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Climate Change and the Blue Whiting Agreement

by

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Abstract

This paper investigates the formation, stability and success of an agreement between the coastal states on the management of the blue whiting fishery under two opposing assumption about the distribution of the stock, based on different climate change scenarios for the Northeast Atlantic Ocean as a result of global warming. Two climate change scenarios for the Northeast Atlantic Ocean are analysed. In one scenario, increased ocean temperature expands the blue whiting's migration pattern and its area of distribution, making Russia a coastal state with regard to the blue whiting stock in addition to the countries already recognized as such. In this scenario, the stability of the coastal state coalition does not change relative to the *Status Quo*, *i.e.*, Ekerhovd (2008), although the payoff to the coalition increases when Russia enters. The second scenario looks at the consequences of a colder climate on the distribution of the blue whiting stock. The stock no longer occupies Russian EEZs and Russia is not regarded as a coastal state by the other countries. In this scenario, the stability of the coastal state coalition is severely weakened such that the formation of a coastal state coalition is an even more unlikely outcome compared to Ekerhovd (2008).

Keywords: Straddling fish stocks, coastal state coalition agreement, cooperation, climate change, blue whiting.

JEL Classification: Q22, Q28, Q54, C72.

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1 Introduction

The ecosystem of the Norwegian Sea and the Barents Sea is one of the world's richest, purest, and most productive marine areas, and where the climate, both in the sea and the atmosphere, is expected to change[1] in response to global warming (Stenevik and Sundby, 2007). Although the prevailing view seems to be that these waters will become warmer over the next 50-70 years, to the extent that the Arctic Ocean could become ice-free during the summer, there is also the possibility that the Gulf Stream and the termohaline circulation could be weakened, leading to a colder climate in northwestern Europe, despite global warming (Anon., 2004).

Higher ocean temperatures could lead to higher plankton production and, because of ice melting, even production in previously inaccessible areas. Changes in prey availability will influence the distribution of straddling fish stocks[2] which seasonally migrate into such areas. Furthermore, higher abundance of plankton could lead to an increased production of plankton feeding fish, and as plankton feeding fish typically serve as important prey for other fishes, this could spill over on the higher trophic levels as well. However, the predator-prey relationship makes it difficult to predict how exactly these changes will affect a specific species, and is further complicated by the fact that individuals of the same species may be at different trophic levels depending on the current stage of their life cycle. Younger and smaller fish, to a large extent, feed on plankton, but as they become older and bigger they prefer larger organisms as prey; and even smaller individuals of their own species.

The blue whiting stock[3] (*Micromesistius Poutassou* Risso) in the Northeast Atlantic

[1]Climate change is usually linked to changes in temperature, but also other climate parameters such as salinity, ocean currents, ice conditions, light (which depends, among other things, on the cloud cover and season), and turbulence (which changes with the wind conditions) affects the ecosystem (Anon., 2008).

[2]Straddling fish stocks are a special category of internationally shared fishery resources that straddle exclusive economic zones (EZZ) where states have special rights over the exploration and use of marine resources, and adjacent high seas. These species, usually targeted by both coastal states and distant water fishing nations, became increasingly disputed after the establishment of exclusive economic zones by the United Nations Convention on the Law of the Sea (Bjørndal and Munro, 2003).

[3]The northern stock of blue whiting migrates between the spawning grounds west of the British Isles

migrates through the exclusive economic zones (EEZs) of the European Union (EU), the Faroe Islands, Iceland, and Norway, considered as the coastal states with respect to the stock, and in the international waters beyond the EEZs, 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. In 2005, the coastal states consisting of the EU, the Faroe Islands, Iceland, and Norway signed an agreement starting in 2006 which includes a long term management strategy that implies annual reductions in the landings until the management goals are reached. Russia will be accommodated by transfers from some of the coastal states and additional catches in the North East Atlantic Fisheries Commissions' (NEAFC)[4] regulatory areas, *i.e.*, the international waters in the Northeast Atlantic (Ekerhovd, 2008).

The blue whiting stock is expected to change its distribution, spawning areas and migration pattern due to climate change. Recently, in years with a relatively warm ocean climate, juvenile blue whiting has appeared in great abundance in the southwesterly parts of the Barents Sea. Currently, the blue whiting stock's main spawning area is west of the British Isles, but some spawning takes place along the coast of Norway as well as in the Norwegian fjords. The northerly distribution of blue whiting might also be an effect of stock abundance caused by the successful recruitment in the 1996-2004 period. The poor recruitment after this period, along with a high fishing mortality, has led to considerable reduction in the blue whiting abundance in the Barents Sea in 2007, even though the temperature was well above its long term mean. This means that the distribution of the

and the feeding areas in the Norwegian Sea, cf. Figure (1). After the spawning period in March-May, the majority of the post-spawning fish pass the Faroe Islands either on the western side through the Faroe Bank Channel or on the eastern side through the Faroe-Shetland Channel. The stock size of the blue whiting has fluctuated substantially during the last three decades, and is currently estimated to be high, at approximately four million tonnes (Bailey, 1982; ICES, 2007). For more details about the blue whiting fishery, see Ekerhovd (2008).

[4]The North East Atlantic Fisheries Commission, 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 advise on the fisheries in the high sea areas mentioned in the convention on which the commission is based. Since 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, 2008).

species is also connected with the abundance of the stock.

This paper investigates the formation, stability and success of an agreement between the coastal states on the management of the blue whiting fishery under two opposing assumptions about the distribution of the stock, based on different climate change scenarios for the Northeast Atlantic Ocean as a result of global warming. Because the EEZs are fixed upon the map, an expansion of the blue whiting stock could affect the distribution of the stock between the EEZs of the coastal states and international waters. These changes could put the coastal state agreement under strain. Some of the coastal states might be discontented with their share of the stock, based on an earlier distribution of the stock, so that they find themselves better off leaving the coalition of coastal states and harvesting the stock taking the others' actions as given. The expansion of the distribution area could make Russia a coastal state, demanding the same status and same rights as the original coastal state coalition members.

