Co-management strategy for the sustainable use
of coral reef resources in the National Natural Park
"Corales del Rosario y San Bernardo" in Colombia

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Abstract

The National Natural Park "Corales del Rosario y San Bernardo", located in the Caribbean Sea, is one of the most important parks in Colombia since it hosts high biological biodiversity, receives more tourists than any other natural park in the country and provides sustenance to several communities settled in and around it. However, lack of governance and incompatibility of incentives among authorities, communities and visitors threaten its conservation and sustainability. Using experimental economic games with fisherman communities, we tested different rules related with the management of natural resources in the protected area. In addition to standard rules of communication and external regulation, we tested a rule called co-management, in which we explored the complementarities between repeated communication and external non-coercive authority intervention. We also tested inter temporal effects where over extraction (by the group) in a round reduces the availability of resource for next round and, in consequence, increases effort and reduces benefits for fishers. Results confirmed the effectiveness of communication and, to some extent, external regulation. More important than that, co-management treatment exhibit –no matter the location of the communities with respect to the park- the best results in terms of sustainable use of the resource. Participants incorporated dynamic implications in their decisions when information asymmetries were overcome, through internal communication or external guidance. These results highlight the importance of resource management designs that recognize communities as key actors in decision making for the sustainable use and conservation of common pool resources in protected areas.

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1. Background

The National Natural Park "Corales del Rosario y San Bernardo" (NNP-CRSB), located in the Colombian Caribbean Sea, is one of the seven marine protected areas in the country and is considered strategic since it conserves the most developed fringe of coral reef in the Continental Colombian marine platform, hosting high biological diversity. This park was established in 1977 and expanded to its current extension (approximately 120,000 ha) in 1997 (Pineda *et al.*, 2005).

Despite the national and global relevance of this park, it presents some particularities that restrict the achievement of the conservation goals established for this marine protected area. There exist many sources of pressure for resources in this protected area, being over exploitation of marine resources by native communities and uncontrolled tourism two of the most important –or at least the most visible-. When the park was created, in 1977, many fisherman communities were already established within and around the park. These communities exhibit low standards of living and their main income generating activity is the extraction of hydro biological resources from the protected area. On the other hand, given the beauty and attractiveness of the park, it is largely visited by national and international tourists. In fact, this is not only the most visited park in the country but also one of the most hardly exposed to overexploitation. The presence of an intensive tourism generates an additional pressure due to, among others, the need of satisfying fish and other marine resources demand from visitors (Camargo *et al.*, 2007).

In spite of the creation of the park and the existence of laws and regulations controlling access and uses, scientific reports and perception from both authorities and communities indicate a reduction in hydro biological resources during last decades. Many species in the park are under threat and some of them seem to have disappeared locally, as in the case of the snail *Strombus gigas*[2], and other species of fish and coral reef. As a response to reduction in resources, fishermen have increased fishing effort not only by fishing for longer periods or at farther distances but also, in some cases, by violating regulations when using inappropriate fishing

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[2] Type of snail which is not only consumed for food by locals and tourists but also used for craftsmanship and as a construction material

techniques, extracting under minimum permitted sizes and extracting species with full restriction, given their protection or threat status, generating a conflict between communities and park authorities (Camargo *et al.*, 2007).

The conflict between park authorities and fisherman communities is born from a divergence between park conservation social objectives and fishermen private interests. This divergence is typical of common pooled resources -CPR- (Ostrom, 1990) which are characterized by both non excludability and rivalry (Feeny *et al.*, 1990). Non excludability relates to the fact that, given the nature of the resource, it may be prohibitively costly to control the access by potential users, while rivalry means that extraction of the resource by one user affects adversely the benefits of other users (Baden, 1998; Feeny *et al.*, 1990), and even that user´s long-term welfare as well (Baden and Noaan, 1997). These characteristics make that CPR cannot be considered neither as a private nor as a pure public good and constitute the source of conflict between private and collective interests (Cardenas, Ahn and Ostrom, 2003). In the case of a natural park, collective interests are affected beyond fisherman communities, since a national park is established with the clear social objective of conserving the biological diversity it hosts.

Fisheries are perhaps one the best examples of common pooled resources where as long as each additional unit extracted by a fisherman represents additional gains for him, the costs of that unit extracted are shared and distributed among all fishermen and society as a whole. So, individual fisherman assumes merely the private costs of its actions -ignoring social costs-, lading collectively to the over exploitation of a resource that is perceived as "free" (Gordon, 1954; Hardin, 1968). Gordon in his classic paper "The economic theory of a common-property research: the fishery", written in 1954, and 14 years later, Hardin (1968), with his well known "Tragedy of Commons" suggested that self centered and short sighted behavior of agents will lead to overuse and rapid depletion of these resources. In addition, when fishers realize that the resource is being depleted, they often over invest in harvesting technology as each resource user tries to sustain his catch in the face of a diminishing resource (Baden, 1998).

In order to avoid "the tragedy", Hardin (1968; Hardin and Baden, 1977; Hardin, 1978) proposed two general solutions: to allocate property rights either privately or to the state, with clearly instituted regulations to control access and uses. In these solutions, it is implicitly assumed that no other property rights regime -nor a combination of them-, would give enough incentives to agents to maintain and conserve CPR, assumption that comes not only from the fact that

"tragedy of commons" models a purely individualistic behavior of agents –ignoring social or collective behavior (Hanna and Jentoft, 1996)- but also from the fact that –likely- Hardin assumed no difference between communal property and open access (Feeny *et al.*, 1990).

In the National Natural Park CRSB, it appears that state property -in which norms and regulations about uses and users have been imposed-, has been not sufficient to provide for adequate exclusion and that the crescent interests conflict between fisherman communities and park authorities are restricting the achievement of the conservation goals in this marine protected area. There are many factors that might be contributing to this situation making that *de jure* state property seems more a *de facto* open access: i) size of the park, ii) physical characteristics and nature of the resource, iii) strong budget constraints, iv) lack of information and v) a complex relation between community and authorities (Camargo *et al.*, 2007). These factors impede to reach the optimal equilibrium that is supposed to be achieved under centralized control, because assumptions such as accuracy of information, monitoring capabilities, sanctioning reliability and zero cost of administrations do not hold (Ostrom, 1990).

After Hardin´s, other alternatives, based on collective action, have been proposed in order to address CPR dilemma. These alternatives are supported on strong empirical evidence showing that worldwide there are communities that have been able to organize themselves around self governing institutions, to design and define rules and mechanisms as well as sanctions and penalties to solve the divergence between individual and collective interest, that arise from the joint use of CPR (Ostrom, 1990). Experimental evidence has also shown that individuals do not always behave as if they were purely self interested and that they often make decisions balancing own and collective interests (Davis and Holt, 1993; Kagel and Roth, 1995 in Murphy and Cardenas, 2003). During last decades many field and lab experiments have supported the argument that agents' utility is affected by other factors rather than pure material gains, specifically that individual's behavior is also determined by others-regarding preferences (Cardenas, 2004), in which elements of altruism, fairness, reciprocity and reputation could play a relevant role (Ostrom, 1998; Bowles, 1998; Fehr and Gachter, 2000; Fehr and Schmidt, 1999 in Cardenas, 2004; Castillo and Saysel, 2005).

Although there is a consensus that self governing strategies may emerge and succeed, it strongly depends on many factors such as the institutional environment, the production function involved in the use of the commons (Cardenas, 2004), the social cohesion of communities, the

size of the groups involved, and the degree of interaction of these communities with the market. Rova (2004) argues that it is doubtful that a pure self-governing institution be a realistic option for the case of complex and diverse fisheries in a modern industrial society, given that both pressure of the markets and integration with surrounding society, may undermine collective (traditional) management.

