Fishery management games: How to reduce effort and admit of new members

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Abstract: This paper addresses the two main problems that Regional Fishery Management Organizations face. First, how to induce independent nations to reduce their fishing efforts from the competitive equilibrium to prevent the fish stock from extinction or to increase profits. We argue that adjustment from the Nash equilibrium to a state of sustainable yield can be achieved by means of the proportional rule without harming any of the countries involved. Next we propose the population monotonic allocation scheme as management rule for the second problem: the division of profits within an expanding coalition of countries to ensure stability and efficient harvesting.

Key words: *fishery management, proportional rule, population monotonic allocation scheme, Shapley value.*

JEL classification: C71, C72, D62, D74, Q22

1 Introduction

The United Nations Convention on the Law of the Seas of 10 December 1982 granted coastal states the right to extend their jurisdiction over fishery resources out to 200 nautical miles by establishing exclusive economic zones (EEZ). The rationale for the EEZ regime was to mitigate the fisheries common property problem by transforming the status of the bulk of the world's

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marine fishery resources from open access to coastal state property fisheries. Straddling and highly migratory fish stocks, however, cross the borders of EEZs and are found in the adjacent high seas areas, where, in principal, there is free entry for nations to harvesting[2]. This has led to fishing disputes and even fishing wars (e.g. the Spain-Canada dispute in 1995).

The escalation of high seas fisheries and resulting fishing disputes were addressed by the U.N. intergovernmental conference from 1993 to 1995. The conference resulted in the 1995 U.N. Fish Stocks Agreement, which sets out principles for the conservation and management of those fish stocks (OECD, 1997). The Agreement declares that states should cooperate to ensure conservation and optimal utilization of fisheries resources both within and beyond the EEZs. It grants the rights of all states to utilize the fishery resource in the high seas and specifies that harvesting should be coordinated by a coalition of the traditional harvesting states, acting through a regional or sub-regional organization, i.e. a Regional Fisheries Management Organization (RFMO). The Agreement calls for those nations who wish to participate in the harvesting of the fish resource in the high seas, but are not currently members of the RFMO, to declare a willingness to join and to enter into negotiations over mutually acceptable terms of entry. The Agreement entered into force on 11 December 2001 (UN, 2002).

The Agreement, however, provides to the RFMO "no coercive enforcement powers to exclude non-member harvest or set the terms of entry into membership" (McKelvey *et al.*, 2002). There are, among others, two problems casting doubt on the effectiveness of RFMOs (Kaitala and Munro, 1993). First is the "interloper problem", which concerns the difficulty of controlling harvesting by non-member vessels, including individually operated vessels, but also coordinated multi-vessel "distant water fleets". Both seek targets-of-opportunity, and skim off bountiful harvests wherever they occur, but with little interest in the long-term conservation of the stocks. Second is the "new member problem", which concerns the inherent difficulties of negotiating in a timely manner, mutually acceptable terms of entry that specify the petitioning nation's membership rights and obligations (Kaitala and Munro, 1995)[3]. Indeed, the interests of current members and of applicants are often strongly

[2]See, amongst others, Bjørndal and Munro (2003) for analyses of straddling and highly migratory fish stocks. For a survey of the economics of fishery management, see Bjørndal and Munro (1998).

[3]We refer to Pintassilgo and Duarte (2000) who discuss the problem of new entrants in a dynamic setting for the Northern Atlantic Bluefin Tuna.

opposed: the current members face the likelihood of having to give up a portion of their present quotas to the newcomer, and the applicant believes that it may be better off by staying outside of the coalition and continuing to harvest while facing fewer constraints[4].

According to Kaitala and Munro (1995), the resolution of the new member problem may call for the creation of de facto property rights for the charter members of a RFMO. The quotas allocated to the charter member would take the form of individual transferable quota (Munro, 2000). Thus, the charter members would become the sole beneficiaries of the fishery resource. Moreover, a potential new entrant could only access the fish stock in question by buying the fishing rights and quotas of an incumbent fleet. However, it is not evident that such a system based on assumptions of economic efficiency and resource sustainability is viable. It would vest substantial interests with the incumbent fleets, which is likely to be strongly opposed by potential entrants. As an alternative to the transferable quota system, in this paper we suggest enlargement of the RFMO by admitting new members. A basic problem in this regard is the allocation of the payoffs in the enlarged organization such that non-members have an incentive to join and incumbent members to adjust to the enlargement rather than leaving the coalition and starting to exploit the resource in an unsustainable manner.

For this purpose we propose the population monotonic allocation scheme (PMAS). This management rule makes both charter members and potential entrants better of compared with a situation of unregulated exploitation (i.e. the competitive or Nash-Cournot equilibrium). As such, the competitive equilibrium is a threat that induces charter members to admit new entrants and potential entrants to join the agreement in order to avoid a situation characterized by competitive behaviour[5]. Next we introduce the proportional rule to reduce effort to achieve sustainable and efficient harvesting[6].

The organization of this paper is as follows. In section 2 the fishery resource management problem is set up. This section also presents results that

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[4]Observe that the interloper problem and the new member problem are closely related: potential members who do not join the RFMO or frustrated charter members who leave the RFMO may become interlopers.

[5]Note that under the U.N Agreement the members of a RFMO do not have the right to prevent any potential member to access the resource. It is a threat to the long run viability of a cooperative agreement.

[6]Observe that this management rule can be applied in general and is not necessarily related to the admission of new entrants.

are needed in section 3, which presents the population monotonic allocations scheme and the proportional rule as management rules for an expansion of a coalition and the reduction of efforts, respectively. Conclusions follow in section 4.

