Socio-Ecological Dynamics of Artisanal Lobster Fishery System in Providence and Santa Catalina Islands – Colombian Caribbean

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Abstract

The objective is to study the resilience of the artisanal fishery system in Spiny Lobster *Panulirus argus* as a social-ecological system. Three subsystems were analysed using as methodology dynamic modeling tools and semi structural interviews. The first subsystem is the lobster population which simulates life history, population and meta-population dynamics, as well as density-dependence effect. The second subsystem is the fishery activity analysed from two perspectives: *material fishery,* based on historical data extraction; and *virtual fishery,* based on experimental economic approaches to fishermen behavior in a context of common pool resource (CPR), simulating the effect of institutions as communication, allowance and monitoring of external norms accomplishment.

Both approaches simulate multiple stability domains in order to find variables or interactions between themselves capable to explain the resilience gains or losses between these equilibrium domains. This approach was complemented by a third analytical perspective: the study of traditional ecological knowledge (TEK) and the misperceptions as a cultural subsystem.

The findings show dynamic failures directing the system to undesirable stability domains where fishery is unsustainable. These failures are related with the subsystems interactions and they are expressed in several aspects as losses of species reproductive potential, perception of not resource exhaustion, the poverty trap of fishing effort increases, high yield of exploitation, or norms breaking.

Based on the results, we suggest vital strategies for the local resource management: *i)* the change of equality notion inside the fishermen population and external agents, *ii)* recovering the fisherman labour prestige in order to sustain the social memory, and finally *iii)* to go further in the harvest arrival monitoring, regarding capture sizes and gender looking for to estimate reproductive potential. This last variable has shown to be sensitive to changes in resilience gains and losses inside the biological subsystem. From a regional management view, fishery must be analyzed regarding the resource natural scale, as a Pan-Caribbean meta-population. It is therefore mandatory to make international cooperation efforts for sharing fisheries information, in addition to find ways to understand meta-population dynamics of lobster and the second order CPR.

Keywords: *Common pool resource, lobster fishery, misperceptions, institutions, system dynamics, ecological modelling*

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INTRODUCTION

Natural resources dynamics is a source of problematic uncertainty for resource management. We really can not forecast the future consequences of present harvesting levels. Therefore it is mandatory to take actions under parametres of uncertainty and absence of ideal information or data.

Traditionally, in Providence and Santa Catalina islands (Colombia Caribbean Sea) stakeholders have recognised sustainability as an ideal strategy on resource management. Base organizations and environmental authorities have led projects *in situ* in order to find better fishing practices. Even so, the technical data (Medina, 2004; Yanovich, 1997; Arango & Márquez, 1996; Ragua & Rubio, 1995), fisherman perception (Gorricho & Rivera, 2004a; Márquez, 2005) and legal measures show us a deep failure between the desired or expected results of local community and those that they finally achieve. This failure is due in part of different sustainability concept interpretation, and therefore, to the the actions that stakeholders take according their interpretations and individual interest.

Sustainability is the fundamental issue that underlies management of natural resources. The following definitions are the concepts that orient our vision of natural resources management. "*Sustainaility is the use of environment and resources to meet the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1999 in Kates *et al*., 2005; Berkes *et al*., 2003). According to Walker *et al.* (2002) "*sustainability involves maintaining the functionality of a system when it is perturbed, or maintaining the elements needed to renew or reorganize if a large perturbation radically alters structure and function. The ability to do this is termed resilience*" (Walker *et al.*, 2002). As a result of our empirical work with local communities in Colombia and in line with Gunderson & Holling (2002), we claim the management of resilience of socio – ecological system should be a central factor in the management of socio-ecological systems in order to deal with uncertainty. We use resilience concept of Gunderson & Holling (2002): "*Resilience is measured by the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour*". Consequently, the sustainability paradigm could be reached by improving and looking after the resilience of system desired states and reducing the resilience of system undesirable states as proverty traps, subsistence or semi-subsistence equilibria (Gurnderson & Holling, 2002).

This paper reports the results of a study which fundamental goal is to understand the artisanal lobster fishery system behavior in order to find stability domains (Gunderson & Holling, 2002; Scheffer et al, 2001; Carpeter et al, 2001; Perrings, 1998), the variables who define it and system relevan feedbacks.

The case study chosen is the spiny lobster (*Panulirus argus)* fishery in Providence and Santa Catalina islands. Before to deepen in the local fishery's features it is important to clarify some concepts. Fishery is a common pool resource (CPR), it means that users tend to prefer increase his individuals profits rather the colecive benefits. A CPR present a dilemma between the individual and colective interest and it is defined by excluidable and sustractibility properties (Cárdenas et al, 2003; Ostrom, 2000).

According to resolve the dilemma, people make institutions understood as "laws, informal rules, and conventions that give a durable structure to social interactions,

influencing who meets whom, to do what tasks, with what possible courses of action, and with what consequences of actions jointly taken" (Bowles, 2003).
Eventually, well designed institutions contribute to good managing of resources (Ostrom, 2000), but it is not enough because of the counterintuitive nature of the resource system (Moxnes, 2002; Andrade *et al.,* 2001). Authors who have studied social vulnerability have identified that critical misundestanding of resources system dynamics plays a central role on this problem, such as misperceptions of feedbacks (Moxnes, 2002) and spatial misperceptions or scale problems (Costanza *et al.*, 2001). The stakeholders of any fishery system are vulnerable of this kind of failures and we think that misperceptions are a fundamental issue to understand the failure of sustainability.
First, we describe the study area, some remarks about the lobster population, his modeling process and the interviews context. Then, we present the results of simulation process and the differences with the system stakeholders perception. In the following section we discuss the misperceptions found and the possible explanation of norms breaking. Finally, we conclude with some recomendations about local and regional strategies of management.

BACKGROUND

Providence and Santa Catalina islands are part of the Archipelago of San Andrés and Providencia which is situated in south west of Colombian Caribbean sea at 13°N y 80°W (Gorricho *et al*., 2004b). The Archipelago is 480 Km. from Colombia continental coast and 180 Km. from Central America. Providence and Santa Catalina have 23.2 Km^2. of area, and they are separated by Aury channel (Valdés *et al*., 1997). Their place is strategic from geopolitical perspective, because they have limits whit Nicaragua, Jamaica, Costa Rica, Panamá, Republica Dominicana, Venezuela and Haití; and it comprises almost 12% of Caribbean sea area (Gorricho *et al*., 2004).

[Figure 1 about here].

