastal state coalition on the management of the Northeast Atlantic blue whiting fish stock. We assume that the blue whiting will change its migration pattern and distribution area in response to changes in the ocean environment. Two possible distributional scenarios were analyzed. In the first scenario, the blue whiting is distributed in a more westerly direction, abandoning Russian waters altogether. In the second scenario, an increased sea temperature in the Norwegian Sea and the Barents Sea shifts the distribution of the blue whiting in a northeasterly direction with spawning activity in Norwegian waters and blue whiting catches in Russian waters, making Russia a member of the coastal state coalition.

Based on these scenarios, we formulated two possible combinations of quarterly shares. Each share represents the fraction of the stock available for harvest in a certain area, i.e., the different exclusive economic zones or international waters, at certain times. These shares, along with the bioeconomic model, were used to calculate the best-response Nash equilibria, based on the NPVs, to coalitions and players under different coalition structures.

Finally, this allowed us to analyse the coalition formation, success, and stability in particular coalitions among the coastal states. The coalition analysis indicates that the stability of the blue whiting agreement between the coastal states would remain unchanged relative to today's agreement (cf. Ekerhovd (2008)) if global warming means an increase in sea temperatures in the Norwegian Sea and the Barents Sea. However, if the distribution remains as it is today and the stock is shared among the EEZs of the EU, the Faroe Islands, Iceland, and Norway and the high seas areas in the Northeast Atlantic, excluding Russia as a coastal state, this would weaken the stability of the current coastal state agreement on the management of the blue whiting stock.

In scenario 2, with increased ocean temperatures and salinity in the Norwegian Sea and the Barents Sea, we assumed that the blue whiting migrated into Russian waters and that Russia achieved the status of being a coastal state with regard to the management of this stock. The change in status from being regarded as a DWFN by the original coastal states to being accepted and included as a coastal state in the management of a straddling fish stock when the stock for some reason changes its migration pattern and distribution is not necessarily a straightforward process. It might take years before the new status is generally accepted by the others, as the shift in the distribution can be a gradual process with a considerable amount of short-term variation, meaning that there may be considerable doubt as to whether a shift in distribution is only a temporary change or if the fish stock actually has changed its migration pattern and area of distribution permanently. During the period of transition, the underlying uncertainty might put an established agreement on the management of the stock among the original coastal states at risk, as the emerging coastal state tries to prove its claim to the stock by severely increasing its fishing effort and thus its catches to establish rights to the fishery and gain acceptance for its new status. The original coastal states members might try to limit the prospective coastal state's profit by increasing their fishing efforts too. If this transient period lasts for a long time and the noncooperative behaviour is allowed to continue, it might threaten the fishery, as the stock cannot sustain a too high fishing mortality indefinitely without either becoming extinct or being driven to the break-even stock level (the level at which further fishing becomes unprofitable).

However, when an agreement that includes all countries is finally reached, as in the case of scenario 2, the coastal state coalition will act as a sole owner and not as in scenario 1, where Russia always acts as a singleton player while the coastal state coalition maximizes its own profit, taking the action of Russia as given. With the sole-owner NPV being the maximum attainable value, the players in scenario 2 will never find themselves in a situation like scenario 1, where the sum of the NPVs in a coalition structure where some or all players act as singletons exceeds the NPV to the coastal state coalition.

In scenario 1, Russia is no longer regarded as a coastal state; the coalition of coastal states is no longer stable, even if the coalition formation options were restricted to full cooperation among the coastal states or reversion to a state where all act as singletons. In the opposite case, the coastal state coalition would be stable if such a restriction were put on the coalition structure. However, if this is not the case, the individual members of the coastal state coalition would have incentives to free ride on the agreement if the remaining coalition continued to cooperate. What has become evident from our exercise is that if the distribution area of the blue whiting stock in the Northeast Atlantic were to be reduced, the cooperation among the coastal states would become even more difficult than it is already.

