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Can Co-Management Improve the Governance of
A Common-Pool Resource? Lessons From A Framed
Field Experiment in A Marine Protected Area in
the Colombian Caribbean

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**CAN CO-MANAGEMENT IMPROVE THE GOVERNANCE OF A COMMON-POOL
RESOURCE? LESSONS FROM A FRAMED FIELD EXPERIMENT IN A MARINE
PROTECTED AREA IN THE COLOMBIAN CARIBBEAN**

**ROCIO DEL PILAR MORENO SÁNCHEZ
JORGE HIGINIO MALDONADO**

Abstract

Complexities associated with the management of common pool resources (CPR) threaten governance at some marine protected areas (MPA). In this paper, using economic experimental games (EEG), we investigate the effects of both external regulation and the complementarities between internal regulation and non-coercive authority intervention—what we call co-management—on fishermen’s extraction decisions. We perform EEG with fishermen inhabiting the influence zone of an MPA in the Colombian Caribbean. The results show that co-management exhibits the best results, both in terms of resource sustainability and reduction in extraction, highlighting the importance of strategies that recognize communities as key actors in the decision-making process for the sustainable use and conservation of CPR in protected areas.

Key words: Common-pool resources, governance, co-management, experimental economic games, fisheries, Latin America.

JEL Classification: C93, C72, D02, D70, Q01, Q22, Q28, C23, C25.

**COMANEJO Y GOBERNABILIDAD DE RECURSOS DE USO COMÚN:
LECCIONES A PARTIR DE EXPERIMENTOS ECONÓMICOS EN UN ÁREA
MARINA PROTEGIDA DEL CARIBE COLOMBIANO**

**ROCIO DEL PILAR MORENO SÁNCHEZ
JORGE HIGINIO MALDONADO**

Resumen

La gestión de los recursos de uso común (RUC) presentes en áreas marinas protegidas (AMP) es especialmente difícil, debido a varias complejidades asociadas con su aprovechamiento. En este documento analizamos, utilizando juegos experimentales económicos (JEE), el efecto que sobre las decisiones de extracción de recursos tienen dos estrategias de manejo: la regulación externa y el comanejo. Operativamente, definimos el comanejo como la complementariedad entre regulación interna (comunicación) e intervención no coercitiva por parte de las autoridades. Los juegos experimentales se desarrollaron en ocho comunidades de pescadores que habitan en la zona de influencia de un área protegida en el Caribe colombiano, el Parque Nacional Natural Corales del Rosario y San Bernardo. Los resultados de los JEE muestran que la estrategia de comanejo, relativa a la de regulación externa, mejora significativamente la sostenibilidad en el uso del recurso y reduce la extracción. Estos resultados resaltan la importancia de reconocer a comunidades locales, usuarias de recursos, como actores clave en el proceso de toma de decisiones para el uso sostenible y la conservación de recursos de uso común en áreas protegidas.

Palabras clave: recursos de uso común, gobernabilidad, comanejo, juegos económicos experimentales, pesca artesanal, Latinoamérica.

Clasificación JEL: C93, C72, D02, D70, Q01, Q22, Q28, C23, C25.

1 Introduction

Marine protected areas (MPA) worldwide are intended to conserve—and in some cases provide for sustainable use—the resources and biodiversity they host. In developing countries, however, MPA are exposed to pressures generated by human activities, the most important of these being tourism and fishing. The conflict between conservation goals in MPAs and fishermen's private interests is typical of common-pool resources, characterized by both non-excludability and rivalry (Feeny *et al.*, 1990; Ostrom, 1990). At fisheries individual fishermen only assume the private costs of their actions, ignoring the social costs, and collectively engaging in the over exploitation of a resource they perceive as “free” (Gordon, 1954; Hardin, 1968). Hardin (1968), suggested that the self-centered and shortsighted behavior of these leads to the overuse and rapid depletion of fisheries' resources, in what he calls “the tragedy of the commons.”

Hardin (1968) proposed two general solutions for avoiding “this tragedy”: (i) establishing private property rights; and (ii) establishing state property rights, whereby access and use are clearly instituted and regulated. That is the case of the National Natural Park “Corales del Rosario y San Bernardo” (NNP-CRSB), located in the Colombian Caribbean Sea.

This park is considered to be of great strategic importance, as it conserves the most developed fringe of the coral reef of the Continental Colombian marine platform (UAESPNN, 2006). One of the most visible sources of pressure on this protected area's resources is its exploitation by native communities. Similar to other protected marine areas around the world, the creation of a national park with laws and regulations controlling access and use has not been sufficient to protect it from exploitation. In the NNP-CRSB, many species are endangered and some of them have even apparently disappeared locally. In response to this reduction in resources, fishermen have increased their efforts, not only by fishing for longer periods and at greater distances from port, but also, in some cases, by violating regulations—using inappropriate fishing techniques, extracting fish smaller than the minimum size allowed, and even extracting prohibited species. This has resulted in conflict between local communities and park

authorities, mining MPA governance and making *de jure* state property seem more *de facto* open access (Camargo *et al.*, 2009).

Given the problems of assigning property rights and the often weak enforcement of fishery regulations, there has been a shift towards the decentralization of the management of fisheries, especially in developing countries. In the case of decentralization, the communities themselves are responsible for defining the regulatory framework, both with respect to what is and is not allowed, and in determining the appropriate punishment if the regulations are not obeyed (Ostrom, 1990). This suggests that, to some extent, fishermen exhibit others-regarding preferences (e.g., Bolton and Ockenfels, 2000; Dufwenberg and Kirchsteiger, 2004; Fehr and Schmidt, 1999).

Experimental evidence has also shown that individuals do not always behave purely out of self-interest, and that they often make decisions that balance their own and collective interests (Davis and Holt, 1993; Kagel and Roth, 1995). Many field and lab experiments support the argument that the behavior of an individual might be determined by—in addition to the possibility of pure material gain—a consideration of others-regarding preferences (Cárdenas, 2004); among these, such elements as altruism, fairness, reciprocity and reputation could play a relevant role (Castillo and Saysel, 2005; Fehr and Gächter, 2000; Fehr and Schmidt, 1999).

