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Searching for a New Model of Governance in the High Seas: Game Theory Applied to International Commons Management

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Abstract: In the last decade, the United Nations took important steps for the creation of a new instrument for biodiversity protection in areas beyond national jurisdiction. This put under discussion the central issues of international commons management and of the governance model for the High Seas. The aim of this paper is to discuss and evaluate critically the political negotiations already made and yet to come, as well as their rationale. For this purpose, the paper applies game theory to fisheries management to get insights. This research aims to contribute toward more qualified and grounded decisions. The key role of cooperation in the sustainable use of common resources is stressed.

Keywords: biodiversity; fisheries management; governance; games

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1. Introduction

The creation of a legally binding instrument for the conservation and management of biodiversity beyond the limits of the so-called Exclusive Economic Zones (EEZs) is under discussion in the United Nations [1–3]. The issue is of fundamental importance, as it has to do with the management of the oceans and implies the definition of a governance model for the High Seas' common resources, with an incalculable value and central importance for the sustainability of the planet [4–7]. The political, economic, social and environmental issues involved are absolutely relevant [8–12].

According to the Save the Sea report, the oceans are the largest ecosystem on Earth. Oceans represent a considerable part of the Earth (70% of the planet's surface), and their economic impact is very important. Several economic activities (fisheries, ports, shipping, tourism, oil and gas production, etc.) contribute significantly to the world's gross domestic product (GDP) [5,13]. More than 90% of the world's trade is transported by sea. Around 45% of the world's population lives within 150 km of the coastline, and 8 of the 10 most populated cities in the world are located along the coast. Three billion people depend on marine and coastal resources. Oceans contribute extensively to food security, and fisheries are an important source of proteins. Oceans are central for coastal tourism and maritime recreational and cultural activities. Fisheries constitute an important basis for significant ways of life and have a large and intrinsic social and political value [14]. In environmental terms, the oceans are extremely relevant as they are the primary regulator of the global climate. Oceans are a large absorber of carbon dioxide and contribute around 50% of the world's oxygen.

One may find more than half (up to 80%) of all forms of life in the oceans. Oceans comprise the highest font of biodiversity on Earth, and therefore, healthy oceans are critical for the conservation of this priceless giving of nature's. According to Narula (2016) [7], the goods and products provided by marine biodiversity include food (about 100 million tons per year) and natural substances and ingredients for biotechnology and pharmaceuticals.

Genetic resources have significant commercial value. Ecosystem services are also highly valued. The associated functions range from coastal protection to climate management (as a CO_2 sink), waste storage and mineralization, among others.

Overfishing and pollution, among other anthropogenic impacts, put under stress the oceans' health [13–15]. The overexploitation of fish stocks is well documented worldwide; many important marine habitats (such as coral reefs and mangroves) are experiencing destruction. The media have noticed this: plastic is the fire of the oceans' hell.

The United Nations Convention on the Law of the Sea (UNCLOS) established the rules of the game for the management and governance of the so-called "areas beyond national jurisdiction" in 1982. Beyond the 200 miles of the EEZs, we can find two extensive areas (equivalent to 95% of the global volume of the oceans in total): the High Seas and the "Area". The High Seas corresponds to the waters and respective resources overlying the seabed beyond the limits of 200 miles, and the Area comprises the resources of the seabed beyond the limits of the Continental Platform (350 miles). On the High Seas, the principle of "free access" to all potential users applies, and rights are equal, namely in terms of fishing and scientific research. In the "Area", resources are understood as part of the "common heritage of mankind" (a concept that gained visibility after a speech by A. Pardo in the United Nations in 1967), and only the International Seabed Authority (ISA), an institution created at the level of the United Nations for this purpose, has the power to use and manage its resources [5,6,10]. These important regulation norms integrate parts VII and XI of the UNCLOS.

While no state has the jurisdiction to make laws regarding marine conservation, regional fishery arrangements have emerged to regulate fishing [16]. The main problem that the governance model underlying this convention poses concerns the fact that these areas are, to be precise, beyond national jurisdiction. This means that the regulatory power of national states ends, and the capacity to impose rules for the sustainable use of resources is severely limited [17]. Take the example of fishing and the so-called "flags of convenience" [18–20]. When a vessel is illegally operating in the international area, if it is detected, it may be involved in a judicial process that, according to the rules of international law, will have to be tried in the country whose flag the vessel flies. This leads many vessels' owners to register their ships in poor countries with weak or corrupt governments. These countries, naturally, will not have great internal conditions to develop the legal processes that arise to deal effectively and harshly with the illegal behavior of those users. "Flags of convenience" are one of the most damaging forms of Illegal, Unreported and Unregulated (IUU) fishing [21,22].

In what relates to the conservation of marine biodiversity, the legislators' awareness is clearly reflected in the importance given in the UNCLOS to this matter (an entire section is devoted to this issue). However, there are important limitations. To deal with the insufficiencies of this generic construct, another important convention was assigned: the so-called Convention on Biological Diversity (CBD) [23–25]. This convention defines the scope and the principles, as well as the procedures and the regulation and control norms, and it is a fundamental instrument for the promotion of the sustainable and fair use of common resources. However, it also has limits. The most important one lies in the fact that this convention is to be applied mostly to land and at the national jurisdiction level; that is, the regulation responsibility ends where the national jurisdiction ends, and the problem of international commons persists!

In a global view, those are the fundamental rules of the game in what relates to the biodiversity of marine ecosystems. The purpose of this paper is to revisit the stepping process to find a new agreement on the conservation of biodiversity and on the governance model of the High Seas and critically discuss the economic rationale of the decisions that have been made and that may succeed. We use the fisheries case and apply game theory to form our opinion and take insights from the rest of the ongoing political process of decision making and, of course, to evaluate the impacts at the political, socioeconomic and environmental levels that may occur.

Note that this paper's primary objective is to discuss the governance model of High Seas fisheries. However, we must not forget that a multilateral agreement on such a complex question as marine biodiversity beyond national jurisdictions must be balanced between several issues under debate [5,26,27]. The fisheries case is very interesting and has some specificities to address, and it can illuminate important topics for the overall discussion. Our aim is to present a series of insights resulting from previous and actual investigations that can facilitate the discussions between the decision makers and the interested public figures and show how mathematics can provide important support for reasoned choices. In this context, we stress the complexity of social system behavior and the role of complexity science to better understand the dynamics of such a bio-social-cultural problem [28,29].

This paper has the following structure. In the second part, we introduce the problem, refer to the historic and legal background and state the fundamental research questions to address. The third section refers to the methodology used in the investigation. The fourth section develops the analysis of the problem. This paper introduces a basic model of fisheries management and, by using game theory, forms the central role of international cooperation in the use of shared resources. In the fifth part, the basic hypotheses are extended, and the potentialities of current governance models are studied, as well as their limits and risks. The sixth part lays out the conclusions and analyzes the future impacts of the new situation created with the probable introduction of a new convention on biodiversity beyond national jurisdictions. Finally, this paper suggests new areas of research for this fruitful association of game theory and fisheries management.

2. The Problem(s): The History and Legal Background

The absence or lack of definition of property rights is at the heart of fisheries management. When fisheries are straddling in nature, the problem becomes more complex. This problem was enhanced by the new Law of the Sea, UNCLOS-82 [9,30,31]. Part V of this convention brings together the provisions that frame the development of fisheries. In the global context, a significant change in the capacity for efficient management of resources was created with the 200-mile regime. Exclusive rights for the coastal state over fishing in the EEZs was the most distinctive feature of UNCLOS and represented, for many observers, an authentic "promise of abundance" [32].

However, the process of "creeping jurisdiction" did not mean the exclusion of free access in international fisheries. In the convention, the "freedom of the seas" (the old principle defended by Hugo Grotius in the beginning of the 17th century in his thesis about the Mare Liberum and, since then, the center of maritime international law [33]) is maintained and still applies to the High Seas. The problem persists. Since the seminal work of Gordon (1954) [34], the central idea of fisheries economics is that the market, in conditions of free access, does not lead to the best allocation of resources. The "invisible hand" does not work in this case, and we face a situation of market failure. The character of "common property" of fish resources and the effects of production externalities lead to socially inefficient solutions that imply the overexploitation of the resources and the sector's overcapacity. In other words, this means the empirical evidence of the sector's "tragedy of the commons" (Hardin, 1968) [35].

As a reflection of the provisions of the UNCLOS, new questions have been posed for the management of international fisheries. With the introduction of the EEZs, one of the issues that has emerged is that of shared resource management [31,36]. Fish are mobile. Inevitably, the coastal countries found that they were sharing some of these resources with neighboring countries (one can call this type of resources transboundary resources) and that some of the stocks acquired passed the border from the EEZs to the High Seas, where they were subject to the exploitation of distant-water fishing countries (naming them straddling stocks). Other stocks (e.g., tuna stocks) make long migrations. In those movements, sometimes they are in the EEZs of different coastal countries, and sometimes

they can be found in the areas of the High Seas. We designate those stocks as highly migratory species.

Since the late 1970s, economists and mathematicians have been looking for an answer to these situations, but the development of a theory for these cases is still a "work in progress" [31]. It is the second case that interests us particularly. Our research questions are as follows: How can we regulate shared stock fisheries, especially the so-called straddling stocks? What model of governance must the international community design to overcome the problems arising from the imprecise definition of rights for the High Seas areas adjacent to the EEZs? To what extent can mathematics and economics contribute to practical solutions in resource management? Given the particular characteristics of this problem, how can game theory represent an interesting form of support for the development of practical policies?

