On the stability of fishery agreements under exogenous change: An example of agreements under climate change

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ABSTRACT

Many international fishery agreements contain cooperative agreements involving sharing rules, such as the sharing of quotas within an agreed total allowable catch (TAC). Some agreements are stable in the sense that none of the participants in the given fishery has an incentive to deviate from the agreement. This paper explores what happens to the set of stable agreements if changes occur which are exogenous to the fishery. The cod stock in the Baltic Sea (under climate changes) serves as an illustrative example. Given the projected climatic changes by the Intergovernmental Panel on Climate Change (IPCC), the stability of cooperative fishery agreements is not guaranteed. This paper presents some initial results of simulated changes in fishing agreements. These results show that climatic changes that have a negative effect on the resource rent decrease the set of possible stable cooperative agreements, thereby making cooperative solutions less likely.

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1. Introduction

The most recent and best estimate presented by the Intergovernmental Panel on Climate Change (IPCC) (2007) of average global surface warming is a 1.8–4.0 °C increase by 2090–2099 relative to 1980–1999. Many international environmental treaties and international resource-sharing arrangements will be affected by these climate changes. In particular, international fish-sharing arrangements are especially vulnerable to climate changes, since such changes directly affect the spatial distribution, growth, migration and recruitment of fish resources, which are all variables that are likely to affect resource rents and thereby the stability of fish-sharing agreements. We address this issue by setting up a model for a Baltic Sea cod fishery, which will be evaluated in the context of simulated climate changes. The fishery is assumed to be exploited by groups of countries called players. These players can form different coalitions, which are interpreted as cooperative agreements over shares of quotas. Such cooperative agreements induce either internal stability or stand-alone stability, assuming that no one has incentives to free-ride or deviate from the agreement (Barrett, 2003; Pintassilgo, 2003). Note that free-riding is interpreted as catching more fish than the agreed-upon quotas. In some fisheries, including, for example, the Baltic Sea cod fishery, there is a set of possible sharing rules that secures stand-alone stability (Kronbak and Lindroos, 2007). Here, a set is defined as a collection of possible stand-alone stable agreements. The size of this set is vulnerable to exogenous impacts, such as climate changes, which alter the ecological environment of the fishery. Our paper discusses how to measure whether climate change increases or decreases the set of internally stable cooperative agreements with no incentives to free-ride using the empirical example of the Baltic Sea cod fishery. The biological framework cited here is intended to simulate some first-order effects in order to understand how fishing agreements might be affected by climate change. Note that at present, the results cannot yet be used as a basis for fisheries management advice or decision-making. The changes in the set of stable fishery agreements are rather interpreted as a measure for change in robustness of the stable cooperative agreement.

Through the implementation of our model, we show that if climate change affects the value of the resource stock by decreasing the size of the biomass or by yielding a smaller recruitment param-

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eter, stability is deteriorated if the payoffs to the grand coalition decrease more than the sum of the gains achieved through free-riding. Our aim is to demonstrate the robustness of internal stability agreements should exogenous changes occur as well as to provide some illustrative first-order examples of how climate changes could affect a fishery agreement for the Baltic cod fishery.

Many fish resources are no longer subject to open access; they are now exploited by a limited group of countries acting within the context of explicit agreements. Several papers analyze the effect of emerging climate changes on the stability of such agreements. Miller (2007) analyses catch agreements of highly migratory fish resources such as the Pacific northeast salmon and tropical tunas. The main effect of (temporary) climate changes in this case is that the fish resource moves so that the premises on which the agreements rest change, rendering the agreement unstable. The lessons from Miller (2007) can be used to predict the instability of institutionally similar treaties induced by climate change, such as the treaty between Norway and Russia on the shared fish stock in the Barents Sea, which includes cod, haddock, and capelin. Miller (2007) as well as Miller and Munro (2004) conclude on the basis of a study of several commercially important shared fish stocks that the main management challenge in the presence of climatic changes is the limited understanding and poor predictability of the biological impacts, which contribute to the dysfunction or even breakdown of existing cooperative arrangements. A better understanding of the role of unanticipated climatic trends of shifts in current resources is needed, since better-informed management negotiations may help to smooth the path of adaptation, for example, by encouraging the development of more flexible allocation rules (Miller and Munro, 2004). The conclusions are also present in Miller (2007, p. 56) when she discusses the provision by the 1995 United Nations Fish Stock Agreement of a legal framework for the creation of regional fishery management organizations (RFMOs): "The stability and success of those organizations will depend, in part, on how effectively they can maintain member nations' incentives to cooperate, despite the uncertainties and shifting opportunities that may result from large climate-driven changes in the productivity or migratory behaviour of the fish stocks governed by the agreement".

Our work differs from the above papers, since we focus on economically valuable stocks and the stability of cooperative agreements. We present a specific case based on a simplistic biological model coupled with some comparatively more advanced economic models, and we find that this particular case carries lessons for other shared fisheries in which a change in climate or other exogenous factors may slowly change the environmental conditions of the fish stocks. In our paper, we show how the possibilities of achieving a cooperative agreement for a jointly exploited resource change if the resource itself is subject to an exogenous change. We apply this model to the Baltic Sea cod fishery and show that if climate change increases the biomass of the stock, then there is an increased possibility of achieving a cooperative agreement.

The paper is organized as follows: Section 2 describes the conditions for stable agreements and develops a new measure for the robustness of stable agreements. In Section 3, a bio-economic model is described. Section 4 describes the Baltic Sea fishery and the effect of climate changes on cod fish. Section 5 introduces the scenarios and simulations, while Section 6 concludes the paper.