Two climate change scenarios for the Northeast Atlantic Ocean are analysed. In one scenario, increased ocean temperature expands the blue whiting's migration pattern and its area of distribution, making Russia a coastal state with regard to the blue whiting stock in addition to the countries already recognized as such. In this scenario, the stability of the coastal state coalition does not change relative to the *Status Quo*, *i.e.*, Ekerhovd (2008), although the payoff to the coalition increases when Russia enters. The second scenario looks at the consequences of a colder climate on the distribution of the blue whiting stock. The stock no longer occupies Russian EEZs and Russia is not regarded as a coastal state by the other countries. In this scenario, the stability of the coastal state coalition is severely weakened such that the formation of a coastal state coalition is an even more unlikely outcome compared to Ekerhovd (2008).

The analysis is conducted, drawing on the model described in Ekerhovd (2008), by changing the quarterly zonal attachment shares of the blue whiting stock in accordance with the climate change scenarios outlined in the previous paragraph.

The chapter is organized as follows. Section 2 describes the climate change scenarios and how we imagine this will affect the distribution of the blue whiting stock. In Section 3 we presents results of the blue whiting game by applying the distributions derived in the previous section. Finally, Section 4 sums up the results and concludes.

2 Climate Change Scenarios

In this section we outline two alternative scenarios regarding climate change in the Norwegian Sea and the Barents Sea. An increased inflow of Atlantic water into these areas causing the ocean temperatures to rise is described first. Then the opposite outcome of global warming on the ocean temperatures in the Northeast Atlantic, with a reduced inflow of Atlantic water to the Norwegian Sea and the Barents Sea, is outlined. Finally, we describe how we imagine the blue whiting stock will be distributed geographically under the respective climatic regimes. These distributions will later be used when we simulate the coalition payoffs under the different climate change scenarios.

The two climate change scenarios are linked to fluctuations in the North Atlantic Oscillation index. The North Atlantic Oscillation (NAO) is a large scale oscillatory fluctuation of atmospheric mass between the Icelandic low-pressure centre and the Azores' high-pressure ridge that normally extends from continental Europe to the Azores. It is manifested by a weakening of the intensity in one of the centres of action and a simultaneous strengthening in the other. The NAO index is determined from the difference in atmospheric sea level pressure between the Azores high and the Iceland low, for example between Lisbon, Portugal, and Stykkisholmur, Iceland. It is seen most clearly from December to March, when the atmospheric circulation is most intense. Variability in the NAO is associated with the strength of the westerly winds across the North Atlantic into the Nordic Seas. A high NAO winter index is associated with the path of the low pressures along a "pressure trough" that extends from the Iceland low, across the Norwegian and Barents Seas, to the margins of Siberia (Blindheim, 2004). A high NAO index is associated with high inflow of Atlantic water, while the opposite is true for a low