In 1992, the United Nations scheduled an intergovernmental conference on fisheries management on the High Seas. The call for this conference originated from the Rio Conference. The results of the debate held are embodied in the 1995 Agreement on the Management of Transboundary Resources and Highly Migratory Species [37–39]. Nowadays, as mentioned earlier, there is again an important discussion at the UN to create a legally binding instrument to conserve and manage biodiversity beyond national jurisdictions. Assuming that the current regulation formulas do not provide the desired results, what new solutions can be suggested? What effects can they have in the perspective of the evolution of international maritime law? What new research clues does the current context point to?

This paper seeks to clarify this problem.

The Background

A previous bundle of questions exists. Why is there this concern with trans-zonal species and stocks that straddle? How did this problem emerge? The answer must be primarily found in a series of in-definitions of the 1982 convention. Article 56 of the UNCLOS gives the coastal state almost exclusive property rights over fisheries at a range of up to 200 miles. This article reflects one of the central innovations of this convention: the sovereign rights of coastal countries to exploit, manage and conserve fish resources in their EEZs. However, there were issues that remained inconclusive, and one of the most relevant concerned trans-zonal stocks [40–42].

During the Conference of Montego Bay, distant-water fishing nations (DWFNs) argued that, given the mobility of the stocks, their management should not be under the jurisdiction of the coastal states but rather under the jurisdiction of Regional Fisheries Management Organizations (RFMOs). This position was vigorously opposed by many coastal countries, especially developing countries that thought that this arrangement undermined their management powers.

The debate led to the compromise set out in Article 64, which turned out to be the focus of further controversy [36]. Article 64 contains two paragraphs that are apparently contradictory. Paragraph 1 states that where there are Regional Fisheries Organizations (e.g., NAFO for the Atlantic northwest area), coastal states must cooperate with maritime potencies of long-distance fishing. In the understanding of the latter, this obviously means that within those organizations, they should be able to influence the management and regulation of resources. On the other hand, paragraph 2 says that Article 64 is to be applied "in addition" to the other provisions of part V of the convention. Coastal states interpret this paragraph as implying that Article 56 must be applied in full in their EEZs and, therefore, also to migratory trans-zonal species. In other words, the management regime for straddling stocks applicable in the High Seas areas cannot be incompatible with the regime applicable, for the same stocks, in the EEZs of coastal countries. A "preferential right" to the coastal state seems to be admissible [30,36,43].

This lack of clarity created a potential conflict and, in fact, only the high negotiation costs implied to solve the problem were sufficient to maintain this situation of uncertainty.

However, at the dawn of the 1990s, the problem would resurface strongly. Consideration of the small importance of migratory resources carried out in the early 1980s (the FAO estimated that about 90% of fish resources would remain in the domain of EEZs) proved to be wrong. Furthermore, the access of distant-water fishing vessels to the EEZs of coastal countries, on the basis of the principle of surpluses, was successively eroded, and the belief of the coastal countries that they could easily monitor and inspect the action of fleets in waters adjacent to EEZs was a mistake. The pressure of distant fishing fleets on straddling stocks has increased sharply [31,44].

In essence, this is a problem of property rights. The conviction of the coastal states that they would have "de facto" (if not "de jure") rights over cross-border resources has proven to be invalid. These virtual rights turned out to be empty. In fact, these resources remain an "international common property", and hence the maintenance of the "tragedy of the commons" [30]. They are the "unfinished business" of the Law of the Sea [44], and the imprecise form in which they are defined in the Convention of 1982 is the root of the problem.

3. Methodology

In more recent times, new research methodologies have emerged that go beyond the traditional methodologies based on the construction of models and the validation of causality hypotheses that explain the relationships between variables. These emerging methodologies are characterized by the flexibility of the methods used and the diversity of options suggested for the analysis of phenomena in the business area. Without questioning the importance of the methodologies based on modeling and statistical inference, these new methodologies can be complementary. To a large extent, the actual existence of a substantial volume of data has favored the development of new methodologies. The analysis of a massive amount of information in order to identify evolution trajectories and prepare management decisions that improve the performance of the institutions has promoted very efficient methods of analysis and meta-analysis. One of these emerging methodologies (that we use in this investigation) is business analytics.

The purpose of business analytics is to give the agents involved in the management and resolution of identifiable problems significant indications to make better and informed decisions. This implies collecting, analyzing and making intelligent interpretations of data. Then, to achieve those objectives, one must select the appropriate analysis techniques, depending on the problem and existing data. In this sense, business analytics can be understood as "the general process of exploring and analyzing data to discover new and significant patterns" (as defined by Delen and Zolbanin [45]).

For development of the tasks, several dimensions have been proposed in terms of research fields, methods and orientations. This last dimension gives birth to a typology of three sequential phases or dominions of analysis: descriptive, predictive and prescriptive. The first is what one calls business reporting. This is a preliminary step. This phase describes the information in order to identify the great lines of historical evolution of the phenomena and prepares the data to be used as a basis for reasoned decisions. To a large extent, this is about answering to questions like "What is up?" or "What has been happening?" Descriptive analytics helps the researcher to identify the strategic variables and their pathways and relationships. For this, one can use all the disposable instruments of analysis, from visualization techniques to traditional business intelligence.

Predictive analytics refers to the creation of algorithms to derive empirical predictions based on the indications given by descriptive analytics. Finally, the aim of prescriptive analytics is to find the best trajectory for the strategic variables, given the circumstances, and prepare recommendations for the agents involved in management. Not only is the best performance expected, but new relations and new theories to be validated can emerge in the process. In this sense, this methodology can be a complementary and useful method to assist the most common construction of mathematical models and hypothesis validation.

In this paper, we employ a mixture of business analytics with the usual narratives one develops when trying to review the literature of a particular scientific area, evidencing the most important theoretical results and supporting those results with empirical evidence. At the same time, the predictive and prescriptive analysis intends to give important indications for the agents involved, finding the best pattern of action and making policy prescriptions and recommendations to get a better result, as well as introducing new routes for further investigation.

This mixed method, using several fonts and data, seems to be ideal for the purpose we develop. The central idea is to give a useful "manual" in the form of a guideline paper aimed at various types of audiences interested in this issue. In this sense, we are looking for a language that maintains the rigor of analysis that is expected from a leading journal in the field of mathematics but with content that is easy to assimilate by other audiences with different backgrounds and whose performance in terms of discussion and decision making is essential. In this context, the paper can be a relevant contribution for more qualified and grounded decisions.

4. Analysis: Fundaments for Cooperation

4.1. Levels of Cooperation

Munro [40,46] suggested that a reasonable way of proceeding to formalize a theory suitable to these cases is to start by analyzing the "big questions", especially those from someone quite experienced in this field, and then develop a rigorous analysis, testing the vitality of the hypotheses with several empirical cases.

The basic questions were asked by Gulland [47], an experienced FAO biologist. The essential premise of Gulland's work is the non-consideration of faith in the altruism of the co-managers. In the situations to be analyzed, there are two or more states that share the use of a given fishery resource, and each state intends to maximize its own economic benefits over time.

To Gulland, different levels of management cooperation can be suggested. First, there is the so-called primary cooperation. Cooperation in fields related to scientific research is an excellent example. Since the players both hope to have benefits, it is relatively easy to establish this level of cooperation. The next (secondary) level of cooperation involves establishing the management coordinates themselves. Here, the problems are bigger. The fundamental prerequisites for cooperation at the secondary level assume that the exploitation of the resource by one of the co-owners significantly affects the others and that they are convinced that the benefits of cooperation must exceed a considerable minimum.

The secondary cooperation at the management level implies the consideration of issues such as the distribution of quotas between partners, the determination of the optimal management strategy (which involves computing resource usage rates over time) and rules for monitoring and controlling the implementation of the compromises. This creates some difficulties that are already well-documented. The first links with the division of quotas. The negotiation involved in this process is what makes more intense references in the media and is mostly discussed in the political arena, but in fact, it is the easiest issue to resolve. This depends, of course, on the political will and on the physical conditions of abundance and the health of the stocks and the economic and social realities of the fisheries.

Choosing the best strategy for the future development of one specific fishery is much more difficult. The objectives of the different players, countries and regulation agencies may differ substantially. One of the players may be more conservationist in the sense that he or she prefers an intertemporal consumption program that gives more importance to the generations to come, implying that he or she prefers lower usage rates in the closer periods. This means he or she will adopt a discount rate close to zero. Others can be more myopic and give preference to short-term benefits (i.e., the use of higher discount rates). Furthermore, strategies mutually accepted by co-owners do not offer more than temporary benefits if there is no monitoring mechanism that discourages fraud and blackmail between partners.

If these conditions hold, is cooperation worthwhile? Co-users are not expected to engage in a cooperation process if they are not convinced of the severe consequences of non-cooperation. Game theory studies strategic situations in which a decision maker is influenced not only by his or her decisions and actions, but also those made by others. Therefore, game theory can be understood as an analytical tool applicable to problems of interaction, and in this case, its value is obvious.

4.2. Non-Cooperation, Dilemmas and Tragedies

One can start the analytical approach to this problem using so-called non-cooperative games. The classic approaches to this problem in international fisheries date from the early 1980s in the works of Clark (1980) [48] and Levhari and Mirman (1980) [49].