Around the world, the CPR dilemma associated with marine fishery resources has shown to be very complex to counteract because, on one hand, it is impossible to allocate individual property rights and, on the other, state property has proved, in many cases, not to be an effective strategy in the goal of protecting and conserving marine biological resources. Feeny *et al.* (1990) suggest that a viable option could be a combination of state regulation and user self-management, in a type of shared governance. Worldwide many state protected areas, facing governance problems and over use of resources, are increasingly opting for trying collaborative or joint management strategies in which power, making decision process and responsibilities are shared at different degrees between local agents -users of resources-, and authorities (McCay, 1996). This institutional arrangement, that might also be seen as a combination of communal and state property rights is also known as co-management. Co-management has been seen as an alternative that improves both effectiveness and equitability of fisheries management as well as compliance with agreed upon rules (Jentoft, 1989; McCay, 1996).

In the complex context of conflict between park authorities and fisherman communities, and deterioration of the marine resources in the park, the objective of this paper is to identify the characteristics, incentives and mechanisms both individual and collective, that can motivate the agents to a sustainable use of the resources in the National Natural Park "Corales del Rosario y San Bernardo" (NNP-CRSB). Particularly, this paper is aimed to answer, using economic experimental games, the following question: *is collaborative management or co-management a possible strategy for the management of fish and reef resources in the NNP-CRSB, which might improve the governance and lead to a sustainable use of hydro biological resources in the protected area?*

Economic experimental games –EEG- have been used not only to validate and support the classical model in market settings but also to challenge the rational choice model in non market settings, particularly when talking about CPR and public goods (Walker, Gardner and Ostrom, 1990; Ostrom, Walker and Gardner, 1992). These experimental games have become an

important tool to analyze the dilemma between private and collective interests and the behavior of agents using CPR (Ostrom, Gardner and Walker, 1994; Ostrom, 2000).

In Colombia, many economic experimental games have been carried out in field to analyze the behavior of individuals facing in their daily life the conflicts associated with the use of CPR (Cardenas, Strandlund and Willis, 2000; Cardenas, 2003; Cardenas, 2004; Velez, Murphy and Strandlund, 2006). Those studies have analyzed several issues ranging from the role of both individual cooperation and external institutions in CPR dilemmas, to the effect of individual wealth and social distance in individual game decisions, testing different types of informal communication, several degrees of external regulation and individual economic wealth (Cardenas, Strandlund and Willis, 2000; Cardenas, 2000; Cardenas, Ahn and Ostrom, 2003; Cardenas, 2004).

Generally speaking, the findings of these experiments support the arguments that individuals facing CPR dilemmas are able to cooperate and make decisions that might lead them to obtain greater benefits and to conserve the resources they extract. In addition, those findings also show that external control or regulation on CPR or public goods may not be as effective as it is expected from theory and that it could even crowd-out other regarding behavior in favor of greater self interest (Cardenas, 2000; Cardenas, Strandlund and Willis, 2000; Cardenas, 2004). Those studies also show that individual decisions about CPR may be affected by the economic wealth of individuals, the dependence of individuals on the resource, the type of allowed communication and the degree of imposed regulation.

In Colombia, however, very few experiments have tested combinations of institutions in which cooperation and external control play a simultaneous role. Velez, Murphy and Strandlund (2006) conducted a field experiment with fisherman communities in three regions in Colombia. They examined the complementarities between face-to-face communication and external regulation to conserve a local natural resource. They found that the hypothesis of complementarities between communication and external regulation cannot be supported in general, although it holds for some communities and under some regulations.

Given the particular complex relationship between fisherman communities and authorities in the national natural park CRSB, in this study we test the complementarity –that we have called co-management- between repeated communication and non-coercive government regulation, to

manage and conserve resources at the natural park. Particularly, the non coercive government strategy we test here requires the participation of officials from the NNP-CRSB who work with communities on environmental education. So, the involvement of a real official of the NNP-CRSB as an additional player on the experimental game and the environmental education strategy -opposed to coercive strategies as penalties- constitute an innovative approach for field experimental games analyzing CPR dilemmas.

On the other hand, most experimental games developed with real communities facing CPR dilemmas have not taken into account the inter-temporal effect of the extraction of the resource. Dynamic issues of CPR might exacerbate CPR problems as individuals –acting myopically- do not consider the full impact of their current decision about extraction on their own and others future extraction costs (Herr *et al.*, 1997). Herr *et al.* (1997) use laboratory experiments to analyze time-independent and time-dependent externalities in non-renewable commons, and found that myopic behavior not only exacerbates CPR problem, but also that even individuals who take into account current and future effects of their extraction decisions might enter into a race for resources if they believe others may be acting myopically. In this paper we analyze, using field experimental games, if fisherman communities in NNP-CRSB behave myopically when making extraction decisions on renewable natural resource, as suggested by results from lab experiment conducted in a non-renewable resource setting by Herr *et al.* (1997).

This paper is organized as follows: Following this background we present the theoretical model in order to arrive to the experimental design in third section. In the fourth part of the paper we present the empirical model we use and its main results, and in fifth section we present the conclusions of the paper.

2. The theoretical model

In the presence of externalities the social optimum differs from private equilibrium. Particularly, when facing social dilemmas as the one associated with CPR, in which private interests diverge from social or collective interests, the theoretical prediction from non cooperative game theory establishes that individuals (players) will not make decisions that lead to a social optimum; instead, individuals will play strategies that lead them to a suboptimal Nash equilibrium (Cardenas, Ahn and Ostrom, 2003), arriving to the prisoners dilemma. Non cooperative game theory also establishes that this prediction will not change even if individuals (players) are

allowed to communicate with others without external enforcement of agreements (Cardenas, Ahn and Ostrom, 2003). In other words, the standard theory predicts that purely self-interested individuals will extract more fish than is socially optimal even if other institutions are in place. However, empirical evidence challenges this theoretical prediction: behavior in public good and common-pool resource experiments deviates from Nash equilibrium strategies not only when subjects are merely allowed to communicate with one another (Ostrom and Walker, 1991) but also when they are unable to communicate. Following those ideas, we postulate a theoretical model that let us to understand how fishermen in NNP-CRSB make decisions about fish extraction and how much and under what situations or institutions those decisions deviate from theoretical predictions. In this sense, our purpose is to compare the empirical results of economic experimental games carried out in fisherman communities with expected results from two theoretical standard benchmarks: i) the social optimum, which maximizes the aggregated group welfare, and ii) the standard model of purely self-interested strategic behavior, that lead to a Nash Equilibrium (Cardenas, 2004). Moreover, we modify the later benchmark to include the effect of external regulation –a penalty- on private individual benefits.

a) Standard non-cooperative model

The model presented here is based in the one proposed by Cardenas (2004) to which we are introducing dynamic effects so that benefits of individuals will be affected not only by private and collective decisions on extraction but also by inter-temporal effects of those decisions. Suppose a person that extracts a resource and obtain benefit from it, for example a fisher. The benefits (and costs) that he/she receive from the extraction can be divided in two categories; on the one hand, there is a private benefit that depends on the level of extraction (x) but whose costs depend on the availability of the resource (S); on the other hand, there are benefits (or costs) from the decisions of all the fishers using the resource and affecting the availability for the other fishers. That is, this is a common-pool resource (CPR) that faces non exclusion but rivalry when fishers decide to extract fish. These benefits can be captured as it is shown in expression (1):

$$\pi_{i,t} = f(x_{i,t}, S_t) + g(\sum_i x_{i,t}),$$
(1)

where $\pi_{i,t}$ indicates the benefits that fisher *i* obtains in period *t* from extracting the resource, which depends on the private benefit (*f*) –given by the own extraction (x_{it}) and the availability of the resource (S_t)-, and the public effect (*g*) of the decisions –given by the sum of the decisions of all the fishers using the resource[3].