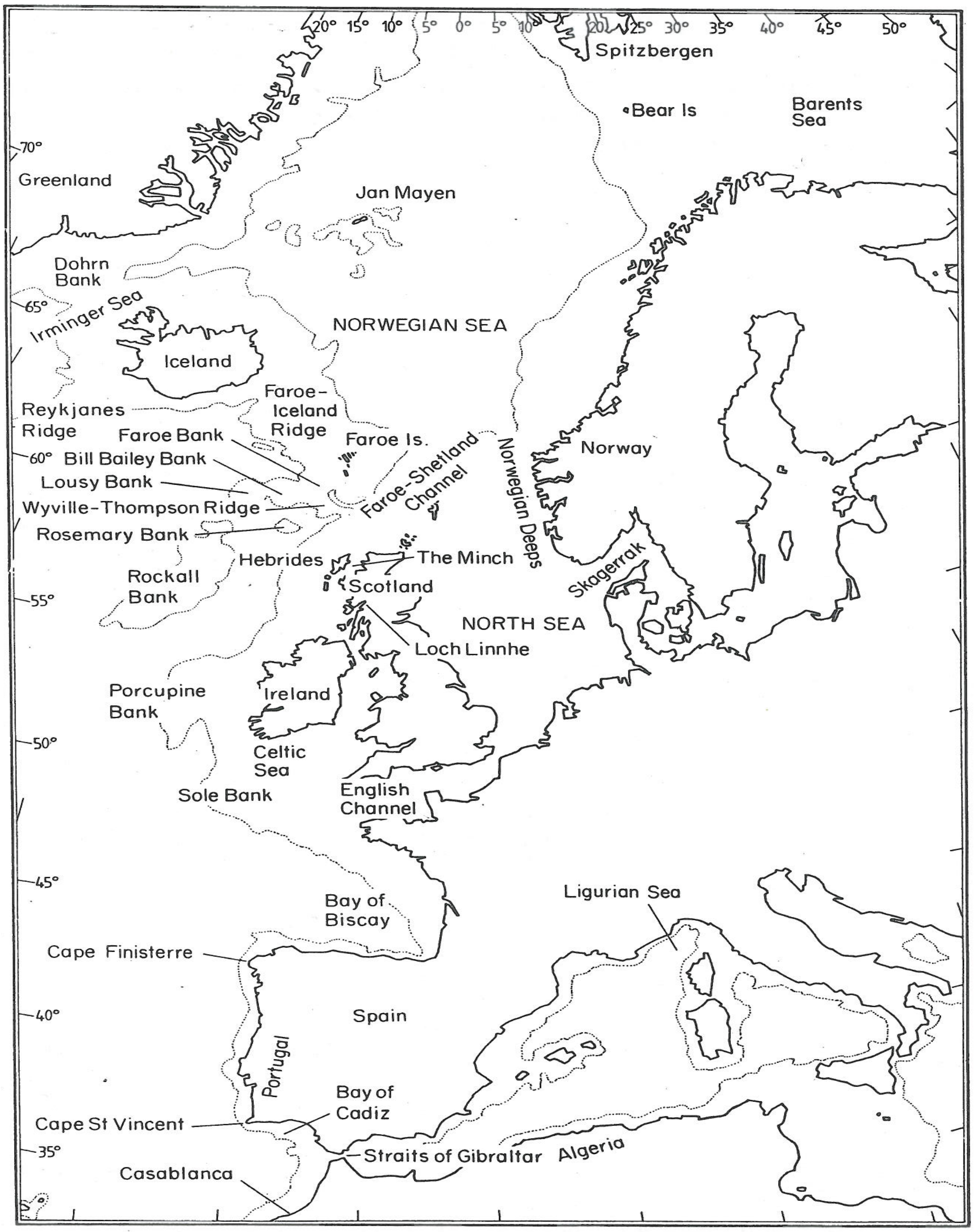

Figure 1: Map showing the Northeast Atlantic and adjacent waters (Bailey, 1982).

NAO index (Stenevik and Sundby, 2007; Hátún *et al.*, 2007).

2.1 Scenario 1. High NAO, high inflow of Atlantic water and higher temperatures in the Barents Sea

The blue whiting is one of the species that will probably expand its distribution in a more northerly direction in response to a warmer ocean climate. Recently, in years with relatively warm ocean climate, juvenile blue whiting has appeared in great abundance in the south-western part of the Barents Sea. The blue whiting stock's main spawning area is currently west of the British Isles, but some spawning activity occurs off the coast of Norway as well as in the Norwegian fjords. With spawning occurring in the Norwegian Sea and adolescent blue whiting growing up in the Norwegian Sea and the Barents Sea, the blue whiting would be able to take advantage of the production of plankton in the Greenland Sea in a warmer ocean climate (Anon., 2008).

A more northerly distribution of blue whiting may also be caused by the increased stock abundance due to an exceptionally high recruitment to the stock during the 1996-2004 period. The poor recruitment in the following years, combined with a high fishing pressure, led to a significant reduction in the abundance of blue whiting in the Barents Sea in 2007, even though the temperature was well above the long term mean. This indicates that the distribution of fish species also is linked to the over-all stock abundance (Anon., 2008).

This scenario is associated with a high NAO index, and a high inflow of Atlantic water into the Norwegian Sea and the Barents Sea accompanied by an increase in temperature (Stenevik and Sundby, 2007). Following an increase in inflow of Atlantic water and a resulting increase in temperature, the character of the ecosystems in Norwegian waters will most likely change. The borders between the temperate ecosystem in the Atlantic and the boreal ecosystems of the Norwegian Sea/Barents Sea and the Arctic areas may move northwards, resulting in substantial changes to the fish communities in the different areas.

2.2 Scenario 2. Low NAO, less inflow of Atlantic water

With a reduced NAO index, on the other hand, the inflow of Atlantic water will become weaker but broader (Stenevik and Sundby, 2007). This could lead to increased temperature in the western part of the Norwegian Sea and changes in the migration and spawning distribution of the blue whiting.

During a phase of negative NAO index, the inflow of Atlantic water to the Barents Sea is reduced. This leads to a colder climate, particularly in the southern part of the Barents Sea. Also, the abundance of the copepode *Calanus finmarchicus*, an important zooplankton prey for blue whiting, decreases due to less inflow.

After spawning, blue whiting migrate from the spawning grounds west of the British Isles, past the Faroe Islands and into the feeding areas in the Norwegian Sea during the spring months March to early June. The changeable migratory route through Faroese waters, as inferred from fisheries statistics, is found to be closely linked to the hydrography along the Rockall Bank, as simulated by an ocean circulation model (Hátún *et al.*, 2007). Furthermore, Hátún *et al.* (2007) suggests a variable spawning intensity around the bank as the causal mechanism for this link. The observed variability is primarily governed by the strength and extent of the subpolar gyre[5] (Hátún *et al.*, 2005). The blue whiting is especially sensitive to both temperature and salinity during the spawning period and will

[5] Wind stress induces a circulation pattern that is similar for each ocean. In each case, the wind-driven circulation is divided into large gyres that stretch across the entire ocean: subtropical gyres extend from the equatorial current system to the maximum westerlies in a wind field near 50° latitude, and subpolar gyres extend poleward of the maximum westerlies. The subpolar gyres are cyclonic circulation features. In the North Atlantic the subpolar gyre consists of the North Atlantic Current on the equatorward side and the Norwegian Current that carries relatively warm water northward along the coast of Norway. The heat released from the Norwegian Current into the atmosphere maintains a moderate climate in northern Europe. Along the east coast of Greenland is the southward-flowing cold East Greenland Current. It loops around the southern tip of Greenland and continues flowing into the Labrador Sea. The southward flow that continues off the coast of Canada is called the Labrador Current. This current separates for the most part from the coast near Newfoundland to complete the subpolar gyre of the North Atlantic. Some of the cold water of the Labrador Current, however, extends farther south. Source: "ocean." Encyclopædia Britannica. 2008. Encyclopædia Britannica Online. 07 Jul. 2008 <http://www.britannica.com/EBchecked/topic/424285/ocean>.

only spawn in waters warmer than 8-9° C and salinities in excess of 35.2-3. The average hydrography in the region east of the Rockall Bank is near these threshold values, although the variations are considerable.