The success and sustainability of internal norms strongly depends on many factors; among these are the institutional environment, the social cohesion of the relevant communities, the size of the groups involved, and the degree of interaction these communities have with the market. Some authors argue that it is doubtful that a pure self-governing institution is a realistic option for a case as complex and diverse as fisheries in a modern industrial society, inasmuch as market pressures and the reality of integration with surrounding societies may effectively undermine collective management (Rova, 2004). An intermediate solution would be to combine state regulation and user self-management —what is known as co-management—as suggested by Feeny *et al.* (1990). Co-management has been seen as an alternative that would improve both the effectiveness and equitability of fishery management as well as compliance with agreed upon rules (Jentoft, 1989; McCay, 1996).

Although many economic experimental games aimed at analyzing the behavior of individuals in response to daily-life problems have been carried out in the field (Cárdenas *et al.* 2000; Cárdenas *et al.* 2002; Cárdenas, 2003; Cárdenas, 2004; Vélez *et al.*, 2006), few have tested combinations of institutions in which cooperation and external intervention play simultaneous roles.

In this study, we apply a framed field economic experiment—i.e., a laboratory experiment using real framing (fishing decisions) and real decision-makers (fishermen) (Harrison and List, 2004). In the experiment, we compare three different fishery management approaches using a common pool resource model: (i) open access; (ii) external regulation with random monitoring and monetary punishment; and (iii) co-management. These management strategies are compared using a between subject design, across real fishermen inhabiting the national park's influence zone. Within the context of the conflict between park authorities and local communities, and given the deterioration of the marine resources in the NNP-CRSB, the objective of this paper is to investigate the effect of introducing a co-management strategy on fishing decisions, relative to open access or external regulation strategies. Additionally, we investigate whether behavior differs depending on actual place of residency—that is, whether fishermen living in communities located within the park behave differently than those living in communities located outside of it.

Based on the motivations discussed above, the contribution of this paper is to analyze the complementarities between repeated communication and non-coercive government intervention—what we call co-management—in reducing extraction for two possible levels of stock. In particular, the non-coercive government strategy we test here requires the participation of officials from the NNP-CRSB, individuals who work with communities on environmental education issues. The involvement of a real official from the NNP-CRSB as an additional participant in the experimental game, one which depends on an environmental education strategy—as opposed to relying on such coercive strategies as penalties—constitutes an innovative approach for field experimental games analyzing CPR dilemmas.

The findings are analyzed using parametric and non-parametric tests; they show that the co-management rule is the best strategy in terms of both reducing extraction and in

sustaining the resource. The parametric analysis also shows that extraction decisions depend on socioeconomic characteristics such as per capita income and the main income-generating activity; and the condition of the stock (at present and previous periods), among others. Complementing these findings, this study shows that co-management rule might be an effective strategy not only for individuals located inside national parks but also those located outside of them.

The paper is organized as follows: following the provision of background, we present our theoretical model. From this, we arrive in the third section at our experimental design and game procedures. In the fourth part of the paper, we show our main findings. We present our conclusions in the fifth section.

2 The Common Pool Resource Experiment

2.1 A dynamic common pool resource game

The experiment is a framed field experiment, which in our case means that we represent an actual fishing problem with real resource users. The common pool resource (CPR) for a fishery is described by the difficulties in excluding people from fishing where open access exists, yet where at the same time, only one person can consume a specific unit of the given resource. Essentially, the key characteristic of the common resource problem is that, if acting alone, an individual has an incentive to appropriate more of the resource than if coordinating with others regarding how much of the resource should be appropriated—i.e., the Nash solution and the social optimal solution differ. The model presented below is based on the one proposed by Cárdenas (2004). We extend this model by introducing certain dynamic effects by letting the catch rate for fish in one period determine the stock of fish in the following period. The benefits (and costs) that a fisherman receives from catching fish can be divided into two categories: (i) a private benefit, function $f(x_i, S)$; and (ii) the benefits from (or costs of) the catching decisions of all relevant fishermen such as affects the resource's

availability for others, function $g(\cdot)$.¹ The features of non-exclusion and rivalry when fishermen decide to fish are given by the following pay-off function for fisherman i in period t :

$$\pi_{i,t} = f(x_{i,t}, S_t) + g(\sum_i x_{i,t}) = \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + \gamma \sum_{i=1}^n (e - x_{i,t}), \quad (1)$$

where $\alpha > 0, \beta \geq 0, S > 0, \gamma \geq 0$. The first two terms of equation (1) —private benefits— shows individual revenues depending on parameter α (e.g., the price of the fish), the individual catch rate (x_{it}), and the individual cost of extraction based on the catch rate, the stock, and a technical parameter associated with the cost, β . The last expression shows the effect of the joint catch rate on individual benefits. Parameter e represents the maximum amount that each fisherman can catch, which is assumed to be equal for all fishermen and that, aggregated as n fishermen— ne —reflects the maximum amount of fish that it is possible to catch, given the fishermen's technical capacity. In this way, the expression $\sum_{i=1}^n (e - x_{i,t})$ shows the availability of the resource after extraction by n fishermen, while parameter γ represents the extent of individual benefits affected by the common-pool resource availability.

We introduce the inter-temporal effects of the catch rate by letting the stock of fish change according to the following evolution equation:

$$S_{t+1} = S_t - \sum_{i=1}^n x_{i,t} + F(S_t) = S_t - \sum_{i=1}^n x_{i,t} + \theta S_t (1 - \frac{S_t}{K}). \quad (2)$$

The evolution equation shows that in period $t+1$, the resource will equal the stock at the beginning of period t , minus the extraction of all fishermen during that period plus the net growth function, $F(S_t)$, which depends on the parameters θ and K .²

Given these functional forms, the Nash equilibrium for this model is obtained using the maximization of each fisherman's net present value of benefits subject to the evolution equation:

¹ It is assumed that $f_x \geq 0, f_{xx} \leq 0, f_S \geq 0, f_{SS} \leq 0, g_x \leq 0, g_{xx} \geq 0$.