2. Stability of agreements

2.1. Measuring stability

Consider several agents extracting a renewable resource, such as a limited number of fishermen or players, n, who exploit a common fish stock. The fishermen are assumed to adopt rational, profit-maximising behaviour over a finite time horizon from year y_1 to year y_2. The actions of the fishermen are thus defined based on the present value of profit, which is determined as the functional where the control variable is the fishing mortality for player $\{i\}$, $f^{\{i\}}$, and the state variable is the total number of fish in the stock, N. The instantaneous profit in year y for player $\{i\}$, π^i, is defined as follows:

$$\pi_y^{\{i\}} = pY_y^{\{i\}}(f^{\{i\}}, N) - Q_y^{\{i\}}(f^{\{i\}}, N), \tag{1}$$

where p is a constant exogenous ex-vessel price, $Y_y^{\{i\}}$ is a yield function measured in weight depending on fishing mortality and the fish stock, and $Q_y^{\{i\}}$ is a cost function similarly depending on fishing mortality and the fish stock. The net present value of all future profit for a single player $\{i\}$ is defined by the functional:

$$J^{\{i\}}(f^{\{i\}}, N) = \sum_{y=y_1}^{y_2} \frac{\pi_y^{\{i\}}}{(1+r)^{y-y_1}}, \tag{2}$$

where r is a discount rate.

The players choose their optimal fishing mortality as a constant fishing mortality over the simulation period by maximising the functional J as defined in Eq. (2). When fishermen are committed to their strategies only at the beginning of the game it induces a sort of open-loop control. The open-loop control allows the players less rationality and flexibility as compared to closed-loop control, according to which fishermen can change their strategies during a game.

Decisions are made under complete but imperfect information because all fishermen know all payoff functions but are moving simultaneously. Subgroups of the n players can form coalitions in order to cooperatively exploit the stock. In a coalition, the players agree to jointly decide their actions, and this action is based on the maximum net present value to the whole coalition. Therefore, a coalition basically indicates a group of players acting as a single player in deciding actions. If all players involved in a game agree to form a coalition, this is called a grand coalition. The net present value of future profits to the coalition then must be shared among the players joining the coalition. Let $s \subseteq K$, where K refers to $2n - 1$ possible coalitions. For coalition s, the strategy is denoted by f^s, indicating the strategy chosen when coalition s plays a Nash game (Nash, 1951) against players outside the coalition. Note that this is called a γ-type game (Chander and Tulkens, 1997). For small coalitions, including a singleton, that are outside a larger coalition, there are free-rider benefits if there are positive externalities present in the model. Note that there are positive externalities present in the model if a merger of coalitions increases the payoff of a player belonging to a coalition not involved in the merger. If a coalition tends to adopt a more conservative fishery management strategy, then non-members of the coalition are typically better off when more players join the coalition, and moreover, free-rider benefits exist. This is because the available fish stock is an important parameter in determining the optimal fishing mortality. Note that this paper addresses a case with positive externalities.

2.2. Requirements for an internally stable agreement

We assume that the players in the grand coalition, which is a coalition composed of all players, form a cooperative agreement regarding how to share the benefits of their joint actions. This is referred to as a sharing rule or a sharing imputation. A crucial point for the cooperative agreements to be stand-alone stable involves the way the benefits within cooperation are shared among the players (i.e., the sharing rule); see Kronbak and Lindroos (2007). The classical theory of games in coalitional form ignores the possibility of externalities. This means that the action available to a

coalition is assumed to be independent of the actions chosen by non-members (Greenberg, 1994). Since this paper is concerned with the extraction of a renewable resource by several agents, a stock externality is present, and thus, the classical approach has to be modified (Kronbak and Lindroos, 2007). The essence of this modification is that the presence of externalities affects the success of stable coalition structures. The approach is applied as a stability measure approach in Kronbak and Lindroos (2007) in which free-rider values are included as threat points. A free-rider is defined as a player that deviates from the agreed coalition, and a threat point is the value a player can achieve if he decides not to cooperate with the coalition. This definition of threat points build upon an assumption of individual rationality, namely, that a player should only join a coalition if this makes him/her at least as well off as he/she would be by not joining the coalition.

This approach implies that the stability of an agreement is increased when the aggregate gain from cooperation increases relative to the sum of free-riding gains. Based on traditional cooperative games, the general understanding is that with smaller gains, it is easier to achieve a cooperative solution. In our suggested approach, we are not interested in the actual size of the gain but rather in the difference between the gain and the sum of free-rider profits. The reason for this is that compared to the free-rider profits, there is a larger excess profit that can prevent free-riding. Excess profit is defined as the profit from the grand coalition minus the sum of profits from free-riding behaviours. In such cases, free-riding is less attractive, and thus, there will be a larger set of different sharing imputations that could form stable agreements. Therefore, when a larger surplus in the grand coalition exists, this can be used for deterring free-riding; the excess profit can be distributed to buy off potential free-riders. From that perspective, one can say free-riding and non-compliance both become less likely. Both free-riding and non-compliance contain risks of compromising the agreement. Therefore, the higher the gain in the grand coalition relative to the free-rider gains, the more internally stable cooperative agreements exist. This paper only discusses sufficient and necessary conditions to deter free-riding in the context of three players. The conditions are not sufficient with more players, since the grand coalition must be stable with respect to all other possible coalition formations and not only for free-riders. The three-player case is, however, sufficient for our illustrative example.