After the spawning period in March - May, the majority of the post-spawning fish pass the Faroe Islands either on the western side through the Faroe Bank Channel or on the eastern side through the Faroe-Shetland Channel, cf. Figure (1).

When the fishery takes place on the western slope of the Faroe Plateau the fishable concentrations are confined to a narrow and often dense band along the shelf edge which also is associated with a sharp hydrographic front. When, on the other hand, the fishery takes place in the Faroe-Shetland Channel the shoals are more dispersed and less fishable.

High values of the gyre index are associated with cold and fresh conditions in the Northeast Atlantic. This seems to coincide with years when the stock has an easterly distribution, while low gyre index values, associated with warm and saline conditions, seem to coincide with years when the stock has a western distribution.

The NAO index is directly related to the westerlies through the sea level pressure difference between Iceland and the Azores-Gibraltar region. This index showed record high values during the early 1990s. This resulted in a relatively fresh, strong and inflated subpolar gyre, and the subarctic front was moved far eastwards into the Northeast Atlantic. The spawning/migration waters between Rockall Bank and the Faroe Islands were fresh and cold during these years, and the blue whiting stock was small.

An extreme reversal in the NAO index in the winter 1995-1996 was followed by a dramatic decline in the subpolar gyre, a westward shift in the subarctic front, a temperature and salinity increase in the spawning/migration region, replacement in the plankton community[6], a threefold increase in the blue whiting spawning stock biomass, and a clear shift from years with a persistent easterly migration route to a period of a

[6]Prior to 1996, an inverse relationship between the abundance of *Calanus finmarchicus* and NAO winter index appeared to exist. However, with the change to the strongly negative NAO index in 1996, when the regression predicted high abundance of *Calanus*, there was in fact a record low abundance. Low abundance continued for the rest of the 1990s (Skjoldal and Sætre, 2004).

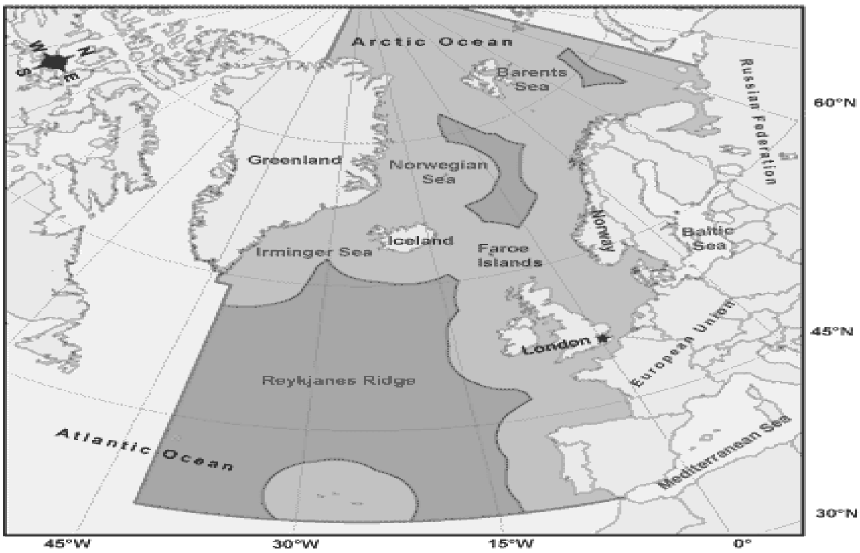

Figure 2: The high seas of the NEAFC Regulatory Area (dark shaded) inside the NEAFC Convention Area (shaded) in the Northeast Atlantic http://www.neafc.org/about/ra.htm

persistent western migration.

Under a climate regime with a reduction in the NAO index and less inflow of Atlantic water, the distribution of the blue whiting stock will move in a south-western direction, with no blue whiting in Russia's exclusive economic zone (EEZ) and no spawning activity in Norwegian waters. However, with an increased density of blue whiting on the banks between Iceland and the Faroe Island, spawning activity in Icelandic waters is possible.

2.3 Distribution of the Blue Whiting Stock

In the following, we will illustrate the above scenarios by suggesting a quarterly area distribution for each of them that is consistent with the implied spawning and migration patterns.

The year is divided into quarters, y, whereas i denotes the respective EEZs in the case of the EU, Faroe Islands, Iceland, Norway and Russia, and NEAFC regulatory area (RA)[7] meaning international waters, shown in Figure (2). Thus, $S_{i,y}$ denotes the shares

[7]There are three regulatory areas within the NEAFC convention area. In the the Northeast, and of minor relevance in the blue whiting context, the 'Loop Hole', a 67,100 km^2 area in the Barents Sea,

of the blue whiting stock available for harvest in the different waters throughout the year. Typically, each scenario is not characterized by a single combination of shares. Several combinations are possible and each scenario is defined by a sub-group of all possible combinations. Therefore, three alternative combinations of shares are presented for each scenario.

First, Table (1) shows the shares, $S_{i,y}$, in the case where there is an increase in the amount of Atlantic water entering the Norwegian Sea, causing an increase in sea water temperature and salinity in both the Norwegian Sea and the Barents Sea. This means that the habitat of the blue whiting expands north-eastward into the Barents Sea, such that Russia becomes a coastal state, and the blue whiting spawns in Norwegian waters in addition to EU and Faroese waters. At times when the blue whiting is not present in a coastal state's EEZ, the fishermen from that country can only fish blue whiting in international waters if possible[8]. Otherwise, they can harvest in their home waters as well as on the high seas.

