SCOPE AND COMPATIBILITY OF MEASURES IN INTERNATIONAL FISHERIES AGREEMENTS

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Abstract

We set up a model which captures the spatial dimension of international fisheries in legal (i.e. internationally accessible high seas versus state-owned exclusive economic zones) and biological (i.e. various intensities of fish migration between zones) terms. We compare the success of regional fishery management organizations (RFMOs) for consistent and various forms of inconsistent management options, related to limitations of scope and compatibility of measures. While the performance of an RFMO declines in the presence of inconsistent management, participation might improve as free-riding becomes less attractive and the overall net effect may well be positive. This suggests to first broaden participation before deepening fishery treaties.

JEL References: C72, F53, H87, Q22

Keywords: shared fish stock, regional fishery management organizations, scope of cooperation, compatibility of management measures, bioeconomic model, non-cooperative coalition theory.

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1. Introduction

Managing global and international commons requires voluntary international cooperation due to the absence of a supranational institution that could enforce a cooperative management strategy. While, in general, a tragedy of the commons is not inevitable, internationally shared fish resources seem to be particularly vulnerable to overexploitation.[1] In an attempt to address this problem, state-owned property rights have been established under the legal regime of the United Nations Convention on the Law of the Sea (UNCLOS; see UN 1982). According to Articles 56 and 57 of the Convention, every coastal state has the right to establish an Exclusive Economic Zone (EEZ), adjacent to its territorial waters, extending 200 nautical miles into the sea, in which it exercises sovereign rights regarding the management of all (living and non-living) marine resources. Beyond the EEZs, in the high seas, the open access regime persists, i.e. resources are subject to the exploitation by all nations (Art. 87).

Despite this large-scale allocation of property rights, many commercially valuable fish stocks are still exploited (and overexploited) by more than one fishing nation because they either occur in the high seas and/or migrate through more than one jurisdictional area.[2] Addressing this problem requires a comprehensive and consistent international management of shared fish stocks. International marine law recognizes this need for international coordination and cooperation. Art. 63 and Art. 64 of the UNCLOS call for a cooperative management of straddling and highly migratory fish stocks, either directly through bilateral negotiations or through the development of regional fisheries management organizations (RFMOs). This call for cooperation is repeated by the UN

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1 For a documentation of the state of internationally shared fish resources, see Maguire et al. (2006).

2 The common classification of shared fish stocks (cf. Munro et al. 2004, p. 3) is as follows: *transboundary stocks* inhabit (or cross) the EEZs of two or more coastal states, *highly migratory stocks* are to be found both within the EEZs and the adjacent high seas and are highly migratory in nature, s*traddling stocks* also cover both EEZs and the high seas but are more stationary, discrete high seas stocks occur only in the high seas.

Fish Stocks Agreement in 1995 (UN 1995) which deals explicitly with the conservation and management of straddling and highly migratory fish stocks.[3]

While there is a broad consensus in the international community that the management of shared fish stocks requires a cooperative approach, the details have been controversial during the negotiations preceding many fishery agreements. The undisputed sovereignty of coastal states with respect to the management of intra-EEZ resources obviously conflicts with the aim of a consistent management of shared fish stocks across the entire geographical area of their occurrence. The UNCLOS in 1982 calls for cooperation "both within and beyond the exclusive economic zone" (Art. 64 (1)) in the case of highly migratory species, whereas for straddling stocks Art. 63(2) only requires a cooperative management in the high seas. The UN Fish Stocks Agreement in 1995 restates this distinction (Art. 7(1)) and emphasizes both the sovereignty of coastal states regarding intra-EEZ fishery management but also the importance of the compatibility of conservation measures at the same time (Art. 7(2)). Accordingly, most currently existing RFMOs confine the area of actual management to the high seas, but call for a compatibility of intra-EEZ and high seas management measures, though they remain vague how this compatibility shall be achieved.[4]

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3 Highly migratory species are listed in Annex I of the UNCLOS and include most tuna species, as well as marlins and swordfish. Examples of straddling stocks include for instance the commercially valuable stocks of the Alaskan Pollock and the Norwegian Spring-Spawning Herring.

4 The ambiguity inherent in Art. 7 of the UN Fish Stocks Agreement in 1995 leaves room for several interpretations. While Oude Elferink (2001) argues that it should be interpreted as favouring neither coastal states nor RFMO management authorities, Molenaar (2005) clearly supports the position of many coastal states which claim priority and sovereignty for coastal fisheries management. The latter position is sometimes referred to as the *bottom-up* approach, in contrast to a *top-down* approach which gives priority to RFMO management (Örebech et al. 1998). Based on an analysis of the aforementioned Art. 7, Goltz (1995) concludes that priority will depend on the specific circumstances. In order to avoid conflicts, some RFMOs simply ignore this issue. For instance, a recent performance review criticized that the International Commission for the Conservation of Atlantic Tunas (ICCAT) „*has not taken any measure aimed at ensuring the compatibility between conservation and management measures adopted by a coastal State with respect to the areas under its jurisdiction and those adopted by ICCAT*" (Hurry et al. 2008, p. 16).

A good representative example is the herring in the North East Atlantic which is shared by Norway, Iceland, the Russian Federation, the European Union, the Faroe Islands and Greenland, accounting for an annual catch of more than 1.6 million tons in 2009. The RFMO in charge of managing this stock, the North East Atlantic Fisheries Commission (NEAFC), states the ”long-term conservation and optimum utilization of the fishery resources in the Convention Area” (Art. 2 NEAFC Convention) as its objective. Although the Convention Area comprises both areas within and beyond areas under national jurisdiction, NEAFC's regulatory power is limited to the high seas in recognition of the sovereign rights of coastal states within EEZ boundaries (Art. 5(1)).[5] A consistent management is defined as one that respects the management measures adopted by coastal states within the areas under their national jurisdiction (Art. 5(2)). Similarly vague and contradictory provisions are part of the conventions of many RFMOs, creating a constant source of conflict between RFMO member states. For example, a recent performance review of the North Atlantic Fisheries Organization (NAFO) criticized that "the language used [in the NAFO Convention] does not create an obligation on either the [NAFO] Commission or coastal State to ensure consistency in their measures" (NAFO 2011, p. 22). Consequently, conflicts arise such as in 1999, when the EU accused Canada for intra-EEZ cod fishing being not being compatible with conservation efforts established by NAFO (Oude Elferink 2001).