To model and explore the situation, we introduce a basic model of fisheries management. Two relevant issues are discussed: the "common property nature" (meaning free access) of fish resources and the consequent effect of dissipation of rents, as well as the program of intertemporal consumption of the resources. We used the Gordon-Schaefer model and combined this basic model of fisheries with the Nash theory of non-cooperative games with two players (Nash, 1951) [50].

Consider a given country 1, and assume the conditions of the basic model [51–53]:

$$dx/dt = F(x) - h(t)$$

$$h(t) = q\, E(t)\, x(t)$$

The first equation represents the dynamics of the resource as a function of the natural growth of the species and the rate of capture. The function of natural growth of the species, F(x), in a macro-biological, "general production" approach, is given by a differential equation that relates the growth of the stock with the size of the biomass at each moment. This means that a higher stock has a higher capacity of renovation and vice versa. However, it is not a monotonic relation. In the first phase, when the stock is rising, the renewal capacity is rising too, but after approaching the so-called maximum sustainable yield (MSY) (i.e., the stock with the maximum biological productivity), the capacity of renewal decreases as the conditions of the habitat, nutrient abundance, etc. create difficulties in the renewal of a big stock. The capacity of renewal will be zero in the "carrying capacity", which is the maximum stock that is compatible with the environmental conditions. Therefore, in the Schaefer model [54], a quadratic function is used for F(x). When integrated, this function leads us to the popular Lotka–Volterra logistic curve of biological dynamics of several species and organisms [55].

The second equation can be identified as the production function of the fishery, making the capture dependent on the size of the stock, the level of effort applied and a coefficient of the capture ability (constant) specific to each species and area. Biomass is represented by x, and the rate of capture is represented by h(t). E(t) is the measure of the fishing effort (a "capital jelly" measure of the resources devoted to the fishing activity, where we can use the number of hours of fishing by season as a proxy of this variable, for example), and q is the coefficient of the capture ability.

The growth function satisfies the following conditions:

$$F(0) = F(K) = 0 \text{ and } F(x) > 0,\ F'(x) < 0 \text{ for } 0 < x < K$$

where K is the carrying capacity.

Assuming that the fishery is operated by this single country, the total cost function is $C = a_1\, E_1(t)$, where a_1 is the unit cost of the effort. The unit cost of the effort is a constant, which implies that the effort supply is perfectly elastic (a similar condition applies to demand, with p being the fixed price of fish).

We are confronted with a problem to be solved with the Optimal Control Theory. The nature of the problem can be described in this form: the biomass constitutes the state variable (the one which is intended to be controlled), and this biomass can be controlled

over time by adjusting the rate of capture or effort (which is the control variable). The objective of the problem is to maximize the actualized value of the net benefits of fishing over time; that is, the following equation applies for country 1:

$$\text{Max } PV_1 = \int_0^{\infty} e^{-\delta_1 t}(p - c_1(x))h(t)\, d_t$$

where δ_1 is the social discount rate in the country 1 and $c_1(x)$ is the capture unit cost.

The Optimal Control Theory problem can be solved using the Maximum Principle of Pontryagin [56]. The solution is the modified golden rule:

$$F'(x_1^*) - [c'(x_1^*).\ F(x_1^*)]/[p - c_1(x_1^*)] = \delta_1$$

This equation establishes the rule for determining how society should invest or disinvest in a resource over time. The economic meaning of the equation is as follows. The optimal situation implies that we should only consume an extra unit of a resource if we are guaranteed that the immediate marginal benefit that results from this consumption is equivalent to the sum of the future actualized benefits that would result from the conservation of this additional unit and its consumption deferred in time. In this sense, the left side of the equation represents the interest rate of the resource, where the first term is its immediate marginal productivity. The second term is the marginal stock effect that reflects the impact of the biomass level on the capture costs. The greater this effect, the greater the value of x_1^*.

The approach to the optimal solution, given that the problem is linear, will be the fastest ("bang bang" solution), and we will have $h_1^*(t) = h_1^{Max}$ if $x(t) > x^*_1$ and 0 if $x(t) < x^*_1$, where h_1^{Max} is the maximum arbitrary capture rate.

The fundamental result of the model is that, under conditions of free access, fishery rents will be totally dissipated. In fact, the system will work toward a market equilibrium solution (the "bionomic" equilibrium, as Gordon called it) corresponding to a competitive situation but implying an excessive level of fishing effort from the society's perspective and, therefore, a stock level lower than what is socially desirable. At this point, the marginal cost equals the average revenue. It is a case of "market failure". The belief in the "invisible hand" that conducts the system to a socially efficient solution has no place in this case.

Now, suppose that country 1 is not an exclusive user of the resource. There is a co-user that shares the resource (country 2). The action of the fleet of country 2 has significant effects on the results obtained by country 1 and vice versa.

We assumed that the two countries had perfectly elastic curves for the effort supply and demand for fish and that they used the same discount rate ($\delta_1 = \delta_2$). If country 2 was the only user of the resource, we could define the optimal biomass, according to the perspective of 2, x_2^* in the same way as we did for country 1. Therefore, the "bionomic equilibrium" would be at the level where $c_2(x_2^*) = p$.

Suppose that the resource manager in each country is perfectly rational and can exercise total control over its fleet. Assuming that there is no cooperation between the two countries and there is no communication between the managers, we are in the presence of a non-cooperative game, which brings us closer to the so-called prisoner's dilemma. We resort to Nash's theory about non-cooperative games between two people. The nature of Nash's solution is that each player has no incentive to change his strategy given the other player's strategy. Thus, in the context of a fishery shared between the two countries, the Nash equilibrium implies, for both countries, that the catch rates ($h_1^{**}(t)$ and $h_2^{**}(t)$) are stable. These rates must satisfy the following inequalities:

$$PV_1\ (h_1^{**}, h_2^{**}) \geq PV_1\ (h_1, h_2^{**}) \text{ for any } h_1$$

$$PV_2\ (h_1^{**}, h_2^{**}) \geq PV_2\ (h_1^{**}, h_2) \text{ for any } h_2$$

The meaning is easy to follow; for each country, it is the best answer given the strategy defined by the other player.

Suppose, for example, that the costs of fishing effort in the two countries are different and that there are barriers to labor and capital mobility that perpetuate this inequality; therefore, $a_1 < a_2$ (in this case, country 1 has low capture costs). If $a_1/p < a_2/p$, then $x_1^* < x_2^*$. In these circumstances, supposing that h_1^{Max} and h_2^{Max} are sufficiently big, the solution for the non-cooperative game of Nash should satisfy the following:

$$h_1^{**}(t) = \begin{cases} h_1 \text{ Max} & \text{if} \quad x > \min(x_1^*, x_2\,\infty) \\ F(x) & \text{if} \quad x = \min(x_1^*, x_2\,\infty) \\ 0 & \text{if} \quad x < \min(x_1^*, x_2\,\infty) \end{cases}$$

$$h_2^{**}(t) = \begin{cases} h_2 \text{ Max} & \text{if} \quad x > x_2\,\infty \\ 0 & \text{if} \quad x < x_2\,\infty \end{cases}$$

where $x_2\,\infty$ is the bionomic equilibrium for country 2.

The result means that player 2 will have to abandon the activity. We can identify two possible solutions. If $x_1^* < x_2\,\infty$, we have a punctual solution which is not especially good for player 2, and if $x_1^* > x_2\,\infty$, the global result will imply that the resource will approach $x_2\,\infty$. That is the worst result for both players and identifies a prisoner's dilemma situation. It seems that the independent decisions of the two players will lead the game to a result that is undesirable for both. Without cooperation, the dominant strategies of the players will lead the system to this obnoxious solution. The consequences of non-cooperation are clearly close to the result that would be achieved by an unregulated fishery of only one country. Overexploitation and overcapacity will occur. In short, non-cooperation translates into results very similar to those of fishing with free and unregulated access (i.e., the dissipation of rents). Therefore, an incentive for cooperation exists.

Levhari and Mirman [49] also examined the consequences of non-cooperation and found similar results. In more general terms, the model developed by these authors is based on a Cournot–Nash model. Each of the co-users considers the other's strategy as given and proceeds to maximize his or her net benefits, expressed as utilities. Each competitor is assumed to have full control over their fleets. The model is a discrete time model, and the conclusion is that, even if both countries resolve their regulatory problems internally, and even if the management objectives are the same, non-cooperation leads to overexploitation of resources. In certain cases ("the great fish wars"), this can even lead to the extinction of species (see also [57,58]).

The predictive power of the theory is substantial. See, for example, the case of salmon fishing in the Pacific [31,59]. This anadromous species is shared by fishermen from two countries—USA and Canada—and is captured when it returns to rivers to spawn. Thus, American fishermen produce salmon that is intercepted in the migration by Canadian fishermen and vice versa. Since the late 1930s, the two countries maintained separate management. Cooperation was, however, developed in relation to the Fraser River salmon. In 1970, they sought through negotiation to expand this cooperation in relation to the other salmon species from Oregon to Alaska. The negotiations revealed little progress and increased mutual distrust. Salmon from the Fraser River has, however, been defended from this climate of suspicion.