In order to model the empirical approach for the experiment, some functional forms must be assumed. For this particular case:

$$f(x_{i,t}, S_t) = \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t}$$

$$g(x_{i,t}) = \gamma \sum_{i=1}^{n}(e - x_{i,t}) = \gamma n e - \gamma \sum_{i=1}^{n} x_{i,t}$$

(2)

where $\alpha > 0, \beta \geq 0, S > 0, \gamma \geq 0$. The first one is a typical function whose revenues depend on a parameter α (perhaps the price of the resource in the market) and whose costs depend in a quadratic direct form from the extraction and inversely from the stock, and β represents a technical parameter associated to the costs. The second expression shows that the availability of the resource is affected negatively by extraction. This effect depends, in turn, on the parameter γ, that represents the proportion in which the common-pool resource availability affects the own benefits. The parameter *e* represents the maximum amount that each fisher can extract and *n* the fishers using this resource.

Additionally, the stock changes according to an evolution equation

$$S_{t+1} = S_t - \sum_{i=1}^{n} x_{i,t} + \theta S_t (1 - \frac{S_t}{K}).$$

(3)

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[3] It is assumed that $f_x \geq 0, f_{xx} \leq 0, f_S \geq 0, f_{SS} \leq 0, g_x \leq 0, g_{xx} \geq 0$

The evolution equation states that the amount of the resource in period *t+1* will equal the stock at the beginning of period *t* minus the extraction of all fishers during that period plus the net growth function –that in this case depends on the parameters θ and K[4].

Given these functional forms, the Nash equilibrium of this model can be obtained by the maximization of each fisher's benefits through time subject to the evolution equation:

$$\max_{x_{i,t}} \sum_{t=0}^{T} \delta^t \pi_{i,t} = \sum_{t=0}^{T} \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + \gamma n e - \gamma \sum_{i=1}^{n} x_{i,t} \right\}$$

$$s.t. \quad S_{t+1} = S_t - \sum_{i=1}^{n} x_{i,t} + \theta S_t (1 - \frac{S_t}{K})$$

(4)

Where δ represents the discount factor *(δ=1/(1+r))*, being *r* the relevant discount rate. The dynamic Lagrangian expression will be as follows:

$$L = \sum_{t=0}^{T} \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + \gamma n e - \gamma \sum_{i=1}^{n} x_{i,t} - \delta \lambda_{t+1} (S_{t+1} - S_t (1+\theta) + \sum_{i=1}^{n} x_{i,t} + \frac{\theta S_t^2}{K}) \right\},$$

where λ_{t+1} represents the dynamic Lagrangian multiplier for every period. Considering the first order conditions for this problem and abstracting for the conditions related to the state and the co-state variables, the maximization condition with respect to the decision variable implies that:

$$x^P_{i,t} = \frac{S_t}{\beta} (\alpha - \gamma - \delta \lambda_{t+1})$$

(5)

This expression represents the Nash equilibrium for the game and shows that the optimum private extraction depends positively on the available stock and the parameter α (the price of the resource), and negatively on the costs of extraction (β), the impact on aggregated benefits (γ) and the discounted inter-temporal price of the available resource ($\delta \lambda_{t+1}$). Note that in a static framework the private fisher will not consider this latter term.

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[4] The parameter θ can be thought as the implicit growth rate and the parameter *K* as the carrying capacity of the resource, and so, the growth function can be viewed as a logistic function.

b) Social optimum model

In order to obtain the level of extraction that maximizes the social welfare, a central planner would aggregate the benefits of all individuals, in this case the *n* fishermen:

$$\max_{x_{i,t}} \sum_{i=1}^{n} \sum_{t=0}^{T} \delta^t \pi_{i,t} = \sum_{i=1}^{n} \sum_{t=0}^{T} \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + \gamma n e - \gamma \sum_{i=1}^{n} x_{i,t} \right\}$$

$$s.t. \quad S_{t+1} = S_t - \sum_{i=1}^{n} x_{i,t} + \theta S_t (1 - \frac{S_t}{K})$$

(6)

Rewriting the function to be maximized and constructing the Lagrangian, the problem is to maximize

$$L = \sum_{t=0}^{T} \delta^t \left\{ \alpha \sum_i x_{i,t} - \frac{\beta}{2S_t} \sum_i x_{i,t}^2 + \gamma n^2 e - n\gamma \sum_i x_{i,t} - \delta \lambda_{t+1} (S_{t+1} - S_t(1+\theta) + \sum_i x_{i,t} + \frac{\theta S_t^2}{K}) \right\}$$

The first order condition with respect to the extraction implies:

$$x^{soc}_{i,t} = \frac{S_t}{\beta}(\alpha - n\gamma - \delta \lambda_{t+1}).$$

(7)

Expression (7) shows that when analyzing social welfare, the optimal level of extraction must be lower than that in expression (5) as the proportion in which the availability of CPR affects benefits (gamma) must be aggregated for the total number of fishers -*n*- in order to capture the full costs of extraction decisions.

Expressions (5) and (7) are used to construct pay-off tables that participants will use during the game. We assigned values to the parameters[5], in those expressions such that, we could generate a pay-off structure clear enough that re-creates conflicts between individual and group

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[5] There are two equations, but six parameters to be defined, so some of them must be exogenously determined.

gains, showing a social dilemma situation. Following previous field experiments conducted by Cardenas (2004) we chose the range of plausible extraction varying between 1 to 8 units, so that $e = 8$. For the case of social optimum, it is assumed that individual fishers could extract at least one unit[6] while the Nash equilibrium is adjusted to be equivalent to eight units of extraction. The pay-off tables show the benefits for individual i of different combinations of individual and aggregated extraction (annex 1). From tables it is possible to observe that as individual i increase his/her extraction, his/her payoffs increase, but as the aggregate extraction increases, i´s payoffs decrease, which emulate the social dilemma between individual and collective interests.

c) Standard non-cooperative model with external regulation

In order to incorporate the effect of external regulation, specifically a penalty, on fishermen extraction decisions, we include an additional expression to the inter-temporal maximization of individual private benefits:

$$\max_{x_{i,t}} \sum_{t=0}^{T} \delta^t \pi_{i,t} = \sum_{t=0}^{T} \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2 S_t} + \gamma n e - \gamma \sum_{i=1}^{n} x_{i,t} - \rho m (x_i - x_i^{soc}) \right\}$$

$$s.t. \quad S_{t+1} = S_t - \sum_{i=1}^{n} x_{i,t} + \theta S_t (1 - \frac{S_t}{K})$$

(8)

The expression $(x_i - x_i^{soc})$ is the level of extraction above the one allowed. In this case, the permitted level of extraction is the social optimum; m is the level of penalty that is externally imposed for each additional unit that is extracted above the permitted level and, finally, recognizing that control and monitoring is, at best, imperfect, ρ represents the probability for a fisherman of being monitored and penalized by an authority.

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[6] Cardenas (2004) argues that it is convenient to eliminate the zero extraction option to avoid conflicts in conducting experiments that arise because there is strong aversion by villagers towards prohibitions to use resources. In addition, in the NNP-CRSB fishermen are allowed to extract resources for "self-consumption".

Constructing Lagangrian expression and solving for first order conditions we obtain the following expression that show the optimal private level of extraction when an external regulation is imposed and monitoring is imperfect.

$$x^r_{i,t} = \frac{S_t}{\beta}(\alpha - \gamma - pm - \delta\lambda_{t+1}).$$ (9)

Expression (9) shows that the optimal private level of extraction when an external regulation is imposed –assuming risk neutral individuals- should be lower than the level of extraction with no regulation, and depends –in addition to other factors already mentioned- upon the magnitude of the penalty and the probability of being monitored and sanctioned. So, the higher the penalty and the better the enforcement of regulations, theory predicts less extraction, *ceteris paribus*.