² We can assume that the growth function is a logistic function, one where parameter θ represents the implicit growth rate and parameter K the carrying capacity of the resource.

$$\begin{aligned} \max_{x_{i,t}} \quad & \sum_{t=0}^T \delta^t \pi_{i,t} = \sum_{t=0}^T \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + me - \gamma \sum_{i=1}^n x_{i,t} \right\}, \\ \text{s.t.} \quad & S_{t+1} = S_t - \sum_{i=1}^n x_{i,t} + \theta S_t \left(1 - \frac{S_t}{K}\right) \end{aligned} \quad (3)$$

where δ represents the discount factor ($\delta=1/(1+r)$), and r is the relevant discount rate. Considering the first order conditions for this problem and abstracting from those related to state and co-state variables, the maximization condition with respect to the decision variable implies that

$$x^p_{i,t} = \frac{S_t}{\beta} (\alpha - \gamma - \delta \lambda_{t+1}). \quad (4)$$

This expression represents the game's Nash equilibrium, and shows that the optimum private catch rate depends positively on the stock and parameter α , and negatively on the costs of catching fish (β), the impact on aggregated benefits (γ), and the discounted inter-temporal price of the stock of the resource ($\delta \lambda_{t+1}$), which is the user cost. In a static framework, fishermen would not consider the latter term.

In order to obtain the catch rate that maximizes the social welfare, a central planner would aggregate the benefits of all fishermen n :

$$\begin{aligned} \max_{x_{i,t}} \quad & \sum_{i=1}^n \sum_{t=0}^T \delta^t \pi_{i,t} = \sum_{i=1}^n \sum_{t=0}^T \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + me - \gamma \sum_{i=1}^n x_{i,t} \right\}, \\ \text{s.t.} \quad & S_{t+1} = S_t - \sum_{i=1}^n x_{i,t} + \theta S_t \left(1 - \frac{S_t}{K}\right) \end{aligned} \quad (5)$$

The first order condition with respect to the catch rate then implies that

$$x^{soc}_{i,t} = \frac{S_t}{\beta} (\alpha - n\gamma - \delta \lambda_{t+1}). \quad (6)$$

Expression (6) shows that when analyzing the social welfare, the optimal catch rate must be lower than that indicated in expression (4), as the proportion of the available stock of fish affecting benefits (γ) needs to be aggregated for n fishermen in order to capture the full cost of the catch rate decisions.

2.2 A dynamic common pool resource game with a monetary penalty

In order to incorporate the effect of any external regulations—that is, the probability, ρ , that a fisherman is being monitored—we define overfishing as the amount of fish caught above the social optimal level $(x_i - x_i^{soc})$, and the fine for each unit caught above the permitted level as m . If we add these variables to equation (5), we get

$$\begin{aligned} \max_{x_{i,t}} \quad & \sum_{t=0}^T \delta^t \pi_{i,t} = \sum_{t=0}^T \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + me - \gamma \sum_{i=1}^n x_{i,t} - \rho m (x_i - x_i^{soc}) \right\} \\ \text{s.t.} \quad & S_{t+1} = S_t - \sum_{i=1}^n x_{i,t} + \theta S_t \left(1 - \frac{S_t}{K}\right) \end{aligned} \quad (7)$$

Solving for the first order conditions (and assuming a risk-neutral individual) we obtain the optimal private catch level when external regulations are imposed with imperfect monitoring:

$$x_{i,t}^r = \frac{S_t}{\beta} (\alpha - \gamma - pm - \delta \lambda_{t+1}). \quad (8)$$

Based on this theoretical framework, we are able to design our experiment.

3 Experimental design and procedures

At every location, a group of 25 to 30 people was gathered and organized into subgroups of five persons each. Each five-person group represented the collective decision-making entity with respect to the experiment; each member made individual, private and confidential decisions that were treated anonymously. The experiment was performed in two phases, both of which were divided into ten rounds. During the first phase of the experiment, all of the groups played a CPR game without any regulations (open access). During the second phase—i.e., the last ten periods—the groups were randomly allocated one of three possible treatments: (i) open access or baseline, (ii) external regulation, or (iii) co-management.

Expressions (4) and (6) are used to construct the pay-off tables that participants used during the game. Following the CPR experiments conducted by Cárdenas (2004), we determined that each participant should be able to extract any integer amount

between 1 and 8.³ To create the pay-off matrix utilized in the experiment, we set the parameters as $\alpha = 100$; $\beta = 800$; and $\gamma = 20$. In order to make the game cognitively easier and understandable for the subjects, we decided to only simulate two levels of stock—a high level (abundant) and a low level (scarce). More specifically, we set the former at 80 units and the latter at 40 units. Based on this, we constructed two payoff tables, one for each stock level. The pay-off tables show the net benefits for individual i of different combinations of individual and aggregated extractions (see Appendix A). If a player does not take into account the inter-temporal effects of his or her decisions, the model predicts that the term $\delta\lambda$ converges to zero. Expression (4) then reduces to

$$x^p_{i,t} = \frac{S_t}{\beta} (\alpha - \gamma). \quad (9)$$

Expression (9) is equivalent to a myopic Nash equilibrium, which we used as a benchmark in the experiment. To obtain Nash equilibriums, we used the parameters and two levels of stock mentioned above; this yields a Nash equilibrium equal to 8 units (40 units per group) for the high stock level and 4 units (20 units per group) for the low stock level. Given that x ranges between 1 and 8 and that the benefit function is quadratic for the level of extraction and non-linear for the level of stock, the predicted Nash equilibrium for abundance (high stock) is a corner solution, while that for scarcity is an interior solution. On the other hand, the social equilibrium corresponds to a level of extraction of 1 unit (5 units per group) for either stock level.