For a grand coalition to be stand-alone stable, we apply the definition of stand-alone stability provided by Pintassilgo (2003), which states that a joint agreement is stable if no player is better off free-riding than joining the grand coalition. This is a parallel to the traditional individual rationality assumed in games without externalities, which ensures that the players are as well off as when playing as singletons. The difference between games with and without externalities involves the threat points. In games with externalities, the free-rider profits are applied as threat points, while in games without externalities, singleton profits are applied. The boundary for internal stability can be defined as the benefits from the grand coalition exceeding the sum of individual benefits from free-riding, which is the difference between the functional for the grand coalition and the sum of functional for free-riders:

$$J^M(f^M, N) - \sum_{i=1}^{n} J^{\{i\}}(f^{\{i\}}, N), \tag{3}$$

where M corresponds to the grand coalition. This condition ensures that in a cooperative agreement, the profit gain is large enough to possibly compensate all players so they can achieve at least the profit the player would have achieved when free-riding on the grand coalition. Condition (3) describes the excess profit available in the grand coalition. The larger this excess is, the less likely is free-riding; that is, the excess (or surplus) profit could be said to be a proxy for the number of possible internally stable agreements.

In what follows, we consider how the stability of an agreement is affected by changes in exogenous parameters. On a general level, let z be any exogenous variable that causes changes in, for instance, the environment or climate that in turn have ecological effects on the stocks in terms of changes in recruitment, growth or mortality, for example. These ecological changes (denoted by) have an effect in the availability of the number of fish in the stock, which thereby changes the conditions for internally stable agreements.

We define the change in the stability of an agreement as the change in the proxy for the number of possible internally stable agreements when an exogenous change has occurred. This is a "with–without measure" measure of surplus profit that compares the case without exogenous change to the case with exogenous change:

$$\text{change in surplus profit} = \frac{\Delta \left[J^M(f^M, N; \ z) - \sum_{i=1}^{n} J^{\{i\}}(f^{\{i\}}, N; z) \right]}{\Delta z} \tag{4}$$

The change in the exogenous factor could be a one-shot change in the environment, but it could also be a gradual change over time. The above measure provides an indication of available surplus profit when cooperation is feasible and internally stable (Kronbak and Lindroos, 2007). If the measure is negative, this means that there are fewer possible ways of achieving an internally stable agreement after the exogenous change. Alternatively, if the measure is positive, then there is an increase in the number of possibilities for internally stable sharing agreements.

3. The applied bio-economic model

In this section, we present a model that serves as the bio-economic basis for the profits gained from exploiting the resource. Consider a bio-economic model in which population dynamics are described by a discrete time-age structured model. This is a standard type of cohort model. The motivation for this type of model is that climate changes can have different effects on the different cohorts. The number of fish in each year-class is determined as follows:

$$\begin{aligned}
&N_{2, \, y} = R_y & y > y_1 \\
&N_{a+1, \, y+1} = N_{a, \, y} e^{-m_a - S_a f y} & a \in \{2, 3, ..., A-1\}, \\
&N_{a, \, y_1} \text{ known} & a \in \{2, 3, ..., A\}
\end{aligned} \tag{5}$$

where R_y describes recruitment into the stock in year y, m is natural mortality, f is the total fishing mortality, and S_a is the selectivity of the fishing year such that if an age class is not harvested, then the selectivity is zero; otherwise, it is one. We assume that the initial abundance for all age classes in year y_1, $N_{a, \, y_1}$, is known. The population dynamics are determined by $A - 1$ age classes, namely $a = \{2, 3, \ldots, A\}$ where the recruits are 2 years of age before they enter the stock. y_1 is the initial year for the simulation model. The biomass is determined as the total number of fish multiplied by their stock weights at age, over all age classes:

$$B_y = \sum_{a=2}^{A} SW_a N_{a, \, y}, \tag{6}$$

where SW_a is the stock weight at age and B_y is the biomass in year y. The total spawning stock biomass is given by the sum of mature fish over all age classes:

$$SSB_y = \sum_{a=2}^{A} MO_a SW_a N_{a, \, y}, \tag{7}$$

where MO_a is the proportion of mature fish in age class a and SSB_y is the spawning stock biomass in year y. We assume a Beverton–Holt stock-recruitment relationship:

$$R_y = \frac{cSSB_{y-1}}{1 + bSSB_{y-1}}, \tag{8}$$

where c and b are biological recruitment parameters. c is the maximum number of recruits per spawner in a low-spawning stock size, while c/b is the maximum number of recruits when the spawning stock biomass is very large.

The catch measured in numbers of fish for country i and for a specific cohort is given by:

$$C_{a,y}^i = \frac{S_a f_y^i}{m_a + S_a f_y} \left(N_{a,y} - N_{a+1,y+1} \right), \tag{9}$$

where f_y^i is the fishing mortality by country i, f_y is the total fishing mortality, and $C_{a,y}^i$ is the catch in number of fish by country i during year y of a specific cohort a. The catch function is defined as the number of fish that does not survive to the next year and are not subject to natural mortality.

The yield or harvest for a single country is defined by inserting the number of fish (5) into the catch in terms of number of fish (9) multiplied by the catch weights at age:

$$Y_y^i = \sum_{a=2}^{A} CW_a N_{a,y} \frac{S_a f_y^i}{m_a + S_a f_y} \left(1 - e^{-m_a - S_a f_y}\right), \tag{10}$$

where Y_y^i is the total yield in weight for country i in year y.