Using this theoretical framework, we design the experiment to be conducted in field, as shown in the next section.

3. Experimental design

Economic experimental games were carried out in five fishermen communities, three of them located within the limits of the NNP-CRSB and the others, located outside those limits. At every place, a group of approximately 30 people were gathered and organized in subgroups of five people each. The five-person group represented the collective decision entity in the experiment but every person made individual, private and confidential decisions that were treated as anonymous. Anonymity and confidentiality of individual decisions were guaranteed by seating players back to back and by the presence of a researcher who monitored and supervised each group and who collected individual extraction levels that fishermen wrote in an individual piece of paper.

Experimental game was performed in two stages, both of them divided in ten rounds of decisions. In every round of the first stage (base line), each player must decide a level of extraction ranging from 1 to 8 units, and these decisions generated points, convertible in monetary units. In general, the higher the individual extraction the higher the profits, but a decreasing rate. These profits, however, depended not only on individual decisions but also on the decisions made by the five-person group as a whole. The higher the full group extraction the

lower the value of each extracted unit for every player. The purpose of this design was to highlight the dilemma of common-pool resources and the trade off between individual and social benefits. Each individual, privately, calculated his/her profits based on his/her own anonymous extraction and the aggregated extraction –which was made "public" after finishing every round by the researcher in charge of collecting individual extraction decisions-.

In this experiment, as mentioned in the theoretical model, players were facing inter-temporal effects of their current decisions. In order to make the dynamic part of the game understandable for fisherman, and practical and operative for field work, we decided to manage two levels of the resource stock: *High* and *Low*. So, the dynamic part of the game was designed as follows: if the aggregated extraction (five-person group extraction) exceeded 20 units, the stock of the resource for next round will be *low*, meaning low availability of the resource in next round caused by over-extraction in current round. In this case, every unit of extraction was paid with fewer points as low availability of the resource implies more effort per unit of catch, which in turn generates, *ceteris paribus,* lower benefits. If the extraction by the whole group was less than 20 units, for the next round all the players will face an abundant resource (High availability) that required less effort per unit of catch, and so higher returns to the activity. These two levels of stock will produce two different pay-off tables according with the benefit function in expression (1).

Figure 1 shows the main components of the first phase of the experiment. This diagram is a summary of the explanation above as well as of the protocol used for experimental games.

14
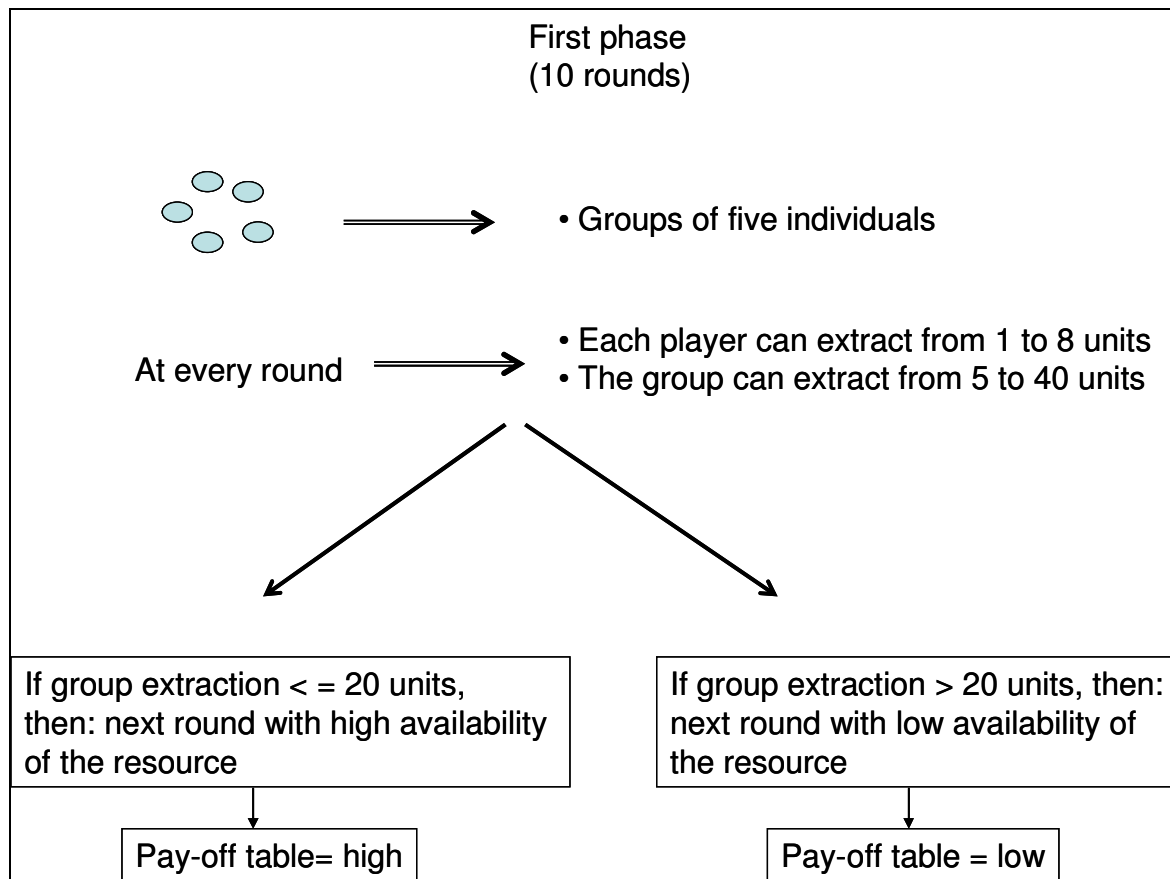
Figure 1 First phase of economic experimental games in NNP-CRSB

Following the first 10 rounds, the groups started a second phase, with 10 additional rounds subject to different rules. There are four rules that were assigned to each group, which worked as follows:

Rule 1: Continue on baseline. This rule is assigned to a control group and the players continue playing as in the first phase for 10 additional rounds.

Rule 2: External regulation: Fine or penalty. The objective of this rule is to convince players to extract only one unit of the resource, using a fine imposed by an external regulator. In order to simulate the imperfect enforcement that is common in developing world, the monitoring decision is random and every player has $1/10^{th}$ of probability of being monitored at every round. Operatively, imperfect monitoring is carried out using 10 balls, five white and five red (each red one with a number). One ball is picked up from a black bag and if the picked ball is white, there

15

is no monitoring at all, while if the ball is red, the player with the number in the ball is inspected. For every unit of extraction above the one permitted, the monitored player must pay a fine, which is deducted from the points she/he got in the corresponding round. The extracted ball is returned to the bag so that a player could be monitored more than once. All the other rules keep as in the baseline, and decisions as well as fines keep being private and confidential. No communication among players is allowed.

Rule 3: Internal regulation: Communication. Under this rule, before starting the second stage, the group is allowed to have an internal talk of -at most- five minutes. Only the five members of the group are able to participate in this conversation, and although they are permitted to talk about the pay-offs, the game and the strategies, among others, they cannot make any promises or threats to their partners. Following this talk, a new set of ten rounds starts in which, repeated communication of two minutes is allowed between rounds. Despite the possibility of communication, extraction decisions continue being private and confidential.

Rule 4: Internal and external regulation: Co-management. Under this rule, and before starting the second phase, the group has the opportunity of talking, during five minutes, with an officer from the national park who enters into the game as an additional player. During that time, the representative of the authority exposes his/her ideas about the conservation of the park and tries to convince every member of the group to extract only one unit of the resource. Passing that period, the group has five more minutes to talk about the pay-offs, the game, the strategies or any other issue. Neither the representative of the authority nor the members of the group are allowed to make promises or threats during or after the game. Interventions of the park officer are recorded. When the group makes their decision –private and confidential- for the first round and the total extraction is announced, the park representative has another minute to talk to the group, and then, the group has an additional minute to discuss. For resting rounds this rule behave as in the second round.