In the early 1980s, an authentic war was declared between the two players in the remaining stocks. That was an extremely dangerous war; stocks had fallen to very low levels, especially those of highly valued species. The resumption of the competitive nature of salmon fishing can be understood as a punishment rule. After difficult negotiations, a treaty was signed in 1983. Given the high commercial value of the species and the level of benefits expected from the cooperation, it was possible to maintain the agreement, up until the moment when the state of Alaska blocked the treaty. Canada restarted the war for the competitive use of stocks until the most affected American state, Oregon, entered

into negotiations with Alaska itself. A new agreement in 1985 was necessary to prevent extinction.

The character of the prisoner's dilemma was also visible in the countries' actions regarding the fisheries' restocking strategies. Both countries traditionally developed important projects in this field; however, fearing the interception of juveniles on the part of the opponent, both countries interrupted their actions. The effects of non-cooperation again proved to be negative. On the contrary, the salmon fishery on the Fraser River remained a healthier fishery over this period, thanks to the cooperative environment maintained in the relations between the partners.

4.3. Cooperative Games

In recognizing the advantage of cooperation for some fisheries, one must develop a cooperative management analysis. The process is the same, combining the basic fisheries model with game theory, in this case, with cooperative games between two people (Nash, 1953) [60].

Again, altruism does not play any role here. We relax the non-communication restriction as, in cooperative games, players can communicate and establish compromises. These agreements can be of two types: binding and non-binding. In the first case, we find coercive agreements, with clear and perfectly delimited rules and with an authority to oversee and enforce the agreements. In the second case, we speak of more flexible agreements with less demanding rules and without the need for a command-and-control structure. Game theory has shown that the analysis and implementation of fisheries agreements of the first type are more efficient.

The study of this type of model comes from the end of the 1970s with Munro's seminal analysis [61].

The analytical approach we developed started from the formulation of a problem whose functional objective could be defined as follows for the two co-managing players:

$$\text{Max PV}_1 = \int_0^\infty \text{e}^{-\delta_1 t}\,(\text{p} - \text{c1}(\text{x}))\alpha(\text{t})\,\text{h}(\text{t})\,\text{dt}$$

$$\text{Max PV}_2 = \int_0^\infty \text{e}^{-\delta_2 t}\,(\text{p} - \text{c2}(\text{x}))(1 - \alpha(\text{t}))\text{h}(\text{t})\,\text{dt}$$

where $\alpha(t)$ is the quota share in the total capture for country 1.

The two countries have to consider two subjects: the division of the liquid benefits and the possibility of different management objectives. If the countries have the same management objectives, in theory, the problem is relatively simple; the appropriate strategy is that of management as if it was a single user. The division of economic benefits will result from the negotiation process, and the simple use of the Nash model will lead to the determination of the solution.

The complexity of the analysis increases significantly when different players or countries have different goals and strategies regarding the fishery they both share. Suppose the situation where $\delta_1 < \delta_2$ (this is equivalent to $c_1(x) > c_2(x)$). In this case, it is easy to demonstrate that country 1 will be more conservationist than country 2, and then $x_1^* > x_2^*$. If the discount rate of country 1 is lower, this means that country 1 will have a greater incentive to invest in the resource than their competitor, which is more shortsighted. If country 1 has higher costs per unit captured than country 2, country 1 will be more sensitive to the cost benefits that result from increased stock.

In these situations, it is necessary to know if the co-users are prepared to contemplate transfers (side payments) among themselves and to what extent they are willing to accept a program in which the percent shares vary over time. The acceptance of greater flexibility generally leads to more satisfactory results. In practice, even when they are not formally recognized, transfers are used. If, for political or other reasons, this type of flexibility is difficult to achieve, what can be done? This usually implies a two-stage negotiation process in which a formula for dividing quotas is found, and then the question of the

optimal strategy is discussed. That is what we call a case of cooperative management with restrictions.

In this case, the problem defines a situation in which the two players maximize the joint benefit and introduces a negotiation element (to be determined in the resolution of the cooperative game) identifying the extent to which each player's preferences will influence the overall strategy pursued. Thus, we will have a functional objective given by

$$\text{Max PV} = \beta PV_1 + (1 - \beta)\, PV_2, \text{ with } 0 \leq \beta \leq 1$$

where β is the negotiation coefficient, varying from 0 to 1. If $\beta = 0$, the preferences of the country 2 are dominant, and if $\beta = 1$, the preferences that are dominant are those of country 1. By taking the values of β between 0 and 1 and maximizing the expression for each β value, we computed the Pareto efficiency frontier in the space of the results (payoffs) performed. In addition, consider the so-called "threat point", which consists of the payments that each player would have in the absence of cooperation (in general, these payoffs are those that would result from the solution of a non-cooperative game). Denote π and θ as the payoffs for country 1 and country 2, respectively. Denote π^0 and θ^0 as the payoffs correspondent to the threat point and π^* and θ^* as the payoffs resulting from the resolution of the cooperative game.

In these circumstances, Nash proves that, if it exists, the solution of the cooperative game will be determined by the following expression:

$$\text{Max } (\pi^* - \pi^0)\,(\theta^* - \theta^0)$$

An acceptable hypothesis in the Nash model is that no player will accept a lower payment than he or she would have had if there was no cooperation. No fishing state enters into a cooperative arrangement if it anticipates greater profit from non-cooperation.

There will be situations in which there is a "prima facie" for cooperation, but it does not happen because it is not possible to convince both players simultaneously.

The previous rule implies that the negotiating power of each player depends on how much each one expects to lose if the cooperation collapses. The more one expects to lose, the weaker his or her bargaining power. Therefore, supposing that there is a solution for the cooperative game, as soon as the point solution of the Pareto frontier is known, we will have the β value. Then, one can proceed with the analysis of the fisheries management "commitment program".

Munro [62] showed that without pre-determined transfers and quotas, this program can be specified, but it can be embarrassing. Then, returning to the initial program, with β determined, one can write the following:

$$PV = \int_0^\infty \left\{ \beta \alpha^{-\delta_1 t} + (1-\beta)(1-\alpha)\ \alpha^{-\delta_2 t} \right\} [p - c(x)]h(t)\ dt$$

With this functional objective, one can proceed with the determination of the optimum compromise in fishery management. The Hamiltonian expression is

$$H : \left\{ \beta \alpha e^{-\delta_1 t} + (1-\beta)(1-\alpha)e^{-\delta_2 t} \right\} [p - c(x)]h(t) + \lambda[F(x) - h(t)]$$

By taking the applicable routine, we found another modified golden rule, from which it was possible to determine the level of the optimal biomass corresponding to the commitment x_3*:

$$F'(x^*) - \frac{c'(x^*)F(x^*)}{p - c(x^*)} = \frac{\delta_1 \beta \alpha e^{-\delta_1 t} + \delta_2 (1-\beta)(1-\alpha)e^{-\delta_2 t}}{\beta \alpha e^{-\delta_1 t} + (1-\beta)(1-\alpha)e^{-\delta_2 t}}$$

As we have a linear control problem, the optimal approach is also the fastest.

The right side of the equation is a complex weighted average of δ_1 and δ_2. Let us call it δ_3. Note that δ_3 is a function of time and that the limit of δ_3, when the time tends

toward infinity, is δ_1. The rationale of the result is as follows. In the near future, the weight of country 2's preferences is greater, but in the long run, this weight decreases because country 2 attributes less value to future benefits than country 1. Therefore, in the long run, there is an asymptotic approximation to the optimal biomass of one; that is, the preferences of country 1 become dominant.

In fact, the existence of different discount rates (meaning different alternatives and different preferences regarding the objectives and strategy to be pursued) leads to different solutions to the compromise program defined and to be implemented. If a player is more conservationist—that is, if his or her discount rate approaches zero—this means that he or she is willing to practice lower usage rates, valuing future benefits and allowing for a more sustainable management that is focused on future generations. On the other hand, the commitment favors the most short-sighted co-user in the immediate future. By using a higher discount rate, he or she values the benefits coming closer. However, in the long run, the preferences of the most conservationist player will be the most considered.

Anyway, without regard to transfers, these agreements still create situations of embarrassment. Rigidity in the distribution of quotas implies a lack of flexibility that is essential to the establishment of the program. If α varies with time—that is, if the key distribution of quotas varies—even when ignoring transfers, the management program becomes less clumsy.

If transfers are allowed, the objective of the cooperative game becomes maximizing the set of fishing benefits, giving PV_1 and PV_2 equal weight. Negotiation takes place around the division of global benefits. In general, the use of side payments gives more efficiency when treating fishing problems to be solved with cooperative games. Those transfers may take the form of money transfers but also other schemes of political or commercial facilities. The economic consequences of introducing transfers are that players are encouraged to focus on allocating economic benefits rather than sharing quotas.

With transfers allowed but the percentage shares in the catch rate remaining fixed over time, progress is minimal; the program has no substantial benefits. By allowing variations in the relative catch rates (percentage shares), the problem becomes much simpler. The result will be $\alpha(t) = 1$ for $0 < t < \infty$. In other words, country 1 "buys" the part of country 2 and manages the fishery as a "sole owner".

To summarize, the fundamental results of the analysis are as follows. Different discount rates imply different arrangements. The co-manager who uses a relatively lower discount rate prefers a conservationist policy. The commitment favors the most shortsighted co-manager in the immediate future, but in the long run, the preferences of the most conservationist player will be considered. According to Munro [62], an optimum will be found if the preferences of the one who attributes the highest value to the fishery are dominant. This country should be the one to establish the management program, obviously having to compensate the other members. That is what one calls the "Compensation Principle" [40,62].