2 The fishery game

We adopt the *Gordon-Schaefer* model of fishery (Clark, 1990, McKelvey *et al.*, 2002). In this model, the biological response of the fish stock to harvesting is characterized by the following steady state *yield-to-effort* relationship:

$$\dot{x} = F(x) - H(e, x) \tag{1}$$

where x is a non-negative state variable representing the fishery resource or biomass; $F(x)$ is a *growth function* of biomass satisfying $F(0) = F(b) = 0$, and $F''(x) \leqslant 0$ for $x \in (0, b)$, where b is the *carrying capacity* of the resource; e is the *total fishing effort* and $H(e, x)$ is the *harvesting* or production function. For further details, we refer to Clark (1990 and 1999) Observe that the harvesting function is often assumed to be *bilinear* in the stock, x, and the fishing effort, e, such that $H(x, e) = qex$, where q is the catchability coefficient (Clark, 1990).

Although equation (1) is dynamic, we will proceed in a static setting[7]. This can be justified on the basis of common practice in transboundary fishery management, where production conditions are set periodically based on the status of the fish stock. Particularly, the static model seems consistent with the management of many open access regimes throughout history and across cultures (Conrad, 1999, p.39). For example, the Individual Transferable Quota systems (ITQs) represent harvesting rights designed for a one-year period (Bjørndal and Munro, 1998). Hence, the presumed environment is one in which only the current fishing effort and stock variable determine the management decision. The approach we adopt here comes down to choosing across different steady states, ignoring transitional dynamics.

The above assumptions imply that for a given e, the stock evolves towards the *sustainable equilibrium* $x = x_b(e)$ defined by

$$F(x_b(e)) - H(e, x_b(e)) = 0, \text{ i.e. } \dot{x} = 0.$$

[7] Observe that the static model comes down to periodic adjustment of current exploitation of the fish stock (Bjørndal and Munro, 1998).

It is convenient to assume that $F(x)$ and $H(e,x)$ are of the forms:

$$F(x) = x(b-x) \text{ and } H(e,x) = ex.$$

In that case, the steady-state relation between effort and stock is given by $x_b(e) = b - e$, if $e \leqslant b$. If $e > b$ the stock decays rapidly (Clark, 1990). Therefore, to avoid depletion of a fish resource, e should be less than b. The corresponding level of harvesting at the equilibrium $x_b(e)$ is determined by

$$H(e, x_b(e)) = e(b-e), \text{ for } 0 \leqslant e \leqslant b. \tag{2}$$

To simplify the analysis, we *normalize the unit price* of harvest landed so that the *payoff* (or *economic rent*) is

$$\pi(e) = e(b-e) - ce \tag{3}$$

where c is the unit cost of effort. Note that in the case of a large high seas fishery, costs may not be constant, as assumed here. However, for convex cost functions (rather than linear cost functions) the results obtained below would not basically change (for details, see Norde *et al.*, 2002). The harvest is thus profitable only if $0 < e < b - c$.

As a preliminary to the next section, we generalize the above model to a set of N countries ($N = \{1, 2, ..., n\}$) harvesting the fish stock independently and simultaneously. We assume that each country's set of effort levels (or fishing fleet) is E_i, where $E_i = [0, l_i]$, and $l_i \in [0, \infty)$ is the maximum effort level of country i. Let e_i be a given effort level of country i, $e_i \in E_i$. In addition, let $e = (e_1, e_2, ..., e_n) \in E_1 \times E_2 \times ... \times E_n$ denote the vector of fishing efforts of n countries. (For the remainder of this paper e denotes a vector of effort level).

In this setting, the total harvest of N countries is $H(e,x) = \sum_{i \in N} H_i(e,x)$, where $H_i(e,x) = e_i x$ is the harvest level of country i. The structure of the yield-to-effort equation (1) does not change (given b), but the total effort now is the sum $\sum_{i=1}^{n} e_i$, and the corresponding equilibrium fish stock is $x_b(e) = b - \sum_{i=1}^{n} e_i$. Hence, the economic rent of each country k is $\pi_k(e) = H_k(e, x_b(e)) - c_k e_k = (b - \sum_{i=1}^{n} e_i)e_k - c_k e_k$, where c_k is the unit cost of effort of country k.

Since the equilibrium $x_b(e)$ depends upon both the carrying capacity b and the total (competitive) effort $\sum_{i=1}^{n} e_i$, we can consider it as the linear inverted supply curve in a Cournot situation with n producers. For a give b, we use notation $p(e)$ to denote $x_b(e)$. Thus, if the individual country payoffs are proportional to the corresponding fishing effort levels, and if each country has its own cost function (i.e. each country has its own technology), then country k's payoff can be written as

$$\pi_k(e) = \pi_k(e_1, ..., e_n) = p(e)e_k - c_k e_k \tag{4}$$

where $p(e) = b - \sum_{i=1}^{n} e_i$.

Equation (4) shows that each country's payoff depends on the aggregate effort and on the country's own effort or fishing fleet. Particularly, for a country to maximize its payoff, it will calculate its optimal effort level taking into account the effort levels of its opponents.

We now present a formal definition of a noncooperative fishery game:

Definition 2.1 *A noncooperative fishery game (NFG) is an n-person game*

$$\Gamma =< E_1, ..., E_n; \pi_1, ..., \pi_n >, \text{ where}$$

(i) $E_k = [0, l_k]$ *is the strategy set of player* k*, and* $0 < l_k < \infty$.
(ii) $\pi_k(e) = p(e)e_k - c_k e_k$ *is the payoff function of player* k *, where* $p(e) = \max\{b - \sum_{j=1}^{n} e_j, 0\}$ and $c_k > 0$.