Figure 2 shows a diagram with treatments used during the second phase of experiments.
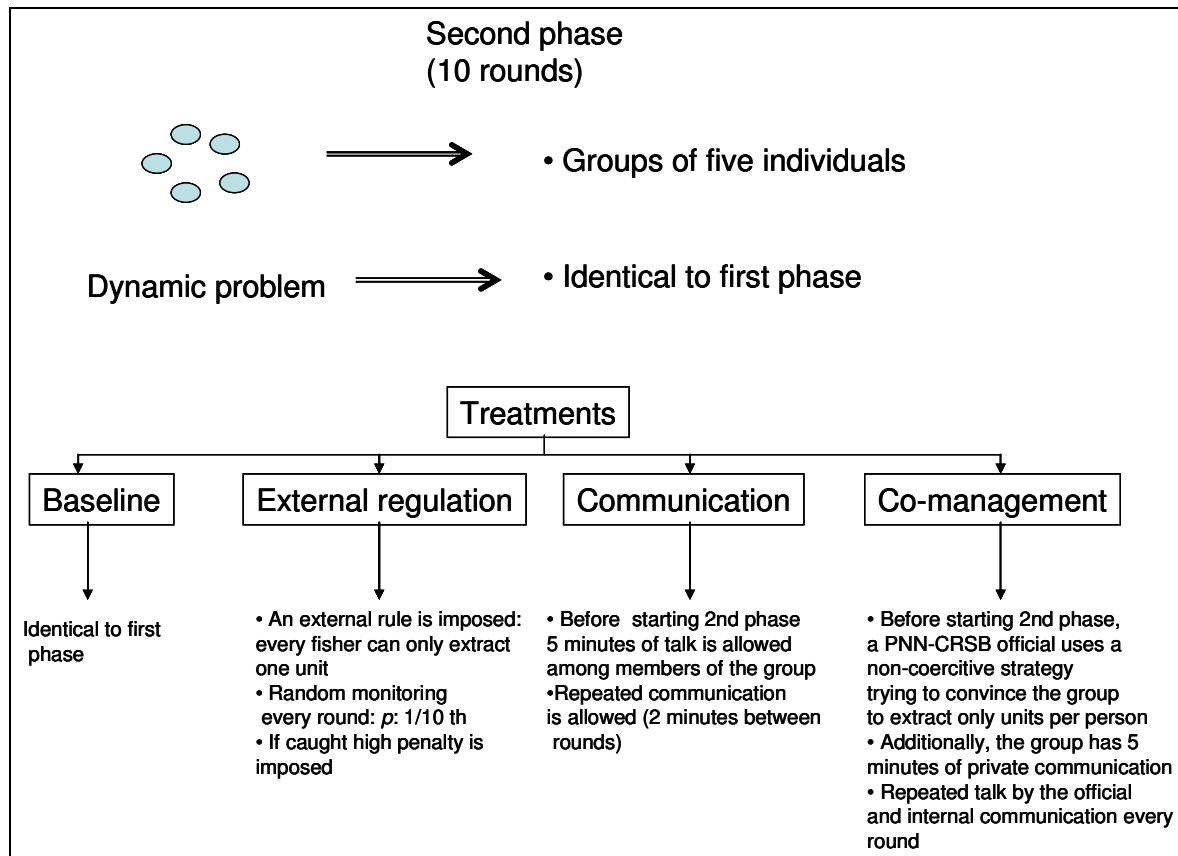
Figure 2 Second phase of economic experimental games in NNP-CRSB

Following the theoretical model, the expected equilibrium of the game under base line is a level of extraction of 40 units (8 units per player), while the social equilibrium is a level of extraction of 5 units (1 unit each). Under the external regulation treatment, the expected equilibrium is a level of extraction of 15 units (3 units each). The model does not predict any change in the decision under communication or co-management beyond the Nash equilibrium.

Every participant in the experiment obtained points, convertible in money, being the average final payment an equivalent to the income they would have obtained in a typical working-day (about 1.5 daily minimum-wage equivalents). At the current rate, this payment is equivalent to 10 dollars, so the five players playing the 20 rounds obtain about 50 dollars. The payments were confidential.

After finishing the game, participants completed a survey and the main results of the game were presented and discussed openly with players and park officers. This socialization was very

useful to think and discuss about different ways of managing resources in the park, and several lessons for the use of resources were obtained.

4. Empirical model

There are five places where games were performed. These five places are divided according to the proximity to the National Natural Park into places *inside* the park and places *outside* the park. This distinction obeys to the assumption that communities inside the park are more willing to participate in initiatives with the authorities, while people living outside the park have been, historically, less attended by authorities and, in consequence, less able to engage in activities for the sustainable use of the park. In fact, people in communities inside the park use to blame those living outside the park as responsible for inadequate fishing arts and over exploitation in the park. There is no evidence of this assertion but it is expected a differentiation in the attitude between these two groups. Inside the park, the communities involved are Isla Grande, Santa Cruz del Islote and Mucura islands. Outside the park, there are two communities, Tierrabomba and Bocachica (Figure 3). In total, 135 persons participated in the games, 80 of them in locations inside the park and 55 in locations outside the park.
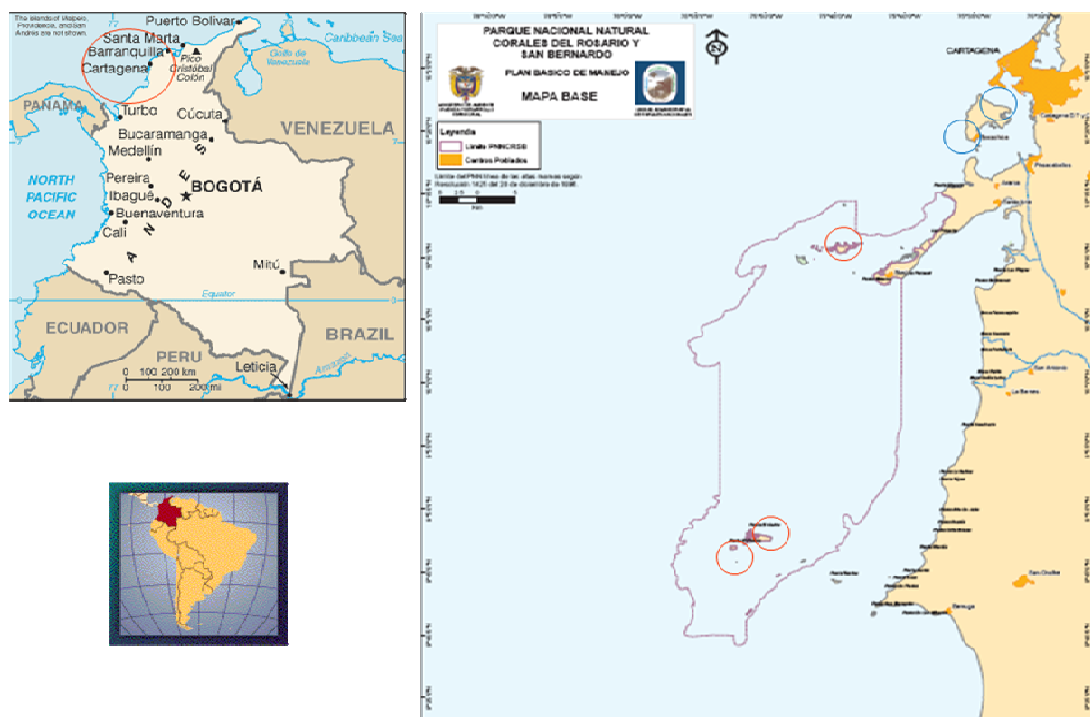
Figure 3 Location of the park and communities