In the second climate change scenario in which the Norwegian and Barents seas are expected to warm up and the distribution of the blue whiting stock is expected to expand northeastward into the EEZ of Russia, the coastal state coalition would be stable if the option of the member states to free ride on the agreement for some reason did not exist. Then the NPV of the coastal state coalition would always exceed the sum of NPVs to the coastal states acting as singletons, and the coastal states would be better off cooperating in a coalition. However, when the coastal state coalition does not include all of the countries that participate in the fishery, as is the case in the first scenario and in Ekerhovd (2008), Russia is excluded from participating in the coastal state coalition, the coalition NPV is less than a potential grand coalition NPV would be, and a mechanism that prohibits free-riding among the coastal states is not necessarily sufficient to make the coastal states coalition stable. An example where this turns out to be true is scenario 1 of this paper. What might help remedy this weakness is for the coastal states to transfer some of their sovereignty over the fish stock staying in their national EEZs to a regional fisheries management organization (RFMO) and let it manage the fish stock. According to the law of the sea, membership in a RFMO is open to all countries with real interest in the fish stock (Bjørndal and Munro 2003). The open membership of the RFMO guarantees a share of the profits to all interested parties, as well as being able to provide a higher NPV than any partial cooperation. Furthermore, if it is able to enforce mechanisms that will deter its members from free-riding, the prospects for cooperation will be improved.

However, it is possible that this is partially achieved in the management of the blue whiting stock. The coastal states agree on a total allowable catch (TAC) for the stock. This TAC is then divided among coastal states, and in addition, a share thereof is set aside to be harvested in international waters. The local RFMO, the North East Atlantic Fisheries Commission (NEAFC), is given the responsibility of dividing this share among all interested parties, including Russia. Moreover, Russia could be further accommodated by exchange of quota in their waters against being allowed to fish some of the coastal states' shares in their respective EEZs. This can be seen as a way of sharing the benefits of cooperation through side payments, and by providing higher benefit than a simple coastal state regime would be able to, a more stable management is achieved.

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Appendix A. Management plan for the blue whiting fishery

In December 2005, the coastal states (EU, Norway, Iceland, and Faroe Islands) agreed on a sharing arrangement for the blue whiting stock (Agreed record of conclusion of fisheries consultations on the management of the blue whiting stock in the north-east Atlantic. An agreement between the blue whiting coastal states consisting of the EU, Denmark, on behalf of the Faroe Islands, Iceland, and Norway, December 2005; Anonymous 2006). This arrangement provides for catches in 2006 of 2 million tonnes, allocated as follows: EU, 30.5%; Faroe Islands, 26.125%; Norway, 25.745%; and Iceland, 17.63%. Russia will be accommodated by transfers from some of the coastal states and additional catches in the NEAFC regulatory area (International Council for the Exploration of the Sea 2006).

Agreed Record of Conclusions of Fisheries Consultations Between the Faroe Islands, the European Community, Iceland and Norway on the Management of the Blue Whiting Stock in the North-East Atlantic in 2006

1. A Delegation of the European Community, the Faroe Islands, Iceland and Norway met in Oslo on 15 and 16 December 2005 to consult on the management of the Blue Whiting stock in the North-East Atlantic.
2. The Delegations agreed to recommend to their respective authorities the arrangement for the regulation of the fisheries of Blue Whiting in 2006 and subsequent years set out in Annex I to this Agreed Record. They also agreed to recommend to their respective authorities the multi-annual management arrangement set out in Annex II.
3. The Delegations agreed to recommend that, in 2006, ICES be requested to evaluate, as soon as possible, whether the multi-annual management arrangement as

set out in Annex II is in accordance with the precautionary approach and to make the results of this evaluation available to the Parties. The Delegations agreed to review the multiannual management arrangement on the basis of evaluation by ICES.

4. This Agreed Record, including bilateral arrangements related to the implementation thereof, shall be applied provisionally from 1 January 2006 and enter into force when all Parties have notified each other of the completion of their necessary procedures.
5. For subsequent years, Delegations agreed to allocate allowable catches in the proportions that are set out in paragraph 1 of Annex I.
6. Unless one or more of the Parties notifies its withdrawal not later than by the end of June, the Agreed Record shall be renewed annually, including Annexes, in which years, maximum catch limit and quotas are updated.
7. The Delegations agreed to inform the NEAFC Secretariat about the regulatory measures they intend to take on the basis of this Agreed Record, for the fisheries of Blue Whiting in 2006 and in subsequent years.