Currently there around 200 artisanal fishermen (Fish & Farm Coop *et al.*, 2005), who use 50 boats made of wood or fiberglass, powered by 40 – 200 HP engines (Medina, 2004). The effective fishing day is almost 4 hours, usually in the morning. After noon fishermen comercielize the losbter in the local market, where the cost by individual is around COL$ 10.000 (US$ 5) and by tail's pound at COL$ 30.000 (US$ 15).
Lobster is a decapoda marine invertebrate of Crustacea order, Palinuridae family. In figure 2., the distritubion is ilustrated, from Bemuda Islands and Carolina (US), until Rio de Janeiro (Brazil), across Yucantán (México), Central America and the Antilles (Cruz, 1999).
[Figure 2 about here]

Methods

Dynamic modelling was used as methodological tool to understand the lobster population dynamics, and the fishery dynamic effects. This tool was selected because it facilitates to understand the complex dynamic elements which are often absent of our

mental models of reality understanding[3] (Sterman, 2000) in order to follow dynamic fails and misperceptions.
The model built is a *causal – descriptive* model, which validity depends of the purpose for it was built and the validity of his internal structure, rather than statistical fit between the model outputs and data (Barlas, 1986; Barlas, 1989 in Castillo & Saysel, 2005). The model purpose is to identify variables and their interactions which confer system resilience. The intention was to study the structure and behavior of the system looking for the causes of such behaviour and the critical points that radically shift the system from our reference mode: sustainability.
The model validation was carried out based in structure-oriented behavior tests (Barlas, 1996). It is a heuristic process that implies "*several simulation experiments, which yield strong information about the validity of the structure*" (Castillo & Saysel, 2005).
According to Barlas (1996) “*Extreme-condition (indirect) test involves assigning extreme values to selected parameters and comparing the model-generated behavior to the observed (or anticipated) behavior of the real system under the same extreme condition. Behavior sensitivity test consist of determining those parameters to which the model is highly sensitive, and asking if the real system would exhibit similar high sensitivity to the corresponding parameters. Phase-relationship test uses the phase relationships between pairs of variables in the model, obtained as a result of simulation. If certain phase relationships obtained from the model contradict the phase relationships that are observed/expected from the real system, this may indicate a structural flaw in the model*".
The semi-structured interviews were analyzed since the sustainability perspective and the resilience features. The fishermen perception was specifically analyzed for each subsystem (biologic, economic and cultural) in terms of how those are maintained trough time. On the other hand, for resilience, we used the characteristics that Gunderson & Holling (2002) analysis suggests: change, vulnerability, innovation, historical external shocks, slow and fast variables. An information matrix was used to cross data in order to investigate the differences and similarities of stakeholders’ system information. With this income it could be able to identify perceptions and to compare the traditional ecological knowledge (based on Buitrago, 2004; Márquez, 2005; Wilson, 2003) with the dynamic simulation model behaviour in terms of losbter population, CPR dilemma and market dynamics.
Before arrive to the results it is important to elucidate the modelling language. "The modelling language consists of building blocks (variables) classified as stocks, flows and auxiliary variables. Stock variables (symbolized by rectangles) represent the state variables and are the accumulation in the system. Flow variables (symbolized by valves) are the decisions, which act to alter the stocks (the sate of the system); they fill or drain the stocks. Auxiliary variables (represented by circles) describe the flows and help to perform miscellaneous calculations. Connectors (the arrows) are not variables but they point the causal relation between two varialbes and carry the information within

3 "*the temporal and spatial boundaries of our mental models tend to be too narrow. They are dynamically deficient, omitting feedbacks, time delays, accumulations, and nonlinearities*" (Sterman, 2000).

the model structure" (Castillo & Saysel, 2005).

RESULTS

In the present section we present the results in terms of subsystems: biological, socio-economic and cultural. Each one represents a different structure in model dynamics. Next, we discuss some relevant aspects about the validation process, and finally, we present the critical points between the virtual system and stakeholders' perception.

Lobster population

Spiny lobster (*Panulirus argus*) is a species widely studied because of its capital gain appreciation given by the market in relatively to another fishery products (Cruz, 1999). Spiny lobster is a decapod crustacean from *Paniluridae* family. It is geographically distributed from Bermuda and North Carolina in United States until Rio de Janeiro in Brazil, through Yucatán, Central America and the Antilles (Cruz, 1999).
Providence lobster population was modeled as a cohort structure according with: *i)* the development (growth) delays in its life cycle (Cruz, 1999), *ii)* its birth rate (calculated based on Arango & Marquez, 1996; Munro, 1979), *iii)* its death rate (under high uncertainty, they are supposed in the model), *iv)* possible population movements such as local and regional migrations, and finally, *v)* a density-dependence structure used to limit the population growth related to the system charge capacity.
The simulated cohorts were eggs, larvae (phyllosoma), puerile, youths (*Youths 1*) and three adult categories that are represented in the model as a stock variables. All individuals above reproductive age and under the minimum capture size (14 cm of tail[4]) are included in the first stock; *Adults 2*. The second (*Adults 3*) are lobster with the legal size until half asymptotic length. Individuals represented by stock *Adults 4* have size above 26cm-tail until the asymptotic length (maximum possible size) (Arango & Márquez, 1996).
Youths and adults are states of lobster which implies a settlement process, in other words, they live in the coastal platform of the islands. On the other hand, eggs, larvae and puerile are migratory states. It is absolutely uncertain the provenance of Providence lobsters, or where they go during migration epoch. Nevertheless, it is mandatory to understand this dynamics in order to manage the lobster fishery. Indeed, Cruz (1999) has reported that evidence pointed to think in Lobster as a Pan-Caribbean meta-population.
There is one mor aspect to be considered, it is uncertaintly in lobster population. Despite the amount of information, there are lacks of it that make difficult the modeling process, principally, the population size related to the system charge capacity.
In order to deal with this problem, it was modeled a density-dependence relation to limit the growth (figure 3). Potential density was calculated based on Bello *et al*. (2005) as a mean datum between all density per marine landscape unit that they calculated in Alacranes reef, Mexico. Therefore, the carrying capacity was calculated using the potential density datum by the area of Providence sub marine platform. With the sum of juveniles and adults, one can know if the population size is over the carrying capacity

4 Agreement 017 of 8th May 1990 from INDERENA (Nationa Renewable Natural Resources Institute, whose fuctions were assumed by INCODER – Rural Development Colombian Institute)

obtained. That means we assume homogeneous density over all the platform.
[figure 3 about here]

Thus, it was necessary to built a new variable called *effect*, which change the reaction velocity of the system when the population get its maximum size and help to approach the model behavior to the expected level in the real system. But it is necessary to explain the fishery system to understand how the density-dependence structure was adjusted. A detailed description about modeling process can be found in Rocha (2006). Before going on to next section, it is worth to examine some validation process aspects regarding the model structure so far. Lobster population behavior was the expected: a sigmoid curve with sustained oscillations around the carrying capacity as figure 4 shows. Growth is particularly steep because lobster has a reproductive strategy *r* (Curtis & Barnes, 2000), in other words, it is a species whose strategy is leaving plenty of descendants. This situation is due to a high growth speed reflected in the curve's slope, that typically present groups like insects and fishes (Curtis & Barnes, 2000; Morgan, 1995). Even though, the model produces an oscillatory range in the population curve, it is quite difficult to assure that it is the accurate range because of high levels of uncertainty in information about the rial system.
[figure 4 about here]

On the other hand, hypothetical meta-population dynamics were tested with behavior sensitive and extreme-condition tests (Barlas, 1996). As figure 5 shows, in general, the velocity with the system arrives to the attraction domain (an oscilation range around the carrying capacity) changes. It decreases if the population acts as source or increases as drain, with delays around 3 and 14 months.
[figure 5 about here]

So far, the lobster population structure in the model was explained as a cohort model. Despite the amount of species' information, there are uncertainty sources: mortality, population size in Providence and migratory dynamics. Nevertheless, validation tests have been applied until now, showing that in general the model structure is able to reproduce a behavior expected in real life. Furthermore, meta-population dynamics are quite important in terms of delays, which are susceptible to be misperceived.
The following section explores the fishery as socio-economic system. The focus is on extraction process and its effect on lobster population, the density-dependence adjusting, the commercial activity, and the assessment of institutional scenarios.