<u>Socioeconomic information of game participants</u>

As highlighted in the background section, people in these islands are mainly engaged in fishing activity (Figure 4). Education levels are in general low, averaging 6.1 years (elementary school) with small differences between inside and outside of the park participants (5.7 vs. 6.4).
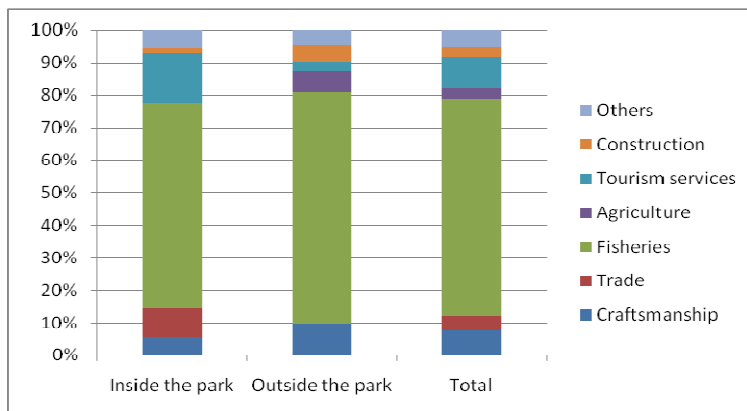
Figure 4 Main economic activities of participants

Poverty is the rule in the area (and so standard of living is low), as can be observed in Figure 5: half of the experimental game participants' households earn less than US$ 200 per month, and more than 90 percent of them do not reach the threshold of US$ 400 per month. Given an average of 5.5 members per household, it implies that half of the people survive with less than US$ 1.21 per capita and 90 percent with less than US$2.42.
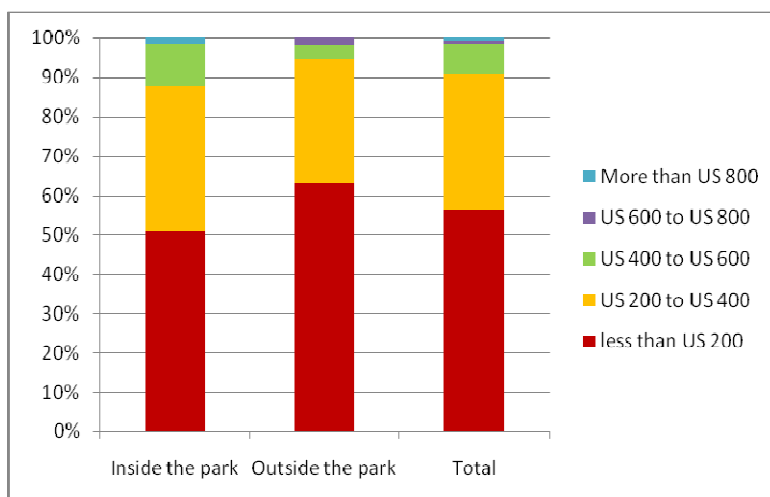
Figure 5 Household monthly income of participants

Despite difficult conditions, these populations have been settled there for more than 50 years (on average more than three generations have been born there), showing that access to fish and other hydro biological resources might constitute –in addition to a source of income- a basis of consumption that might not be included in the calculation of income but can be of importance for subsistence of these households.

The game

The distribution of players for each zone, according to the treatments they were exposed to, is presented in Table 1.

Table 1 Number of players inside and outside the park according to treatment

Zone	Treatment				
	Baseline	Communication	External reg	Co-management	Total
Outside the park	10	15	15	15	55
Inside the park	15	25	15	25	80
Total	25	40	30	40	135

According to the design of the experiment, the expected extraction level under non-cooperative setting was eight units of resource, while the social optimum was adjusted at one unit. When players were exposed to the game under the baseline (first 10 rounds), however, the extraction was lower than the theoretically-predicted Nash equilibrium. On average, the extraction during the first phase was 4.6 units, which is more than three units lower than the expected Nash equilibrium. Presumably, the state of the resource may explain part of this result. Comparing the extraction at different states, however, shows that, even though under high availability of stock the extraction tends to be higher than that under low availability (4.82 versus 4.44), both levels of extraction are considerably lower than the expected level of eight units. Although the difference is statistically significant there is no a great variation in decisions along first ten rounds (Figure 6).
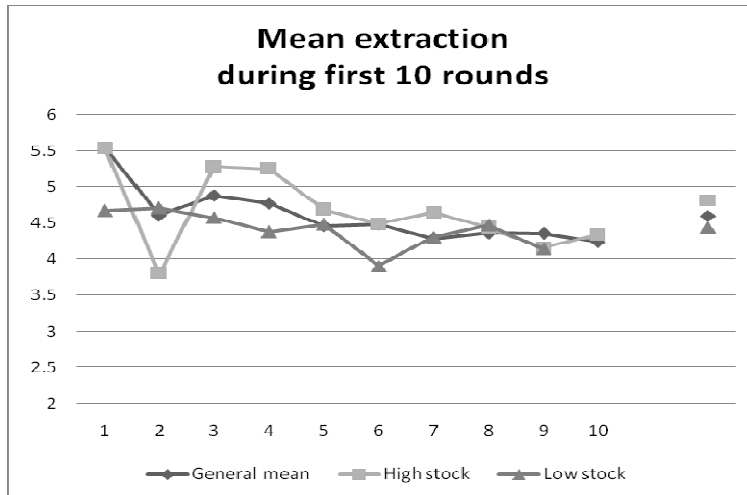
Figure 6 Mean extraction decisions during first ten rounds under the two available resource stocks

When comparing the first 10-round decisions between locations, it is observed that players in locations inside the park tend to extract lower than those located outside the park (Figure 7). Although the difference is not notorious, it is statistically significant (4.41 versus 4.88).
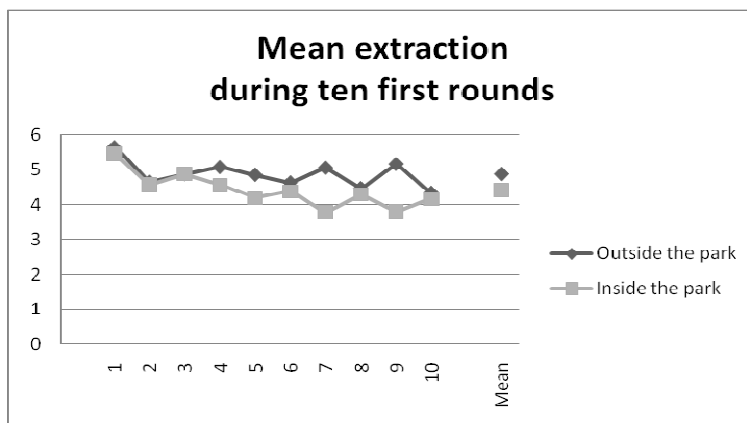
Figure 7 Mean extraction decisions during first ten rounds according to the location

Therefore, there is some evidence supporting the existence of differences on extraction level decisions between zones and under different resource stock availabilities.

Having observed those facts, the most interesting part of the analysis is what happened during the second phase (set of rounds 11-20), when rules (treatments) where included in the game. In fact, during second phase, extraction decisions dropped to 3.23 on average. These results, however, vary from rule to rule as can be observed in Table 2. As expected, game participants that continued in baseline did not exhibit a significant change in decisions. For the other three

rules, communication allowed to reduce extraction in less than one unit, external regulation (high fee) reduced extraction, on average, in almost two units, and co-management resulted to be the most effective rule, reducing the average extraction in more than two units with respect to the first phase (Table 2). This is a compelling result for policy recommendations. However, further analysis including location and resource availability should complement these findings.