Obviously, a single decision maker aiming at maximizing global welfare would implement a consistent management of fishing resources across all zones, being aware of migration patterns. Technically speaking, he would maximize the aggregate economic rent from fishing in all zones, taking into account linkages across zones through migration. However, in reality, there is no single decision maker, participation in an RFMO has to be voluntary and hence participation is often incomplete due to free-riding and the members of an RFMO may depart from the implementation of a consistent

[5] Regarding fishing in the EEZ of a member state, the NEAFC Commission has only limited influence. First, it can only make recommendations if the coastal state in question requests this. Second the coastal state has to approve the recommendations in order for them to become effective (Art. 6(1)).

fishery management. It is the aim of this paper to evaluate the success of RFMOs in such a strategic setting and under the restriction that RFMOs have to be self-enforcing. In particular, we are interested in comparing the performance of RFMOs with consistent to those with inconsistent management strategies.

In a strategic setting the outcome of such a comparison is not obvious for at least two reasons. First, due to strategic interaction between fishing nations, either as an RFMO member or non-member, what is optimal at the individual level does not necessarily have to be optimal at the aggregate level and vice versa.[6] Second, even if a departure from a first-best management strategy negatively impacts on economic rents, this may be compensated by higher participation in an RFMO.[7] A less ambitious management strategy may buy more participation which may improve the overall performance of an RFMO. Whereas it is straightforward to define consistent management, the possibilities of second-best designs are numerous. In order to test the robustness of our conclusions, we will consider two versions of inconsistent management strategies related to the scope of cooperation and the compatibility of measures.

The issue at stake requires an approach that captures two essential features of international fisheries simultaneously. First, we have to set up a bioeconomic model which captures different geographical areas (high seas and EEZs) and the migration of fish stocks across zones. Second, we require a coalition formation model which tests for stability of RFMOs. In the literature on fishery economics such an integrated approach is missing so far. The first aspect is dealt with in several papers considering the exploitation

6 For instance, in the context of climate change, uncertainty and learning, Kolstad (2007), Finus and Pintassilgo (2012) and Na and Shin (1998) show that no learning may lead to better global outcomes than learning due to strategic interaction across players.

7 In the context of global emissions, such countervailing effects have been described by Barrett (2002) ("consensus versus focal treaty") and Finus and Rundshagen (1998) ("majority versus unanimity voting") in a repeated game framework and by Finus and Maus (2008), who call it "modesty versus ambition" in a coalition formation model of the type we use in this paper. See also more recently Courtois and Haeringer (2012) on the trade-off between environmental treaty objectives and participation.

of a migratory fish stock by two or more competing fishing nations (e.g. McKelvey et al. 2002, Hannesson 1997, Naito and Polasky 1997, and Arnason et al. 2000). These papers typically consider the Nash equilibrium outcome in a competitive game and demonstrate its inefficiency by contrasting it with the outcome of a fully cooperative management scheme. They do not, however, examine the stability and success of coalitions, and if so, they only test for stability of the grand coalition but not of partially cooperative agreements. Also on the second aspect there exists an extensive literature on international fishery coalitions which can be broadly divided into two categories (for an overview, see Lindroos et al. 2007). Most of the early papers apply *cooperative* game theory to examine the implications of various sharing rules such as the Shapley value under full cooperation (e.g. Kaitala and Lindroos 1998 and Duarte et al. 2000). This approach, however, does not allow studying the impact of free-riding explicitly. This requires concepts from *non-cooperative* coalition theory, first applied by Pintassilgo (2003) to the analysis of international fisheries. In a similar paper, Pintassilgo and Lindroos (2008) conclude that the non-cooperative Nash equilibrium is the only stable outcome whenever the number of fishing nations exceeds two. However, these papers confine their analysis to one zone; hence migration does not matter. Our work extends Finus et al. (2011), who incorporate different geographical zones and migration into the analysis of international fishery coalitions, by including suboptimal management strategies.

Our paper is organized as follows. Section 2 describes the bioeconomic model, which is an extension of the Gordon-Schaefer model accounting for different geographical zones and migration. Section 3 deals with the economic behavior of countries. It introduces the coalition formation model and the various scenarios of consistent and inconsistent fishery management strategies. Section 4 details our solving procedure and outlines the model and parameter specifications. Sections 5 and 6 discuss our results and section 7 concludes.

2. The Model

2.1 Preliminaries

The analysis of cooperation in international fisheries requires concepts from biology in order to describe the biological processes of the fish stock (e.g. growth and migration patterns), has to take into account the legal framework of international marine law, and should capture the essential features of economic behavior of the protagonists in the "fishery game". The biological part is based on the classical Gordon-Schaefer model (Gordon 1954 and Schaefer 1954) which has been frequently used to analyze the steady-state of an exploited (fish) resource (for an introduction, cf. Clark 2005). The economic and behavioral part is based on the single coalition open membership game due to d'Aspremont et al. (1983) which has been frequently applied in the literature on international environmental agreements (e.g. Carraro 2000 and Finus 2003, 2008 for surveys).

2.2 The Biological and Spatial Dimension

We assume that a given number of fishing nations N exploit a shared fishery resource which is characterized by an intrinsic reproduction process. The steady state of the fish stock in the classical Gordon-Schaefer-model is described by the following equation:

$$\frac{dX}{dt} = G(X) - H(X, \boldsymbol{E}) = 0 \ . \tag{1}$$

Eq. (1) states that in the steady-state, growth G and harvest H are balanced such that the stock X remains constant over time. For intrinsic growth it is usually assumed that growth requires an initial population $\left(G(X = 0) = 0\right)$, it is positive as long as the carrying capacity k has not been reached $\left(G(0 < X < k) > 0\right)$ and it stops at the carrying capacity k of the system $\left(G(X = k) = 0\right)$. Total harvest depends on the stock X and the vector of individual fishing efforts $\boldsymbol{E} = \left(E_1, ..., E_N\right)$.

In order to capture the fact that the traditional open access and laissez-faire regime has been replaced by the legal framework defined by the UNCLOS in 1982, we have to extend the classical model by partitioning the sea into various zones: the high seas, i.e. the common property where all nations can fish, abbreviated HS, and the exclusive economic zones, the state-owned zones where only coastal state i is allowed to fish, abbreviated EEZ_i. We denote the entire size of the system by k_{tot}, assuming that a share α of the habitat of the resource is subject to access by all fishing nations and define:

$$k_{HS} = \alpha k_{tot} \text{ and } k_{EEZ} = \frac{1-\alpha}{N} k_{tot} \tag{2}$$

Hence, in our context, players are sovereign countries engaging in fishing, i.e. coastal states, each owning an EEZ with exclusive fishing rights, but they can also fish in the high seas. The vector of fish stocks, $\boldsymbol{X} = \left(X_1,...,X_N, X_{HS} \right)$, describes the population in each zone. The modified steady-state condition (1) then reads:

$$\frac{d\boldsymbol{X}}{dt} = \boldsymbol{G}\left(\boldsymbol{X}\right) - \boldsymbol{H}\left(\boldsymbol{X},\boldsymbol{E}\right) + D\boldsymbol{X} = 0 \tag{1'}$$

where the term $D\boldsymbol{X}$ accounts for the migration of fish stocks across zones with D a diffusion matrix which is explained in more detail below. The components of the growth vector $\boldsymbol{G} = (G_1,...,G_N, G_{HS})$ describe intrinsic growth in each zone. Similarly, harvesting in each zone is defined by the harvest vector $\boldsymbol{H} = (H_{EEZ,1},...,H_{EEZ,N}, H_{HS})$ which depends both on the vector of stocks, $\boldsymbol{X}$, and the vector of efforts, $\boldsymbol{E} = \left(E_{EEZ,1},...,E_{EEZ,N}, E_{HS,1},...,E_{HS,N} \right)$. Note that each fishing nation i has two strategic variables, its fishing effort in its own EEZ, $E_{EEZ,i}$, and the fishing effort in the high seas, $E_{HS,i}$. Due to the migratory behavior of fish stocks, harvest from each zone generally depends on all fishing efforts.