The Choice and the resource

The fishery sub model was built with three components: resource extraction structure, fishermen's profits, and, a hypothesis about the relation between economic experiments in the field (Cárdenas, 2003; Castillo, 2005) and synthetic data. A detailed description about the modeling process can be found in Rocha (2006).
The structure of the resource extraction was build with a series of flows variables which allow to drain lobsters from the stocks, principally, from youths and adults stocks. Fishing dynamics were modeled based on Medina (2004), calculating *capture per effort unit, monthly fishing time* and *effort unit* per *time unit*. Thus, the fishing behavior in the

model reflected important similarities with fishermen's perception reported by the interviews, in terms of temporalities and gains. Both, model and interviews show that profits are better in the first term of the year. Figure 6 represents such temporal dynamics and the first fishing period delay. The last is, in other words, the time what a lobster needs to mature. Furthermore, it is the time necessary to perceive the consequences of any change in the system, such a hurricane or a periodical fishing ban that lasts around two years.
The profit structure was modeled based on socio-economic information from the interviews. This structure represents the aggregated expenses and gains of fishery activity. This structure was used to validate the density-dependence structure in the biological sub model. Thus, the density-dependence was adjusted in such a way that the model behavior was plausible. That means, a point where fishermen would profited what it was reported in the interviews, where they would obtained lobster of the reported size: 5 to 6 pounds, so *Adults 4* were exhausted; where the annual capture in the model were similar to the 6 tons reported (Medina, 2004), and where the first fishing period were recognized. At this point, the potential density adjusted with the model is 150 individual per hectare of Providence's platform. However, this figure is not comparable with any real density, because it is aggregated to all the platform. An ideal measure would be aggregated by marine landscape unit (mangrove, seagrass, sand, coral patch and coralreef barrier), but this information does not exist for Providence Island.
[Figure 6 around here... las del retrazo de la pesca y los diferentes equilibrios]

Activation of fishing structure changed the population balance in the model. Before fishing, the population age distribution was pyramidal; it means that there were more eggs than puerile, more puerile than youths and more youths than adults. Even into the adults' categories, there was the ages adjustment. But, as figure 7 shows, when fishing is activated there are an expected decrease in eggs, larvae, puerile and youths, but surprisingly there were changes in adults stocks. *Adults 2* and *3* increase while *Adults 4* decreases.
[figure 7 about here]

This phenomenon is due to lobster resilience. As we said before, lobster has a reproductive strategy *r*, which confers a lot of resilience to the population in such disturber as fishing. The free niche left by *Adult 4* tends to be occupied by *Adults 2* and *3* after the disturbance. Thus, this age range increases meanwhile all the population tends to reach the system carrying capacity despite fishing disturbance.
This result suggest the importnace of monitoring sex and size of individuals captured in order to study reproductive potential rather than population size, because it could be a critical point in terms of misperceptions. Indeed, elder female lobsters are able to produce more eggs than younger (Cruz, 1999). Therefore, reproductive potential are a key variable to study fishing system resilience.
The third component of fishing sub model was an hypothetical relationship between economic experiments in the field (Cárdenas, 2004; 2003; Cárdenas & Ostrom, 2004; Castillo & Saysel, 2005) and synthetic data. The questions at this level was firstly, whether the social behavior obtained through the economic experiments could be related with real harvesting rates and the resource attributes?, and secondly, which

stability domain would the system tend to?
The economic experimental data were produced by a typical common pool resource (CPR) dilemma game (Cárdenas, 2004) with different treatments: communication, allowance and monitoring of external norms accomplishment. In each game there were 20 rounds, 10 for base line and another 10 for a treatment. During the rounds, players should choice between 1 (minimum) and 8 (maximum) extraction effort level, where 1 was the social optimum and 8 Nash strategy. Experimental data were aggregated to social behaviour, in other words, to the collective level. With this information, it was calculated average of choices under each treatment and this was transformed to a new scale, where 0 was none extraction, 0,125 was the social optimum and 1 Nash strategy. Nash strategy is the maximum possible choice given the choices of others players, but in real life it is related with the maximum effort determined by technological limit of fishing arts (Grant, *et al.*, 1997). Therefore, in order to establish comparisons between game's extraction levels and real levels, it was mandatory adjust effort variables. That means, a virtual scenario where all fishers harvest utilizing all their vessels every day at the same time. The variables adjusted were *effort unit per day* and *fishing time monthly*. Capture per unit effort (*CPUE*) was not adjusted because that would meant a technological change in fishing system, however this option is contemplated when effort level is increased to levels over Nash strategy.
Figure 8 is the hypothetical relationship between economic game's data and real extraction. In Y axis there are the extraction levels, where 0 is no fishing, 0.125 is the social optimum, 0.5 is the base line in the games and the real extraction data, 1 is Nash strategy and CP is the collapse point of lobster population caused by overfishing. In X axis there are different population size related whit each point in Y, where K is the carrying capacity of the ecosystem, and *a, b* and *c* are related whit each effort level. The expected behaviour patterns is asymptotic.
[figure 8 about here]

Tests used to validate the hypothesis were phase-relationship and extreme-condition tests (Barlas, 1996). Four simulations were carried out, all of them using activated fishing as initial condition in order to avoid data dispersion. The first one was run with average data for each effort variable, except *CPUE*, looking for a base line scenario. The second one simulated Nash equilibrium using maximum data for each effort variable except *CPUE*. The third and fourth simulations were extreme-condition test, where a technological improvement allows to obtain the maximum *CPUE* (third simulation), and a Nash equilibrium effort was duplicated (2Nash) in order to find the lobster population collapsing point CP.
Figure 9 shows the adult stocks change under the mentioned scenarios. *Adults 4* decrease meanwhile *Adults 3* increase in the second scenario (blue) but collapses in the others. Although the figure 9 does not show *Adult 2* outputs, the behavior is the same as *Adult 3*, but increasing in the second scenario (red) and collapsing after that.
[Figure 9 here]

Figure 10 shows the same dynamics but applied to *settled lobster population* variable (addition of adults and youths) and *birth proportion* variable related with the egg production average of whole population. The first variable has a decreasent behaviour

and collapses in 2Nash point. Meanwhile, *birth proportion* tends to decrease, but during the third and fourth runs there are picks of eggs production related with the density-dependence effect, where *Adults 2* and *3* increase their stocks. But after that, the eggs production tends to domain attraction that erodes system resilience, at least from the biological perspective.
In order to test the hypothesis, non-linear regressions were applied to the phase-relationships diagrams. Figure 10 shows the result, in wich relation between fishery levels and lobster population describe an exponential negative curve. The difference with respect to the hypothesis is due to density-dependence effect. Therefore, the population size is not an appropriate variable as indicator of the population state, because it is not enough sensitive to harvest increases levels.
On the other hand, figure 10 also shows that the relation between fishery levels and *birth proportion* is highly sensitive to changes. It describes a positive asymptotic curve as the hypothesis does. That means that the monitoring of females sizes and their reproduction capacity is quite important in order to study the population state and its relation with the harvest levels. Table 1 synthesizes the non-linear regressions results.
[Figure 10 and Table 1 about here]