The total cost of harvesting is assumed to follow the following function:

$$Q_y(t) = \alpha^i \frac{Y_y^{i2}}{B_y}, \tag{11}$$

where α^i is a cost parameter and B_y is the total biomass in year y. Given the definition of this model, there is a direct link between fishing mortality and yield; it is therefore appropriate for the control variable to be the yield. Fishing mortality would then be determined as a residual. The dependent variable, costs, is defined as total costs less depreciation, interest payments, and skipper wages. The cost function is defined such that if the total biomass is increased, fish are easier to locate, and costs therefore decrease; the effect of other players also exploiting the stock is included in changes in the biomass. The cost function is identical to the function applied to harvesting cod in the North Sea for Denmark, Iceland and Norway (Arnason et al., 2000). For an application of the above-described model, please see Kronbak (2004).

4. Climate change and its effect on cod fish

Access to the Baltic Sea is shared among members of the European Union (EU), including Denmark, Finland, Germany, Sweden, Estonia, Latvia, Lithuania and Poland, as well as the Russian Federation. The Baltic Sea consists of the central Baltic Sea, the Gulf of Bothnia, the Gulf of Finland, and the Sound and the Danish Straits; see Fig. 1.

The Baltic Sea contains no international waters, and therefore, only a limited number of nations have access to the sea. The most valuable fishery in the Baltic Sea is the cod fishery, which is managed by a bilateral agreement between the Russian Federation and the EU. The main management measure is the total allowable catches (TACs). In more recent years, Russia has only caught some 5–8% of all Eastern Baltic Sea cod landing in terms of weight (ICES, 2007). Within the EU, Denmark, Poland and Sweden account for the largest amount of landings in weight (approximately 75%) (ICES, 2007). If we include all cod landings from the Eastern Baltic Sea (including the unallocated landings), then Denmark, Poland and
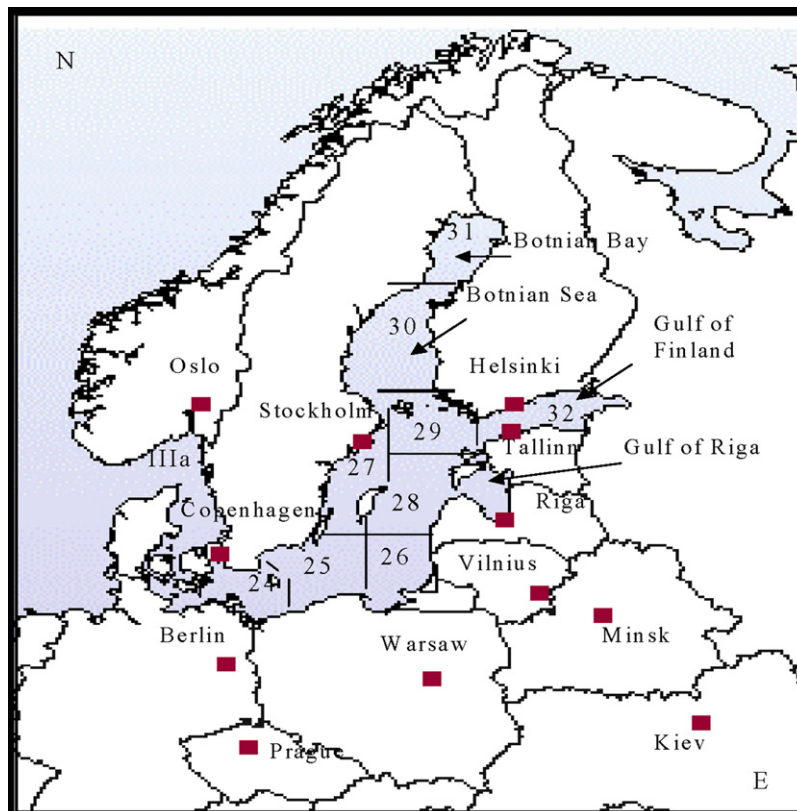

Fig. 1. Map of the Baltic Sea.

Sweden account for around 50% of all landings in weight. Within the EU, nations can deviate from the agreed TAC, and therefore, this model considers the internal stability of the EU agreement. Thus, this model groups the countries into three players, namely, Denmark/Sweden/Germany, Poland and the remaining countries.

Thus far, we have been rather vague about how climate changes precisely influence the recruitment and size of fish. According to IPCC (2007), particularity strong warming is projected for high latitude areas in the Northern Hemisphere due to global trends involving climate change, particularly in winter. This is predicted to occur not only over sea but even over the Arctic Ocean, where warming can be greatly amplified by reduced sea ice. Turning to the Baltic Area, Graham et al. (2008) reports a rather robust finding that the temperature over the Baltic Area is expected to increase between 0.3 and 0.5 °C per decade. Regional differences are also present, with the highest temperature increases in the northeast during winter and the lowest increases in the southwest during summer. Precipitation tends to increase up to 25% in winter, while in summer, this increase is more ambiguous, with a likely increase in the north and a small decrease in south. Most models show a general increase in most westerly winds, with the mean at about 4% by the end of the 21st century. The largest uncertainties are related to the projected changes in runoff (Graham et al., 2008, p. 193), but no solid conclusions can be drawn given the present models.