The year begins with blue whiting present in all areas except for Russia's EEZ. Spawning takes place in the second quarter, and the stock is equally divided between EU, Faroese and Norwegian EEZs (Scenario 1a, and 1b), or alternatively between EU, Faroese, Icelandic and Norwegian EEZs (Scenario 1c). After spawning, the stock migrates out into the Norwegian Sea and the Barents Sea, abandoning EU waters altogether, with either 1/3 of the stock in international waters and 1/3 in the Norwegian EEZ (Scenario 1a) or, as in Scenario 1b, with 1/4 of the stock in international waters and 1/4 in the Norwegian EEZ; the rest is equally divided between the EEZs of Iceland, the Faroe Islands and Russia in the third and fourth quarters. In Scenario 1c, the stock is equally divided

surrounded by the EEZs of Norway and Russia, and the fishery protection zone around the Svalbard archipelago (Spitzbergen); in the Norwegian Sea, the 321,700 km^2 area, known as the 'Banana Hole', surrounded by the EEZs of Norway, Iceland, the Faroe Islands and Greenland, the fishery zone around Jan Mayen, an island under Norwegian sovereignty, and the fishery protection zone around Svalbard; and finally, the area in the Northeast Atlantic with the Reykjanes Ridge in the centre, c.f Figure (2), which is limited to the north by the EEZs of Greenland, Iceland and the Faroe Islands, and to the east by the EEZ of the EU (Bjørndal, 2008).

[8]This is a simplification that we make. In reality, bilateral agreements exist allowing foreign vessels access to the stock in national waters.

Table 1: Scenario 1: Quarterly zonal attachment of the blue whiting stock $S_{i,y}$

Scenario 1a				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/3	0	1/3	1/3
European Community	1/3	1/3	0	0
Faroe Islands	1/9	1/3	1/9	1/9
Iceland	1/9	0	1/9	1/9
Norway	1/9	1/3	1/3	1/3
Russian Federation	0	0	1/9	1/9
Scenario 1b				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/4	1/4
European Community	1/8	1/3	0	0
Faroe Islands	1/8	1/3	1/6	1/6
Iceland	1/8	0	1/6	1/6
Norway	1/8	1/3	1/4	1/4
Russian Federation	0	0	1/6	1/6
Scenario 1c				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/4	0	1/5	1/5
European Community	1/4	1/4	0	0
Faroe Islands	1/6	1/4	1/5	1/5
Iceland	1/6	1/4	1/5	1/5
Norway	1/6	1/4	1/5	1/5
Russian Federation	0	0	1/5	1/5

between the NEAFC regulatory area and the EEZs of the Faroe Islands, Iceland, Norway, and Russia in the third and fourth quarters.

As to Scenario 2, Table (2) shows the quarterly distribution of the blue whiting stock in national and international waters when the penetration of Atlantic water into the Norwegian/Barents Seas is reduced because of less wind-induced ocean currents. This means colder sea water with reduced salinity, in spite of global warming, and a more western 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 western distribution reduces the availability of the blue whiting in international waters and Norwegian waters, and Russia is no longer regarded as a coastal state.

During the first quarter the stock is equally divided between the North East Atlantic Fisheries (NEAFC) regulatory area in Northeast Atlantic and EU waters west of the British Isles and Ireland. Spawning takes place in the second quarter, in EU waters (1/2) and in national waters between Iceland and the Faroe Islands (1/4 each). In Scenario 2c, we allow for spawning in the Norwegian EEZ, as well as in the EEZs of the EU, the Faroe Islands and Iceland, and the stock is equally divided between the zones. During summer and autumn the blue whiting migrates into the Norwegian Sea, but because of colder and fresher water in the eastern part, along the coast of Norway, it now has a more western distribution, with highest densities in the EEZs of Iceland and the Faroe Islands. This means that there will be no blue whiting in Russia's EEZ, only in the NEAFC regulatory area in the Norwegian Sea and the EEZs of the Faroe Islands, Iceland, and Norway. For the respective scenarios and shares we refer to Table (2).

3 The Coalition Game of the Blue Whiting Fishery

In this section, we calculate the net present values for the coalition game setting. We do not, however, calculate the net present values for every possible coalition structure of the game but restrict our analysis to calculate the payoffs of the coastal state coalition and

Table 2: Scenario 2: Quarterly zonal attachment of the blue whiting stock $S_{i,y}$

Scenario 2a				
$i \backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/6	1/6
European Community	1/2	1/2	0	0
Faroe Islands	0	1/4	1/3	1/3
Iceland	0	1/4	1/3	1/3
Norway	0	0	1/6	1/6
Russian Federation	0	0	0	0
Scenario 2b				
$i \backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/4	1/4
European Community	1/2	1/2	0	0
Faroe Islands	0	1/4	9/32	9/32
Iceland	0	1/4	9/32	9/32
Norway	0	0	3/16	3/16
Russian Federation	0	0	0	0
Scenario 2c				
$i \backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/4	1/4
European Community	1/2	1/4	0	0
Faroe Islands	0	1/4	1/4	1/4
Iceland	0	1/4	1/4	1/4
Norway	0	1/4	1/4	1/4
Russian Federation	0	0	0	0

the payoffs accruing to its members from unilateral free-rider behaviour. In addition, we calculate the individual payoff to players when all act noncooperatively.

For the single-player coalitions (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 it can do is maximize its own profit, taking into account the strategies of the other players.

For a coalition consisting of three or four countries, 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.

To simulate the possible outcomes of this fishery under the climatic scenarios outlined above, an age structured bioeconomic model was used[9]. Assume that all the countries participating in the blue whiting fishery are represented in the game as the EU (European Union), FO (Faroe Islands), IS (Iceland), NO (Norway), and RU (Russian Federation). Also consider the management of this fishery to be the constant effort strategy[10] that maximizes the net present value of profits (NPV) over a 35-year period. A general description of the model is presented in the Appendix.