Based on regressions results, it was searched the possible indicator variable values for each one of the treatments used in the economic games. This kind of data is not related with real population size because of model uncertainly. Nevertheless, it is useful to identify tendencies and impacts of human behavior (induced by the institution in the game) on the resource dynamics.
Figure 11 and table 2 present three attraction domains that can be identified. Firstly, none fishing, social optimum and low allowance are nearly states in terms of egg production average, and therefore, a state of high positive resilience. In fact, there is a little increase of egg production in fishing scenario of social optimum. Other studies in forest dynamics demonstrate the same effect, where ecosystem potential is increased by periodical and low intensity disturbances (Guariguata & Kattan, 2002; Gunderson & Holling, 2002), comparable in this case with low harvest levels. The second domain is an acceptable decrease of eggs production related to communication, focalized monitoring and low monitoring treatments. The third domain is characterized by high harvest levels, and consequently, lobster population resilience is eroded. Those scenarios represent the Nash equilibrium (maximum fishing capacity) and 2Nash levels. We claim that the base line is an intermediate state that is shifting towards an undesirable domain attractor where fishing effort increases.
[Figure 11 and table 2 about here]

We have presented in this section the results about the model fishery structure. We conclude preliminary, that fishery system resilience is related with eggs production rather than population size. Moderated harvest effort levels related with institutional treatments tend to sustainable levels of resource exploitation, in particular, low allowances which will be discussed in the next section. Baseline, which represents the actual harvest level in the real system is shifting to unsustainable states whereas harvest level increase. Furthermore, the managerial measures taken based on population size studies could induce misperceptions about the fishery systems, thus

mal-adaptations to its dynamics. Birth proportion is a better variable which can be used as indicator of population state.
In the next section, the reader can find the results about the cultural analysis of fishermen, their adaptation strategies and misperceptions about the dynamics of social-ecological system . This analysis includes some historical findings which interpreted as feedback could explain attraction domains of negative resilience or poverty traps. This is a key point in order to explain why the whole system carries on behaving as it has been doing.

Misperceptions and poverty traps
Fishing is not only an activity about resources extraction. It is also related with knowledge about how, when and where must it be done. Fishing is an activity strongly charged of occupational symbols which base decisive values of individual and cultural identity (McGoodwin, 2002 in Buitrago, 2003). Traditional ecological knowledge (TEK) is an important issue that must be studied in order to build a complete interpretation of fishery system. According to Berkes *et al.* (2003) TEK is "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about relationship of living beings (including humans) with one another and with their environment".
In this context, it is important to know the historical processes, which have formed the actual lobster-fishing panorama. After, it worth to explore some remarks about the TEK around fishing and how is it trasmitted. With this approach, one can focus the misperceptions issue, by comparing TEK with model structure and experts knowledge.
Lobster fishery has been an activity relatively recent. Before 1950 fishery in general was perceived as a recreation activity, mainly as sport. Lobster haverst was more a subsistence activity occasionally practiced and sometimes given as a gift to neighbors and relatives, even though it was not common in the island gastronomy. Fishing more than needed was a huge problem, because there was not storage technology (Márquez, 2005).
This situation has dramatically changed when the archipelago was named free port in 1953, determining a shift from a traditional to monetary economy (Márquez, 2005). This change boosted the tourism development in the islands, and produced an important increase on the lobster demand, consequently, the harvest levels increased as well.
The new political status impelled a technological boom without precedents. In 1960's out-board engines and kerosene freezers were implemented as fishing arts. By the seventies arrived the basic diving equipments, new boats designs and electricity availability during few hours per day in the administrative zone. Electricity was generalized by 1980, and with it, electric freezers, autonomous diving equipment, fiberglass boats and harpoons were brought to the islands. There was the first drug smuggling issues by the epoch. During the decade of nineties GPS (Global Positioning Systems) appeared, but it has not been so popularized (Márquez, 2005).
All these technological improvements contributted to increase the fishing effort with the purpose of improve income. But it has not been always perceived as an advantage. Expenses have increased also, because of gasoline usage principally. Gasoline is imported from the Colombian continent, for this reason the price reflects transport cost. In fact, gasoline cost is a fast changing variable, which makes very uncertain the system

in terms of profits. According to fishermen perception, fishery now is not as rentable as before. Even if they actually earn more money, they also spent more in a fishing day initial cost; thus, their quality life has been affected too (Fishermen interviews, 2005). On the other hand, fishermen reported the belief that diving and engines noise have produced migrations of sub marine fauna producing shortage of these resources. However, these tools provide accuracy in harvesting improving vessels autonomy.
The first poverty trap is related with the economic efficiency and non-exhaustion perception. Figure 12 shows a conceptual model where positive (P) and balance (B) feedbacks explain the trap. In the measure that engines and fuel is more used, increase the operation cost (B1) and consequently, fishing effort (B2) and harvest (P1) also increase in order to cover the cost and search economic efficiency. This capture level intensifies the disturbance in the ecosystem (B3) and reduces the recuperation possibility, and consequently its resilience (P2).
[figure 12 about here]

Obviously, it implies a dramatic decrease of population size whereas the harvesting levels increase, but surprisingly fishermen do not recognize this effect. The reason, as it was duscussed before, is that population size is not a variable sensitive to changes in extraction levels, inducing misperceptions. It is not rare that fishermen think that lobster population is abundant based on their observations and experience (Fishermen interviews, 2005). Therefore, there is a misperception of non-exhaustion lobster. Nevertheless, fishermen affirm that there is a strong decrease of profits even if harvest and gains (but also cost) have increased in the last decades (Fishermen interviews, 2005). Thus, this is the feedback loop that fishers perceive based on their daily fishing transactions.
TEK about lobster is related with species spatial distribution (which are the most abundant places), interpretation of environmental signs for orientation and an wide knowledge of marine landscape and fishing places (Buitrago, 2004; Wilson, 2003). However, another kind of misperceptions are related with biological features of lobster, such as the growth delays. Any fisher recognizes the time that lobster take to be an adult (2 years average according to Cruz, 1999), the same time that must be waited in order to recognize the result of any political measure or any environmental change.
It is important to recall that when fishermen admit that the resource could be exhausted by overfishing, it is generally industrial fishery that is recognized as guilty (Fishermen interviews, 2005). This is an evidence of spatial misperception of lobster dynamics. Industrial floats always fish in the north cays (Roncador, Luna Verde, Quitasueño) and south cays (Serrana and Serranilla), which are connected with Providence lobster population only by theoretical meta-population dynamics[5]. Nevertheless, as the model shows, Providence's spiny lobster population could be exhausted only by the effect of artisanal fishery at Nash equilibrium level.
Therefore, there are two more misperceptions. First of all, most of fishermen do not know that lobster is recruited in mangrove and lives all their mature live (puerile, youths and adults) in the Providence platform. Thus, industrial fishery only can affect them