Generally, in specific geographical areas, climate changes might have both negative as well as positive effects on the growth rate or availability of renewable resources such as fish stocks or forests. Climate variations are likely to have an impact on fish stock parameters such as spatial distribution, growth, migration and recruitment. Therefore, in order to calculate the effect of climate change on the stability of an agreement, we must calculate how climate change is likely to affect the biomass of the relevant species. For a constant value of biomass, the result shows how climate change affects the profitability of a given agreement. Thus, we must transform the multidimensional space of environmental conditions into a one-dimensional profit function.

In order to do this, we define a climate change index (I_{CC}), where $I_{CC} = 100$ for example, could indicate the present climate pressure. This index could also measure the severity of the climate change as described by the various IPCC scenarios. Climate change is expected to influence (and has already influenced) air temperature, wind speed and direction, precipitation and, as a consequence, water temperature, salinity and oxygen. As already noted, we are interested in how profitability changes with changes in the climate, $\partial \pi / \partial I_{CC}$. Focusing on environmental variables, we note that $d\pi/dI_{CC} = (dB/dT \cdot \partial T/\partial I_{CC} + dB/dS \cdot \partial S/\partial I_{CC} + dB/dO \cdot \partial O/\partial I_{CC}) \cdot d\pi/dB$.

Here, B is the relevant biomass, T is the relevant sea water temperature, S is the salinity, and O the oxygen content. Once this relationship is established, we couple this with our model based on game theory to calculate the stability (SA) of the agreement, e.g. the change in the surplus profit. The expected climate change in the Baltic area affects the recruitment and size of cod directly through changes in the temperature, but it also indirectly affects the fish resource through its effect on salinity and oxygen content in the water.

4.1. Temperature

The average air temperature between 1994 and 1998 across the entire Baltic Sea was 4.6 °C. Obviously, Bothnian Bay, which is located in the northern area of the Sea, had the lowest average temperature at 0.3 °C, while the Baltic Sea proper had the highest average temperature at 7.2 °C. Nissling (2004) reports that in Baltic Sea, egg survival is unaffected in the range of 3–9 °C but is significantly lower at 11 °C. MacKenzie et al. (1996) estimate the average

water temperatures experienced by cod eggs in the Bornholm basin to be 5.5–6 °C. (We note that peak egg abundance occurred in the 1.5–6 °C range during 1987–1990.) Moreover, in no circumstance have cod eggs been found at temperatures higher than 9 °C during 1986–1996. However, temperature also affects the development rate of fish larvae directly and, consequently, the duration of high mortality and vulnerable stages decreases with higher temperatures. Hence, the expected temperature increase in the Baltic Sea might potentially have a (small) negative impact on recruitment as well as a (small) positive impact on growth rate. MacKenzie et al. (2002) summarize various findings and conclude that although temperature is a factor that influences cod recruitment in many other areas (see Brander, 2000), its effect on cod in the Baltic Sea is probably obscured by the effects of salinity and oxygen.

4.2. Reproductive volume

Salinity and oxygen have direct impacts on the development of the Baltic Sea cod eggs, which require a minimum salinity ($S \geq 11‰$) and oxygen concentration ($c[O_2] \geq 2$ mL/L). Below these thresholds, the development of cod eggs ceases before they are hatched (Nissling and Westin, 1991). The water that has the characteristics necessary for hatching has been termed the "reproductive volume" (RV) for Baltic Sea cod (Jarre-Teichmann et al., 2000). That is, the RV is the volume of water suitable for the successful development of the early life stages of Baltic cod. Note that the RV substantially fluctuates due to natural causes (Jarre-Teichmann et al., 2000), and so our estimates must be understood as averages over several years.

4.3. Salinity

The present salinity in the Baltic Sea is between 12 and 15% according to Meier et al. (2006). Salinity in the Baltic Sea is highest in the southwest and lowest in northwest; that is, we see decreasing salinity from west to east and from south to north. According to Graham et al. (2008), Baltic Sea salinity is controlled by river runoff, net precipitation and water exchange with the North Sea. Overall, the general prediction is that salinity is likely to fall. Climate change will change salinity in the Baltic Sea between +4 and up to −45% by the end of the 21st century, and most likely, there will be a significant reduction in salinity. The main reason being increased fresh water inflow and increased mean wind speed. However, although salinity in the entire Baltic Sea is expected to be significantly lower, the level of halocline is still expected to remain, which means that the upper and lower layers of the Baltic Sea will remain separated (Graham et al., 2008, p. 200). Most importantly for our analysis, the expected reduction in salinity on average reduces the RV in the Baltic Sea.

4.4. Oxygen

A certain concentration of oxygen is necessary for recruitment. As already stated, eggs require an oxygen content of at least 2 mL/L; otherwise, they simply die. Oxygen content is directly affected by changes in wind, the inflow of waters from the North Sea and temperature. This is due to increased levels of the oxygen-consuming demineralization of organic materials, but it is also because increasing water temperature reduces oxygen resolution (Röckmann et al., 2008).

Ambiguous results are found regarding changes in oxygen content. According to Vermaat and Bouwer (2009), foreseen climate change will further reduce ice extent, enhance wind mixing and increase oxygen availability at the deep sediment–water interface. However, oxygen concentration is more likely to decrease in warmer than in cold waters not only due to the increased oxygen-consuming demineralization of organic materials but also
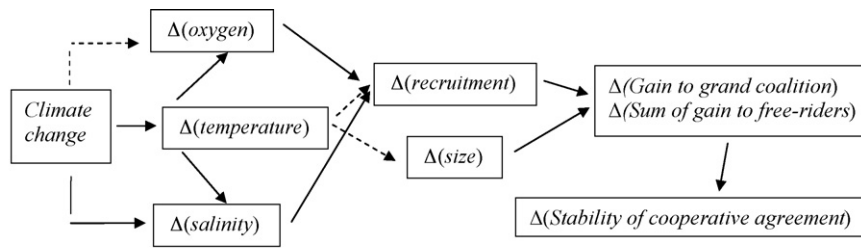
Note: The picture is a modification from Roessig *et al.* (2005). Δ indicates a change.