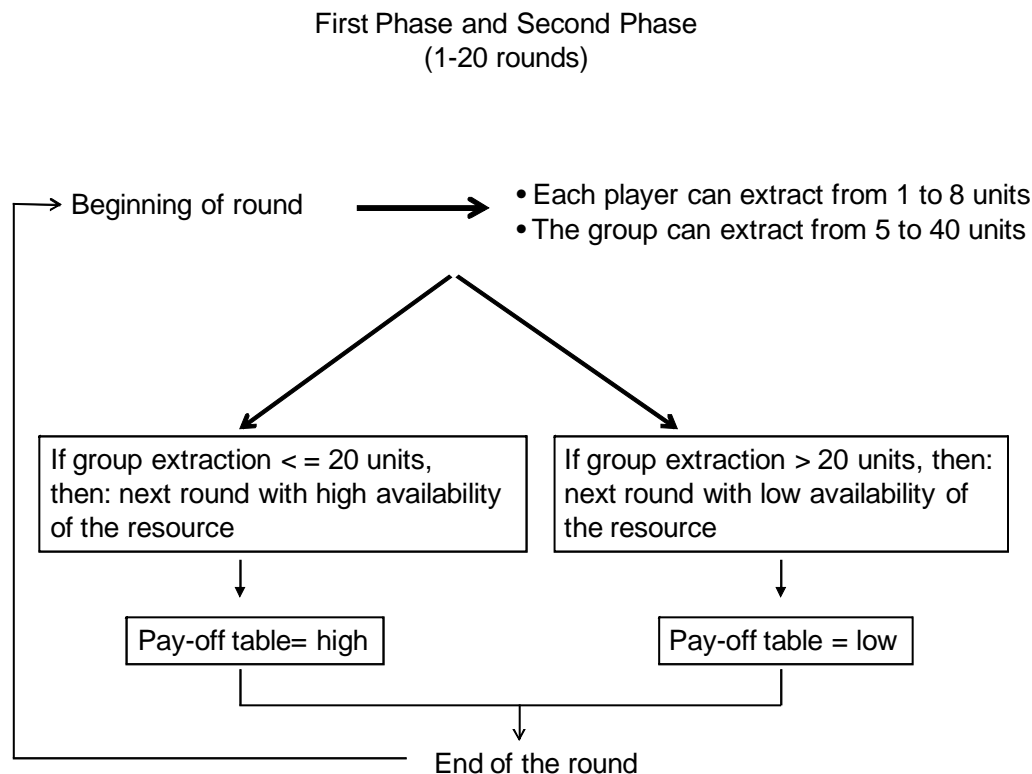
In the case of external regulation, the Nash equilibrium corresponds to an individual extraction of six units for high stock and three units for low stock.

The dynamic part of the game was designed as follows: if the aggregated extraction of the group's five members exceeds 20 units, the stock of the resource for the next round becomes low; the low availability of the resource in next round is caused by over-extraction during the current round. Under a low-stock scenario, every unit of extraction earned fewer points than under a high-stock scenario, inasmuch as the low availability of the resource implies more effort per unit of fish caught—which translates into fewer benefits. Conversely, if extraction by the whole group is less than or equal to 20 units,

³ Cárdenas (2004) argues that it is convenient to eliminate the zero extraction option when conducting experiments so as to avoid conflicts that arise due to villagers' strong aversion to prohibitions against using resources altogether.

during the next round the stock of the resource becomes abundant (i.e., there is high availability). High stock requires less effort per unit of fish caught, and thus translates into higher returns. Figure 1 shows the dynamic component of the experiment.

Figure 1. The dynamic component of experiment.



During the first ten periods, there was open access fishing; the last ten periods, conversely, were characterized by one out of the three treatments randomly assigned to each group.

Treatment 1: Open access. This treatment was assigned to the control group; the same conditions prevailed as during the first phase.

Treatment 2: External regulation with fine. The objective of this treatment was to induce subjects to extract only one unit of the resource, using an imposed fine as an external regulator. In order to simulate imperfect enforcement, the monitoring decision was random and every player had a one-tenth probability of being monitored per round. Operatively, imperfect monitoring was carried out using 10 balls in a bag—five white and five red, with each red one being numbered. Each player was assigned a

corresponding number. For each fishing round, a ball was taken from the bag—if it was white, no monitoring occurred; if it was red, the player whose number corresponded to that on the ball was inspected. If the individual inspected had violated the rule (to extract one unit), he or she had to pay a fine equivalent to 200 points per each unit extracted above what was allowed; this was deducted from the gains made during that round. The ball was then returned to the bag; in this way, each player had the possibility of being monitored more than once. All of the other rules were the same as in the baseline, and decisions, as well as fines, were kept private and confidential. No communication was permitted between players.

Treatment 3: Co-management, with internal communication and external non-coercive intervention. Under this treatment, before starting the second phase, the group had the opportunity to talk for up to five minutes with a national park ranger, who was introduced to the game as an “advisor.” The ranger had to base his or her conversation on a pre-designed script, effectively expressing his or her ideas about conserving park resources and trying to persuade each group member to extract only one unit of the resource. After that, the group had five minutes to discuss the ranger’s recommendations between themselves. Any interventions by the park officer were recorded. The group members then made their final decisions—in private and under strict confidentiality—for the first period of the second phase; the total amount extracted was then announced. For each successive round, the park representative was given one minute to talk with the group, following which, group members had one minute to discuss.

The anonymity and confidentiality of individual decisions were guaranteed by seating players back-to-back as well as by the presence of a researcher who monitored and supervised each group and collected the individual extraction levels written down by the fishermen. With the support of an environmental educator—an expert in working with communities—the game was explained to each group of fishermen. To facilitate this—inasmuch as the participants all tended to come from low-educated communities—different visual aids were used, such as drawings and posters. In addition, following explanation, three training rounds were carried out in order to ensure that the participants fully understood the game before starting it.