5 There are also reported unusual migrations related with environmental changes such violent as hurricanes or storms.

through meta-population dynamics. This is a spatial dynamics misperception. The second misperception is that fishers are not aware that they have the power to deplete lobster in Providence only by using their fishery capacity at the maximum.
Through all the interviews, there is the idea of *the others*, which represent agents perceived as external to the social islander dynamics. They are the environmental authorities (in terms of fishing) and industrial fisheries. Traditionally, external authorities are the responsible of design and enforce formal rules for fishery management. INCODER (Spanish abbreviation for Rural Development Colombian Institute) is responsible of national level measures for natural resource management, whereas CORALINA (Environmental and Development Local Governamental Agency) is its regional pair. Rules as minimum size for fishing (14cm-tail), seasonal ban, ban to fish pregnant females and the usage of scuba diving are imposed and regulated by INCODER. There are also regulation related with the amount of gasoline that could be used, vessels size and departure permit, all of them regulated by the marine authority (DIMAR).
Although all those rules are well known by fishermen, and perceived as needed, there are strong evidences of rule breaking (Fishermen interviews, 2005; Márquez, 2005, Wilson, 2003). It seems that there is a kind of informal rules for rule breaking because all fishers have done and recognize that their pairs do the same. But there is not any social punishment or complaints to the competent authorities.
In fact, asking for help to a non islander to solve the island troubles is an act very bad saw, even worse than the fault itself (Wilson, 2003). Indeed, it is due to a strong sense of association to reject the presence of external agents in their territories, physicals and imagined. Artisanal fishermen do not understand why industrial fishermen have fishery rights on their marine territory, even if artisanal fishers do not use to fish there; or why external (continental) authorities impose norms about their resources. There is an implicit perception of territorial *invasion*.
Invasion is a key point, because it seems to be a way to claim for equality into Providence society (Wilson, 2003). As response, artisanal fishermen tend to break rules in order to attack the external agent's reputation and interest. Breaking rules is a way to evidence the lack of efficiency in rules enforcement for authorities, whereas it is also a way to take lobster first, before industrials do.
According with Wilson (2003) *crab antics* is a common behavior similar to a situation where a group of black crabs in a recipient and one of them is close to the edge to get out, the rest of crabs pull him down (trying to climb) and stop his escape. This situation is interpreted, for islander society, as a mechanism by which nobody is allowed to make a difference and the society guarantee certain levels of equity.
Wilson (2003) uses this metaphor to explain a social equilibrium between reputation and respectability in Providence. Figure 13 represents an interpretation of his thesis. More reputation means more inequality, because the reputation recognizes goals and differentness, as a crab near to the edge. Reputation is a masculine quality, thus fishermen always will try to increase their reputation in the Providence social order. However, less inequality means more respectability in terms that all the islanders are perceived as equals (in the bottom of tonel). Respectability is a feminine quality; and it is related with the straight behavior of islanders in terms of their moral system.
Based on Wilson (2003) abstraction of Providence social equilibrium, rule breaking is

explained. In this case, respectability is expressed as the rule fulfillment and moral principles (externally imposed) that affirm an islander as respectable (Wilson, 2003). Reputation is reflected in the islander's territory defense, it is achieved by the resistence to external power (environmental authorities) and the reject of *the other* non islander (industrial fishery), claiming equity principle which prevails island society. In this order, it seems that is preferable an unsustainable state for all rather than sustainability for a few people (industrials) who gain more profits and who are not stigmatized by environmental authorities.
[figure 13 about here]

Drugs smuggling is the reason of stigmatization. Fishermen are potential smugglers because their wide knowledge of ocean dynamics. In fact, fishery is now a second option job, because is not as lucrative as illegal activities. Indeed, fishermen reputation has decrease as good sailors, and it is not more a job which brings prestige to a man. Thus, TEK about fishery is now eroding because young people do not want be fisherman.
Summarizing, some misperceptions and two poverty traps has been studied. In terms of misperceptions the principal issue is about *i)* temporal resource dynamics as the fishing effect and the growth delays, *ii)* spatial resource dynamics as local platform movements and meta- population connections, and finally *iii)* about the role, responsibility and power action of each agent (industrials, artisanal fishermen and authorities). The poverty traps studied are related with, first, a fishing effort structure which support the misperception of non-exhaustion, and second, the dialectics of respectability (equality) and reputation (inequality) which helps to explain the rules breaking phenomenon.

DISCUSSION
First of all, the limits of this work are discussed. Secondly, based on the results, sustainability of lobster fishery is analyzed as a whole system, using resilience as concept background.
Biological sub model is limited to Providence platform. It cannot discriminate productivity of traditional fishing areas into the platform nor the connectivity with neighbor areas as north cays. Density-dependence data was used as validation variable, but it can be compared with other studies because of the area units wideness. With this submodel, superior scale dynamics and their emergent effects could be studied like metapopulation.
Socio-economical submodel is also aggregate to collective level, it means, individual behaviour cannot be discriminated. However, it was an important sector for the model validation, where comercial structure of gains and interviews played a fundamental role.
In spite of cultural sub model is not a formal model as the last, its concpetual models helped to clarify social dynamics. With this approach the system could be though from individual and its perception.
On the other hand, combination of modelling and interviewing tools has been useful in terms of assuming uncertainty, information lacks and avoiding misperceptions.
In terms of system sustainability, the inicial belief was that the sustainability of one sub system does not imply the same for another. This paradoxe that, altough could be contradictory, is definitively not excludable. In fact, sustainability discussion turns

around avoid the undesirable system states and achieve those that are desirable. Sustainability of biological system is hard to study because lack of information in population size and metapopulation movements. With out these uncertainty nuclei, it could be possible to think in terms of Pan Caribbean lobster population and, therefore, a second order CPR.

Whereas those uncertainty nuclei exist, natality proportion is a variable that can be used as measure of lobster system resilience. The eggs average that the population is producing can be inferred monitoring the size of lobster caught (specially females). This approach can be done by fishermen in cooperation with environmental authorities as participatory monitoring. According with Carpenter *et al.* (2001) resilience can be measured as change between a fast variable against a slow variable; in this case, looking for the change magnitud in nataly proportion respect harvest level.

Socio-economic sustainability is related with avoiding resource collapse whereas net gains are maintained by institutional arrangements. Here, institutions are anaysed from its efficience in comercial and biological structures, after it will do from cultural perspective.

Against the fishermen belief, socio economic subsystem can collapse just by the effect of artisanal fishery. In fact, profits begin to collapse in maximum fishing scenario, in Nash equivalent effort. Whereas lobster population lost resilience, the population can collapse in 2Nash scenario when CPUE is variable month by month, or in 4Nash scenario with CPUE constant. For this reason, fishermen recognize exhaustion through rentability changes rather than population size changes. Previous studies inferred resource degradation based on capture size decreasing and the capture per unit effort. This study formalizes an antecedent of relationship between the harvest levels and the population state.

The institutional treatment, which is nearest to social optimum, is low allowance, followed by communication and low and focalized monitoring. All of them are considered desirable equilibria, however low allowance and communication represent atraction domain where resilience is gained respect non-fishing equilibrium. In the case of low allowance, the fishermen notion that the Goverment have to seek the possible solution to fishery problems, probably increase the cooperation levels. In fact, during the interviews fishermen confirm that the better solutions to actual situation are the management of marine protected areas with spatial and temporal rotation, and a better plan of norms enforcement; all of them are State functions. Here, allowance is not only money but also any benefit that the State could give to fishermen.

There is evidence of cooperation between fishermen by communication, but it works only in small groups as crew (Wilson, 2003) or natural groups that arrive at the same landing point (Buitrago, 2004). Forced communication does not have the same results. Indeed, there are a lot of cases referenced of cooperative failures (Fishermen Interviews, 2005; Gorricho & Rivera, 2004; Wilson, 2003). On the other hand, low and focalized monitoring shows the minor resilience gain. It is explained by the legitime brake norms notion of Providence fishermen.