The following basic results for noncooperative fishery games will serve as a benchmark for the cooperative game theoretic analysis presented next.

Theorem 2.1 *Every noncooperative fishery game* Γ *has a unique Nash equilibrium* e^**. Moreover, the equilibrium vector* e^* *satisfies* $\sum_{k=1}^{n} e_k^* \leq b$.

Proof. (see Appendix) ■

From the above, it follows that the competitive outcome is a worst case scenario in the sense that the stock is at risk of extinction and resource rent will be dissipated. This situation characterized by Theorem 2.1 might prevail in the case of independent countries that have not restrained their competitive efforts (section 3.2) or when negotiations between new members and incumbent nations break down and the latter give up conservation to turn to competitive efforts. However, when traditional harvesting countries have restrained their efforts to preserve or build up a stock or when distant water fleets belonging to countries that have not yet participated in a given announce an intention to begin harvesting and at the same time petition to join a RFMO, the situation may be less gloomy.

Remark The outcome of the noncooperative game is virtually identical to that of the unregulated open access fishery, particularly when the combined harvesting effort in the Nash equilibrium is larger than $b/2$ (for further details, see Clark, 1980). This is due to the fact that at $b/2$ the yield of the fish resource is maximally sustainable, and $p(e) = b - \sum_{i=1}^{n} e_i$ can be considered as the Cournot price[8].

We now turn to cooperative fishery games. Recall that a *cooperative game* or *transferable utility game* (*TU game*) is an ordered pair (N, v) where N is the set of players, and $v : 2^N \to \mathbb{R}$ is the *characteristic function* relating to each coalition $S \subseteq N$ a real number $v(S)$ representing the total payoff (profit) which S is able to generate through internal cooperation, with the convention that $v(\phi) = 0$.

Consider an n-player noncooperative fishery game, and a coalition $S \subseteq N$. The aggregate payoff function of coalition S equals the sum of payoff functions of players belonging to S. That is, with $e = (e_S, e_{-S}) \in E$,

$$\pi_S(e) = \sum_{j \in S} \pi_j(e) = \sum_{j \in S} [p(e_S, e_{-S})e_j - c_j e_j]. \tag{5}$$

For each fishery game, we define two related cooperative games by means of the α- and β- conversions, introduced by Aumann (1959), as follows.

The α-*characteristic function* of a fishery game Γ is the function v_α defined by

$$v_\alpha(S) = Max_{e_S \in E_S} Min_{e_{-S} \in E_{-S}} \pi_S(e_S, e_{-S}), \tag{6}$$

whereas the β-*characteristic function* of the fishery game Γ is the function v_β defined by

$$v_\beta(S) = Min_{e_{-S} \in E_{-S}} Max_{e_S \in E_S} \pi_S(e_S, e_{-S}). \tag{7}$$

The $\alpha-$*characteristic function* represents a *prudent perception* by the members of the coalition S about their capability to guarantee themselves

[8] For ease of exposition we take as reference point the maximum sustainable yield rather than the maximum economic yield which requires information on the interest rate, the cost of harvesting as a function of inter alia stock size and the in situ value of the stock (Tahvonen and Kuuluvainen, 2000).

the payoff $v_\alpha(S)$ if they choose the joint strategy e_S when the opposition $N\backslash S$ acts to minimize its payoff (i.e. coalition S can ensure to its members the maximum (total) payoff while choosing the strategy combination e_S regardless of what the opposition $N\backslash S$ does).

The $\beta-$*characteristic function* represents an *optimistic perception* by the members of the coalition S in the sense that the opposition $N\backslash S$ can prevent the players in S from getting more than $v_\beta(S)$. It is the payoff to which the opposition can hold the coalition. Therefore, in the α- framework, a coalition S obtains the payoff it can guarantee itself, irrespective of the strategy choice of the players in $N\backslash S$, whereas in the β- framework, the coalition S obtains the maximum payoff from which it can not be prevented by the players in $N\backslash S$.

It is easy to see that

$$v_\alpha(S) \leqslant v_\beta(S) \text{ for all } S \subseteq N \text{ and } \ v_\alpha(N) = v_\beta(N).$$

The $\alpha-$ and $\beta-$characteristic functions coincide for fishery games, as the following proposition states.

Proposition 2.1 *The payoffs defined by (6) and (7) coincide for each fishery game, i.e.* $v_\alpha(S) = v_\beta(S)$ *for all* $S \subseteq N$.

Proof. (see Appendix) ■

Proposition 2.1 states that for every coalition S the amount $v_\alpha(S)$ which this coalition can guarantee itself, and the maximum amount $v_\beta(S)$ from which it can not be prevented by the opposition are the same.

The game (N, v) with $v = v_\alpha = v_\beta$ will be called a *cooperative fishery game* (CFG*)*.

We now present some important characteristics of cooperative fishery games. First of all, the convexity[9] of a cooperative fishery game follows directly from Theorem 1 in Norde *et al.* (2002). Observe that a cooperative

[9] A cooperative game (N, v) is called convex if for every $S, T \subset N$ and every $i \in N$ such that $S \subset T \subseteq N\backslash\{i\}$, it follows that $v(T \cup \{i\}) - v(T) \geq v(S \cup \{i\}) - v(S)$.