2.3. The Economic Dimension

2.3.1 Introduction

Within the framework of international fisheries, each fishing nation has to decide whether to join an RFMO or not, and it has to choose the level of fishing effort for its fleet. Cooperation among a group of players corresponds to the establishment of an RFMO with the purpose of managing and conserving the fish stocks jointly. Participation in an RFMO is open to all nations as reflected by Article 8(3) of the UN Fish Stocks Agreement in 1995. Moreover, states which decide against membership in an RFMO cannot be prevented from harvesting.

In order to capture exactly these institutional features, we choose from the set of coalition formation games the single coalition open membership game which is a two-stage game. In the first stage, players decide upon their membership. Those players that join the RFMO form the coalition and are called members or signatories; those that do not join are called non-members or non-signatories and act as singletons. The decisions in the first stage lead to a coalition structure $K = \left\{ S, \mathbf{1}_{(\text{N-n})} \right\}$, where S is the set of n coalition members, and $\mathbf{1}_{(\text{N-n})}$ is the vector of $N-n$ singletons. Given the simple structure of the first stage, a coalition structure is fully characterized by coalition S.

In the second stage, players choose their economic strategies which are fishing efforts in our bioeconomic model. The standard assumption is that the coalition members cooperate among each other, maximizing the aggregate payoff to the coalition whereas all non-members maximize their individual payoffs. The simultaneous solution of these maximization tasks leads to an equilibrium vector of fishing efforts $\boldsymbol{E}^* = \left(E^*_{EEZ,1},\ldots,E^*_{EEZ,N}, E^*_{HS,1},\ldots,E^*_{HS,N} \right)$ and individual economic payoffs $\Pi^*_i = \Pi^*_{EEZ,i} + \Pi^*_{HS,i}$ from fishing in the own EEZ and the high seas, respectively:

$$\Pi^*_{EEZ,i}\left(\boldsymbol{E}^*\right) = pH_{EEZ,i}\left(\boldsymbol{X},\boldsymbol{E}^*\right) - C_i\left(E^*_{EEZ,i}\right) \text{ and } \Pi^*_{HS,i}\left(\boldsymbol{E}^*\right) = pH_{HS,i}\left(\boldsymbol{X},\boldsymbol{E}^*\right) - C_i\left(E^*_{HS,i}\right) \quad (3)$$

where p is the (exogenously) given fish price and $C_i(\cdot)$ denotes player i's cost function. Note that all stocks and therefore payoffs depend on the entire vector of fishing efforts due to the process of migration that links the various fishing grounds. For notational convenience, we will omit the arguments in the payoff functions subsequently.

In the following, we have a closer look at the two-stage game which is solved backward. Our main focus in this paper and the departure from the standard assumption is related to the second stage where we distinguish between consistent and two versions of inconsistent fishery management. However, because second stage outcomes affect equilibrium payoffs, this will also affect the choice of membership in the first stage.

2.3.2 Second Stage of the Game: the Choice of Fishing Efforts

Consistent Management

A consistent management requires that each player, including the coalition with signatories as a kind of meta-player (Haeringer 2004) as well as all non-signatories as singletons, maximize an objective function comprising payoffs obtained from fishing in the high seas and from the exclusive economic zones.

Non-signatories: $$\max_{(E_{EEZ,j},E_{HS,j})} \Pi_{EEZ,j} + \Pi_{HS,j} \quad \forall\, j \notin S \tag{4}$$

Signatories: $$\max_{(E_{EEZ,i},E_{HS,i})} \sum_{i \in S} \left[\Pi_{EEZ,i} + \Pi_{HS,i} \right] \quad \forall\, i \in S \tag{5}$$

The difference between signatories and signatories is that the former maximize their individual payoff whereas the latter maximize the aggregate payoff across all coalition members. Hence, equilibrium fishing efforts, as derived from (4) and (5), form a Nash equilibrium in a game between outsiders and the coalition. This is sometimes called a coalitional Nash equilibrium in order to distinguish it from an ordinary Nash equilibrium with which it coincides if coalition S is empty or comprises only one player. Moreover, if coalition S comprises all players, $S = \{1,...,N\}$, the coalitional Nash equilibrium corresponds to the socially optimal fishing vector. Hence, the entire range from no cooperation, partial cooperation to full cooperation can be captured with this approach.

Consistent, in contrast to inconsistent management, means in particular two things. In terms of the scope of cooperation, the coalition extends cooperation beyond the high seas and includes the EEZs. De facto, this implies that coalition members fully concede their sovereignty to the governing body of the RFMO. In terms of the compatibility of measures, all players fully realize the interaction between fishing efforts in the high seas and the exclusive economic zones and vice versa.

While there is only one way of defining consistent management, there are various possibilities of a departure from first-best. Based on an analysis of international fisheries agreements (e.g. NAFO 2004, NEAFC 2007 and ICCAT 2007) and secondary literature on international marine law (e.g. Oude Elferink 2001 and Molenaar 2005), we consider two scenarios as particularly relevant in practice (see also the discussion in the Introduction). Clearly, formalizing this in a model implies a stylized representation of inconsistent behavior.