Every participant in the experiment obtained points, convertible into money; the average final payment was thus equivalent to the income they would have obtained during a typical working-day. At the current rate, this payment is equivalent to 10 dollars per player. Payments were confidential.

Following completion of the experiment, the participants filled out surveys. The main results of the game were then presented and discussed openly with the subjects and park officers.

4 The Results

The experiment was carried out in eight northern Colombian fishing communities, and was inclusive of 195 subjects. Three of the communities are located within the borders of the NNP-CRSB; the other five are located outside of them, yet extract resources from the park area. In addition to testing the effects of the co-management treatment, we were interested in learning whether communities located inside and outside the park borders responded differently to the different management strategies.

Within the communities located inside the park, players averaged 30 years of age; 13 percent were women and the per capita income was equivalent to almost half the minimum wage when family-size was weighted (adults were weighted double what kids were). Outside the park, the average age of players was close to 39; only 3 percent of players were women and scaled income was lower than that of players residing inside the park. Most of the participants reported fishing as their main activity (68 percent for those inside the park, and 84 percent for those outside of it). The distribution of players for each zone based on the treatment they were subjected to is presented in Table 1.

Table 1. The Number of players and groups residing inside and outside the park based on the treatment they were subjected to.

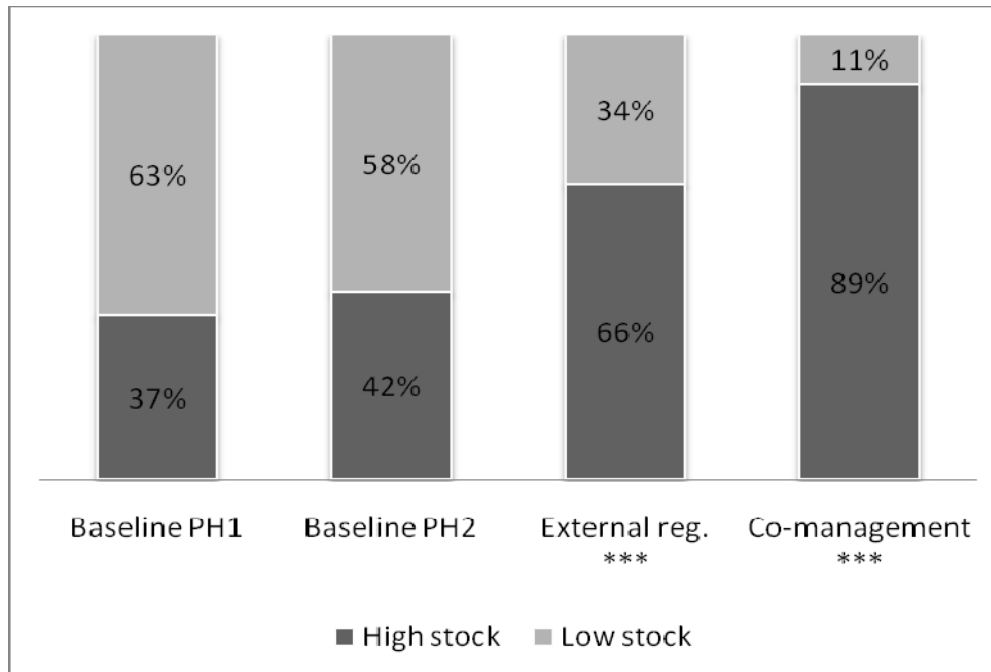
Zone	Treatment			Total
	Baseline	External reg.	Co-management	
Players outside of the park	25	45	45	115
Players inside of the park	20	25	35	80
Total players	45	70	80	195

4.1 Sustainability of the use of the resource

Recalling that the stock level in the game reflects the inter-temporal effects of decisions, we measure the sustainability in the use of the resource as the proportion of periods that a group achieves a high stock during a phase of the game. The measurement ranges from 0 to 100 percent; the closer the number to 100, the higher the level of sustainability. The results show that while during the first phase (periods 1-10), on average, the stock exhibited abundance 37 percent of the time, during the second phase (periods 11-20), and under the treatment where players continued to have open access, high stock availability was achieved 42 percent of the time. The difference between phases 1 and 2 is not statistically significant.⁴ Under the treatment featuring external regulation, a high stock was achieved 66 percent of the time during the second phase. This is significantly higher than what was achieved under the baseline. Under the treatment featuring co-management, high availability was achieved 89 percent of the time. Again, this is significantly higher than what was achieved under the baseline (Figure 2).

⁴ Given that there is no *a priori* information by which we can assume any particular distribution, we performed non-parametric tests in order to evaluate the differences in means. Specifically, a Mann-Whitney statistic, MWS (Wilcoxon test) was performed to evaluate the hypothesis that two independent samples are from populations with the same distribution.

Figure 2. The proportion of rounds at each stock level according to treatment



Asterisks denote significant differences compared to the baseline PH1 with a confidence level of 99%.

In Table 2, we present the same analyses as in Figure 2, but here the figures are discriminated by location, i.e. inside versus outside the park. The difference in the proportion of periods with high stock levels is significant across locations for the open-access treatment and external-regulation treatment; there is no significant difference for the co-management treatment. If the proportion of periods showing high availability reflects the sustainability of the use of the resource, the external regulation treatment applied to those players living outside the park proved relatively effective as a tool for encouraging sustainable use of the resource; this reflects the reluctance of those communities located outside the park to comply with external and coercive rules. The results also show that the impacts associated with co-management are consistently better for communities located both inside and outside the park.

Table 2. The percentage of periods in the second phase during which stock was highly available according to location and treatment.