The term $v(S \cup \{i\}) - v(S)$ is the marginal contribution of player i to the coalition S. So a game is convex if the marginal contribution of a player to some coalition increases if the coalition which he joins grows larger.

fishery game (CFG) can be an oligopoly game with or without transferable technology. Since the transfer of technology under substantial costs of replacing fishing, hence, a CFG is more likely to be an oligopoly game without then with transferable technology in the short run.

Proposition 2.2 *Every cooperative fishery game is a convex game.*

The following corollary follows from Proposition 2.2.

Corollary 2.1 *A cooperative fishery game has a non empty core*[10]*. Moreover, for every* S, T *such that* $S \subseteq T$, $v(S) - \sum_{k \in S} v(\{k\}) \leqslant v(T) - \sum_{k \in T} v(\{k\})$.

Corollary 2.1 implies that for a cooperative fishery game expansion of the coalition can be rewarding to its players.

Theorem 2.2 *The Shapley value*[11] *of a cooperative fishery game is a solution that is both individually rational and efficient. Moreover, the Shapley value is in the midpoint of the core of the CFG.*

Proof. (see Appendix) ■

The concepts, propositions and theorem presented above will be applied to develop RFMO management rules.

[10] For a cooperative game (N,v), a payoff vector $(w_i)_{i \in N}$, where w_i is the payoff of player $i \in N$, is called a core element of the game (N,v) if

$$\sum_{i \in N} w_i = v(N) \text{ and } \sum_{i \in S} w_i \geq v(S) \text{ for all } S \subset N.$$

The first part of this definition ensures that the payoff vector is *feasible* (the so-called *efficiency* condition) for the *grand coalition* N. The second part introduces a *stability* requirement which states that no subcoalition S, by acting on its own, can achieve an aggregate payoff which is higher than the sum of the elements of payoff vector w. If we take for S the singleton sets we get the *individual rationality* requirement, stating that every player should receive at least his *stand-alone* value.

[11] For a cooperative game (N, v), the Shapley value (Shapley, 1953), $\Phi(v) = (\Phi_k(v))_{k \in N}$, is defined as

$$\Phi_k(v) = \sum_{S \subseteq N \setminus \{k\}} \frac{|S|!(n-1-|S|)!}{n!}(v(S \cup \{k\}) - v(S)).$$

Roughly speaking, the Shapley value means that each player should be paid according to how valuable her/his cooperation is for the other players. In general, the Shapley value needs not generate a core element. However, for convex games it does (Shapley, 1971).

3 RMFO management rules

As mentioned in section 1, the management problem a RFMO most often encounters are the new member problem and the reduction of efforts. In the following, the new member problem is discussed in section 3.1 in a cooperative setting. The redutions of effort problem is discussed in section 3.2.

3.1 The new member problem

In a cooperative setting a stable coalition S may divide the aggregate revenue according to a vector $(w_{j,S})_{j\in S}$, where $w_{j,S}$ denotes the share of player j. When country k enters S, the coalition $S\cup\{k\}$ faces the problem of dividing their aggregate revenue according to the vector $(w_{j,S\cup\{k\}})_{j\in S\cup\{k\}}$. The new entrant k can be accepted to join the coalition S if it does not harm any member of S, that is, if $w_{j,S\cup\{k\}} - w_{j,S} \geq 0$ for all $j \in S$. Moreover, the new entrant should be better off by joining the coalition rather than staying out of it. This feature forms the so-called *monotonicity property.* In other words, an allocation scheme[12] satisfying the monotonicity property is acceptable for every player. In game theory, there is one solution concept that reflect these monotonicity requirements, namely the *population monotonic allocation schemes.*

The notion of population monotonic allocation scheme (PMAS), introduced by Sprumont (1990) reads as follows.

Definition 3.1 *A vector $(w_{j,S})_{S\subseteq N, j\in S}$ is a population monotonic allocation scheme (PMAS) for the cooperative game (N,v) if it satisfies the following conditions:*

$$(i)\quad \sum_{j\in S} w_{j,S} = v(S) \quad \text{for all } S\subseteq N$$
$$(ii)\quad w_{j,S} \leqslant w_{j,T} \quad \text{for all } S,T\subseteq N \text{ with } S\subseteq T \quad \text{and all } j\in S.$$

The number $w_{j,S}$ represents the payoff to player j if coalition S decides to cooperate. Condition (i) is an efficiency requirement and condition (ii) states that if, instead of coalition S, the larger coalition T decides to cooperate (i.e., the members of $T\backslash S$ are new comers and included in the cooperation), then the payoff of players in S should not decrease. A PMAS, therefore, guarantees that once a coalition S has decided upon an allocation of $v(S)$, no player

[12] An allocation scheme is a payoff scheme that does not only provide a payoff vector for a specific game but also for all its subgames.

will have an incentive to form a smaller coalition. The reason is that the players' payoffs in the smaller coalitions would decrease. Sprumont (1990) also shows that convex games have a PMAS. In fact, he proves that the Shapley value for the game that includes all players and for each subgame provides a PMAS. The following theorem is a direct consequence of Sprumont's result and Proposition 2.2 which states that every fishery game is a convex game.