Inconsistent Management – Restricted Scope of Cooperation

As pointed out by Molenaar (2005) and Oude Elferink (2001), many coastal states are unwilling to give up their national sovereignty with respect to intra-EEZ fishery management. Moreover, as mentioned in the introduction, the sovereignty of coastal states is commonly recognized as undisputable and the legal framework in international fisheries is not always clear about the scope of cooperation required in RFMOs. In order to capture the possibility of a restricted scope of cooperation in a systematic and simple way, we replace conditions (4) and (5) by the following three conditions:

Non-signatories: $$\max_{(E_{EEZ,j},E_{HS,j})} \Pi_{EEZ,j} + \Pi_{HS,j} \quad \forall j \notin S \tag{6}$$

Signatories:

$$\max_{E_{EEZ,i}} \Pi_{EEZ,i} + \Pi_{HS,i} + \gamma \sum_{k \in S, k \neq i} \left(\Pi_{EEZ,k} + \Pi_{HS,k} \right) \quad \forall i \in S \tag{7}$$

$$\max_{E_{HS,i}} \sum_{i \in S} \left[\Pi_{EEZ,i} + \Pi_{HS,i} \right] \quad \forall i \in S \tag{8}$$

where $\gamma \in [0,1]$ denotes the *scope parameter*. The first condition describes non-signatories' non-cooperative behavior, which is unaffected by the scope of cooperation. Accordingly, conditions (4) and (6) are identical. In contrast, condition (7) captures the idea that the decision about intra-EEZ fishing remains with the coastal state even if a country decides to become a member of an RFMO. A coalition member may not take full account of the impacts on the stocks in the high seas and the EEZs of other coalition members when choosing its fishing effort in its EEZ. Specifically, a coalition member, when choosing fishing efforts in his own EEZ, maximizes his individual payoff, which is the sum of the payoff from his own EEZ, $\Pi_{EEZ,i}$, and from the high seas, $\Pi_{HS,i}$, plus a share γ of the payoffs of the other coalition members, which is the last sum. Hence, γ describes the scope of cooperation. One interpretation is that γ captures the extent by which a signatory takes into account the payoffs of his coalition partners when choosing fishing efforts in his own EEZs. Another interpretation is that γ captures the extent by which the RFMO can control fishing in the EEZs. Condition (8) reflects the assumption that the coalition decides upon the fishing efforts in the high seas.

If $\gamma = 0$, signatories are completely self-interested and/or the RFMO has no control over fishing in the EEZ of its members. At the other extreme, $\gamma = 1$ implies full scope of cooperation and accordingly, condition (7) and (8) merge into condition (5). It is important to note that a restricted scope of cooperation does not mean incompatibility of measures as assumed in our next scenario. In (7) RFMO members behave fully rationally in their EEZs as they are aware that fishing in their own EEZ will affect their payoff derived from the high seas and in (8) they understand that fishing in the high seas will impact on their EEZ stocks (and hence payoffs).

<u>Inconsistent Management – The Incompatibility of Measures</u>

The second scenario captures the idea of incompatibility of measures. This acknowledges the fact that though compatibility of measures is called for in many international fisheries agreements (e.g. in Art. 7 of the 1995 UN Fish Stocks Agreement), it is usually insufficiently implemented, especially if a fishing nation puts the management of intra-EEZ and high seas fisheries under the control of different national authorities (see Arbuckle et al. 2006, p. 36). A simple way of modeling this is to assume that the coalition as well as non-signatories only partially account for their payoffs from the high seas when determining optimal fishing efforts in the EEZs and vice versa:

$$\max_{E_{EEZ,j}} \quad \Pi_{EEZ,j} + \lambda \Pi_{HS,j} \quad \forall j \notin S \tag{9}$$

Non-signatories:

$$\max_{E_{HS,j}} \quad \Pi_{HS,j} + \lambda \Pi_{EEZ,j} \quad \forall j \notin S \tag{10}$$

Signatories:

$$\max_{E_{EEZ,i}} \quad \sum_{i \in S} \Pi_{EEZ,i} + \lambda \sum_{i \in S} \Pi_{HS,i} \quad \forall i \in S \tag{11}$$

$$\max_{E_{HS,i}} \quad \sum_{i \in S} \Pi_{HS,i} + \lambda \sum_{i \in S} \Pi_{EEZ,i} \quad \forall i \in S \tag{12}$$

The *compatibility parameter* $\lambda \in [0,1]$ describes the degree of compatibility of measures. Condition (9) and (10) define the maximization behavior of non-signatories whereas condition (11) and (12) refer to the behavior of coalition members. If $\lambda = 0$, players fully ignore the need for compatible measures. At the other extreme, $\lambda = 1$ corresponds to fully compatible measures, i.e. conditions (9) to (12) collapse into conditions (4) and (5), our consistent scenario. Non-signatories are assumed to implement always the same degree of compatibility as signatories for simplicity.

<u>Computations</u>

Viewed together, regardless whether we consider a consistent or one of the inconsistent management scenarios in the second stage, the solution of the respective first order conditions (together with the steady-state conditions eq. (1') of the biological equilibrium) leads to an equilibrium vector of fishing efforts which allows to determine steady-state stocks (eq. (1')) and equilibrium payoffs (eq. (3)).[8] Each scenario can be viewed as a clear instruction how to choose fishing efforts in the second stage, given some coalition S has formed in the first stage. Hence, in order to simplify the following notation, we can replace $\Pi_i^*(E^*) = \Pi_{EEZ,i}^*(E^*) + \Pi_{HS,i}^*(E^*)$ by $\Pi_i^*(S) = \Pi_{EEZ,i}^*(S) + \Pi_{HS,i}^*(S)$ or simply $\Pi_i^*(S)$.

3.3 First Stage of the Game: Membership Decisions

For the first stage, we use the equilibrium concept of internal and external stability, i.e. a coalition S is considered to be stable if it fulfills the following two conditions:

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8 This implies to compute ex-post payoffs. This keeps with the tradition of other papers modelling different economic behaviour through different objective functions, but using the "true" welfare function for evaluation. See for instance Finus and Maus (2008) and Hoel (1991).

Internal Stability

No member $i \in S$ *finds it profitable to deviate, i.e. the gain* G_i *from leaving the coalition is non-positive:* $G_i := \Pi_i^*(S \setminus \{i\}) - \Pi_i^*(S) \leq 0 \ \ \forall i \in S$.

External Stability

No non-member $j \notin S$ *finds it profitable to join the coalition, i.e. the gain* Q_j *from joining the coalition is non-positive:* $Q_j := \Pi_j^*(S \cup \{j\}) - \Pi_j^*(S) \leq 0 \ \ \forall j \notin S$.

Note that the incentives G_i and Q_j depend on the coalition structure, the scope and compatibility parameters γ and λ as well as other parameters of the model (see subsection 4.1). The grand coalition is externally stable by definition as there is no outsider left that could join the coalition. Moreover, the coalition structure comprising only singletons is stable by definition, which ensures existence of a stable coalition structure. This follows from the fact that the singleton coalition structure can be supported as an equilibrium if all players announce not to be a member of the coalition, i.e. $S = \emptyset$, and hence a single deviation by one player will make no difference.

4. Solving Procedure and Model Specifications

4.1 Preliminaries

In general, solving the second stage of the game requires solving a system of $3N+1$ equations ($2N$ economic FOCs and $N+1$ biological steady-state equations) for N optimal intra-EEZ efforts $E_{EEZ,i}$, N optimal high seas efforts $E_{HS,i}$ and $N+1$ steady-state stocks $\left(X_1,...,X_N,X_{HS}\right)$. As optimal efforts in the second stage of the game depend on stock levels and vice versa, they all have to be determined simultaneously. Obviously, any solution will depend on the specification of the functional relationship between stocks, efforts and payoffs. That is, we have to specify growth, harvest and cost functions and define a dispersal matrix which describes the migration process. This is done in subsection 4.2. Due to migration, the model is significantly more complex than the standard Gordon-Schaefer model and cannot be solved analytically any more. Therefore we have to rely on numerical simulations of which the underlying assumptions are described in subsection 4.3.