Fig. 2. Schematic picture of how climate change affects the stability measure.

because increasing water temperature reduces oxygen solubility (Röckmann et al., 2008).

Therefore, we abstain from making assumptions regarding the effects of expected changes in temperature on the number and size of cod in the Baltic Sea. Rather, we discard these effects as well as effects from potential changes in conditions affecting the oxygen content, thereby focusing exclusively on salinity and oxygen content.

4.5. The relationship between climate change and other variables

In a multi-species context, an increase in water temperature favours the reproductive capacity of sprat; i.e., sprat reproductive success increases, which may be unfavourable for cod due to the potential increase in the predatory behaviour of adult sprat in the early life stages of cod (Röckmann et al., 2008). In addition, these exogenous changes are likely to change the entire composition of the ecosystem, including the fishery food-chain. Though these other exogenous effects are important and relevant for fisheries, for illustrative purposes, we have limited our analysis to consider changes in the recruitment of cod due to changes in salinity.

Rather, we exclusively focus on recruitment; a schematic overview of effects is shown in Fig. 2. The broken arrows show where major uncertainties exit for the Baltic Sea. We include some biological parameters only in order to provide some first-order results regarding how simulated fishing agreements might be affected by climate change. Nevertheless, the model should be expanded with, for instance, future climate trajectories if these results are to be used as basis for managerial advice.

Let us now describe the causal link between changes in the climate and change in the stability of agreements in more detail. As noted above, we exclusively focus on changes in the salinity, and hence, the overall chain of cause and effect can be expressed as:

$$\Delta I_{CC} \to \Delta S \to \Delta RV \to \Delta B \to \Delta \pi \to \Delta \text{stability}$$

4.6. Modelling the link $\Delta I_{CC} \to \Delta S$

The change in salinity is dependent on numerous climatic factors, but Röckmann et al. (2008) consider three scenarios based on different climate scenarios from the IPCC reports. (See Röckmann et al. (2008) for a thorough description of these scenarios.) There is a low-effect scenario, with a reduction of 3.5% in salinity over 50 years, a medium-change scenario with a 12.5% reduction in salinity over 50 years, and finally, a high-change scenario with a 23.5% reduction in salinity over 50 years. As is often the case with IPCC, no probability estimates of the relative likelihood of these three scenarios are provided. The estimates fall well within the figures provided by Meier et al. (2006), if we assume, as like Röckmann et al. (2008), that salinity decreases linearly over the century.

4.7. Modelling the link $\Delta S \to \Delta RV$

According to Röckmann et al. (2008), more than 50% of the variance in reproduction can be explained by changes in salinity concentration. However, they do not include the expected changes in oxygen concentration due to a lack of knowledge at present of the deep basin dynamics of oxygen, which follows our assumption. Röckmann et al. (2008), moreover, perform a simple linear regression to establish the link between salinity and RV, which is presented in a reduced form here:

$$RV^{25}(S) = -504 + 56.6 \cdot S$$

$$RV^{26}(S) = -1029 + 105.2 \cdot S$$

$$RV^{28}(S) = -533 + 53.6 \cdot S$$

S is measured in ‰ and the superscripts indicate area (see Fig. 1). In case that RV is negative, it is set to zero.

We use this information to calculate how the RV is affected by climate change. In Table 1, we present the factor (RV^{new}/RV), through which the RV is reduced for different salinity levels, including the highest and lowest value for the three areas across the three climate scenarios. We present these changes for different initial values of salinity between 12 and 15‰ to represent current values. The effect of changes in salinity on reduction in the RV depends more on type of climate scenario and less on the initial salinity level.

4.8. Modelling the link $\Delta RV \to \Delta BM$

The most critical link involves calculating the effect of changes in environmental variables on changes in biological variables. Our first assumption is that climate change in the Baltic area only affects the recruitment through its effect on the RV. Second, we must consider that fish might migrate in response to changes in salinity, temperature and oxygen variables. Fish might migrate from unfavourable

Table 1
Changes in the reproductive volume.

‰	S = 12	S = 13	S = 14	S = 15
Low change	0.61–0.86	0.73–0.89	0.79–0.90	0.82–0.91
Medium change	0.09–0.52	0.35–0.60	0.48–0.66	0.56–0.69
High change	0.00–0.09	0.00–0.25	0.10–0.35	0.23–0.42

Note: The lower values in the table correspond to area 28 and the higher values correspond to area 25.

Table 2
The impact of climate change on the recruitment parameter.