Theorem 3.1 *Every cooperative fishery game has a PMAS. Furthermore, the Shapley values calculated for all subgames give a PMAS.*

Example 3.1 We numerically illustrate the calculation of the PMAS for a simple example. Consider the 3-person fishery game, where $N = \{1, 2, 3\}$, $l_1 = 14$, $l_2 = 8$, $l_3 = 12$, $c_1 = 2$, $c_2 = 4$, $c_3 = 16$, and $b = 60$. The first step in the computation of the PMAS is the calculation of the characteristic function of the cooperative fishery game, i.e. the calculation of the value of $v(S)(= v_\alpha(S) = v_\beta(S))$ for all possible coalitions S. Observe that the characteristic function is calculated under the budget constraint in the form of the total quantity of resource rent available. Norde *et al.* (2002) provides a formula for calculation of the value $v(S)$. For the sake of completeness, it has been included in the Appendix. Applying this formula we obtain

$$v(123) = 776;\ v(12) = 512;\ v(13) = 520;\ v(23) = 321;$$
$$v(1) = 336;\ v(2) = 176;\ v(3) = 121.$$

Recall that the cooperative game (N, v) represents both the $\alpha-$ and $\beta-$conversion of the corresponding noncooperative fishery game. So, $v(1) = 336$ reflects on one hand the fact that player (country) 1 can guarantee himself the value of 336, regardless of what the other players 2 and 3 do and on the other hand the fact that players 2 and 3 can prevent that player 1 gets more than 336. Similarly $v(12) = 512$ reflects the fact that players 1 and 2 can guarantee themselves a value of 512 and player 3 can prevent them from getting more.

The next step in the computation of the PMAS is the calculation of the Shapley value for all players in a given coalition. For a given player it can be obtained as the average over the marginal contributions for all possible orders of the players joining the coalition. Finally, the Shapley value for all possible subgames gives the PMAS.

Table 1 illustrates the calculation of the Shapley value for the 3-person CFG. The first column of Table 1 shows the possible orders of joining the grand coalition, whereas columns 2, 3, 4 show the marginal contributions of player $1, 2, 3$ joining the grand coalition for a given order, respectively. Consider, for instance, the order 1-2-3, where player 1 is the first to enter the grand coalition followed by player 2 and player 3. Player 1's marginal contribution is his stand alone value $v(\{1\}) = 336$.[13] Player 2 is given his marginal contribution to coalition {1, 2}, i.e. $v(\{1,2\}) - v(\{1\}) = 176$, and player 3 is given his marginal contribution to coalition {1, 2, 3}, i.e. $v(\{1,2,3\}) - v(\{1,2\}) = 264$. For each of the six orders of joining, we can compute the marginal contribution for each player and the average of these contributions is the Shapley value.

Table 1. Marginal contributions from joining the grand coalition and the Shapley value for the 3-country CFG

order	marginal contribution of player 1	marginal contribution of player 2	marginal contribution of player 3
1-2-3	336	176	264
1-3-2	336	256	184
2-1-3	336	176	264
2-3-1	455	176	145
3-1-2	399	256	121
3-2-1	455	200	121
Shapley value	$386\frac{1}{6}$	$206\frac{4}{6}$	$183\frac{1}{6}$

Computing the Shapley value[14] for every subgame we get the $PMAS$ (Table 2). From Table 2 we conclude first of all that for each player the payoffs increase with increasing coalition size. This illustrates the monotonicity property referred to above. Secondly, player 1's fishing capacity l_1 is largest,

[13] Note that the stand-alone values in the cooperative game indicate the payoffs of single coalitions. For example, in this game $v(\{1\})$ $(= v_\alpha(\{1\}) = v_\beta(\{1\}))$ is the maximum payoff of single coalition {1} when player 1 considers players 2 and 3 as the coalition {2,3}. Therefore, these values differ from the competitive payoffs in the Nash equilibrium (336,176,120).

[14] Observe that the calculation of the Shapley value circumvents the problem of path dependence. In practical applications the actual situation has to be taken into account and corrections for the distance between the actual situation and the benchmark, the Shapley value, need to be made.

his cost is lowest, and his payoff is the largest in every coalition. We observe that the rewarding of notably capacity and efficiency are important in the allocation of TACs to nations. Whereas in principle efficiency could be achieved by a simple tender of the total TAC and the division of the rent between stakeholders, this mechanism will not work for the allocation of TACs to nations because of national goals such as the preservation of employment which is related to the capacity of their fleets. In other words, capacity and efficiency need to be "rewarded" under PMAS in this example.

Table 2.PMAS for the 3-country CFG.

	1	2	3
123	$386\frac{1}{6}$	$206\frac{4}{6}$	$183\frac{1}{6}$
12	336	176	*
13	$367\frac{1}{2}$	*	$152\frac{1}{2}$
23	*	188	133
1	336	*	*
2	*	176	*
3	*	*	121

3.2 Reduction of fishing effort: allocation of harvest quotas

As described in section 2, resource rents will be dissipated and a stock will be depleted if total effort exceeds the carrying capacity of the stock b. In a similar vein, if total effort exceeds $b/2$, then total profit is below the maximum sustainable yield (for details, see Clark, 1990). For both cases the management problem comes down to a reduction of harvest levels (i.e. quota shares). To develop a reduction policy for the RFMO we make use of bankruptcy analysis. Particularly, the proportional rule which is frequently used in the context of bankruptcy problems because it is generally considered to be a fair rule in the sense that each country incurs the same reduction rate (see, among others, Thomson, 1995)[15].