It is worth to recall that, according with metapopulation dynamics, lobster fishery is also a second order CPR. It emerge another scale of dynamics in terms of economics due to resource asymmetries. In other words, Providence lobster fishery must be understood as a collective, as an agent which interact with other local fisheries or agents (islands,

cays, coasts of Caribbean) sharing the same resource. The drain subpopulations are in advantage rather than source ones, it all depends of marine current dynamics and the connectivity degree for each subpopulation. Nevertheless, decisor agents do not perceive these kinds of dynamics, and consequently the norms about fishing are poorly adapted to resource dynamics, in particular the seasonal ban.
From cultural perscpective, rules' breaking is a bad adaptation to change. Indeed, cultural sustainaibility perception is widely related with the equality notion. But, in presence of unequality perception (with industrials for example), fishermen plead to norms breaking, especially if the norms are imposed by agents percieved as foreign. It seems that emotional incentives are stronger that logical and normative in terms of making decisions. Those differences in value system (in the case of equality) are barriers for building social resilience (Berkes *et al.*, 2003; Adger, 2000).
In fact, López *et al.* (2007) found that social emmotions are quite important in cooperation enhance, and for Providence, it was found that guilt induce major cooperation that shame. Further, there is not shame because as norm breaking is justified it is neither unmoral nor damaging for the man reputation by the way. However, if a fisherman known how his norm breaking behaviour affects himself and others, they could feel guilty because, in this case, the equality principle was also broken.
This finding can be used in resource management publishing the infractor name in order to produce guilt rather than fining him.
On the other hand, the loss of TEK is supported by unemployment and drugg smugling problems. Nowadays, fishing is a second choice job, sporadic and tipically in epoch of economic depression. Young people do not know about temporay and spacially fishing dynamics. Possible future adaptations to change are losing while the system is made vulnerable (Berkes *et al.*, 2003). In terms of cultural sustainability, it is not enough technical knowledge, either traditional knowledge. Both of them are vulnerable to misperceptions and poverty traps. However, both are complementary to each other, for this reason the notion of co-management (Berkes *et al.*, 2003) is supported.

CONCLUSION

This document studied the lobster artisanal fishery system in Providence and Santa Catalina Islands. Relationships and interactions between agents were looked for in order to use resilience concept to deal with system sustainability.
The resilience of a stability domain in a subsystem could harm another's, situation reinforced by misperceptions. Strategies that support social capacity to deal with change do not needfully direct the ecological system to better stability domains (Huitric, 2005). Therefore, system could be resilient from ecological viewpoint but socially undesirable and socially resilient but ecologically undesirable (Berkes *et al.*, 2003). Management strategies that are only related with biological or social dimension are not effectives (Márquez, 2005; Monsalve, 2002), for this reason it is mandatory holistic approaches (Berkes *et al.*, 2003).
Model shows that stakeholders are vulnerable to misperceptions because lobster dynamics and reproductive strategy. Metapopulations dynamics change the resilience of lobster system, but also become in a second order CPR. This dynamics imply asymmetries due to resource attributes.
Norm breaking is an adaptive strategy that confers social resilience (negative) to the

system, but the system is directed to undesirable stability domains. Therefore, this research support Huitric (2005) conclusion, social resilience may not confer ecological resilience. Norm breaking could be deal by using social emotion in policy design, appealing to equiality principle supported by efficient communication in natural groups. Finally, the study of misperception of feedbacks and poverty traps are useful in order to understand the sustainability failure.

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TABLES AND FIGURES

Figure 1. Map (Márquez, 2005)

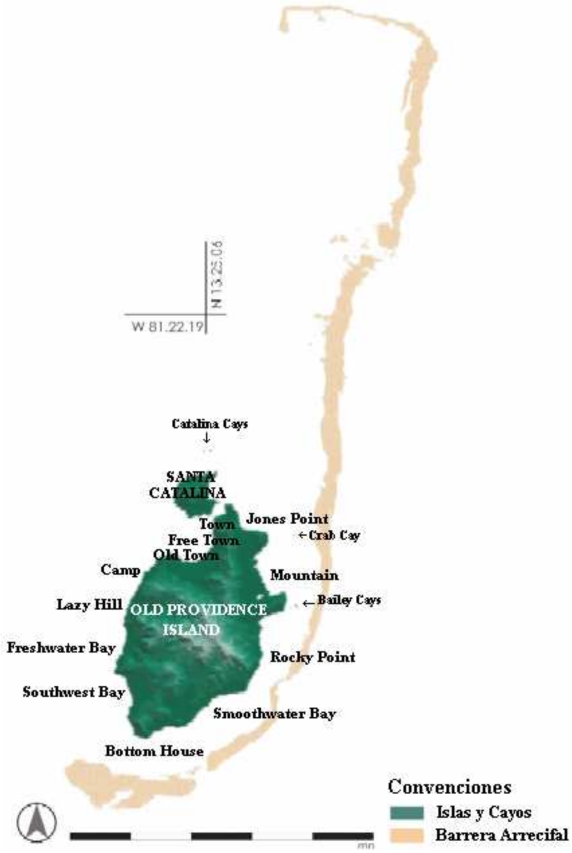


Figure 2. Distribution map of *Panulirus argus* (Carocci, 2000)

Figure 3. Density – dependence structure

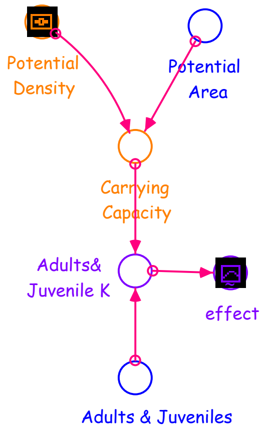


Figure 4. Stability domain of Juvenile and Adults (red) around the carrying capacity (blue)

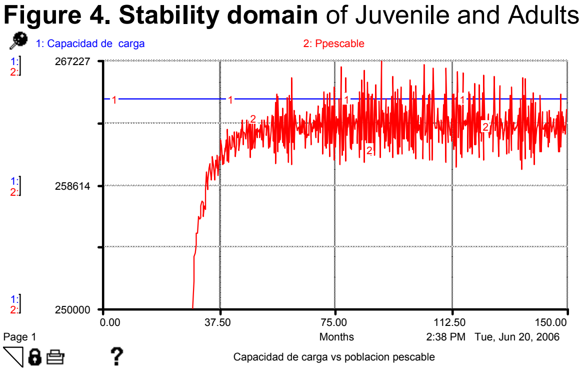
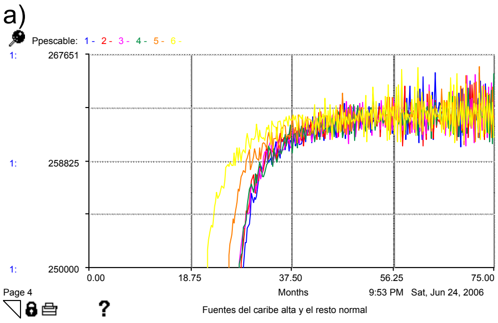


Figure 5. Effectos of metapopulation dynamics. Each color represent the population available for fishing (sum of juvenile and adults settled on the marine plataform). a) represent the lobster population in Providence when dominate source dynamics, showing delays in reaching the carrying capacity of around 7 months. b) represent the lobster population when dominate drain dynamics, showing delays about 18 months.

a)



b)

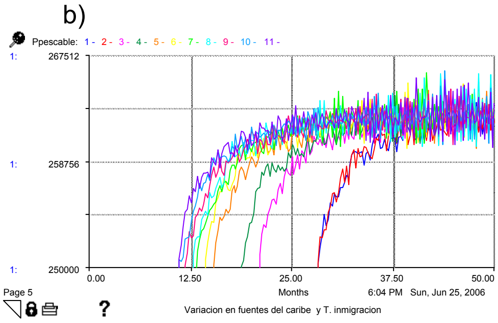


Figure 6. Sensibility test to *Potencial Density*. a) represents the net gains for a fisherman who fish 6 days per week (maximum effort reported). Fishing is activated at month 120, and during 24 months approximatly. There are a depression on the curve showing the delay on the net gains recognizing the first fishing period. b) represent periodical dynamics in harvesting reported by the fishers. In blue is an *cost/benefit* variable and in red *minimum gain* reported on the interviews. Gains fix in periodicity (green valley) and in range according to fishers interviewed.