Let us continue with the coalition analysis of the climate change scenarios outlined above. First, an increase in inflow of Atlantic water, cf. Scenario 1 Table (1), in contrast to Ekerhovd (2008) and the second scenario, cf. Table (2), expands the distribution of the blue whiting eastward into the Barents Sea such that Russia will become a coastal state, and the grand coalition (sole-owner) and the coastal state coalition is identical. The resulting payoffs to the various coalition structures are shown in Table (3). The first result

[9] This model is presented in Ekerhovd (2008)

[10] A constant effort strategy (although it may seem very simplistic) corresponds to a variable catch strategy, which depends positively on the stock level. This type of strategy is especially relevant when there are significant costs of effort adjustment, as in the presence of high costs or difficulties in transferring fishing effort between different fisheries (Pintassilgo, 2003).

is the payoff to a coalition consisting of all the coastal states. Next, Table (3) presents the payoff to the individual nations from unilaterally leaving the grand coalition, starting with Russia, if they act as singletons (free-riding) while the other nations remain in a coalition. The latter's payoffs are listed under CS in the tables. We see that, although the grand coalition's payoff of NOK 7,871 million (m) is large enough to compensate one member its free-riding payoff while the rest remain in the coalition, and leave the remaining countries as least as well off (subtract the payoffs under CS in Table (3) from 7,871 m, and compare the results with each coastal state's free-rider payoffs), the sum of all the free-riding payoffs exceeds the payoff of the grand coalition; NOK 12,937 m, 19,328 m, and 16,214 m for the scenarios 1a, 1b, and 1c, respectively, compared to NOK 7,871 m. Therefore, in a strict sense, the grand coalition cannot be said to be a stable coalition structure.

Let us now consider the stability of the coastal state coalition if unilateral deviations 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 is shown in Table (3), there is no unique solution when all act as singletons. There are multiple strategy combinations that can be considered best response for all players. Table (3) presents average payoffs to each player along with maximum and minimum payoffs. The maximum solutions are probably not feasible for all players simultaneously and the minimum is zero for all players. However, if the average (mean) payoffs can be taken as an example of what the players can expect to gain by acting noncooperatively, the sum of all the singleton payoffs is less than the payoff to the grand coalition. The sum of the payoffs of the coastal states when they all act noncooperatively, NOK 4,367 m, 5,205 m, and 4,922 m for the scenarios 1a, 1b, and 1c, respectively, are less than NOK 7,871 m; the payoff of the grand coalition. Thus, the coastal state agreement can be considered stable and the Nash equilibrium of the coalition game.

Table (4) shows the coalition payoffs of the second climate change scenario, *i.e*, the stock is distributed according to the shares shown in Table (2), where the inflow of

Table 3: Scenario 1: Blue Whiting Game - Payoffs

Scenario 1a								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
Sole-Owner		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				
	MEAN	4367		1024	903	775	882	784
(EU),(FO),(IS),(NO),(RU)	MAX			2178	2072	1932	2066	1743
	MIN			0	0	0	0	0

Scenario 1b								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
Sole-Owner		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				
	MEAN	5205		1095	1077	1046	1039	947
(EU),(FO),(IS),(NO),(RU)	MAX			2590	2607	2482	2847	2556
	MIN			0	0	0	0	0

Scenario 1c								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
Sole-Owner		7871						
(EU,FO,IS,NO),(RU)		6774	3810					2964
(EU,FO,IS,RU),(NO)		6903	3621				3282	
(EU,FO,NO,RU),(IS)		6903	3621			3282		
(EU,IS,NO,RU),(FO)		6903	3621		3282			
(FO,IS,NO,RU),(EU)		6996	3592	3404				
	MEAN	4922		1068	1019	1019	1019	797
(EU),(FO),(IS),(NO),(RU)	MAX			2431	2335	2335	2335	2056
	MIN			0	0	0	0	0

†Values of NPV in million Norwegian kroner (NOK).

Table 4: Scenario 2: Blue Whiting Game - Payoffs

Scenario 2a									
			Payoffs - Net Present Value†						
Coalition Structure		Total	CS	EU	FO	IS	NO	RU	
(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	
	MEAN	4886	4055*	1228	961	961	905	831	
(EU),(FO),(IS),(NO),(RU)	MAX			2546	2223	2223	1971	1820	
	MIN			0	0	0	0	0	
Scenario 2b									
			Payoffs - Net Present Value†						
Coalition Structure		Total	CS	EU	FO	IS	NO	RU	
(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	
	MEAN	5124	4121*	1193	1003	1003	922	1003	
(EU),(FO),(IS),(NO),(RU)	MAX			2955	2509	2509	2233	2298	
	MIN			0	0	0	0	0	
Scenario 2c									
			Payoffs - Net Present Value†						
Coalition Structure		Total	CS	EU	FO	IS	NO	RU	
(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	
	MEAN	5128	4120*	1056	1021	1021	1021	1008	
(EU),(FO),(IS),(NO),(RU)	MAX			2494	2435	2435	2435	2357	
	MIN			0	0	0	0	0	

†Values of NPV in million Norwegian kroner (NOK).

*The sum of payoffs from the coastal states acting as singletons.