Under the *proportional rule* (PROP) each country would reduce its effort in proportion to its original effort. Consider, for instance, the management

[15] A bankruptcy problem is a triple $(N, E; d)$, where N is the finite set of players, $E \in (0, \infty)$ is the state which has to be divided and $d = (d_1, ..., d_N)$ is the vector of player claims such that $d(N) = \sum_{i=1}^{N} d_i \geq E$.

objective to reduce effort from the total competitive effort level $e^*(N) = \sum_{i=1}^n e_i^*$ to the effort level corresponding to the maximum sustainable yield $\overline{e}^M = \frac{b}{2}$, where $\overline{e}^M < e^*(N)$ and e_i^* is country i's effort in the competitive situation. In other words, consider the bankruptcy problem where the state to be divided is the maximum sustainable yield effort level, and the claims are the effort levels in the competitive outcome. Under PROP country i's effort level reduces to

$$e_i^{PROP} = e_i^* \frac{\overline{e}^M}{e^*(N)}. \tag{8}$$

Proposition 3.1 *If, in the competitive equilibrium e^*, total effort exceeds half the carrying capacity of the stock, i.e. $\sum_{i=1}^n e_i^* \geq \frac{b}{2}$, then for every player the payoff under the proportional rule which reduces effort from the competitive equilibrium to the maximum sustainable yield is larger than the competitive payoff.*[16]

Proof. (see Appendix) ■

The following example illustrates Proposition 3.1.

Example 3.2 Consider the 2-person NFG in which $b = 30$, $l_1 = 18, l_2 = 16, c_1 = 4$, and $c_2 = 5$.

The competitive equilibrium $e^* = (9, 8)$ which is the intersection of the two solid lines in Figure 1. Since $\sum_{i=1}^n e_i^* = 17 > \frac{b}{2} = 15$ we have a suboptimal profit $\pi(e^*) = (81, 64)$. Adjustment according to the propotional rule leads to $e^A = (9, 8) * \frac{15}{17} = (7.94, 7.06)$, which is the intersection of the two dotted lines in Figure 1. The payoff, $\pi(e^A) = (87.35, 70.59)$ is larger than $\pi(e^*)$.

[16] This proposition holds as long as the following condition is met: $\frac{b - \min_{i \in N} c_i}{2} < \overline{e}^M$. Observe that the steady state assumptions together with zero interest rates are needed for harvest to be at the maximum sustainable yield with biomass at $b/2$ and that positive discount rates will see lower values. We have chosen this extreme situation for expository convenience. However, Proposition 3.1 generalizes to other outcomes with positive discount rates and lower biomasses.

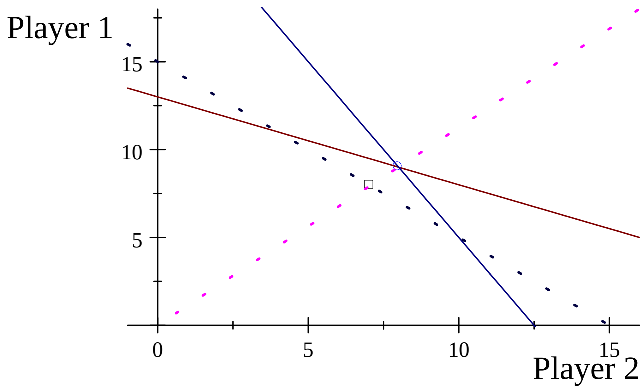

Figure 1. Best replies (solid lines) and adjusted effort levels (dotted lines).

The upshot of this section is that the proportional rule is an appropriate management handle to reduce effort from the competitive equilibrium to the maximum sustainable yield. Moreover, it is straightforward to show that similar results hold for the reduction of effort from other sub-optimal equilibrium by proportional rule. Finally, the prospect of future reduction by proportional rule may induce countries to refrain from increasing their efforts.

4 Concluding remarks

In this paper we examined how a Regional Fishery Management Organization (RFMO) might achieve effective control of a high seas fishery. We showed that the outcome of the non-cooperative solution is virtually identical to that of the unregulated open access fishery. The management problem considered in this paper is the new member problem. We proposed the population monotonic allocation scheme as management rule for coalitions of various sizes. Under this management rule, each player's payoff increases when the coalition is expanded. Moreover, a player's capacity and efficiency are rewarded. Next we considered management rules to achieve adjustment from the Nash equilibrium to a state of cooperation. We proposed the proportional rule for situations where the fishing nations have accepted some coordination but are not fully cooperating in the sense that they have formed a coalition that operates collectively to achieve sustainable and efficient harvesting.

The above mentioned solutions are individually rational and efficient, which are prerequisites for an agreement. Particularly, the management rules induce charter members and new entrants to refrain from competitive behaviour. The management rules imply that the charter members may have to give up some part of their quota or property rights while new entrants may have to accept constraints on their original harvesting levels. Nevertheless, under the management rules, every fishing nation will be better off than in the competitive equilibrium. Hence, competitive behaviour is a threat to induce the countries to accept the management rules.

An important question for further research is the stability of the fisheries games proposed here. Previous research, amongst others Hanneson (1997), has shown that with highly mobile fish stocks, the number of players compatible with a cooperative self-enforcing solution is small for reasonable values of the discount rate. In other words, cooperative fisheries games with other than a small number of fishing nations are inherently stable. Our approach differs from Hanneson's amongst others in the sense that he considers the full cooperative solution without specifying how the benefits from cooperation are to be distributed among the players whereas we, in contrast, focus on the characteristics of the proportional rule and PMAS as management rules. As is well-known (see amongst others, Folmer and von Mouche, 2000), the full cooperative approach as such may imply net welfare losses relative to the competitive outcome for some countries which is an incentive for those countries to free ride.

As shown above, the management rules proposed in this paper ensure that no player is made worse off compared to the competitive outcome which is likely to have a mitigating effect on free riding. Nevertheless, further research on the stability of the cooperative fisheries games presented here is needed[17] as well as on mechanisms to mitigate free riding (in as far as it occurs) such as interconnecting a fishery game with some other game (see e.g. Folmer and Zeeuw, 2000) or side payments (Kaitala and Munro, 1997).