4.2 Functional Specification

The functional relationships underlying our model are summarized in Table 1. It will be apparent that the specifications follow the mainstream assumptions in the literature.

[Table 1 about here]

The most commonly used *growth function* (Table 1, first row) is of the logistic type where r_i denotes the intrinsic growth rate in zone i.

Regarding the *harvest function* (Table 1, second row), we have to bear in mind that all countries are allowed to fish in the high seas whereas only the owner of an EEZ is allowed to fish in this territory. As commonly assumed, (total) harvest depends linearly on (total) fishing efforts and stock densities, with q_i denoting the catchability coefficient, a measure of the technical efficiency of the fishing fleet i.

Two aspects need to be considered when specifying the *migration process*.[9] First, the *arrangement of zones* has to be specified, i.e. which zones are connected through diffusion. We choose an intuitive and symmetric arrangement of the $N+1$ zones: the EEZs are arranged in a circle with the high seas at its center. This avoids boundary effects that would emerge with a linear arrangement and represents a good first-order approximation for the geographical setting of many examples where an area of high seas is surrounded by coastal zones. A perfect match of this assumption is for instance the 'Banana Hole' in the Northeast Atlantic or the 'Donut Hole' in the Bering Sea (see Meltzer 1994).

Second, we have to define what determines the *intensity of migration* between two neighboring fishing grounds. We assume a density-dependent diffusion process, i.e. the strength of migration between neighboring fishing grounds is given by the difference in

[9] For an extensive discussion of our and alternative assumptions see Finus et al. (2011).

stock densities, scaled by the product of the sizes of zones (Kvamsdal and Groves 2008, Table 1, third row).[10] This description of the diffusion process ensures the conservation of biomass in the absence of harvest and growth, i.e. whatever leaves zone i for zone j arrives in zone j without any losses. Furthermore, it reflects the assumption that the intensity and direction of dispersal only depends on the difference in stock densities between zones. The diffusion parameter d_{ij} is an indicator for the intensity of diffusion from zone i to zone j.

It is a common assumption in the literature on fishery management (Gordon 1954, Pezzey et al. 2000 and Sanchirico and Wilen 1999) that *costs* (Table 1, fourth row) depend linearly on extraction efforts, though they are strictly convex if expressed in terms of harvest levels where c_i is the (constant) marginal cost of fishing effort of the fishing fleet of country i.

4.3 Simulations

Simulations require the assumption of numerical values for the parameters of the model. Fortunately, a closer look at the system of equations reveals that results will depend on only few parameters. The choice of parameter values follows good practice, covering a large parameter space as summarized in Table II.

[Table II about here]

First, note that in order to save on computational time, we concentrate on the case of three players ($N = 3$), which, admittedly, is the minimum number of players to study coalition formation but, as we will see, is already sufficient to obtain interesting insights into the incentive structure of cooperative arrangements. For $N = 3$, we have to consider three possible coalition structures, namely the grand coalition, the two-player coalitions, and the all-singletons coalition structure. Furthermore, we restrict the analysis to symmetric parameter values, both with respect to the biological and economic

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10 To see that the entries of the diffusion matrix (Table 1, third row) do indeed imply the described diffusion process, consider the entries of the vector DX , which is relevant in eq. (1').

parameters.[11] Consequently, all possible two-player coalitions are equivalent with symmetric payoffs for coalition members, though they differ from the payoff of a non-member.

Second, note that all subsequent results only depend on what is commonly referred to as the 'inverse efficiency parameter' c/pqk_{tot} (see Mesterton-Gibbons 1993). Since the total carrying capacity k_{tot} just represents a scaling factor, it is normalized to 4 as there are four zones with $N=3$ players.[12] Moreover , we can normalize p and q to 1 and hence only vary c. Thus, a variation of the cost parameter c is, ceteris paribus, de facto a variation of the relation c/pq. Since prohibitive costs at which countries quit fishing are given by $c \geq 1$, irrespective of the scenario of cooperation, we have $c \in [0,1]$. In our simulations, we consider the three values, $c \in \{0.25, 0.5, 0.75\}$. For the intrinsic growth rate r, we also consider three values, $r \in \{0.25, 0.5, 0.75\}$, which includes the commonly used value $r = 0.5$.[13]

For the diffusion parameter d our simulations cover the range $d \in [0 .. d_{max}]$ with the upper bound $d_{max} = 1.28$ that approximates well the limit $d \to \infty$.[14] With respect to α, we cover the whole range $\alpha \in [0,1]$, with $\alpha = 0$ implying that the entire fishing area comprises only state-owned exclusive economic zones and $\alpha = 1$ implying that the entire area comprises only the common property high seas. All results are tested in the entire interval in steps of $\Delta\alpha = 0.05$. Note that the carrying capacities, k_{EEZ} and k_{HS}, follow

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11 The assumption of symmetric players is widespread in the literature on coalition formation, not only on international environmental treaties but also in the context of other economic problems (see e.g. Bloch 2003, and Yi 2003 for an overview). This assumption allows us to focus on the main issues of the paper, namely the effect of the scope and compatibility of measures on the success of RFMOs. Note that for symmetric players it is natural to assume an equal sharing of the coalitional payoff.

12 This is in line with the common normalization $k = 1$ in articles that deal with only a single zone (e.g. Pezzey et al. 2000). In our model, assuming no diffusion between zones with $k_{tot} = 4$ and setting $\alpha = 0.25$ results in four isolated zones with carrying capacities $k = 1$. See equation (2).

13 Our mean values, $c = 0.5$ and $r = 0.5$, are commonly assumed in the literature (e.g. Hannesson 1997 and Tarui et al. 2008).

14 Results for $d = d_{max}$ differ less than 5 % from the results in the limit $d \to \infty$, which can be calculated analytically.

from the allocation parameter α and the total carrying capacity k_{tot} (see section 2.2, equation (2)). Finally, the scope parameter $\gamma \in [0,1]$ as well as the compatibility parameter $\lambda \in [0,1]$ are analyzed in the entire range in steps of $\Delta = 0.2$.

Note finally that if not stated otherwise, all subsequent results hold for the entire parameter range outlined above and summarized in Table 2.

5. Results: The Scope of Cooperation

In this section, we discuss the impact of a restricted scope of cooperation, first with respect to the second stage of the game, i.e. fishing efforts, stocks and payoffs, then with respect to the first stage of the game, i.e. membership decisions. Finally, we pull both stages together.