There is also significant empirical evidence of these results in cooperative games. In the real world, there are examples of cooperative management in which co-owners choose shares and transfers. There are also situations of cooperative management with restrictions where preference is given to the most conservationist co-user.

An example of cooperative management with restrictions is what we find in the case of the Arcto-Norwegian cod (see Armstrong and Flaaten (1998) [63]). This resource was shared by Norway and the former Soviet Union and was managed jointly. Accordingly, the social discount rate in the former USSR was lower than that in Norway. At the same time, the capture costs of the Soviets were lower than those of the Norwegian fleets, and the price obtained for cod by the Soviets was higher than that obtained by the Norwegians. In these circumstances, it would seem to be an appropriate policy for Norwegians to "lease" their fishing rights in the Baltic, a situation which Norwegian fishermen systematically refused. Thus, we are in the presence of a situation of a cooperative game with restrictions. By chance, a happy situation occurs, because differences play in the opposite direction.

In fact, as $\delta_N > \delta_{URSS}$, one should have $x_N^* < x_{URSS}^*$. However, the differences between the costs and prices play in reverse. As was said, the marginal effect on stocks depends on the ratio between the prices and costs of effort; the greater the marginal effect on the stock, the greater x* will be. The effects of the differences between the costs and prices should lead, in this case, to $x_N^* > x_{URSS}^*$. Armstrong and Flaaten concluded that the effects were balanced such that x_N^* and x_{URSS}^* were close and estimated that the consequences of non-cooperation would be severe for both. Armstrong [64] showed that political changes in the former USSR have changed this situation, but it was not difficult to find a stable compromise that was susceptible to successive improvements. For other cases, see the works of Bjorndal (2003) and Bjorndal et al. (2009) [65,66].

Another example of cooperative management is given by the case of North Pacific seal fishing [31,67]. During the 19th century and in the first decades of the 20th century, there was a great expansion of this fishery on the part of four countries: USA, Canada, Japan and the USSR. At the beginning of the 20th century, countries began to notice a decrease in the stocks and entered into a cooperative agreement that led to the 1911 Fur Seal North Pacific Treaty. USA and Russia captured seals on land, while Canada and Japan captured seals at sea. Therefore, Americans and Russians had lower capture costs. Through the treaty, these countries (USA and Russia) not only came to dominate management but became the exclusive users of these resources. Canada and Japan were compensated with transfers. Accepting that their catches were canceled, they would have in exchange a percentage of the sealskins captured by the Americans and Russians in each season. The agreement was repeatedly renewed and worked for decades.

An intermediate situation of cooperative management with less restrictions is given by the case of tuna in the South Pacific [46]. In this case, there is close cooperation between the Pacific Islands, although the resource is not equally distributed among them. Two groups can be distinguished: "those who have" and "those who have not". The first group places special importance on future fisheries yields, while the second group does not; that is, the social discount rate is different in the two groups. What the theory suggests is that the preferences of the first group with the lowest social discount rate should be dominant, with this group being able to make the necessary transfers to the second group. In reality, this has been happening. The so-called Nauru Group, one of "those who have", has effectively dominated tuna management. In this case, the cooperation proved to be essential, because the two groups came up with one single voice in the negotiations with Japan and USA, the maritime powers of tuna fishing in these areas. After the creation of the 200-mile regime, cooperation allowed for greater firmness in the negotiations on access for those fleets, and it encouraged new enforcement practices that made resource depletion more difficult. It has been an adaptive process, but there is no doubt today that non-cooperation between islands would have led to inferior results. For other general cases, see [68–71].

4.4. The Specificities of the Straddling Stocks Case

According to estimates by John Caddy [72], there are between 1000 and 1500 straddling stocks. On the other hand, FAO estimates in the early 2000s pointed to an annual total catch of highly migratory species and straddling stocks of around 15 million tons, equivalent to one fifth of the total marine catch in the year 2001. The weight of these stocks is, therefore, very significant.

The management of straddling stocks maintains, essentially, the approach strategy and several results of the previous analysis [44,73,74]. In any case, there are some new elements to add.

In the analysis of cross-border, transboundary resources, we assumed two countries with two adjacent EEZs. We will now consider situations in which coastal countries are confronted with distant-water fishing nations. All these players intend to manage a common resource in High Seas areas adjacent to the EEZs.

Note that this introduces a new element of difference in the game. In the case of two coastal countries that manage a common cross-border resource, there is a perfect

symmetry in terms of access rights, as each of these countries only has access to the EEZ of the other if they are allowed to do so. However, in the case of straddling stocks, although it is forbidden for the fleet of the distant fishing country to enter the coastal country's EEZ without prior authorization, nothing prevents the fleet of the coastal country from accessing the adjacent waters of the High Seas, where free access is maintained. Therefore, we are now in a situation of asymmetry. This characteristic of symmetry or asymmetry has important influence on game analysis.

Note also that the number of participants may vary. While the two-player hypothesis has seemed plausible so far, in the straddling case, the most common situation is that of a coastal country that confronts several fleets from distant fishing countries. Furthermore, their number may vary over time. When considering the multilateral management of straddling stocks and the possibility of "new entrants", the problem becomes significantly more complex.

Despite these differences, the core of shared resource management may remain with minor changes. The results are also not significantly different. In essence, it is concluded that, if non-cooperation prevails, the result will be the overexploitation. The analysis presented here is only an introduction to the problem [44,75–77]. For simplicity, we assume a situation in which coastal country 1 confronts two identical distant-water fishing nations (2 and 3), except in terms of catch costs. It is assumed that the entry of a new player will only be possible by the leaving of country 2 or country 3.

The dynamics of the resource can be described by

$$\frac{dx}{dt} = F\left(x_{(t)}\right) - \sum_{i=1}^{3} q_i E_i(t) x(t),$$

Consider that the players can be ordered in terms of their efficiency ($x_1\infty < x_2\infty < x_3\infty$, meaning that 1 and 3 are the countries with the lowest and highest costs, respectively, such that $c_1(x) < c_2(x) < c_3(x)$). Thus, if the players act independently, Nash's non-cooperative equilibrium solution has the following meaning: the resource will be exploited as quickly as possible until the "bionomic equilibrium" $x_2\infty$ is reached. As in the game with two countries, the straddling stock will be subject to overexploitation if there is no agreement between the three players.

Then, let us turn to the analysis of the cooperative management of straddling stocks. To understand the complexity that the cooperative management of these stocks introduces, let us imagine a regional fisheries management organization with three participants that is responsible for the management of a stock. We assume that a coastal state C confronts two distant water fishing nations D1 and D2. Suppose, for the sake of simplicity, that D1 and D2 do not abandon the activity and that it is not possible for another distant fishing nation to join the organization and access the fishery. Let us also assume that the effort costs of C, D1 and D2 are the same, and that although transfers between members of the organization are possible, alliances between partners in the game are not allowed. In this case, the situation would be exactly the same as the one we would have for the general case of a shared resource. Thus, by designating with S the benefit derived from cooperation, W the updated net income of the fishery in a situation of cooperation, and TC, TD1 and TD2 the payoffs of the three countries corresponding to the threat point (i.e., the income of players in a situation of non-cooperation), we would have S = W − TC − TD1 − TD2.

We could conclude that cooperation in management would result in a situation in which the payments of each player would be equal to their payment at the point of threat plus 1/3 S. The cooperative agreement would focus on the division of the net benefits resulting from the cooperation. Coastal country C and distant fishing potencies (D1 and D2) would have at least "de facto" property rights over part of the resource. The resource would be jointly owned, with the consequence that each of the participants would have security in relation to their share of the flow of net benefits.

The same situation applies if we consider that the three countries differ only in terms of their capture costs and that a new country will only enter the organization if one of the

members decides to leave. Assuming that monetary compensations are possible between the three players, it would be expected that the most efficient player "buys" the rest. Thus, assuming that coastal country C would be the most efficient, it would buy the part of the least efficient country. The income from the fishery would be what would result in a situation equivalent with an optimizing "sole owner" [78].

Added complexity results from the relaxation of these hypothesis. In the case of the straddling stocks, cooperative management offers several alternatives, depending on the feasibility of alliances between members and the ability to transfer ownership to a possible "newcomer". In practice, this is the essential issue of the design and operationalization of institutions and of the multiple implications at the political and economic level that their functioning introduces [79]. The definition of the so-called RFMOs, their starting constitution and possible subsequent adhesions, rules of action, powers, control and inspection are all at the heart of this debate.

The analysis of new entrances can be complex. Let us simplify these. Suppose an RFMO with two members countries D1 and D2 and a potential new member (D3) and that c(D1) < c(D3) > c(D2). Thus, we have a situation in which the most efficient country D1 will have no incentive to sell its position. The same cannot be said of D2, which may, in fact, have this incentive. The results of applying game theory to the problem are very interesting. The possibility of D2 transferring its property to a new member ends up increasing its negotiation position, thereby extracting a greater part of the net economic income. The simple threat of transferring its position to a new member immediately increases the expected payoff under the cooperative game. Perhaps even more curious is the conclusion that, in the model, the possible adherent not only influences the negotiations but receives part of the income from the fishery, even if the transfer does not take place. This is, of course, a result of the direct application of the method; the theoretical foundations of these games are yet to be proven. However, it is certain that this result shows the difficulty of reaching a stable agreement if there are no clear and restrictive rules for "new entrants" in regional fisheries organizations.