a) b)

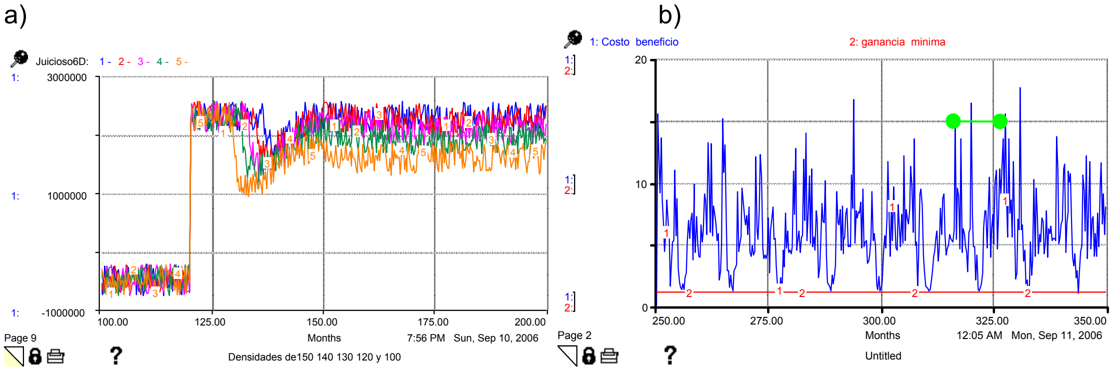
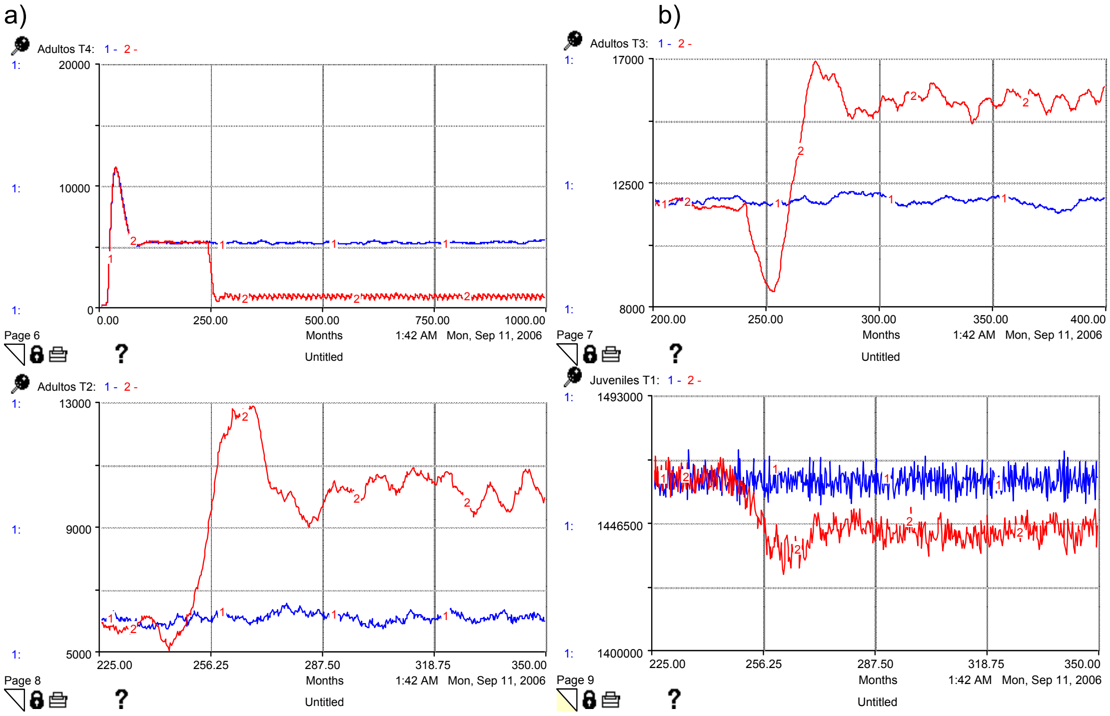


Figure 7. Sensibility test to fishery. All the figures shows in blue an scenario without fishing and in red with fishing. a) represents the dynamic for *Adults 4*, b) for *Adults 3*, c) for *Adults 2*, and d) for *Juvenile*

a) b)



c) d)

Figure 8. Hypothetical relation between experimental economical data and real harvesting level. Virtual fishing are the values related with economical games, where 1 is Nash strategy, 0.5 is base line game and 0.125 is the social optimum.

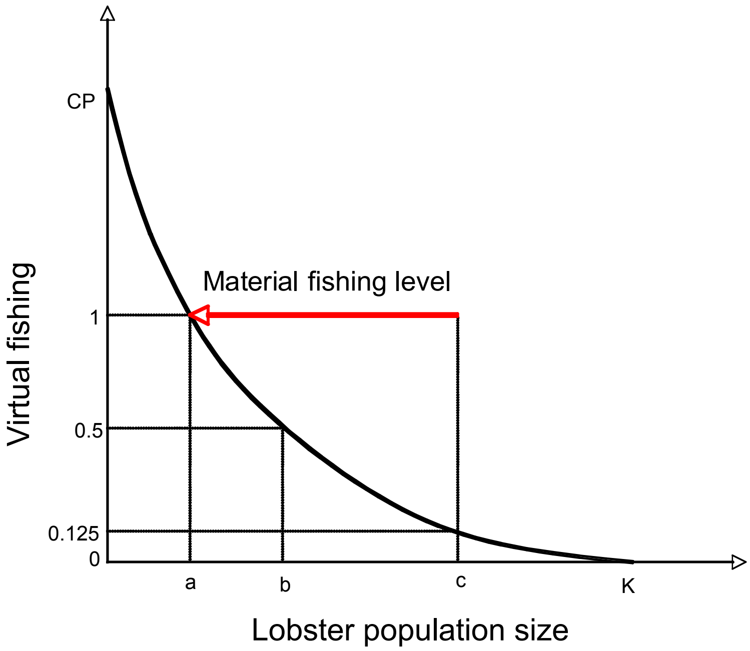


Figure 9. Extreme condition test. Phase-diagram of *Aduts 4* (a) and *Adults 3* (b) on X axis and different harvestign levels. First scenario in blue, red the second, rose the third and green the fourtn.

a) b)

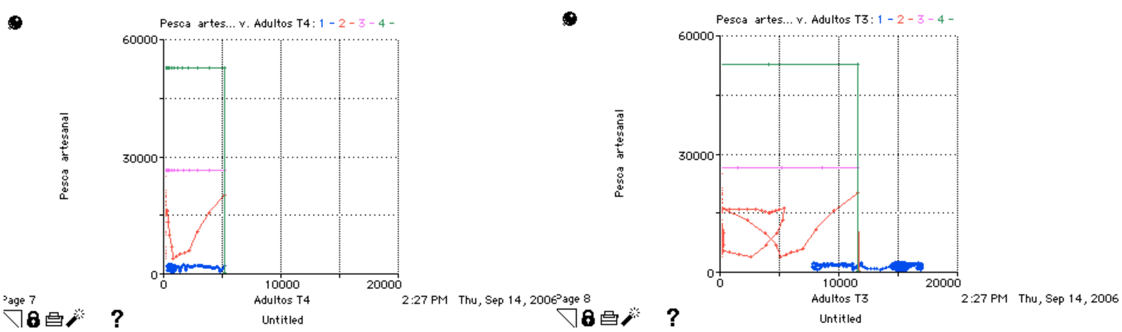


Figure 10. Extreme condition test. Phase-diagram of *Settled population* (a) and *Birth proportion* (b), on X axis different harvesting levels. First scenario in blue, red the second, rose the third and green the fourtn. Under each phase-diagram is the correspondent non-linear regression.