Climate scenario (ΔI_{CC})	Value of the c parameter
Low change	0.9
Medium change	0.6
High change	0.3

areas to more favourable areas with respect to hydrological conditions in terms of temperature, salinity and oxygen. Since the salinity content is larger in area 25, fish might migrate to this area, as salinity contents become lower. According to Röckmann et al. (2008), spawning migration from area 28 into areas 25 and 26 and from area 26 into area 25 can be expected due to relatively better hydrological condition. However, according to Röckmann et al. (2008), an analysis of spawning migration due to environmental factors has not been undertaken for cod in Baltic Sea. Neither has there been any systematic analysis of egg and larval drift. To take this into account, we use the change in the RV in area 25 as the basis for the reduction in recruitment. Our scenario estimates the consequences of a reduction in the maximum recruits per spawner, c, using the Beverton–Holt stock-recruitment function. Initially, parameter c is estimated to be close to one, but we have no estimates of how large the reduction in the recruitment will be due to climate change. Therefore, we include small, moderate and large decreases in the recruitment parameter in this scenario to correspond to low, medium and high changes in Table 1. Table 2 below summarizes the average change in c based on the reduction in the RV in area 25 calculated based on Table 1.

5. The scenarios and the simulations

We assume that the price of fish per weight, p, is constant regardless the size of the fish, which is a common assumption in the literature. Furthermore, we focus only on changes in salinity that affect recruitment.

The basic scenario is a simulation without a climate component. It corresponds to the scenario reported in Kronbak and Lindroos (2007) and is applied as a baseline case for comparison with other scenarios. Kronbak (2004) shows that this is a stand-alone stable pre-climate change scenario.

The salinity reduction scenario describes a scenario in which climate change only affects recruitment (i.e., the fish size is constant). As long as recruitment reduces biomass, the costs per fish caught will increase, since costs are defined inversely as dependent on biomass. Even if a re-optimization is likely to occur, the total effect is a decrease in profit, although it might be reduced by changing the size of catch.

The basic scenario applies parameter values similar to those provided in Kronbak (2004). See the appendix for specific parameter values. As already noted, we simulate the consequences of a reduction in c of 0.9, 0.6 and 0.3.

The uncertainty of regarding the possibilities of stable agreements if climate changes affect fish stock by decreasing recruitment is captured by simulating the scenarios. We estimate excess profit as compared to the free-rider value to determine how the set of stand-alone stable solutions changes in these scenarios. This is done by first simulating the net present value of future profits using Eq. (2) for the grand coalition and the free-riders, respectively, by keeping in mind that players chose the fishing mortality that return the maximum net present value of their future profits given the coalition formation, as described in Section 2. The results from these estimations are summarized in Table 3.

Excess profits can be illustrated graphically using a player 1–player 2 diagram; see Fig. 3. On the axes are the net present values to player 1 and player 2. The line FR1 demonstrates the minimum

Table 3
The net present value of profits from the grand coalition and the singletons in the basic scenario.

Coalition/player	Net present value of future profits over 50 year in 10^8 Dkr
Grand coalition	747.14
Player 1 free-riding on grand coalition	284.70
Player 2 free-riding on grand coalition	210.28
Player 3 free-riding on grand coalition	284.70

Note: Free-riding does not always lead to the same bio-economic break-even return, as changes implying larger asymmetries in the harvesting cost functions and/or different rates of time preferences among the players will alter the results.
Numbers are subject to rounding. 100 Dkr corresponds to app. 13 Euro or app. 17 USD (February 2009).

value player 1 must achieve to deter this player from free-riding on the grand coalition. This corresponds to player 1's threat point. Similarly, FR2 corresponds to player 2's threat point. FR3 illustrates the maximum net present value left to player 1 and player 2 to deter player 3 from free-riding. This is thus the net present value of future profits to the grand coalition minus the value of player 3's threat point.

The shaded triangle in Fig. 3 indicates the set in which there is an excess profit, that is, the set of possible sharing imputations that are stand-alone stable. It is not always the case that such a set exits (Duarte et al., 2000). By measuring the change in the size of this area, we have an indication of whether a stand-alone stable grand coalition is more or less likely.

To formally determine the size of the excess profit, Eq. (3) is applied. This corresponds to the net present value of future profits from full cooperation minus the sum of net present values from free-riding. These estimates are summarized in the third column in Table 4. Finally, the change in excess profit is determined by comparing excess profits for each scenario summarized in the third column in Table 4 to excess profits in the basic scenario. This corresponds to applying Eq. (4); these estimates are summarized in column 4 in Table 4.

The lesson to be learned from this simulation is that in the simulated scenarios, there exists a stand-alone stable grand coalition seen as positive by the numbers in column three in Table 4. The reason for this is that stock externality is strong enough to deter free-riding in the context of a joint solution. Furthermore, it can be seen that the set of stable sharing imputations decreases if the value of the stock decreases, which is illustrated by a decrease in the maximum recruits per spawner parameter, c. A decrease in this parameter implies that the value of the stock decreases. In our simulation, there is a smaller set of stable sharing imputations; if the value of the stock is decreased, the fourth column in Table 4 is negative. The particular size of the numbers in Table 4 is not essential
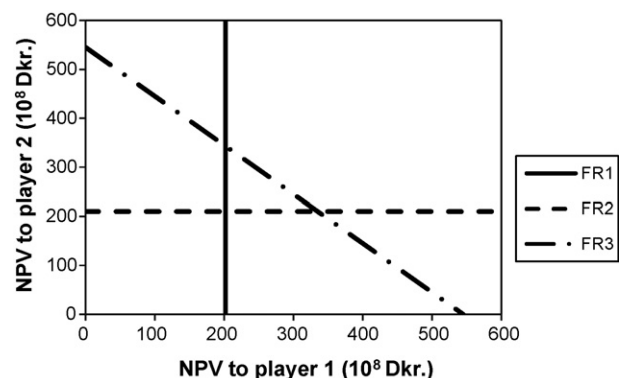

Fig. 3. The set of possible stand-alone stable sharing imputations in the basic scenario.