Therefore, let us consider the following alternatives for addressing the "new entrants" problem. In a first alternative, we assume an organization with two members (C and D1) in which the coastal country (C) has lower effort costs than the country with distant fishing (D1). Suppose that, by hypothesis, there is a new member who wants to join the organization (D2), and that their effort cost is higher than that of C but lower than D1's. In this case, D1 has an incentive to sell (if possible) their "membership card" to D2. If this sale takes place, a new agreement will obviously have to be made. The overall result will be the same, but the threat point changes. It is expected that TD2 > TD1 and that TC1 is lower than the value it would have if the agreement between C and D1 were maintained. Therefore, C certainly loses. D1 recognizes this situation and, instead of leaving, stays in the organization but uses the threat of sale to derive a greater share of the net benefits derived from cooperation. That is, the simple presence of D2 alters D1's threat payoff. Blackmail and "bluff" strategies can thus succeed. Negotiations become more difficult, and the agreement becomes more unstable.

A second alternative suggests the consideration of alliances between players. We assume, for the sake of simplicity, that the membership card is not transferable. In this case, the search for a cooperative agreement requires not just that each partner receives at least the payoff equivalent to the threat point, but also that the partners of any sub-alliance obtain a result at least as good as the one they would have if they chose any partner and refused to cooperate with the organization's third party (i.e., an agreement is required whose payment is greater than the payment for the non-cooperative game and is the largest of all of the possible alliances).

Consider that there is an alliance between D1 and D2. While keeping the cost assumptions, if the coastal country refuses to cooperate and is the most efficient, players D1 and D2 are forced to abandon fishing. Therefore, among the possible options—to act independently or to form an alliance (e.g., D1 buys D2)—these two countries will choose

the option that guarantees a more favorable return. Supposing that the alliance is made between the coastal country and one of the distant fishing countries, the alliance between C and D2, although possible, is not particularly pleasant. Much better is the alliance of the coastal country (C) with the country with the lowest costs in faraway fishing (D1). The game theory approach shows how more efficient alliances between coastal and distant fishing countries improve their positions in the group.

In short, theoretical analysis is complex but leads to some interesting and somewhat intuitive conclusions. The advantages of cooperation are indisputable. The process of establishing the agreements and their ability to operate is an issue whose analysis remains unfinished, and this approach highlights institutional issues and the need to assess transaction costs involved in the process of establishing agreements.

5. Stepping to Find a New Model of Governance: Extension of the Analysis

5.1. The 95 "Solution"

An effort toward solving the problems created with the imprecise definition of property rights of the UNCLOS came up in the mid-1990s. As said earlier, at the 1992 Earth Conference in Rio, one of the issues that was identified as a priority for discussion within the United Nations was the precise management of transboundary resources and highly migratory species. This motivated the launch of a conference for the elaboration of a convention on the management of these resources.

The final agreement [37] came in August 1995. The compromise maintained the free access over 200 miles, but the power of regulation in the areas adjacent to the EEZs was guaranteed to the RFMOs. Those organizations then had the capacity to extend their rules to non-members, but this did not solve the problem of "newcomers". This new convention stated that any country with a "real interest" in the fishery could be a member and should be encouraged to integrate the RFMO. In practice, "real interest" is not defined. RFMOs have the right to establish capture shares and control the number of boats for a given stock or area. The process of decision making is not clearly defined, as it depends on the practice. The problem of enforcement persists, although some important improvements were introduced. The commitment concedes that each member will have the inspection right for the ships of any other country. However, the potential effect of the enforcement is broadly bounded. Only the state of origin of the flag that the ship flies can carry out the judicial process for sanctioning the operator found in an illegal situation. Remember the case of the "flags of convenience". Obviously, the capacity to intervene and the political will to do it is insufficient to carry out a stronger inspection as required.

Generally speaking, this convention calls for international cooperation as a key factor for the sustainable management of these resources. The governance model created is based on regional fisheries management, with a central role for the RFMOs in defining the regulatory framework and creating an environment of trust between players. Over the last 25 years, the agreement had very interesting practical results despite its limitations. This effort toward shared management of the international commons has been visible, for example, in the NAFO area.

To Munro [80–82], the 1995 agreement has been a success in that it has removed some of the players from the temptation of competitive games, but it has also been accompanied by some implementation problems. Some of these problems were already expected and corresponded to the questions that economics and mathematics have been raising since the end of the 1970s. Observers have been highlighting new factors such as climate change [83–85]. The areas of possible extension of the analysis include several domains, including at least the following: the "new entrant" problem and the governance model for international fisheries; the issue of "time consistency" of the agreements, including the effects of climate change; and the issue of monitoring and control (the so-called "interlopers" problem). Game theory can play a determinant role in these issues [86].

5.2. Searching for a Treaty on Biodiversity beyond National Jurisdiction

Anyway, as was said, the discussion on these topics is again at the most significant international level: the United Nations [87–89]. As mentioned above, there are several gaps both in the definition and implementation of the established framework. Much intervention in this domain is limited by the fact that the member states' regulation and inspection take place only in their areas of national jurisdiction, not involving intervention in many of these issues that fall within areas beyond national jurisdiction. The High Seas and the "Area" fall precisely within this situation. For example, states cannot declare marine protected areas in international waters. These situations have to be governed collectively, and currently, there is no international legally binding treaty.

Therefore, following the dictates of Resolution 59/2004 from the United Nations, an informal study group was created within the United Nations. This group had the task of investigating the limits that the current governance model places on the management of ocean resources in the areas beyond national jurisdiction and proposing alternative solutions to be discussed later. The first meeting of the working group took place in New York in 2006. Several meetings succeeded.

In the meeting of 2011, this ad-hoc informal group proposed a package of basic issues to be included in a possible future agreement under the auspices of the United Nations, complementing the 1982 UNCLOS. There are four such basic themes for discussion. The first is marine genetic resources. These high-value resources are fundamental to the development of new areas such as biotechnology and new medicines. The issues of patenting scientific discoveries and the way in which the opportunities to access these resources are defined, including the equitable distribution of the benefits generated between partners in the international community and the rules of conservation and responsible use of common resources. All are part of a set of essential questions for which an agreement must be reached.

The second concerns the use of marine area-based instruments. The definition of these instruments and the discussion of the advantages and disadvantages vis-a-vis other management instruments, whether of the command-and-control type or of the economic type (including rights-based management instruments), are part of this discussion. A central element has to do with the rules for creating and implementing protected marine areas.

The third involves the issue of environmental impact assessment and the conditions for a mandatory and cumulative assessment of all actions developed. The proposals for the pretending governance scheme must rely on the sustainable use of resources, always maintaining special attention to their environmental impacts.

The fourth relates to the transfer of marine technology, especially to less developed countries, and the building capacity of all the members to access and share the benefits derived from the sustainable use of the international commons. This is a particularly sensitive area, as it makes evident the creation of equal distribution conditions, a distribution approach that one wants to be fair and ethically responsible. It will probably be one of the most intense areas of political debate.

In the Rio+20 Conference in 2012, the states agreed to decide by the end of the 69th session of the U.N. General Assembly (September 2015) whether or not to launch negotiations for the conclusion of such a new agreement. The sense of urgency of the problem was well addressed in *"The future we want"* report (Resolution 66/288) [90]. Over the course of various meetings, the UN Informal Working Group deliberated about the scope, procedures and institutional arrangements that seemed to be necessary for the creation of a new binding instrument. In January 2015, the conclusions and recommendations of the Working Group were finally submitted and presented to the delegates of the UN. These conclusions pointed to the need of a new global governance model in the form of an agreement that should address, in an integrated manner, the issues identified in the four major themes mentioned above. Furthermore, the instrument to be created should establish a balance between the various dimensions under discussion and should not come into conflict with

the already-existing regional arrangements. The terms of the agreement should be found in a text that should reflect the consensus that overlies the discussions between the delegates. This important step is reflected in the core of Resolution 69/292 [91].

In the development of this process, there were several moments where fisheries were the focus of attention, and what seems very interesting is that the model proposed in the 1995 agreement on transboundary and highly migratory species was pointed as a source of inspiration for further developments in a global commitment; that is, the regional management of resources, with a fundamental role to be developed by institutions similar to the RFMOs, may constitute a basic formula to work with.

Note that the discussion around the impacts of adopting this governance model is, to a large extent, dependent on the overall outcome of the negotiations, where fisheries are just one of the elements at stake. The final commitment must always be a global agreement, and the way in which the different components are integrated will reflect a complex, balanced result of the various confronted interests. An interesting role also lies in the measures to be implemented in the context of the promotion of the Sustainable Development Goals (SDG) of the UN, particularly those relating to SDG-14 [92].

Taking the (partial) perspective of fisheries researchers, a new type of questions is emerging. All these questions may turn out to be central in the course of future developments. The most pressing one seems to be the confidence in the future of the current governance model and in its resilience and consistency over time. Is cooperative management of the international commons even possible? In practice, the rules defined in 1995 seem to work, but is the current moment of trust between players just the result of the harsh conditions that affect the health of the stocks? If this situation changes, will we return to a competitive situation? How can the free riding of many operators be avoided? Is it possible to find an institutionally strong solution that recalls the idea of a "communal property", a true common property in Bromley's sense, with participatory management of an exclusive group of co-owners [93,94]? What is the effect of climate change on this ongoing process of creating a new governance model? Are the rules sufficiently resilient for such significant transformations?