Finally, we observe that the benchmark of unregulated exploitation analyzed here is an extreme situation, although many fisheries are not far from

[17] Recently games in partition function form have been studied to analyze the fundamental relationships between externalities and the existence of stable coalition structures. We refer to Pintassilgo (2003) for application of this approach to the North Atlantic bluefin tuna and Phamdo and Folmer (2006) for fair allocations in the presence of externalities.

it (see e.g. Munro et al, 2004). However, even if we start from a sub-optimal situation between the competitive equilibrium and the situation under the management rules, similar policy implications hold.

References

Aumann, R. (1959) Acceptable points in general cooperative n-person games. In A. Tucker and C. Luce (eds), *Contributions to the Theory of Games IV.* Annals of Mathematics Studies, vol. 40. Princeton University Press, Princeton.

Bjørndal, T. and G. Munro (1998) The economics of fishery management: a survey. In T. Tietenberg and H. Folmer (eds), *The International Yearbook of Environmental and Resource economics 1998-1999.* Edward Elgar.

Bjørndal, T. and G. Munro (2003) The management of high seas fisheries resources and the implementation of the U.N fish stocks agreement of 1995, in: T. Tietenberg and H. Folmer (eds), *The International Yearbook of Environmental and Resource Economics 2003-2004*, Cheltenham, UK and Brookfield, US: Edward Elgar.

Clark, C.W. (1980) Restricted access to common property fishery resources: a game theoretic analysis. In P.T. Liu (eds), *Dynamic Optimization and Mathematical Economics.* Plenum Press, New York.

Clark, C.W. (1990) *Mathematical Bioeconomics: The Optimal Management of Renewable Resources.* Second edition. John Wiley & Sons, Inc. Canada.

Clark, C.W. (1999) Renewable resources: fisheries. In van den Bergh (eds), *Handbook of Environmental and Resource Economics.* Edward Elgar.

Conrad, J. M. (1999) *Resource Economics.* Cambridge University Press.

Folmer, H., N. Hanley and F. Mißfeldt (1998) Game theoretic modelling of environmental and resource problems: An introduction. In N. Haley and H. Folmer (eds), *Game theory and the Environment.* Edward Elgar, Cheltenham.

Folmer, H. and A. de Zeeuw (2000), International environmental problems and policy, in H. Folmer and H.L. Gabel (eds), *Principles of Environmental and Resource Economics*, pp 447-479. Elward Elgar.

Folmer, H. and P. von Mouche (2000). Transboundary pollution and international cooperation. In: T. Tietenberg and H. Folmer (eds) *The International Yearbook of Environmental and Resource Economics* 2000/2001. Edward Elgar, Cheltenham, 231-67.

Hannesson, R. (1997) Fishing as a Supergame, *Journal of Environmental Economics and Management* **32**: 309-322.

Kaitala, V. and G. Munro (1993) The management of high seas fisheries. *Marine Resource Economics* **8**: 313-329.

Kaitala, V. and G. Munro (1995) The economic management of high sea fishery resources: a game theoretic aspects. In J.A. Filar and C. Carraro (eds), *Control and Game Theoretic Models of the Environment*, Annals of the international society of dynamic games, vol 2. Boston: Birlhauser.

Kaitala, V. and G. Munro (1997) The conservation and management of high seas fishery resources under the new law of the sea. *Natural Resource Modeling* **10** (2): 87-108.

McKelvey, R., L.K. Sandal and S.I. Steinshamn (2002) Fish wars on the high seas: A straddling stock competition model. *International Game Theory Review,* **4**(1): 53-70.

Munro, G. (2000) The UN Fish stocks agreement of 1995: history and problems of implementation, *Marine Resource Economics* **15**: 265-280.

Munro, G, A. Van Houtte and R.Willmann (2004) The conservation and management of shared fish stocks: legal and economic aspects. *FAO Fisheries Technical Paper* 465.

Norde, H., K.H. Pham Do and S. Tijs (2002) Oligopoly games with and without transferable technologies, *Mathematical Social Sciences* **43**(2): 187-207.

OECD (1997) *Towards Sustainable Fisheries-Economic Aspects of the Management of Living Marine Resource*. Paris: OECD.

Okuguchi, K. and F. Szidarovzky (1999) *The Theory of Oligopoly with Multi-product Firms.* Second edition. Springer.

Phamdo, K.H. and H. Folmer (2006) International Fisheries Agreements: the feasibility and impacts of partial cooperation. In "*The Theory And Practice Of Environmental And Resource Economics, Essays in Honour of Karl-Gustaf Löfgren*" (Eds) Aronsson, Axelsson and Brännlund, Edward Elgar

Pintassilgo, P and C. Duarte (2000) The new member problem in the cooperative management of high seas fisheries, *Marine Resource Economics* **15**: 361-378.

Pintassilgo, P (2003) A coalition approach to the management of high seas fisheries in the presence of externalities. *Marine Resource Economics* **16**: 175-197

Shapley, L. (1953) A value for n-person games. In H.W. Kuhn and W. Tucker (eds), *Contributions to the Theory of Games, vol 2.* Princeton University Press.

Shapley, L. (1971) Cores of convex games. *International Journal of Game Theory* **1**: 11-26.

Sprumont, Y. (1990) Population monotonic allocation schemes for cooperative games with transferable utility. *Games and Economic Behavior* **2**: 378-394.