Atlantic water to the Norwegian Sea is reduced, resulting in a more western distribution of the blue whiting stock. The spawning takes place in the EEZs of the EU, the Faroe Island and Iceland; in Scenario 2c in Norway's EEZ as well, and there is no blue whiting in Russia's EEZ. Hence, Russia is not a partner in the blue whiting agreement and therefore always operates as a free rider. We see that the benefits provided in terms of payoff when all the coastal states cooperate in a coalition, NOK 3,635 m and 3,699 m with respect to Scenario 2a, and Scenario 2b and 2c, are insufficient to compensate the free-riders with their payoffs acting as singletons while the others continue as a smaller coalition. Nor is the payoff earned by the coastal state coalition larger than the sum of the payoffs when all players act noncooperatively. The sums of the payoffs of the coastal states when all players act noncooperatively, NOK 4,055 m, 4,121 m, and 4,120 m for the scenarios 2a, 2b, and 2c, respectively, are higher than NOK 3,635 m and 3,699 m; the payoffs to the coastal state coalition for the scenarios 2a, and 2b and 2c, respectively. Thus, in the scenario where global warming leads to a colder climate in Northern Europe and the blue whiting has a more western distribution than at present, a coastal state coalition cannot be stable under any circumstances, not even if the threat points are the noncooperative payoffs.

It is important to note that in the presence of non-unique equilibrium this result was 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 singletons payoffs of the coastal states. However, due to the lack of a better equilibrium selection criteria, in the presence of multiple equilibria we decided use the average of the equilibria payoffs as a representation of the payoffs the players could expect in the coalition structure where non-uniqueness occur.

In Scenario 1, with a high NAO index, 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 distant water fishing nation by the original coastal states to be 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 straight forward 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 in order to establish rights to the fishery and gain acceptance for their 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 1, the coastal state coalition will act as a sole owner, not as in Scenario 2 where Russia always acts as a singleton player while the coastal state coalition maximizes its own profit, taking the action of Russia as given. The sole owner payoff being the maximum attainable profit, the agents in such a management agreement will never find themselves in a situation like Scenario 2, where the sum of the payoffs in a coalition structure where some or all players act as singletons exceeds the payoff to the coastal state coalition. In the case of a low NAO index and less inflow of Atlantic water, Russia is no longer regarded 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 they would revert to a state where all acts as singletons. In the opposite case of high NAO index and increased inflow of Atlantic water, 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 Northeast Atlantic should cool down in spite of global warming so that the distribution area of the blue whiting stock would be reduced, the cooperation among the coastal states would become even more difficult than it is already and the blue whiting stock would almost certainly collapse.

4 Summary and Conclusions

This paper analysed how different climate change 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 ocean temperature and salinity. Two possible climate change scenarios were analyzed. First, an increased inflow of relatively warm and saline Atlantic water into 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. In the second scenario, less Atlantic water flows into the Norwegian Sea and the Barents Sea, reducing the ocean temperatures and salinities along the Norwegian coast as well as in the Barents Sea. In response to this, the blue whiting would shift its distribution and spawning areas in a more south-western direction, abandoning Russian waters altogether.

These two climate change scenarios are linked to the Northeast Atlantic Oscillation (NAO) index. A high NAO index is associated with strong winds blowing in a northeasterly direction across the Atlantic Ocean pushing warm and saline water into the Norwegian Sea and further northeast into the Barents Sea. A weaker NAO index, on the other hand, means that the winds follow an east-west path across the Atlantic, and that less of the warm and saline Atlantic water enters the Norwegian Sea and the Barents Sea. Based on these scenarios, we formulated three 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 model of Ekerhovd (2008), were used to calculate the payoffs to coalitions 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 opposite should happen, *i.e.*, the inflow of Atlantic water into these waters is reduced, and thus the distribution areas of the blue whiting stock is also reduced rather than increased as a consequence of global warming, this would weaken the stability of the current coastal state agreement on the management of the blue whiting stock.

Drastic changes in a fish stock's migration pattern might bring the underlying weaknesses of a management regime into the open and the nations that harvest this stock into conflict with each other (Hannesson, 2007). For instance, the coastal state agreement on the management of the Norwegian Spring-spawning herring 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. Another current potential conflict over a fish stock that has changed/expanded its area of distribution is about the Northeast Atlantic mackerel, which has expanded its migrations northwards, probably due to favourable climatic conditions, and is now found and fished in new areas in the international waters of the Norwegian Sea and within the EEZ of Iceland. Iceland, not being a member of the mackerel management agreement, has landed significant amounts of mackerel during summer and autumn in 2007 and 2008. This, in addition to the amounts landed by the member countries, has lead to a total harvest in excess of ICES's recommendations.

In the first climate change scenario, when the Norwegian Sea and the Barents Sea were expected to warm up and the distribution of the blue whiting stock 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 payoff of the coastal state coalition would always exceed the sum of payoffs 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 the countries that participate in the fishery, as is the case in the second scenario, and in Ekerhovd (2008), Russia is excluded from participating in the coastal state coalition, the coalition payoff is less than a potential grand coalition payoff would be, and a mechanism that prohibits free-riding among the coastal states is not necessarily sufficient to make the coastal state coalition stable. An example where this turns out to be true is Scenario 2 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 RFMOs guarantees a share of the profits to all interested parties as well as being able to provide a higher payoff 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 the 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

The annual spawning stock biomass is given by

$$SSB_t = \sum_{a=1}^{10+} MO_a W_a N_{a,t}, \tag{A-1}$$

where 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, W_a is the individual weight in kilograms at age a , shown in Table (A-1), and $N_{a,t}$ is the number of individuals in age group a in year t.

The numbers of fish at the beginning of a season that have survived last quarter's harvest and avoided death by natural causes, are given as (dropping the year subscript t)

$$\begin{aligned} N_{a,y} =& N_{a,y-1}\Bigg\{ S_{NEAFC,y-1} e^{-[m/4+q_{a,y-1}\sum_i X_i]} \\ &+ \sum_i S_{i,y-1} e^{-[m/4+q_{a,y-1} X_i]} \Bigg\}, \end{aligned} \tag{A-2}$$

where $i = EU, FO, IS, NO, RU$, and the catchability coefficient, $q_{a,y}$, shown in Table (A-2), where a denotes the age group and y the fishing season.

$$N_{1,1} = R_t \tag{A-3}$$

$$R_t = \begin{cases} 500, & if \quad SSB_{t-1} < B_{lim} \\ \alpha, & if \quad B_{lim} \leq SSB_{t-1} < B_{pa} \\ \alpha + \beta \times R_{t-1}, & otherwise. \end{cases} \tag{A-4}$$

Table A-1: Blue whiting: proportion of maturation, weight at age, and numbers at age 2000-2006.