Furthermore, it is indeed interesting to see how the solution chosen in 1995 can act as an *inspiration* for other dimensions of a more global agreement. However, it is true that, from the perspective of fisheries, this 1995 agreement reveals several limits and difficulties for application. Would it not be time, then, to tackle these issues and at least find more satisfactory formulations for problems such as "new entrant" clauses or in the domains of inspection and enforcement? Certainly, the final result of the negotiations corresponds to a complex balance, and perhaps the special case of fisheries cannot have great improvements. However, this apparent acceptance of the status quo and of the acquired state may be symptomatic of some loss of initiative. Are we really convinced of the advantages of "business as usual" [1–3,67,95]?

5.3. On the "New Entrants" Issue and Governance Model

To better instruct the process of negotiation, one can now introduce more results from the investigation. At least in two areas, we can propose more game theory analysis and results and introduce "nuances" in the discussion.

The first domain concerns "newcomers". The "new entrant" problem, as we have already seen, highlights the need to properly define the structure and rules of operation of the RFMOs above everything else. If there are no clear and restrictive rules to "new entrants", the difficulty of reaching stable agreements increases considerably, and that erodes the management capacity of RFMOs. The issue of new entrants is, in fact, at the heart of the 1995 convention. Article 8 points to the management of resources from a regional perspective, with RFMO management being made up of the participation of coastal states and DWFNs that show "real interest" in these fisheries. The question that arises is to know who has real interest: countries with historical rights in the fisheries of that region; countries that once practiced fishing, then abandoned it and want to return again;

countries that now wish to practice this fishery; or all of the above. The 1995 agreement allows RFMO members to exclude new members if they refuse to cooperate under the terms established by the RFMO. However, with only this excluding clause, it is difficult to prevent others from entering the organization.

Members of an RFMO are faced with a dilemma. They can prevent non-members from acting as "free riders" by encouraging them to join the organization. However, if the offer is too generous, the organization is reduced in its management capacity. The entry of new players alters the point of the threat of existing members and the sharing of the benefits of cooperation. It may even happen that, in these circumstances, for some of the effective members of the RFMO, a non-cooperative game is preferable. However, if for the potential "new entrant" the proposed key for sharing the benefits of the agreement is not sufficiently attractive, he or she may return to an explicit free-riding position.

The solution to the problem involves applying coalition negotiation analysis [96,97]. An interesting related question concerns the proposed entry rule solutions for new entrants and their effects [98]. The first solution is to transfer the "membership card". The idea is that a new member would only enter by purchasing the membership card from a member already integrated in the RFMO. Thus, a kind of membership cards' market is created. This new situation would mean the existence of "de facto" property rights and a significant change in the status of the High Seas. In fact, after being reduced to the category of "rest" in the UNCLOS [99], with this new movement of "creeping jurisdiction", the statute of the High Seas is clearly diminished, and everything seems to point to its term's extinction.

A second solution proposes the existence of a "waiting period". This is basically a matter of establishing an initial period in which the "new entrant" demonstrates his or her "goodwill" and his "interest" in the cooperative game, accepting not to participate in the sharing of the benefits of co-management. Kaitala and Munro [74] showed, however, that the existence of an initial waiting period does not totally solve the problem. An initial phase can be established in which the new entrants do not participate in the sharing of benefits, but as we have seen, their mere presence already affects the game dynamics of those who are already in the RFMO. The strategic alliances and threats of some of the effective members affect the stability of the game. The "new entrants" themselves can bluff on future sub-alliances and create an atmosphere of mistrust. All of this alters the point of the threat of the game and the key to the distribution of benefits.

Anyway, if the agreement is of the non-coercive type, there is an interesting scenario. That is the case for the situation in which a permanent position in the cooperative agreement implies permanent costs (e.g., fees and expenses with monitoring). In this situation, fleets with high discount rates may not be interested in joining the RMFO. This is the case for some fleets from distant-water fishing countries. In these cases, the waiting period can be understood as an efficient solution for controlling admissions to new entrants. The existence of fixed costs associated with a non-coercive agreement does, in fact, lessen the threat from the non-member.

Whether in this or other different situations, it is also clear that there is a wide field for investigation that basically involves assessing the issues of how to arrive at fairer rules for sharing the benefits of cooperation and how to prevent the instability that the higher number of players can generate in the game solution. It is precisely in this line of reasoning that the third alternative emerges: the idea of a "just distribution rule". Li (1998) [100] suggested that this type of solution can work in a scenario where all participants are entitled to a part of the catch. The first step in the scheme should lead to a coercive agreement between players in such a way that the cooperative agreement involves the determination of sustainable and efficient catch rates. A second step involves implementing a process of sharing the benefits resulting from the "great alliance" (grand coalition, a kind of cartel in which everyone participates) through a negotiation process. Obviously, with new elements, it is necessary to renegotiate this repartition key. An acceptable concept of a fair sharing rule would be that what each player receives is according to his or her contribution to the great alliance. Inefficient fleets contribute little, so they receive little. Thus, the cooperative

management of common property is less attractive for inefficient fleets that are more interested in a strategy of "free" use of the results of the "grand coalition". According to Li, this idea is explored through a "C-Game", in which the approach to the negotiation process uses a characteristic game function. In this approach, players can form sub-alliances in case the big alliance fails. The final solution depends on the negotiating weight of the players in each of the potential sub-alliances.

Another similar approach involves the application of negotiation analysis within the "grand coalition" in the form of a partition function [97,101,102]. For example, Ekerhovd (2008) [103] used this type of analysis to study the management of blue whiting stocks in the Northeast Atlantic. The fundamental result of this investigation is that coalitions are usually unstable. In particular, the possibility of forming a sub-coalition of coastal states is a fundamental threat to the stability of the agreement. On the contrary, the existence of a partner with great weight, usually a coastal state, makes the agreement more stable.

It should also be noted that this issue of entry rules for new entrants can be integrated into a more general investigation of the "governance" model for international fisheries. The 1995 agreement constitutes an interesting institutional basis for the management of these fisheries, but it does not have to be seen as a "finished" result. Proposals of the governance model can be bolder and go beyond simply discussing the rules of entry. There are authors who propose the creation of an international company (in which countries interested in fisheries would have a share) that would have a monopoly on the exploitation and then share the benefits [104].

5.4. Uncertainty and Resilience

The problem of the mutable number of players and the possible alliances between partners, as well as the instability they cause, enters into another fundamental domain for investigation: that of the temporal inconsistency of many agreements. To what extent are the agreements stable? Are they resilient to the changes that the new practical operation conditions introduce? Should we choose coercive or non-coercive agreements? Should the rules be fixed or flexible? How is it possible to establish flexible agreements that can withstand new situations? In situations of uncertainty in the evolution of stocks, what type of agreement can create more confidence and be less dependent on the particular motivations of member states? It is, therefore, the essential question of the stability of the agreements over time which also presupposes the question of their supervision.

We have already seen that the consideration of side payments is a way of making agreements safer. The hypothesis that the partners enter into a formalized and coercive cooperative agreement is unquestionably strong, especially in the field of international fisheries, but it fails to consider that this leads to important obnoxious consequences. The problem has been addressed according to several approaches that are, at times, excessively complicated from the perspective of the decision makers [105,106].

One of these approaches has been pursued by the "Helsinki Group". Kaitala [73] referred to two types of properties in non-coercive agreements. One can consider "balance" agreements that have the quality of being "sustainable". A "sustainable" agreement is one that does not require periodic renegotiation. A "balance" agreement is one in which no player has any incentive to violate it. The problem lies in defining and analyzing the means to ensure that the partners will not destroy the fragile agreement. Obviously, if the number of players varies over time, the chance of consistency over time decreases.

Vislie [107] considered that the existence of coercive agreements is extremely difficult, because this means that the parties involved in the negotiation have to make strong commitments which cannot be changed in the near future. For this author, the reality comes close to agreements that are not legally coercive but self-supervised and dynamically consistent. The inspection requirements are highlighted, and Vislie demonstrates that the Nash solution must be used locally in each period of time and that the transfers must be distributed throughout the duration of the agreements. Therefore, in the case of the UN decision on biodiversity beyond national jurisdictions, the political will to design a coercive

instrument has to be highlighted and also analyzed with care. We stress the importance of complexity science in the analysis of this kind of problem [28].

Recently, this importance of the issue of the flexibility of the agreements and their resilience to change has been increased by the need to introduce into the analysis the effects of climate change, especially for the uncertainty about the evolution of stocks. In general, climate change alters the dynamics of populations. Warmer waters and changes in the environment, both in terms of habitats and in terms of nutrients, alter species migrations, spawning zones, recruitment characteristics and the locations of the stocks. Thus, new straddling can arise, and other stocks move to cross-border resources approaching the coasts. One can observe a movement to higher latitudes of some stocks, searching for colder waters and so on.