Tahvonen, O. and J. Kuuluvainen (2000) The economics of natural resource utilization. In Folmer, H. and H. L. Gabel (eds) *Principles of Environmental and Resource Economics*. Edward Elgar.

Thomson, W. (1995) *Axiomatic analyses of bankruptcy and taxation problems: a survey.* Rochester CentER WP 413, Rochester University.

UN (2002). *Oceans: the Lifeline of our Planet Anniversary of the United Nations Convention on the Law of the Sea*: 20 Years of Law and Order on the Oceans and Seas (1982-2002).

Appendix

Proof. (**of Theorem 2.2**)

A noncooperative fishery game can be considered as an oligopoly game with linear inverse supply function $p(e) = \max\{b - \sum_{k=1}^{n} e_k, 0\}$. E_k is a closed, bounded interval $[0, l_k]$, where $l_k \in [0, \infty)$, for all k, and the inverse supply function is a differentiable, strictly decreasing function of total efforts. The first part of Theorem 2.1 now follows from Theorem 3.3.3 in Okuguchi and Szidarovszky (1999).

We now turn to the second part. Let e^* be the equilibrium. Let $e^*(N)$ denote the sum $\sum_{k=1}^{n} e_k^*$. Suppose that $\sum_{k=1}^{n} e_k^* = e^*(N) > b$. Thus, $p(e^*) = \max\{b - \sum_{k=1}^{n} e_k^*, 0\} = 0$, and the vector e^* has at least one positive element, which we denote e_m^*. Hence, $\pi_m(e_m^*, e_{-m}^*) = -c_m e_m^* < 0$, and the best response of player m to e_m^* is $e_m = 0$. This contradicts the assumption that e^* is an equilibrium point. ■

Proof. (**of Proposition 2.1**)

A cooperative fishery game can be considered as an oligopoly game without transferable technologies as introduced by Norde *et al.* (2002). The result then follows from Proposition 3 therein. ■

Proof. (**of Theorem 2.2**)

Since a CFG is convex by Proposition 2.2, the result then follows directly from Shapley's theorem (Shapley, 1971). ■

Proof. (**of Proposition 3.1**)

Let $e^* = (e_i^*)_{i \in N}$ be the effort vector in the competitive equilibrium for which $\frac{b}{2} \leqslant e^*(N) \leqslant b$. Furthermore, let $e^{PROP} = (e_i^{PROP})_{i \in N}$ be the effort vector under PROP, i.e. $e_i^{PROP} = e_i^* [\frac{b/2}{e^*(N)}] \leqslant e_i^*$, and $\pi_i(e^*)$ and $\pi_i(e^{PROP})$ the corresponding payoffs for player i, respectively.

Define $\Omega_i = \pi_i(e^*) - \pi_i(e^{PROP})$. It is sufficient to prove that $\Omega_i \leqslant 0$.

If $e_i^* = 0$ then $e_i^{PROP} = 0$ and clearly $\Omega_i = 0$.

Now assume that $e_i^* > 0$. We have

$$\Omega_i = [(b - \sum_{j=1}^{n} e_j^*)e_i^* - c_i e_i^*] - [(b - \sum_{j=1}^{n} e_j^{PROP})e_i^{PROP} - c_i e_i^{PROP}]$$
$$= (b - c_i)(e_i^* - e_i^{PROP}) - [(\sum_{j=1}^{n} e_j^*)e_i^* - (\sum_{j=1}^{n} e_j^{PROP})e_i^{PROP}].$$

Since $e_i^* \geq e_i^{PROP} > 0$, $\sum_{j=1}^{n} e_j^{PROP} = \frac{b}{2}$, and $\sum_{j=1}^{n} e_j^* = \frac{b}{2}\frac{e_i^*}{e_i^{PROP}}$, we obtain

$$\Omega_i = (e_i^* - e_i^{PROP})(b - c_i) - \frac{b}{2e_i^{PROP}}[(e_i^*)^2 - (e_i^{PROP})^2]$$
$$= (e_i^* - e_i^{PROP})[(b - c_i) - \frac{b}{2e_i^{PROP}}((e_i^* + e_i^{PROP}))]$$
$$\leqslant (e_i^* - e_i^{PROP})[(b - c_i) - \frac{b}{2e_i^{PROP}}(2e_i^{PROP})]$$
$$= -c_i(e_i^* - e_i^{PROP}) \leqslant 0. \qquad \blacksquare$$

Calculation of the coalition value $v(S)$.

Let (N, v) be a CFG. Assume that all fishing costs can be ordered in the following way: $c_1 \leqslant c_2 \leqslant ... \leqslant c_n$. Following Proposition 4 in Norde et al. (2002) we have $v(S) = \sum_{j \in S} f_{l_j}(b - c_j - l(N \backslash S) - 2l_{S,j})$ for every $S \subseteq N$, where $l_{S,j} = \sum_{k \in S; k<j} l_k$ and $l(N \backslash S) = \sum\limits_{j \in N \backslash S} l_j$. Here f_{l_j} is the C^1-function, $f_{l_j} : \mathbb{R} \to \mathbb{R}$, defined by

$$f_{l_j}(x) = \begin{cases} 0 & x \leqslant 0, \\ \frac{1}{4}x^2 & 0 < x \leqslant 2l_j, \\ l_j(x - l_j) & x > 2l_j. \end{cases}$$

For example, the values of coalitions {1,3} and {1,2,3} in Example 3.1 are calculated by $v(13) = f_{14}(50) + f_{12}(8) = 504 + 16 = 520$, and $v(123) = f_{14}(58) + f_8(28) + f_{12}(0) = 776$.