Table 4
Results from estimations for different scenarios.

		Excess profit from full cooperation as compared to free-riding (Eq. (3)) (10^9 Dkr)	Change in excess profit as compared to the basic scenario (Eq. (4)) (10^9 Dkr)
Basic scenario		5.00	–
Salinity reduction scenarios	Decrease in recruitment ($c = 0.9$)	4.79	−0.22
	Decrease in recruitment ($c = 0.6$)	3.41	−1.59
	Decrease in recruitment ($c = 0.3$)	1.89	−3.12

Note: Numbers were subject to rounding. 100 Dkr corresponds to app. 13 Euro or app. 17 USD (February 2009).

for our conclusions, as we are merely interested in the signs of the numbers and their relative size.

6. Discussion and implications

Climate changes have an effect on the ecological conditions for marine species, which in turn change the pre-conditions upon which fisheries agreements are based. This paper introduces some of the uncertainties related to a species like the Baltic Sea cod a when climatic changes occur. It formalizes the uncertainty into an illustrative scenario, namely, a salinity reduction scenario resulting in a decrease in the maximum number of recruits per spawner. The biological framework underlying this scenario is only intended to provide some first-order results in order to provide general statements regarding the management consequences of climate changes. Within this scenario, the set of stable joint solutions, as compared to the basic scenario without climate changes, is estimated. A measure for the set of internally stable agreements is defined for Baltic Sea cod fisheries, though we nevertheless find it appropriate to draw some general lessons from it. One finding from our case is that climate changes increase scientific uncertainty and, consequently, the agreement settings on which management rely. This highlights the need for better information and/or the need for a flexible management system that can cope with shifting environments. We develop a method to measure the robustness of the results with respect to the values of parameters that are affected by temperature changes and show that based on this case, the size of the biomass changes the premises for stable cooperative agreements. We find that our particular case carries lessons for shared fisheries in which the climate is slowly changing the environmental conditions for fish stocks.

As with most analyses based on game theory, this paper ignores transaction costs (i.e., negotiation, monitoring, and enforcement costs) and how those costs might be affected by uncertainty. However, our paper considers changes in the excess surplus so that under the assumption of identical or similarly sized transaction costs, these costs cancel out.

Several papers have used case studies to conclude that climate changes and climate variability imply a destabilization of international fisheries agreements, typically due to movements in fish stocks. Our study takes a different stance, since it concentrates on changes in the abundance and size of fish stocks as a response to climate changes. One main finding is that when the value of the stock changes, the size of the set of stable agreements changes in the same direction. That is, if climate changes increase the resource

rent, then there is a larger set of stand-alone stable agreements, implying that stable agreements are more likely. In contrast, if the value of the biomass decreases, there is a smaller set of stable agreements. These conclusions are subject to uncertainties about actual climate changes and other related consequences regarding recruitments and changes in stock size. In general, when a stock externality is present, a decrease in the resource rent implies that the consequences of free-riding become less serious, thereby providing fewer possibilities for a stable solution. Generally speaking, this implies that climate changes that have a negative effect on the resource rent make joint solutions less likely.

Our paper considers only climate changes that affect the salinity of the sea. Climate changes also imply changes in temperature, wind speed and direction, fewer periods of ice coverage and differences in oxygen concentrations. A reduction in oxygen concentration may result in fish migrating to more oxygen-rich areas, thereby changing the entire ecosystem. This can lead to a concentration of fish in certain areas, which can even increase the catch per unit of effort, even if biomass is reduced. Such a scenario could have negative effects due to both reduced oxygen concentration and short-term increased fishing mortality. Longer than that, the low oxygen will suppress recruitment by the spawners which did not get caught by the increasingly effective fishery. As a result the biomass will decline very fast—due to both the effect on recruitment and the increasing effectiveness of the fishery. The effect of changes in oxygen and temperature on the management and stability of joint action is an area for further research that requires a model that includes a spatial relationship.

Appendix A. Applied parameter values & basic scenario

The basic scenario applies parameter values similar to those provided in Kronbak (2004).

Table A.1
Biological parameter values used in this study.

Parameter	Value
Mortality parameter $m_{2, 3, \ldots, 8}$	0.2
Stock-recruitment (B-H) parameters c	0.9814216
b	0.000002340
Age classes in stock A	8

Source: Kronbak (2004).

Table A.2
Initial biological values.

	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8+
MO	0.14	0.32	0.84	0.94	0.98	0.96	1
SW	0.244	0.548	1.230	1.595	2.963	4.624	5.417
CW	0.662	0.773	1.127	1.448	2.337	3.485	4.647
N_0	13,6493	71,852	37,621	15,421	4332	2026	1452

Abbreviations: MO, proportion mature at the start of the year; SW, mean weight in stock (kg); CW, mean weight in catch (kg); N_0, initial abundance (thousands).
Source: Kronbak (2004).

Table A.3
Economic parameter values.

Parameter	Value
First fishing age, a_1	3
Selectivity S_2	0
Selectivity $S_{3,\ldots,8}$	1
Cost parameter, country 1: α^1	9 Dkr/kg
Cost parameter, country 2: α^2	14 Dkr/kg
Cost parameter, country 3: α^3	15 Dkr/kg
Discount rate, r	2%
Price, p	10.74 Dkr/kg
Max. fishing mortality, f_{max}^1	0.35
Max. fishing mortality, f_{max}^i, $i = 2, 3$	0.3

Source: Kronbak (2004).

Tables A.1–A.3.

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