Zone	Treatment ^a		
	Baseline	External regulation	Co-management
Outside of the park	32%	59%	89%
Inside of the park	55%	80%	89%
Difference	-23%***	-21%***	0% ^{ns}
Total	42%	66%	89%
Mann-Whitney stat.	-4.903***	-5.663***	0.141 ^{ns}
Pr(out>in)	0.385	0.394	0.502

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

^a Two tests can be used to evaluate for differences between the groups. The first is a standard t-test on mean differences, the significance of which is presented in the row labeled "Difference." The second is the Mann-Whitney test.

4.2 Extraction decisions

According to the design of the experiment, the expected theoretical extraction level under the non-cooperative setting is eight units for high stock and four units for low stock; the social optimum is one unit. Nonetheless, when players were exposed to the game under the baseline treatment (i.e., during the first phase), the total average extraction was 4.73 units, which apparently seems to constitute a moderate extraction, given the range of plausible extractions (1-8). What is relevant for our analysis, however, is the extraction averages under each stock level. For high stock, the average extraction was 5.19 units, which is almost three units below the expected Nash equilibrium for that level of stock. This finding, which assumes open access, confirms the previous findings from the field experiment literature, where individuals deviated from self-centered and individualistic behavior when making individual decisions that seemed to incorporate collective interests, even where no institutions were present. However, for low stock and open access, the average extraction was 4.45 units, 0.45

units above the expected equilibrium, which constitutes a privately inefficient response from players. Recall that although the private equilibrium for low stock is four units, individuals might still extract up to eight units. Cárdenas et al. (2004) find a similar response in the field experiments they carried out in Colombia, likewise using interior solutions like the one we used here for low stock.

The most interesting part of the analysis concerns what happens during the second phase (periods 11-20), when the treatments are applied to the game. Table 3 shows the findings for extraction decisions during the two phases. During the second phase, extractions dropped from an average of 4.73 units to 3.37 units. The results, however, vary depending on which rules are applied and the level of stock (whether high or low). With respect to differences in extraction decisions, both standard tests on differences and the non-parametric tests are consistent.

Table 3. The effect of management strategies on extraction decisions for both high and low resource stocks.

Phase	Treatment						Total		
	Baseline		External regulation		Co-management				
	High	Low	High	Low	High	Low	High	Low	Total
Phase 1	5.49	4.31	5.51	4.48	4.81	4.54	5.19	4.45	4.73
Phase 2	5.15	4.24	3.59	3.80	2.35	3.04	3.16	3.88	3.37
Diff	0.33 ^{ns}	0.07 ^{ns}	1.92 ^{***}	0.65 ^{***}	2.46 ^{***}	1.49 ^{***}	2.03 ^{***}	0.57 ^{***}	1.35 ^{***}
Rounds	73	107	138	142	206	114	417	363	780
MWS	1.35 ^{ns}	0.34 ^{ns}	9.73 ^{***}	3.80 ^{***}	15.73 ^{***}	5.37 ^{***}	18.23 ^{***}	5.04 ^{***}	18.19 ^{***}
Median test (chi2)	0.37 ^{ns}	0.02 ^{ns}	78.2 ^{***}	7.09 ^{***}	209.1 ^{***}	24.13 ^{***}	263.2 ^{***}	14.59 ^{***}	195.4 ^{***}
*** significant at 1% ** significant at 5% * significant at 10% ^{ns} non-significant									

As expected, differences for high and low stocks are not significant between phases under the open access treatment. Conversely, columns 8 and 9 of Table 3 show

that on average, the rules were effective in reducing the level of extraction regardless of the condition of the stock.

Particularly, in the case of external regulation, it is observed that during the second phase, individuals extracted less—for both high and low stock—than they did during the first phase; these are significant differences. For instance, Table 3 shows that for high stock, the external regulation treatment causes individuals to extract 1.92 units less than they would under open access. In the same way, for low stock, individuals facing external regulation extract 0.65 units less than when facing open access. Similar behavior is observed when the co-management treatment is applied. Here, individuals extract less than when facing open access, regardless of the level of stock. The reduction in extraction when applying the co-management treatment—compared with an open access scenario—was by 2.46 units for high stock and 1.49 units for low stock; those reductions are highly significant.

Another relevant issue that needs to be analyzed is the effect of community location on extraction decisions. Table 4 shows that players living in communities located outside the park extracted more on average than those located inside the park for both stock conditions (0.29 units more for high stock and 0.51 units more for low stock). However, Table 4 also shows that extraction decisions varied between outside and inside communities depending on the treatment applied. For instance, for both the open access and external regulation treatments, extraction averages for communities located inside the park tended to be lower than those for communities located outside it; these differences are significant. The effect was different, however, under the co-management treatment: here, on average, players residing outside the park decided to extract less than players residing inside it when the stock was abundant. When the stock was low, the difference between inside and outside communities was not significant. This observation suggests an interesting policy implication—while external regulation did not have a strong effect on the decisions made by fishermen living outside the park, the combination of internal communication and non-coercive intervention by park rangers did induce them to reduce their extraction to the lowest observed extraction averages. This could imply that, when recognized by authorities and when education, training and participation are used as tools for encouraging

positive action, fishermen are open to participating in rules aimed at the sustainable use of resources.

Table 4 Average extraction decisions for each treatment according to location with respect to the park.