Given that the extraction variable ranges from 1 to 8, taking discrete values, data distribution does not behave normally and so, standard statistical tests might not be appropriate. To deal with this fact, we perform the Wilcoxon test (also known as the Mann-Whitney two sample statistic). Results from this test, as well as an estimate of the probability that the mean extraction for the first group (in this case Phase one or rounds 1-10) is larger than the corresponding one for the second group (Phase two or rounds 11-20), are presented in Table 2. Standard tests on differences are consistent with non-parametric tests in all the cases.

Table 2 Effect of treatments on extraction decisions

Zone	Treatment				
	Baseline	Communication	External regulation	Co-management	Total
Phase 1	4.76	4.17	4.99	4.63	4.60
Phase 2	4.46	3.45	3.11	2.32	3.23
Difference	0.30*	0.73***	1.88***	2.31***	1.37***
Mann-Whitney statistic	1.483^{ns}	4.516***	9.988***	14.729***	16.153***
Pr(PH1>PH2)	0.538	0.591	0.733	0.796	0.678

*** significant at 1%   ** significant at 5%   * significant at 10% ^{ns} non-significant

According to the stock availability, it is interesting to observe that under high availability of resource, decisions averaged 3.1, while during rounds under low availability of resource they were, on average, 3.6 units. That is, unlike first ten rounds, players tended –on average- to extract more resources during low-stock rounds (Table 3). This behavior, however, varies according to the rule the participants were playing. While players under baseline and communication treatments decided to extract, on average, more units when stock was high, those under external regulation and co-management rules decided to extract more when the stock exhibited low availability. Nevertheless, no matter the stock state, co-management rule induced participants to extract –on average- the lowest amounts.

Table 3 Average extraction decisions during second phase at every stock resource availability according to treatments

Stock availability	Treatment				
	Baseline	Communication	External regulation	Co-management	Total
High stock	4.84	3.53	2.84	2.21	3.10
Low stock	4.05	3.13	3.69	3.10	3.60
Difference	0.79***	0.40**	-0.86***	-0.89***	-0.50***
Total	4.46	3.45	3.11	2.32	3.23
Mann-Whitney statistic	2.707***	1.991**	-3.626***	-3.179***	-4.248***
Pr(high>low)	0.598	0.571	0.373	0.371	0.425

*** significant at 1%   ** significant at 5%   * significant at 10%   [ns] non-significant

According to zone, it is observed that players located in communities outside the park extract – during the second phase- significantly more than those inside the park (3.77 versus 2.85). These figures must be analyzed case by case for every treatment before making conclusions.

In Table 4 can be observed that locations outside the park exhibited different average results from locations inside it. Extraction averages inside the park tend to be lower than those outside the park for communication and external regulation treatments, and these differences were significant. For the co-management rule, however, the effect is the opposite: players outside the park decided, on average, to extract less than those playing under the same rule inside the park. This observation presents an interesting policy implication: while external regulation and even communication do not have a strong effect on decisions made by people outside the park, having the chance of combining internal communication and some environmental education from park rangers induced them to reduce extraction at some of the lowest observed extraction averages. This implies that they are open to participate in rules aimed to sustainable use of the park when they are recognized by authorities and when education, training and involvement in participation are used as tools for encourage such positive actions.

So far, these results show some evidence that rules such as communication, external regulation and co-management are able to modify extraction behavior, being co-management one of the most relevant in terms of reducing extraction decisions. These results also imply that participants living in communities outside the park may have different incentives than those living inside it and, therefore, their decisions may also be different. In addition, results show some evidence that stock availability may exert some changes in extraction patterns.

Table 4 Average extraction decisions for every rule during second phase according to location with respect to the park

Zone	Treatment					
	Baseline phase 1	Baseline phase 2	Commu nication	External regulation	Co-management	Total
Outside the park	4.88	5.21	4.08	4.20	2.05	3.77
Inside the park	4.41	3.96	3.06	2.02	2.48	2.85
Difference	0.47***	1.25***	1.02***	2.18***	-0.43**	0.91***
Total	4.60	4.46	3.45	3.11	2.32	3.23
Mann-Whitney statistic	3.93***	4.37***	4.69***	4.22***	-3.90***	6.93***
Pr(out>in)	0.562	0.662	0.638	0.799	0.392	0.609

*** significant at 1%   ** significant at 5%   * significant at 10%   [ns] non-significant

Given that stock availability in this experimental game reflects intertemporal effects of decisions and, ultimately, sustainability in the use of the resource, a deeper analysis of the performance of this variable is included. Results show that, while during first phase (rounds 1-10) stock exhibited, on average, high availability in 42 percent of the rounds, during second phase (rounds 11-20) stock reached high availability in 74 percent of the rounds. Within second phase, rules generated significantly different results (Figure 8). Participants that continued under baseline rule increased in a small amount the proportion of rounds that the stock reached high availability (50 percent); this difference, however, is not statistically significant. External regulation rule induced participants to keep stock under high availability 68 percent of the times, being significantly greater than baseline. Communication rule allowed stock to be on high availability 80 percent of the rounds, and co-management rule allowed it to reach high availability 88 percent of the rounds, being the most effective rule in terms of sustainability of the resource being extracted.
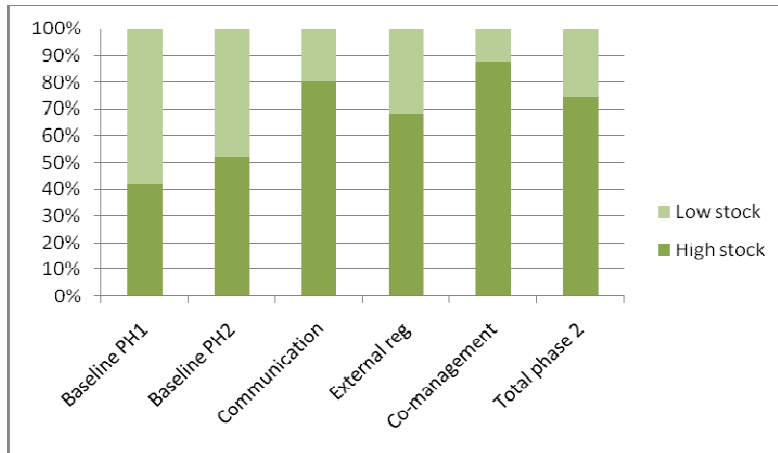
Figure 8 Percent of rounds that stock was in each possible level according to treatments

State of resource stock also varied depending on the location of participants. In general, during second phase, 84 percent of the rounds in locations inside the park exhibited high stock availability while in those locations outside the park only 61 percent of the rounds reached high availability (Table 5). Although these differences were significant along most of the treatments, co-management rule showed the same effectiveness inside and outside the park. If the proportion of rounds under high availability reflects sustainability in the use of the resource, external regulation treatment in games performed outside the park was poorly effective as a tool for encouraging sustainable use, reflecting the reluctance of communities outside the park to comply with external and coercive rules.

Table 5 Percent of rounds that stock was in high availability for games inside and outside the park according to rules

Zone	Treatment				
	Baseline	Communication	External regulation	Co-management	Total
Outside the park	40	63	47	87	61
Inside the park	60	90	90	88	84
Difference	-20***	-27***	-43***	-1	-23***
Total	52	80	68	88	74
Mann-Whitney statistic	-3.095***	-6.447***	-8.054***	-0.390^{ns}	-9.450***
Pr(out>in)	0.400	0.367	0.283	0.493	0.386

*** significant at 1%   ** significant at 5%   * significant at 10% ^{ns} non-significant

Summarizing, these results show that co-management may in fact exert a positive incentive in participants to reduce extraction and maintain the resource at healthy stock levels. While other rules may generate similar effects in some communities, the impacts associated to co-management are consistently better for communities inside and outside the park.