Annex I. Arrangement for the regulation of the fisheries of Blue Whiting in 2006

1. In accordance with the multi-annual management arrangement for the fisheries of Blue Whiting set out in Annex II to this Agreed Record, the Parties agree to restrict their fisheries of Blue Whiting in 2006 to a maximum catch limit of 2,000,000 tonnes on the basis of the following quotas:
   - European Community 610 000 tonnes
   - Faroe Islands 522 500 tonnes
   - Iceland 352 600 tonnes
   - Norway 514 900 tonnes
2. Each Party may transfer unutilized quantities of up to 10% of the quota allocated to it for 2006 to 2007. Such transfer shall be in addition to the quota allocated to the Party concerned for 2007.
3. In the event of overfishing of the allocated quotas by any Party in 2006, the quantity shall be deducted from the quota allocated in 2007 for the Party or Parties concerned.
4. The Parties may fish Blue Whiting within the quotas laid down in paragraph 1 in their respective zones of fisheries jurisdiction and in international waters.
5. Further arrangements by the Parties, including arrangements for access, quota transfers and other conditions for fishing in the respective zones of fisheries jurisdiction, are regulated by bilateral arrangements.

Annex II. Arrangement for the multi-annual management of the Blue Whiting stock

1. The Parties agree to implement a multi-annual management arrangement for the fisheries on the Blue Whiting stock which is consistent with the precautionary approach, aiming at constraining harvest within safe biological limits, protecting juveniles, and designed to provide for sustainable fisheries and a greater potential yield, in accordance with advice from ICES.
2. The management targets are to maintain the Spawning Stock Biomass (SSB) of the Blue Whiting stock at levels above 1.5 million tonnes ($B_{\lim}$) and the fishing mortality rates at levels of no more than 0.32 (F_{pa}) for appropriate age groups as defined by ICES.
3. For 2006, the Parties agree to limit their fisheries of Blue Whiting to a total allowable catch of no more than 2 million tonnes.
4. The Parties recognise that a total outtake by the Parties of 2 million tonnes in 2006 will result in a fishing mortality rate above the target level as defined in paragraph 2. Until the fishing mortality has reached a level of no more than 0.32, the Parties agree to reduce their total allowable catch of Blue Whiting by at least 100,000 tonnes annually.
5. When the target fishing mortality rate has been reached, the Parties shall limit their allowable catches to levels consistent with a fishing mortality rate of no more than 0.32 for appropriate age groups as defined by ICES.
6. Should the SSB fall below a reference point of 2.25 million tonnes (B_{pa}), either the fishing mortality rate referred to in paragraph 5 or the tonnage referred to in paragraph 4 shall be adapted in the light of scientific estimates of the conditions then prevailing. Such adaptation shall ensure a safe and rapid recovery of the SSB to a level in excess of 2.25 million tonnes.
7. This multi-annual management arrangement shall be reviewed by the Parties on the basis of ICES advice.

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Appendix B. NEAFC regulatory measurements

In addition to the coastal states management plan, the following regulatory measures for the blue whiting stock for 2006 are suggested by NEAFC (International Council for the Exploration of the Sea 2006).

1. NEAFC takes note of the Agreed Record of Conclusions of Fisheries Consultations on the Management of the Blue Whiting Stock in the North-East Atlantic for 2006 between the European Community, the Faroe Islands, Iceland and Norway signed in Oslo on 16 December 2005.
2. NEAFC further notes that by way of the said Agreed Record, the aforementioned Parties agreed to restrict their fishery on the Blue Whiting Stock in 2006 on the basis of specified quotas according to a total catch limitation of 2 million tonnes.
3. In accordance with Article 5 of the Convention on Future Multilateral Cooperation in North-East Atlantic fisheries,

the Contracting Parties recommend the following measure for the Blue Whiting Stock for 2006.

(*a*) To ensure consistency and compatibility with the said Agreed Record, NEAFC hereby establishes an allowable catch limitation of 253 000 tonnes of Blue Whiting for 2006 in waters beyond the areas under national fisheries jurisdiction of the Contracting Parties

(*b*) This allowable catch limitation shall be allocated as follows:

- European Community 44 000 tonnes (*)
- Norway 37 000 tonnes (*)
- Denmark in respect of:
- Faroe Islands 37 000 tonnes (*)
- Greenland 10 000 tonnes
- Iceland 25 000 tonnes (*)
- Russian Federation 100 000 tonnes

4. The quotas referred to in paragraph 2 may be fished in the areas defined in paragraph 3*a*.

   (*) Catches taken under these allocations shall be deducted from quotas allocated to Parties to the said Agreed Record.

Reference

International Council for the Exploration of the Sea. 2006. Report of the Northern Pelagic and Blue Whiting Working Group. ICES CM 2006/ACFM:34.