Second Stage of Coalition Formation

In the second stage, equilibrium fishing efforts, stocks, and payoffs depend on the scope parameter γ for every possible coalition structure.[15] Recall that the scope parameter γ denotes the extent to which coalition members consider the payoffs of other coalition members when choosing their fishing efforts in their own EEZ, with the scope increasing from 0 to 1. Before turning to the results, it is worthwhile to point out those situations in which the scope of cooperation does not matter. These include the case 'only high seas' ($\alpha = 1$) or 'all zones are isolated' ($d = 0$). In contrast, whenever $0 \leq \alpha < 1$ and $d > 0$ hold, the scope of cooperation matters. The only exception is the all-singletons coalition structure as no RFMO has formed.

Result 1: The Scope of Cooperation and Equilibrium Efforts, Stocks and Payoffs.

Assume $0 \leq \alpha < 1$ and $d > 0$ and consider the two-player or grand coalition.

a) Total fishing efforts decrease whereas total stocks and total payoffs increase in the scope parameter γ where totals refer to the aggregation over all players and zones.

[15] In the following, we omit the term 'equilibrium' for notational convenience.

b) *The quantitative impact of a marginal variation of the scope parameter γ on total efforts, stocks and payoffs increases in the diffusion parameter d.*

Result 1a conforms to intuition regarding the grand coalition. In the absence of strategic interaction, any restriction of the scope of cooperation reduces the biological effectiveness of a cooperative agreement (i.e. higher fishing efforts and hence lower stocks), and decreases payoffs. As γ approaches 0, the outcome under the grand coalition approaches that under no cooperation. Less obvious is that this also holds under the two-player coalition with strategic interaction between the coalition and the outsider. The reason is that the smaller the scope of cooperation (the smaller γ), the larger are coalitional fishing efforts which are only partially compensated by lower fishing efforts of the outsider. That is, though reaction functions are negatively sloped, slopes are less than 1 in absolute terms. Hence, conceding costal states sovereignty in intra-EEZ fishery management threatens the success of a given RFMO, leading to lower aggregate payoffs and higher stocks. In terms of aggregate payoffs, this is illustrated with an example in Table III.

[Table III about here]

Result 1b stresses the significance of diffusion. The negative impact of a restricted scope of cooperation, both in terms of the biological effectiveness and economic success of an RFMO, is more pronounced when stocks are highly mobile. Thus, the strong emphasis on a fully integrated fishery management in the particular case of highly migratory species, as expressed in the UNCLOS in 1982 and the UN Fish Stocks Agreement in 1995, is supported by our findings, at least as long as we abstract from the stability of agreements, related to the first stage of coalition formation, which we consider now.

First Stage of Coalition Formation

Now we investigate how the scope of cooperation affects the stability of coalitions. Before considering the impact of a restricted scope of cooperation $(\gamma < 1)$, let us briefly review the results under full scope of cooperation $(\gamma = 1)$ as obtained in Finus et al.

(2011). In this case, the grand coalition is never stable except for the parameter combination $\alpha = 0$ and $d = 0$ where there are only EEZs and all zones are isolated. In this case, however, there is no externality across players and zones and hence cooperation does not matter: the second stage outcomes under all coalition structures coincide. Hence, RFMOs are not necessary.

Regarding a two-player coalition, there is a small parameter range for which cooperation can be stable. Specifically, assuming all parameters at their base value ($c = 0.5$ and $r = 0.5$), the two-player coalition is unstable whenever $\alpha \geq 0.02$ or $d \geq 0.32$, but may be stable for smaller values. The intuition is that there are two countervailing forces at work. On the one hand, the stronger the externality across players and zones, i.e. the larger the proportion α of the common pool resource compared to the exclusively state-owned EEZs, and the larger diffusion d, the larger would be the gains from cooperation and hence the more valuable would be cooperation. On the other hand, with increasing α and d, also the incentive to free-ride sharply increases. Overall, the two-player coalition will only be stable if α and d are sufficiently small. Considering a restricted scope of cooperation changes this result.

Result 2: The Scope of Cooperation and the Stability of Coalitions

The parameter space $\alpha \geq 0$ and $d \geq 0$ for which the grand coalition or the two-player coalition is stable can be enlarged by reducing the scope of cooperation, i.e. by departing from the value $\gamma = 1$.

Result 2 is encouraging: in contrast to the negative consequences of a reduced scope of cooperation on second stage outcomes (e.g. measured in terms of stocks and payoffs), it can have a positive impact on first stage outcomes by helping to stabilize RFMOs. This is illustrated with our example in Table II. The largest stable coalition with full scope of cooperation ($\gamma = 1$) is a two-player coalition. Reducing γ to at least $\gamma = 0.4$ allows stabilizing also the grand coalition.

The intuition behind Result 2 is that countries are more willing to join an RFMO if they can keep full or partial national sovereignty over intra-EEZ fishery management. This enables them to derive a larger exclusive benefit in their EEZs from the conservation measures implemented by the RFMO in the high seas. In other words, within their EEZs coalition members are partially allowed to free-ride on the cooperative efforts of the RFMO in which they participate. Hence, we conclude that a departure from first-best – being less ambitious – may buy larger stable membership in RFMOs.

Overall Result

Second stage outcomes, Result 1, and first stage outcomes, Result 2, revealed two countervailing tendencies associated with a reduction in the scope of cooperation. Not surprisingly, combining both results only allows for a very general statement (Result 3), though the subsequent representative example and statistics are quite revealing.

Result 3: The Scope of Cooperation and the Overall Success of Coalitions

Restricting the scope of cooperation, i.e. departing from the value $\gamma = 1$, can be welfare-improving.

For instance, consider again the example in Table III. Without restriction of the scope of cooperation, $\gamma = 1$, the highest aggregate payoff of a stable coalition is generated by a two-player coalition (with a welfare level of 97.3%). For $\gamma = 1$, the grand coalition is not stable. Testing whether an improvement over this outcome is possible means to lower γ to a point which just allows stabilizing the grand coalition. In the example, this requires to lower γ to a value of 0.4. For $\gamma = 0.4$, the grand coalition generates an aggregate welfare level of 98.3% and therefore constitutes an improvement over the two-player coalition. Obviously, lowering γ further makes no sense as this increases the negative second stage effect which cannot be compensated by a positive first stage effect as the maximum membership has already been reached in this example.

Other examples would confirm this relation which implies that global welfare is a step function. Reducing the scope of cooperation γ gradually reduces global welfare until a point may be reached where global welfare jumps up to a higher level due to larger stable membership.