5. Conclusions

Co-management, generally speaking, can be defined as an institutional arrangement in which there exist several degrees of power and responsibility sharing between state and local agents for the management of CPR. This arrangement, also called collaborative management or joint management, implies shared governance of resources between state regulation and self governing institutions (Feeny et al, 1998). In this study, in order to test collaborative strategies, using economic experimental games, we make operative the co-management concept by including an innovative rule that combined repeated communication among players with external non-coercive intervention from actual natural park officials.

Results from this study support previous findings from field economic experimental games. First, our findings show that, unlike standard theory predicts, individuals do not extract the maximum amount of resources they are allowed to and therefore, their decisions deviates from the predicted Nash equilibrium. Second, economic experimental games we performed with fisherman communities confirm empirical evidence related with the role of cooperation in the management of CPR. Specifically, our findings show that repeated communication in experimental games induced players to make decisions about levels of extraction that were lower than those under treatments where communication was not permitted, deviating from Nash equilibrium strategies and approaching to the predicted social optimum. Third, our findings support previous findings about the weak role of external regulation for controlling levels of extraction associated to CPR.

In addition to confirm previous findings from standard treatments, the results from this study make a relevant contribution to both behavioral economics and CPR management literature in two issues: first, the inclusion of a treatment in which a real natural park official –who daily works on environmental education issues with communities- participated as a player in the game, in a rule we called co-management, which was designed for testing complementarities between repeated communication and non-coercive authority intervention –as opposed to

coercive external regulation-. This innovative treatment showed the best results in terms of levels of extraction, not only in communities located inside the park but also in fisherman communities located outside the park but fishing inside it. Levels of extraction under co-management treatment were significantly lower, compared with any other treatment, in all locations were games were performed. This finding suggests that non-coercive strategies –as the one tested here- could generate better responses from communities in terms of conservation and improved management of CPR, not only because asymmetries in information are reduced during the interaction between fishers and natural park officials, but also because communication lets agents understand that social conservation goals, fisherman community –or collective- interests, and individual interests can be reached simultaneously and therefore that they are complementary, no substitutes.

Fishermen know and recognize that over-exploitation and use of inadequate fishing methods cause degradation and, at the end, depletion of marine resources. They also know, however, that acting alone they cannot change the situation. This may be one of the cases, as Ostrom (1990) establishes, in which individuals may not be able to communicate with one another and have no way to develop trust or do not have the capacity to recognize explicitly that they share a common goal. In such cases, some external support is needed to break out the perverse logic of their situation (Ostrom, 1990). This is when the role of authorities providing information and education and facilitating and encouraging community participation in decision making process, in developing strategies, and in monitoring and control activities, is crucial.

A very important finding is that co-management rule induced the lowest level of extraction in fisherman communities living outside the park. This finding becomes relevant by comparing co-management with other treatments, particularly external regulation in those communities. External regulation treatment results show that communities outside the park do not have any fear to be caught violating rules and regulations, maybe because currently the only relationship between those communities and park authorities is a coercive one, unlike the relationship with communities located inside the park, in which communities and park authorities have a wider and more frequent range of interactions.

Another important contribution of this study has to be with the dynamic effect of extraction decisions. We approached a measurement of sustainability in the use of the resource analyzing the proportion of rounds in which individuals let the resource be in a state of high availability.

During baseline rounds –no rules imposed- the number of rounds with low availability of the resource exceeded rounds with high availability although, on average, levels of extraction were smaller under low availability. This finding suggests that although individuals act myopically in the sense that they do not take into account the effect of current decisions on future state of the resource, when the resource exhibits low availability they do restrict their level of extraction, avoiding the over effort required for extracting the last marginal unit when availability of resource is low.

In contrast, during the second stage of the game (rounds 11-20) –rules imposed-, individuals kept , on average, a greater number of rounds with high availability of the resource, implying that rules might have had an effect on inter temporal decision of players. It suggests that rules can play a relevant role on inducing individuals to incorporate future effects of current extraction decisions on state of the resource being exploited.

This study is still in progress and further research including econometric analysis will be performed, in which characteristics of individuals, groups and locations will be tested as variables affecting extraction decisions. Given the nature of data, negative binomial specifications for cross sectional data are being prepared for the econometric approach. Besides, additional and complementary research must be carried out in order to better understand the inter temporal logic of fishers' extraction decisions. Particularly, innovative games should be designed to better capture the implicit behavior of fishers and to illustrate easily to players the effect of overuse of renewable vulnerable marine resources. These innovative designs should include visual tools that facilitate the understanding of the game by communities with very low levels of education.

Additionally, real field experiments, in which the different rules –external regulation, self – regulation and co-management- could be tested in some selected fishing zones during specific periods of time and both communities and park authorities participate actively, would support findings of this type of field experimental economic games.

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Annex 1. Pay-off tables

Green pay-off table for HIGH resource availability and pink pay-off table for LOW resource availability

Green Pay off table or HIGH availability — Their level of extraction (rest f the group) vs My own level of extraction (fish catch)

	1	2	3	4	5	6	7	8
4	795	860	915	960	995	1020	1035	1040
5	775	840	895	940	975	1000	1015	1020
6	755	820	875	920	955	980	995	1000
7	735	800	855	900	935	960	975	980
8	715	780	835	880	915	940	955	960
9	695	760	815	860	895	920	935	940
10	675	740	795	840	875	900	915	920
11	655	720	775	820	855	880	895	900
12	635	700	755	800	835	860	875	880
13	615	680	735	780	815	840	855	860
14	595	660	715	760	795	820	835	840
15	575	640	695	740	775	800	815	820
16	555	620	675	720	755	780	795	800
17	535	600	655	700	735	760	775	780
18	515	580	635	680	715	740	755	760
19	495	560	615	660	695	720	735	740
20	475	540	595	640	675	700	715	720
21	455	520	575	620	655	680	695	700
22	435	500	555	600	635	660	675	680
23	415	480	535	580	615	640	655	660
24	395	460	515	560	595	620	635	640
25	375	440	495	540	575	600	615	620
26	355	420	475	520	555	580	595	600
27	335	400	455	500	535	560	575	580
28	315	380	435	480	515	540	555	560
29	295	360	415	460	495	520	535	540
30	275	340	395	440	475	500	515	520
31	255	320	375	420	455	480	495	500
32	235	300	355	400	435	460	475	480

Red Pay off table or LOW availability — Their level of extraction (rest f the group) vs My own level of extraction (fish catch)

	1	2	3	4	5	6	7	8
4	790	840	870	880	870	840	790	720
5	770	820	850	860	850	820	770	700
6	750	800	830	840	830	800	750	680
7	730	780	810	820	810	780	730	660
8	710	760	790	800	790	760	710	640
9	690	740	770	780	770	740	690	620
10	670	720	750	760	750	720	670	600
11	650	700	730	740	730	700	650	580
12	630	680	710	720	710	680	630	560
13	610	660	690	700	690	660	610	540
14	590	640	670	680	670	640	590	520
15	570	620	650	660	650	620	570	500
16	550	600	630	640	630	600	550	480
17	530	580	610	620	610	580	530	460
18	510	560	590	600	590	560	510	440
19	490	540	570	580	570	540	490	420
20	470	520	550	560	550	520	470	400
21	450	500	530	540	530	500	450	380
22	430	480	510	520	510	480	430	360
23	410	460	490	500	490	460	410	340
24	390	440	470	480	470	440	390	320
25	370	420	450	460	450	420	370	300
26	350	400	430	440	430	400	350	280
27	330	380	410	420	410	380	330	260
28	310	360	390	400	390	360	310	240
29	290	340	370	380	370	340	290	220
30	270	320	350	360	350	320	270	200
31	250	300	330	340	330	300	250	180
32	230	280	310	320	310	280	230	160