Zone	Treatment											
	Baseline phase 1		Baseline phase 2		External regulation		Co-management		Total Phase 2		Total game	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Outside	4.63	5.54	4.41	6.15	3.98	4.18	3.20	2.08	4.06	3.26	4.44	4.00
Inside	4.12	4.85	3.93	4.43	3.12	2.81	2.85	2.69	3.47	3.04	3.93	3.71
Diff	0.51 ***	0.69 ***	0.47 *	1.72 ***	0.86 **	1.37 ***	0.35 ns	-0.61 ***	0.60 ***	0.23 *	0.51 ***	0.29 ***
Total	4.45	5.19	4.24	5.15	3.80	3.59	3.04	2.35	3.88	3.16	4.27	3.86
MWS	3.76 ***	4.09 ***	1.77 *	5.30 ***	2.46 **	6.49 ***	0.36 ns	-5.82 ***	3.15 ***	0.57 ns	4.55 ***	2.01 **
Median test (chi2)	8.59 ***	7.65 ***	0.54 ns	19.0 ***	3.66 *	47.8 ***	1.08 ns	26.4 ***	6.22 **	0.00 ns	12.3 ***	7.31 ***
*** significant at 1% ** significant at 5% * significant at 10% ns non-significant												

4.3 Parametric analysis

So far, these results provide some evidence that rules such as external regulations and co-management are able to modify extraction behavior; co-management would seem the most relevant in terms of reducing extraction and inducing sustainability in the management of the resource. The results also suggest that participants living in communities located outside of the park may have different incentives than those living in communities located inside of it. Consequently, their decisions may also be different. Additionally, the results provide some evidence that stock availability may exert certain changes in extraction patterns. These results, however, do not consider the effects of

certain variables, such as socioeconomic conditions and multivariate relations. A parametric analysis is therefore proposed in order to validate these results.

In our econometric model, the dependent variable is the level of extraction, while the statistic unit of analysis is the individual observation of the level of extraction for each round. Given that there are several observations associated with each particular player (for 10 rounds), the data are treated as a panel, wherein the correlated error with respect to the observations for each participant is considered apart from the error associated with between-player differences. As the dependent variable takes discrete values for integers one through eight, the proposed specification is a count data model. To consider the possibility of over dispersion, the model is treated as a negative binomial one.

With respect to the independent variables, we use several categories of variables:

- a. Treatment variables. The main hypothesis of this study concerns whether different rules have different impacts on individual decisions. To test this, we introduce two categorical variables: an **external regulation**, which takes a value of one if the player was exposed to it, and zero otherwise; and **co-management**, which takes a value of one if the player was subjected to it, and zero otherwise. Given that co-management implies the participation of a park officer, and that we had three different rangers help us with the experiments, two categorical variables are included in order to control for their participation, and to see if the results differed based on which park official was involved—**ranger1** or **ranger2**.
- b. Dynamic variables. Two other variables relevant to participant behavior in the game are also included: the **current stock level**, which takes a value of one if the stock during the round in question was high, and zero if it was low. We also control for the **previous stock level**, with a categorical variable that takes a value of one if during the previous round the stock was high, and zero if it was low.
- c. Socioeconomic and demographic variables. The characteristics of individual players may exert influence on their final decisions. Six variables are included under this category: **gender** is represented by a categorical variable that takes a value of one if the player is a woman, and zero otherwise. **Per capita income** is

calculated by dividing the household income between the household's members; household size is weighted by considering household members younger than 18 years of age as one half an adult. Information concerning the main income-generating activities of participants allowed us to further divide them based on whether they engaged in **agriculture**, the manufacture of **handcrafts**, **trade**, and other activities. Finally, there is a categorical variable, **location**, which takes a value of one if the player lives inside the park, and zero otherwise.

- d. Perception variables. After the experiment, a survey was conducted of the participants. In this survey, questions about perception were included; two of these were used in the model. **The usefulness of participation** was represented by a categorical variable taking a value of one if the respondent answered yes to the question: Do you think that participating in meetings about the management of the park is useful for solving natural resource-related conflicts? The second one, concerning the **enforcement ability of park authorities**, was represented by a categorical variable that took a value of one if the participant answered yes to the question: Do you think that park authorities have enough capability to enforce rules in the park area? In both cases, the variable took a value of zero if the respondent answered no to the question.

The results for the model are presented in Table 5. Our main hypothesis, that treatments are effective in reducing the level of extraction, is confirmed—regulation and co-management did reduce extraction levels significantly. It is also clear that co-management represents a more effective approach, as the reduction in the level of extraction was about five times what the case with external regulation was. Having different rangers participate in co-management affected group performance in a significant way as well—rangers 1 and 2 induced a reduction about one third less than that induced by the base ranger (ranger 3). These results imply that officers might use different strategies in convincing communities to extract less, and that these different strategies may result in significant differences in players' decisions.

Table 5 The negative binomial estimates for individual extraction during the second phase of the game.

Dependent variable: individual extraction	Coefficient	Std. Err.
External regulation (1 yes 0 no)	-0.151*	0.090
Co-management (1 yes 0 no)	-0.785***	0.122
Ranger 1 (1 yes 0 no)	0.339**	0.137
Ranger 2 (1 yes 0 no)	0.368***	0.122
Current stock level (1 high 0 low)	0.171***	0.038
Previous stock level (1 high 0 low)	-0.190***	0.036
Location (1 inside 0 outside the park)	0.031 ^{ns}	0.072
Player gender (1 woman 0 man)	-0.179 ^{ns}	0.143
Per capita scaled income (minimum monthly wages)	0.219*	0.115
Main activity: Handcraft (1 yes 0 no)	-0.666***	0.214
Agriculture (1 yes 0 no)	-0.111 ^{ns}	0.293
Trade (1 yes 0 no)	-0.074 ^{ns}	0.153
Participation is useful (1 yes 0 no)	-0.168**	0.072
Enforcement ability of park authorities (1 yes 0 no)	-0.138*	0.081
Constant	1.580***	0.108
Observations	1590	
Groups	159	
Wald Chi-sq(k)	181.47	
* significant at 10% ** significant at 5% *** significant at 1% ^{ns} not significant		

With respect to the level of stock, an interesting way of analyzing its dynamic effects is by combining previous and current stock availabilities along with observed coefficients. In Table 6, the effect of the four combinations of previous and current stock on extraction decisions is analyzed. The previous and current low availability constitute the baseline. Now, if the previous stock level was low and the current stock level is high, individuals will tend to extract more (0.17 units more than the baseline case);

conversely, if the previous availability was high and the current stock level is low, extraction is reduced by 0.19 units. Where players faced high availability the previous round and the current round also exhibits a high level of availability, the level of extraction remains the same compared to the baseline case (that is, the value is not statistically different from zero). Those results are coherent with expected player behavior with respect to resource extraction under different stock levels.