Hence, given the restriction that RFMOs have to be self-enforcing, in a strategic setting, restricting the scope of cooperation can be welfare improving. Clearly, there are cases where this is not possible, e.g. "unfavourable" parameter values, like large values of α and d, where even with values of γ below 1 no RFMO is stable. If we rule out these parameter values and consider $\alpha < 0.2$ and $d \leq 0.32$ (but consider the full range of all other parameters as stated in Table II), we find that in 15% of the cases a restricted scope leads to better outcomes than a full scope; if an improvement is possible, the "optimal scope" leads to the grand coalition in 92 % of the cases and to the two player coalition in 8% of the cases, with an average optimal scope of $\gamma = 0.7$. Hence, we can conclude that a departure from first-best may well be rational, though the socially optimal welfare level can never be obtained which necessarily requires to set $\gamma = 1$ and the inclusion of all players.

6. Results: The Compatibility of Measures

We now turn to the second scenario of inconsistent management which we have defined above as an incompatibility of measures. Again, we follow the sequence of backward induction.

<u>Second Stage of Coalition Formation</u>

First, note that for the two extreme assumptions $\alpha = 0$ (only EEZs and no high seas) and for $\alpha = 1$ (only high seas) the compatibility of measures is irrelevant for the second stage, irrespective of the coalition structure which has formed in the first stage. The same holds if all zones are isolated because there is no fish migration $(d = 0)$. In contrast, whenever there are two distinct legal regimes $(0 < \alpha < 1)$ and the stocks in the different zones are linked to each other via diffusion $(d > 0)$, the compatibility of measures matters, as described in Result 4.

Result 4: The Compatibility of Measures and Equilibrium Efforts, Stocks and Payoffs

Assume $0 < \alpha < 1$ *and* $d > 0$ *and consider any possible coalition structure.*

a) *Total fishing efforts decrease whereas total stocks and total payoffs increase in the compatibility parameter* λ *where totals refer to aggregation over all players and zones.*

b) *The quantitative impact of a marginal variation of the compatibility parameter* λ *increases in the diffusion parameter* d *.*

Result 4a stresses the biological and economic importance of the compatibility of intra-EEZ and high seas fishery management, irrespective of the number of cooperating countries. As the compatibility parameter λ affects both signatories' and non-signatories' behavior, it also has an impact on the outcome under the all-singletons coalition structure. Neglecting the need for compatibility leads to a rise in aggregate fishing efforts, a decline in stocks and thereby decreasing aggregate payoffs. An example in Table IV illustrates this point for aggregate payoffs, assuming the base parameter values and $\alpha = 0.25$.

[Table IV about here]

Result 4b points to the fact that the compatibility of measures is more important in the case of highly migratory stocks (high value of d) where fishing in one zone creates a stronger externality on stocks in neighboring zones than in the case of straddling stocks (low value of d).

First Stage of Coalition Formation

Recall that the all-singletons coalition structure is stable by definition for all parameter values and that the grand coalition is only stable when cooperation does not matter ($\alpha = 0$ and $d = 0$) if there is full compatibility of measures, $\lambda = 1$. Hence, Result 5 focuses on the more interesting cases when either $\alpha > 0$ or $d > 0$.

Result 5: The Compatibility of Measures and the Stability of Coalitions

a) The grand coalition is never stable whenever $\alpha > 0$ *or* $d > 0$*, irrespective of the compatibility parameter* $0 \leq \lambda \leq 1$.

b) The parameter space ($\alpha \geq 0$ and $d \geq 0$*) for which the two-player coalition is stable is larger under a limited compatibility of measures, i.e. for* $\lambda < 1$.

Result 5 is very similar to Result 3: a departure from a first-best management strategy can help to stabilize larger coalitions. Now, however, compromising on the compatibility of measures does not allow stabilizing the grand coalition, as this was possible when restricting the scope of cooperation, but only allows to stabilize a two-player coalition at best. The parameter space for which the two-player coalition can be stabilized can be substantially increased through lowering the value of λ. The representative example in Table IV illustrates this point. If λ is lowered to $\lambda = 0.2$ the two-player coalition will be stable.

<u>**Overall Result**</u>

We now pull the results from the first and second stage together.

Result 6: The Compatibility of Measures and the Overall Success of Coalitions

A limited compatibility of measures $(\lambda < 1)$ *may increase global welfare.*

In view of the numerous international fisheries conventions that emphasize the importance of the compatibility of measures, Result 6 suggests that conclusions may be different if we explicitly account for strategic aspects of free-riding. Again, to find the optimal departure from first-best, i.e. the value of λ that maximizes global welfare, we have to realize that global welfare is a non-continuous step function of the parameter λ. This is illustrated for the representative example in Table IV. Apparently, a high value of λ leads to higher aggregated payoffs but may not allow to stabilize a non-trivial RFMO. The highest total payoff (86.4%), generated by a stable coalition of two players, occurs for $\lambda = 0.2$ in this example which dominates the highest possible payoff of the all-singletons coalition structure (85%) which occurs for $\lambda = 1$. Hence, a limited compatibility of measures can be welfare-improving. Again, we test for the entire parameter range in Table I, except that we assume $\alpha < 0.2$ and $d = 0.32$, and find that in 49% of the cases a restricted compatibility (i.e. $\lambda < 1$) can improve upon an unrestricted, and in these cases, the optimal λ implies the two player coalition in 93% and the grand coalition in 7% of the cases with an average optimal degree of compatibility of $\lambda = 0.4$.

7. Conclusion

The United Nations Convention on the Law of the Sea (UNCLOS) in 1982 emphasized the sovereignty of coastal states' fisheries management within the substantially enlarged areas under national jurisdiction and, at the same time, called for cooperation of fishing nations in the high seas. However, many commercially valuable species are found both within and beyond EEZ boundaries. This raises the question how a consistent management of fish stocks can be ensured. The UN Fish Stocks Agreement in 1995 and many current RFMOs address this issue by calling for the consistency of management measures implemented by coastal states and RFMO authorities. Moreover, ideally, coastal states should hand over their sovereignty to the RFMO authorities once they become members of an RFMO. However, as argued in the introduction, the current practice provides many examples of inconsistent management and the issue has remained largely unresolved. While several authors have discussed how full compatibility and scope of management could be implemented in detail (e.g. Oude Elferink 2001, Molenaar 2005), it has been little understood so far how inconsistent management schemes affect the overall success of RFMOs if stability is a binding constraint.

To this end, we have developed an integrated model for internationally shared fish resources that explicitly captures the spatial dimension and accounts for the migratory nature of many commercially important fish species. Our model accounts for the fact that coastal states have been granted exclusive sovereign rights over their exclusive economic zones under the UNCLOS in 1982, but the area outside their territory, the high seas, can be exploited by all fishing nations.