a) b)

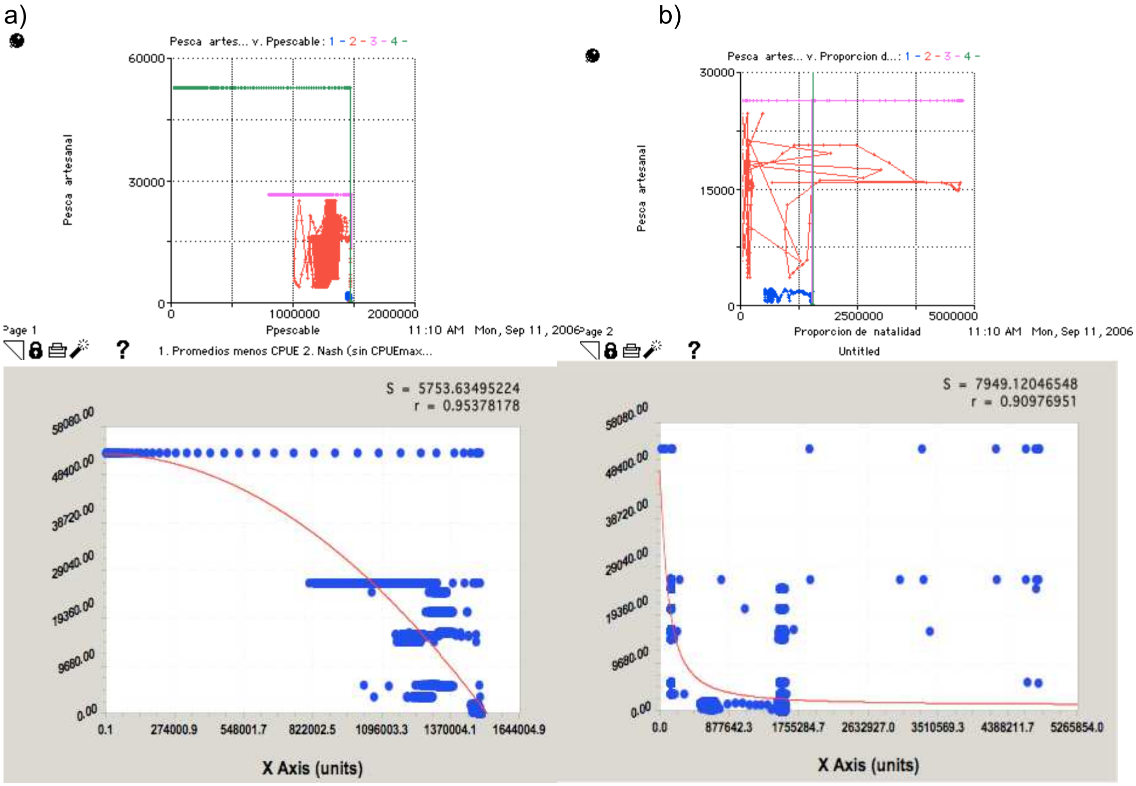


Table 1. Non-linear regressions

	Regresisionn a	Regression b
Function	=a+bx+cx^2	=(a*b+c*x^d)/(b+x^d)
a	52584.827	48537.409
b	-0.0011322953	4588034.5
c	2.2204066e-008	1012.4189
d	---	1.3300272
S	5753.6349522	7949.12046548
r	0.9537818	0.90976951

Figure 11. Virtual and material fishing relation

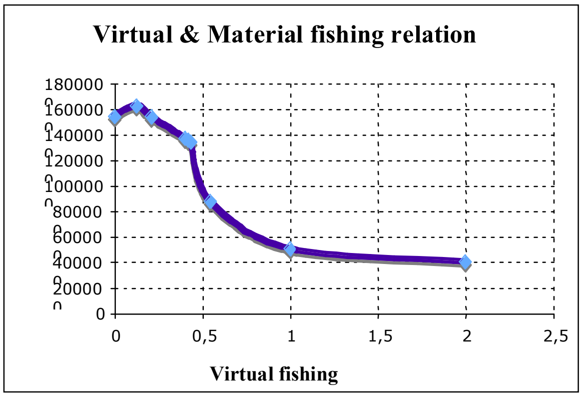


Table 2. Virtual and material fishing relation

Virtual fishing		Material fishing			
Scenario	Value	Average lobster fishable	S	Average Birth proportion	S
2Nash	2	379914,891	640488,233	400513,3342	732212,716
Nash	1	1190701,044	58845,82688	502506,9184	647820,1574
Base line	0,544706938	1469229,561	4163,609544	875568,0556	388088,8566
Low monitoring	0,4337	1452935,626		1342764,508	
Focalized monitoring	0,417713568	1456612,395		1355109,522	
Communicatión	0,4	1460513,336		1369033,587	
Low allowance	0,21	1490914,607		1536750,548	
Social Optimum	0,125	1497738,704		1624640,407	
No fishing	0	1484954,035	3811,571582	1542584,685	16230,06975

Figure 12. Poverty trap of fishing effort

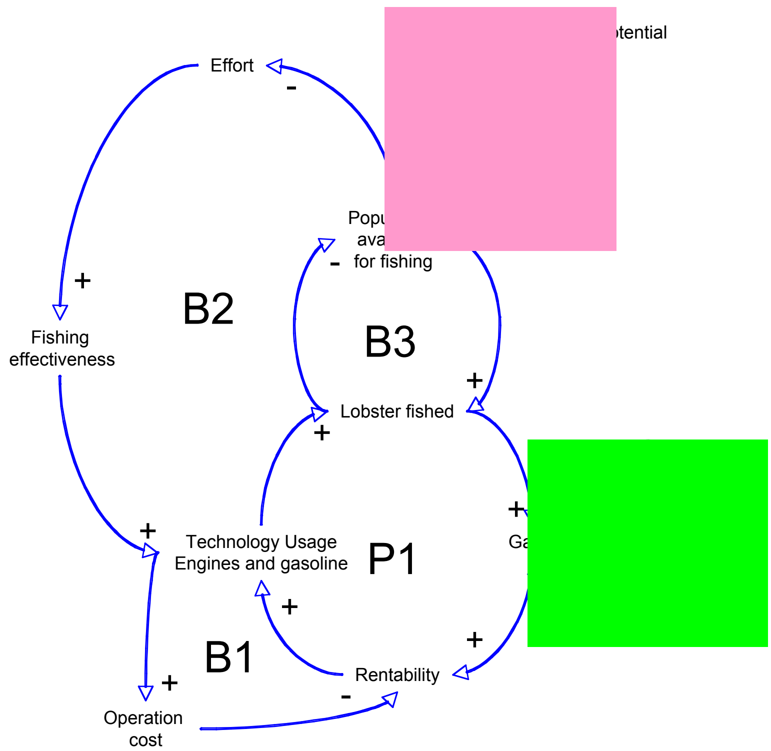


Figure 13. Crab antics metaphor feedback. Based on Wilson (2003)