The effects of these changes can be significant when in the presence of a shared resource. Take, for example, the case of Pacific salmon [108]. In this case, climate change is probably responsible for the different evolution of salmon stocks. Warmer waters in the Alaska area, new conditions of nutrient transport by currents and less pronounced effects of *El Nino* in the California area, among other factors, have led to a significant increase in the regeneration capacity of the stocks further north and, on the contrary, a significant reduction in the biomass of stocks in the southern areas. The effect was a greater interception of Alaska stocks by American fishermen, and to this extent, the 1985 cooperative agreement went under stress. Excessive pressure on stocks in the north has led fishing organizations and the Canadian authorities themselves to present a series of credible threats to abandon the agreement and move on to a competitive game. Mutual recognition of the destructive effects that a "fishing war" would have on stocks and fishermen's incomes led to a new agreement in 1999. In this new compromise, transfers were introduced as a way to make the agreement more consistent in the future. These transfers included the application of American funds for research in the Alaska area, as well as buyback programs for purchasing vessels by the Alaska public authorities as a way to avoid overcapacity problems.

More recently, Punt [109] and Engwerda [110] addressed the strategic interaction between players and management in international fisheries under uncertainty. In the first case, the author investigated the role of sunk costs in a transboundary fishery. In a situation of climate change, with the relocation of the stocks, the possible entry of newcomers in the fishery may require sunk investments that change the outcome of the game. These costs may increase the competition for the stock and may impose a deterrence mechanism for newcomers. In the second case, by taking a broader class of fishing strategies, the author showed that if fishermen are more shortsighted, every fisherman will capture constant amounts of fish over time without being disturbed. However, in the opposite scenario, some fisherman will adopt a stabilization strategy, depending on the state of the stocks.

6. Future Impacts: Roots for Further Investigation

We can summarize our conclusions as follows.

Property rights are at the center of fisheries management.

The UNCLOS gave costal countries almost exclusive rights to fish in the EEZs, and that seemed to be a "promise of abundance".

However, the UNCLOS was also the root of many difficulties arising for the management of international commons beyond national jurisdictions. Free access in the High Seas is maintaining the "tragedy of the commons".

Game theory is an interesting tool for analyzing the problems of shared resources. The fundamental result points to the central role of cooperation in the sustainable use of resources.

The 1995 UN agreement on transboundary stocks and highly migratory species introduced regional regulation by the RFMOs. The construct seems to have important gains and be a source of inspiration for a more general UN binding treaty on biodiversity conservation beyond national jurisdictions, but a lot of flaws persist, namely those that refer to "newcomers" in the RFMOs and time consistency of the agreements, as well as those

related to enforcement and compliance. All those areas can be treated with game theory and constitute important sources of further investigation. The results of the negotiations may also promote the evolution of maritime international law. For example, one interesting subject that was not put under discussion is the possible enlargement of EEZs.

The studies highlight the role of institutions in the development processes and the importance of complexity science in the analysis of such a complex biological, socioeconomic, political and cultural problem.

What about the future?

As was said, in the ongoing process of searching for a new model of governance, the methodology used in the case of the fisheries has been highlighted as a possible source of inspiration, and the centrality of the 1995 agreement was recognized.

Nowadays, one can find 20 RFMOs in action. Tuna fisheries are the most well-covered fisheries in the context arising from the 1995 governance model. However, there are also important insufficiencies in terms of regulation and conservation of non-tuna fisheries. This is the result of the nonexistence or insufficient presence of regional fisheries organizations with mandates to regulate some important areas of the High Seas. Fisheries governance arrangements exhibit considerable diversity.

The discussion around the environmental and socioeconomic impacts of adopting a new conservation binding instrument and governance model is, to a large extent, dependent on the overall outcome of the negotiations where, as was stressed, fisheries are just one of the elements at stake. In what relates specifically to fisheries, we can point out the following aspects.

First, the further rationalization of fishing activities will have an inevitable effect of reducing employment in the fisheries sector. The reduction in the capacity of fleets in line with the need of renewal of the stocks, as well as the greater difficulties that are expected in the segments of distant fishing for many countries, impose this negative impact. It should also be noted that for countries with a long tradition in distant-water fishing such as Portugal, this reduction in activity will end up having some effects of progressive "oblivion" of ways of life and culture that were ingrained before. In the case of Portugal, a culture of cod fisheries in the Newfoundland area and a whole narrative that integrates the political and social development of the "cod campaigns" of the Estado Novo era will end up being lost [111–113].

However, this negative impact can be offset in several ways. One of the issues that is generally pointed out as a problem to be resolved in the future of fisheries beyond national jurisdiction is the problem of "interlopers" (i.e., enforcement and control) [114–117]. As mentioned earlier, the 1995 agreement did not solve the problem, but further deepening is expected in order to create more efficient rules for monitoring and control on the High Seas, both in water and in the seabed. This implies that new professions linked to the inspection and monitoring of activities in those extensive areas can be a source of new jobs. Given the weak interprofessional mobility that usually characterizes fishermen, the possibility of integrating the unemployed fishermen into new professions with a clear link with the sea is important. On the other hand, tighter rules of management of stocks and fleets in these areas can promote better conditions for work and safety onboard [118–120]. At the same time, they can work as a legal instrument to end the plague of "flag of convenience" vessels and put an end to so many known reports of fishermen exploitation and miserable conditions on this kind of vessel, as well as the connection to crime from several sources. A tighter system with fewer people operating in "free-riding" conditions on the High Seas is also a way to create more trust between operators, allowing better planning of activities and the entry into action of young professionals with other skills and qualifications, namely in the areas of study, programming, accounting and evaluation. It is evident that the success of these claims depends on how we are able to deal with the problem of "new entrants". With more RFMOs, clearer rules on membership and "transfer of membership" are needed, as we have seen.

Another very significant issue that goes beyond the problem of fisheries management relates to the question of R&D and technology transfer. This issue is particularly sensitive when it comes to the exploitation of seabed resources, in particular genetic resources. Positive social impacts may be achieved in two ways: the development of new professions associated with research and the exploitation of new resources with higher qualifications and better wages, as well as the development of new sectors, such as biotechnology, that create value, distribute income and reduce poverty.

It is certain that this will be very dependent on the transfer of technology. The current scenario of oligopolistic exploitation by a few large companies that develop patents is worrying. However, if the intention is to maintain significant research efforts, economic theory tells us that it may prove essential to maintain monopoly power for companies that patent it, for some time. Thus, the process will have to be properly balanced, but it cannot go without rules for the transfer of technology to the least developed countries under the risk of becoming an absurdly uneven enrichment process by private groups that absorb all derived income from the use of common resources of humanity.

There are also important generic positive externalities that imply a rise in the social marginal benefit of the whole community: those derived from the gains in public health through the discovery of new medicines, those that result from adequate environmental use of oceans and the subsequent benefits in terms of, for example, climate change.

Another important issue relates to the possible evolution of international maritime law that an agreement like this (and the practices it will develop) may promote. Many observers agreed that the UNCLOS was, perhaps, the most important output in the history of multilateral diplomacy. However, of course, it has flaws, and it is not an ended construct. The 1995 agreement made important progress in the governance model of High Seas fisheries, but it has also limitations. These limitations may be the routes for further investigation and, again, the role of game theory has to be highlighted. Some clues include the following.

First of all, there are the issues related to the fundamental question of enforcement and "interlopers". In fisheries economics, there is already an interesting use of the so-called "crime and punishment" theory of Becker (1968) [121], and one can find researchers trying to show how fishing agents behave in terms of compliance with the law and how they enter schemes of illegal action [116]. Introducing the strategic behavior of different origin vessels in international fisheries and in situations of different institutional frameworks seems to be an interesting and productive task.

Multispecies analysis is another important area of further investigation. In this context, an interesting result comes from the recent study by Salenius [122]. In applying game theory to a problem of interaction between different fishing countries and stocks, he arrived at the conclusion that in a situation of non-cooperative management, the difference between single and multi-species fisheries is not very important. On the contrary, this difference may be highly relevant in the case of a cooperative program of management.

Other important scientific outputs include the study of Gorniewicz and Wiszniewska-Matyszkiel [123] submitting evidence of the Allee effect and the possibility of stock extinction when critical levels of fish stocks are reached. In another direction, see, for example, the work of Liu and Heino [124] addressing the impact of the spatial distribution of a fish stock in international fisheries. These efforts have to be maintained. Multispecies, multi-area and multi-objective management are essential issues for finding a compromise, such as the one the UN is designing. They constitute an extensive domain to be investigated.

Third, there is the consideration of the total economic value of the resources, meaning the consideration of other values than the simple value of direct use, such as the option value or the existence value, and the evaluation of the impacts of this methodology of valorization on the strategic behavior of the agents. In this context, see, for example, the work of Pintassilgo et al. (2017) [125], which extends the literature of coalition games in RFMOs to the case in which the payoffs of the players also account for non-consumptive values and non-use values in addition to the usual harvesting profits. The authors found

that accounting for this kind of value helps to conserve the stocks, even if it does not affect the outcome of the game. The dilemmas and the trap of non-cooperation persist even if those values are accounted for. This issue is also a very relevant point in the negotiations taking place in the UN, (How does one get the total economic value of the resources?) and it will have important practical impacts.

Finally, going far beyond the analysis of international fisheries, the use of game theory in the management of national fisheries is a "new research frontier" [31]. For example, the possibility of cooperation among harvesting rights holders or the double level of cooperation between the fishers and the resource manager can now be introduced, as can the strategic behavior of the agents investigated at the national or regional level. An immense pocketful of opportunities for the association game theory and fisheries management exists.

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