In a two-stage coalitional game where countries first decide upon their membership in an RFMO and then choose their fishing efforts, we have approached the issue along two avenues. The first scenario considered the *scope of cooperation*, allowing for the possibility that coalition members partially pursue their own interest when choosing fishing efforts in their own EEZs. Essentially, this means that RFMO members do not concede their full sovereignty to the governing body of the RFMO. Through a parameterization we have been able to cover the full spectrum between "full sovereignty lies with members" to "full sovereignty lies with the RFMO". The second scenario analyzed the *compatibility of measures*. Again, a parameterization allowed gradually relaxing the assumption that players fully account for the negative impact of fishing in their EEZ on the payoffs they receive from the high seas and also vice versa. Both approaches imply a departure from first-best and capture the notion of various degrees of inconsistent management of fishery resources.

Interestingly, the qualitative results of both "inconsistent" scenarios have been quite similar and hence our conclusions appear quite robust. For any given RFMO membership, inconsistency has a negative impact, either measured in biological terms (fish stocks) or economic terms (payoffs). However, inconsistency can also have a positive impact on membership in that it can "buy" additional membership. Inconsistency, i.e. second- or third-best designs of treaties, de facto means to put less pressure on RFMO members to reduce their fishing efforts in order to preserve fish stocks. In other words, less is required from governments when joining an RFMO, either in terms of giving up their sovereignty or in terms of choosing compatible and consistent management strategies, as an RFMO member, but also as an authority controlling fishing in several jurisdictions, including EEZs and the high seas. Those less ambitious objectives reduce the free-rider incentive, helping to establish larger stable participation in RFMOs. It has been shown that – at least in theory - an "optimal degree of inconsistency" can be determined for this trade-off between the level of ambition and participation, which maximizes global economic rents of stable RFMOs.

In the light of our result, many current suboptimal forms of fishery management may be less harmful than commonly perceived. Clearly, this does not question the normative benchmark of first-best fishery management, but only points to the fact that as long as free-riding cannot be effectively controlled by a global authority, a bird in hand may be more valuable than two in the bushes. This also suggests that in developing treaties, the main focus should be first on encouraging large participation and only later on deepening treaties in terms of their objectives.

For future research several topics come to mind. Our assumption about the migration pattern covers a large group of fish species, but there remain some species which may be better captured by different assumptions, e.g. linear migration patterns. It would be interesting to find out whether our qualitative conclusions would carry over to such alternative assumptions. Furthermore, it would be interesting to test our theory with empirical data. For our model, this would require a quite detailed and comprehensive data set, rarely available on international fisheries. Also the prospects of marine protected areas (i.e. nature reserve with no or restricted fishing, like analyzed in Punt et al. 2012) in the light of migration could be evaluated. Finally, a more sophisticated bargaining protocol as for instance suggested in Caparrós et al. (2004) could be employed.

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Table I: Functional Specification of Model

1)	Growth Functions	$G_i\left(X_i\right)=r_iX_i\left(1-\frac{X_i}{k_{EEZ}}\right),\ i=1,...,N\ ;\ G_{HS}\left(X_{HS}\right)=r_{HS}X_{HS}\left(1-\frac{X_{HS}}{k_{HS}}\right)$
2)	Harvest Functions	$H_{EEZ,i}\left(X_i\right)=q_iE_{EEZ,i}\frac{X_i}{k_{EEZ}},\ i=1,...,N\ ;\ H_{HS}\left(X_{HS}\right)=\sum_{i=1}^{N}q_iE_{HS,i}\frac{X_{HS}}{k_{HS}}$
3)	Migration Process	Entries of the dispersal matrix D: $d_{ij}=\begin{cases} d\sqrt{k_i/k_j} & \text{if i adjacent to j} \\ 0 & \text{otherwise}\end{cases}\quad \forall i\neq j$ $d_{ii}=-\sum_{j\neq i}d_{ji}\quad \forall i$
4)	Cost Functions	$C_i(E_{EEZ,i})=c_iE_{EEZ,i}\ ,\ i=1,...,N\ ;\ C_i(E_{HS,i})=c_iE_{HS,i}\ ,\ i=1,...,N$
r_i, r_{HS} = intrinsic growth rate in region i and HS, respect.; X_i, X_{HS} = stock in EEZ_i and HS, respect.; k_{EEZ}, k_{HS} = carrying capacity in EEZ and HS, respect.; q_i = efficiency parameter of country i; $E_{EEZ,i}$, $E_{HS,i}$ = efforts in EEZ_i and HS, respect.; d_{ij} = diffusion parameter between region i and j; c_i = cost parameter of country i.		

Table II: Parameter Values in Simulation Runs*

Simulation Runs	$c=c_i=c_j$	$r=r_i=r_j$	d	α	γ	λ
Scope	0.25-0.75	0.25-0.75	0-1.28	0-1.0	0-1.0	-
Compatibility	0.25-0.75	0.25-0.75	0-1.28	0-1.0	-	0-1.0

* $p=1$, $q=1$ and $k_{tot}=4$ are assumed throughout.

Table III: The Scope of Cooperation: Aggregated Payoffs*

Coalition Structure	$\gamma = 1$	$\gamma = 0.8$	$\gamma = 0.6$	$\gamma = 0.4$	$\gamma = 0.2$	$\gamma = 0$
No Cooperation	**94.2**	**94.2**	**94.2**	**94.2**	**94.2**	**94.2**
Two-Player Coalition	**97.3**	**96.9**	**96.5**	95.9	95.1	**94.2**
Grand Coalition	100	99.8	99.3	**98.3**	**96.7**	**94.2**

* Total payoff (expressed as a percentage of total payoff in the social optimum) for various coalition structures and values of the scope parameter γ. Total payoffs of stable coalition structures are bold. Note that whenever the grand coalition is unstable, this is due to failing *internal* stability whereas the two-player coalition is unstable for $\gamma = 0.4$ and $\gamma = 0.2$ due to failing *external* stability. The following parameter values are assumed: $d = 0.16$, $c = 0.5$, $r = 0.5$, $p = 1$, $q = 1$ and $k_{tot} = 4$ as well as $\alpha = 0$.

Table IV: The Compatibility of Measures: Aggregated Payoffs*

Coalition Structure	$\lambda = 1$	$\lambda = 0.8$	$\lambda = 0.6$	$\lambda = 0.4$	$\lambda = 0.2$	$\lambda = 0$
No cooperation	**85.0**	**83.3**	**81.5**	**79.5**	**77.4**	**75.1**
Two-Player Coalition	93.3	91.9	90.2	88.4	**86.4**	**84.1**
Grand Coalition	100	99.9	99.5	98.9	97.9	96.6

* Aggregated payoffs (expressed as a percentage of aggregated payoffs in the social optimum) for various coalition structures and values of the compatibility parameter λ. Aggregated payoffs for stable coalition structures are in bold. The following parameter values are assumed: $d = 0.16$, $c = 0.5$, $r = 0.5$, $p = 1$, $q = 1$ and $k_{tot} = 4$ as well as $\alpha = 0.25$.