Age group	Proportion mature	Weight‡	Number of fish† 2000	2001	2002	2003	2004	2005	2006
1	0.11	0.049	39,743.1	62,497.4	45,631.2	48,220.4	33,551.6	24,040.7	1,141.0
2	0.40	0.075	16,963.6	30,681.3	47,661.7	35,374.2	33,551.6	25,544.5	18,435.0
3	0.82	0.102	16,123.1	11,916.0	21,291.1	33,737.2	25,251.3	25,948.5	18,369.9
4	0.86	0.125	12,150.7	9,579,3	6,932.3	12,869.4	2,069.6	14,962.8	15,955.9
5	0.91	0.147	3,813.6	6,318.9	4,784.9	3,602.6	6,808.6	10,467.8	7,862.8
6	0.94	0.168	909.8	1,985.9	3,153.4	2,463.2	1,835.3	3,252.9	5,220.1
7	1.00	0.185	435.0	409.8	875.3	1,427.3	1,141.5	761.2	1,440.2
8	1.00	0.200	207.4	196.0	180.6	396.2	661.6	473.5	337.0
9	1.00	0.222	138.7	93.4	86.4	81.8	183.6	274.4	209.6
10+	1.00	0.254	384.3	235.6	145.0	104.7	86.4	112.0	171.1

†Numbers in millions

‡Weights in kilogram per individual

Table A-2: Blue Whiting: Quarterly age specific selectivity in catches

Age	1	2	3	4	5	6	7	8	9	10+
First quarter	0.11	0.40	0.82	0.86	0.91	0.94	1.00	1.00	1.00	1.00
Second quarter	0.11	0.40	0.82	0.86	0.91	0.94	1.00	1.00	1.00	1.00
Third quarter	1.00	1.00	1.00	1.00	0.50	0.25	0.10	0.10	0.10	0.10
Fourth quarter	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The parameter values in Equation (A-4) are shown in Table (A-3).

The profits earned by the different national fleets during a quarter of the year are as follows (dropping the year subscript t)

$$\begin{aligned}\pi_{i,y} =& pX_i \sum_{a=1}^{10+} q_{a,y} N_{a,y} w_a \left[\frac{S_{i,y}(1-e^{-[m/4+q_{a,y}X_i]})}{m/4+q_{a,y}X_i} + \frac{S_{NEAFC,y}(1-e^{-[m/4+q_{a,y}\sum_i X_i]})}{m/4+q_{a,y}\sum_i X_i} \right] \\ &- c_i X_i,\end{aligned} \tag{A-5}$$

where $i = EU, FO, IS, NO, RU$, and c_i denotes the countries cost parameters, shown in Tables (A-4) and (A-5) for Scenario 1 and Scenario 2, respectively.

Table A-3: Recruitment function parameters for the blue whiting, estimated over the period 1981-2006.

Parameters	α	β
Values	5113.57	0.76
Standard Errors	3790.41	0.14
$R^2_{adjusted}$	0.56	
Durbin-Watson test statistic	1.51	

Table A-4: Scenario 1: Cost parameters†

Scenario 1a								
			Costs					
Coalition Structure	X^{∞}	CS	EU	FO	IS	NO	RU
Sole-Owner	0.1301	6735					1953
(EU,FO,IS,NO),(RU)	0.104	5776					
(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 1b							
			Costs				
Coalition Structure	X^{∞}	CS	EU	FO	IS	NO	RU
Sole-Owner	0.1301	6735					2100
(EU,FO,IS,NO),(RU)	0.106	5540					
(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 1c							
			Costs				
Coalition Structure	X^{∞}	CS	EU	FO	IS	NO	RU
Sole-Owner	0.1301	6735					1684
(EU,FO,IS,NO),(RU)	0.113	5453					
(EU,FO,IS,RU),(NO)	0.113	4989				2148	
(EU,FO,NO,RU),(IS)	0.113	4989			2148		
(EU,IS,NO,RU),(FO)	0.113	4989		2148			
(FO,IS,NO,RU),(EU)	0.113	5437	1701				
(EU),(FO),(IS),(NO),(RU)	0.0815		1584	2160	2160	2160	1627

†Values of NPV in million Norwegian kroner (NOK).

Table A-5: Scenario 2: Cost parameters†

Scenario 2a

		Costs					
Coalition Structure	X^∞	CS	EU	FO	IS	NO	RU
(EU,FO,IS,NO),(RU)	0.111	6071					1253
(EU,FO,IS),(NO),(RU)	0.0945	6017				1961	1339
(EU,FO,NO),(IS),(RU)	0.0945	5054			2925		1339
(EU,IS,NO),(FO),(RU)	0.0945	5054		2925			1339
(FO,IS,NO),(EU),(RU)	0.0945	5134	2845				1339
(EU),(FO),(IS),(NO),(RU)	0.077		2436	2588	2588	1737	1169

Scenario 2b

		Costs					
Coalition Structure	X^∞	CS	EU	FO	IS	NO	RU
(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)	0.077		2734	2706	2706	2043	1446

Scenario 2c

		Costs					
Coalition Structure	X^∞	CS	EU	FO	IS	NO	RU
(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

†Values of NPV in million Norwegian kroner (NOK).