Table 6. The effect of changes in the stock availability on extraction decisions.

		Current stock	
		Low	High
Previous stock	Low	0	0.170***
	High	-0.190***	-0.020 ^{ns}

** significant at 5%

*** significant at 1%

^{ns} not significant

From the non-parametric analysis, some information was obtained about the differences in the results with respect to the place of residence. However, in the parametric analysis, the variable itself shows no significance with respect to extraction decisions. The location effect is absorbed by other variables in the model when a multivariate analysis is performed.

The socioeconomic variables included show that women tend to extract less, although the difference is not significant. The per capita income coefficient shows that the poorest players extracted less than richer ones; here, the difference is significant. This result challenges the usual assumption that the poorest groups in society are responsible for the environmental degradation of ecosystems, and suggests that this assumption should be revisited. It is important to recall, however, that among the participants, income levels were not widely distributed. Those participants that were mainly devoted to the manufacture of handcrafts exhibited a lower level of extraction compared to other groups, while those engaged in agriculture and trade did not exhibit a significant difference from the baseline group, which mainly consisted of fishermen.

Perception analysis shows that those individuals that believe in the usefulness for solving problems of participating in meetings about the management of protected

areas are the same individuals with lower levels of extraction, which is a coherent response. Similarly, those who believe that authorities are well equipped to enforce regulations in park areas also tended to extract less during the game.

The regression as a whole explains extraction decisions, and there is no evidence of over-dispersion in the model.

These results confirm that rules play an important role in defining the pattern of use of common pool resources. Other characteristics, such as socioeconomic and perception variables, also play an important role, and the interaction between them generates the current pattern of resource use in the protected area; this is important to consider when policy recommendations are being determined.

5 Conclusions

Co-management can be defined as an institutional arrangement in which several degrees of power and responsibility are shared between state and local agents for the management of a CPR. This arrangement implies the shared governance of resources between state regulation and self governing institutions. In this study, we test collaborative management strategies by conducting a CPR experiment in which we combined the possibility of repeated communication between players with external non-coercive intervention by actual natural park officials.

The results from our study support some previous findings from other experiments. First, unlike predictions based on standard theory, they show that individuals do not extract the maximum amount of resources allowed—i.e., their decisions deviate from the predicted Nash equilibriums, results that we observed under abundance. Second, the field experiments we performed within fishing communities confirm previous empirical evidence related to the role of external regulation in the management of CPRs. However, our findings reveal that external regulation plays a weak role in controlling the levels of extraction associated with CPRs, in particular, with respect to communities located outside protected areas.

Additionally, the results from our study contribute both to behavioral economics and the CPR management literature for two reasons. First, the inclusion of a treatment

wherein an actual park official—one who works on a daily basis on environmentally educating communities—participated as an agent in the experiment, was for the purpose of testing complementarities between communication and non-coercive authority intervention, as an alternative to coercive external regulation. This innovative treatment showed the best results in terms of extraction levels, not only for communities located inside the park but also for those located outside of it. The levels of extraction under the co-management treatment were significantly lower compared with those under any other treatment, for all locations where the games were carried out. This finding suggests that non-coercive strategies could generate better responses from communities than coercive ones, in terms of the conservation and improved management of CPRs. This may not only be because of reduced asymmetries in information brought about by interaction between local users and park officials, but also because communication allows agents to recognize that social conservation goals, community interests, and individual interests can be satisfied simultaneously, and that they are complementary rather than opposed to one another.

Local users know and recognize that over-exploitation and the use of inadequate fishing methods cause degradation and, in the end, deplete marine resources. They also know, however, that acting individually, they cannot change the situation. This is what happens, as Ostrom (1990) establishes, when individuals are unable 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 necessary to break out of the perverse logic of their situation (Ostrom, 1990). This is where the role of authorities—in providing information and education, in facilitating and encouraging community participation in the decision-making process, in developing strategies, and in monitoring and controlling activities—becomes crucial.

The other contribution is the one related to what we here call resource sustainability. We measured the sustainability in the use of the resource by analyzing the proportion of rounds in which individuals allowed the resource to reach a state of high availability. During open access the number of rounds with low resource availability exceeded the number of rounds with high availability. This suggests that individuals act

myopically, in the sense that they do not take into account the effect of current decisions on the future state of the resource. Conversely, during the second stage of the game, when rules were imposed, individuals maintained a higher number of rounds with high resource availability, implying that rules might have an effect on the inter-temporal decisions of players. This suggests that rules can play a relevant role in inducing individuals to incorporate future effects into their current extraction decisions regarding the state of the resource being exploited.

Parametric analyses confirmed our findings derived from non-parametric tests, regarding (i) the role of rules in reducing extraction; and (ii) the fact that the condition of the resource (whether high or low) is an important determinant of participants' extraction decisions. Our findings regarding fishermen's perceptions on the enforcement capabilities of park authorities and the relevance of meeting with them about resource management have policy implications, as they might indicate that a balanced combination of control and non-coercive intervention may be a suitable strategy for protecting these areas. The parametric analysis yielded another interesting finding that challenges a generally held belief—richer agents extract more than poorer ones. This latter result constitutes a motivation for deeper research.

In addition to their value for testing new rules, field experiments also work as a pedagogical tool that encourages local users to actively participate in, communicate about, and discuss problems related to CPR. This is an important aspect of the experiments, especially with respect to fishermen that often have low levels of education, such as are generally found in developing countries.

Finally, over extraction found under resource scarcity and open access is an issue that deserves further investigation.

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8 Appendix A. Pay-off tables

The green pay-off table for HIGH resource availability, and the pink pay-off table for LOW resource availability.

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