ARTÍCULO

# Identifying spatial and temporal patterns of Lobster abundances in the San Andres Archipelago: an experience of co-management

## Identificando patrones espaciales y temporales de la abundancia de langosta en el Archipiélago de San Andrés: Una experiencia de co-manejo

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## *Abstract*

The bony lobster is the main fishing activity in the San Andres Archipelago, however detailed knowledge of its spatial and temporal distribution patterns remains unknown. This paper presents an experience of co-management in order to locate main fishing areas s well as the lobster abundance trends in a highly exploited region with minimal previous scientific information. A total of 20,870 geographical locations of trap line settings were obtained from 26 captain logs over a twelve- year period. Positions of fishing trap lines were plotted using a geographic information system to generate thematic maps identifying fishing areas on a monthly and yearly basis to determine lobster abundance. The section of the Nicaraguan shelf which belongs to Colombia (Green Moon) was the region supporting the most fishing effort (68.3% of trap locations) and sections of Quitasueño shelf accounted for 14% of the fishing ground. Several, isolated and uncharted locations were identified which expanded the range of known lobster habitat with high lobster densities. On average 1,750 km2 (±SD=1,025) were monthly caught, with each boat covering 179 km2*month-1 (±SD= 74). Traps were moved from one area to another depending on the month, but Green Moon is fished year round. The largest fishing areas were observed in August, coinciding with the peak in lobster reproduction. Annual fishing areas included 2,841 km2*year-1 (±SD=585). Out of the 6,227 km2 of the overall fishing area, only 6% (1,060 km2) were considered a high density of lobster zone. Lobster density decreased from 14.1 lobster per 'lingada'-1 in 1994 to 2.9 lobster per 'lingada' -1 in 2005. Lingada is the common word utilized by fishermen to estimate the number of traps in a line and it is understood as a set with 25 traps, with a line having usually four lingadas (100 traps), The importance of bringing fishermen and managers together to share the knowledge each group possesses and to be able to handle a valuable fishing resource in a sustainable way has been pointed out.

**Key words:** Lobster abundance, *Panulirus argus*, San Andres archipelago, spiny lobster, fishers involvement.

## Resumen

La langosta espinosa es la principal pesquería del Archipiélago de San Andrés, sin embargo sus patrones de distribución especial y temporal aun se desconocen. En este trabajo se presenta una experiencia de co-manejo para localizar las principales áreas de pesca y las tendencias de abundancia de langosta en una región intensamente explotada pero con mínimo conocimiento científico. Un total de 20,870 sitios se obtuvieron de 26 bitácoras de capitanes de la pesca con nasa en un período de 12 años. Posiciones geográficas de las líneas de nasas fueron localizadas utilizando un sistema de información geográfica para generar mapas temáticos de las áreas mensuales y anuales de pesca y de sus abundancias. La sección de la plataforma Nicaragüense que pertenece a Colombia (Green Moon) fue identificada como la zona de pesca de mayor uso (68.3%), y secciones de la plataforma de Quitasueño representaron un 14%. Sorpresivamente, se encontraron zonas de pesca aisladas y no cartografiadas en las cartas náuticas que están siendo pescadas y que resultaron de gran interés, no solo por su pequeña extensión, sino también porque allí se presentaron las densidades de langostas más altas. En promedio 1,750 $km^2$ (±SD=1,025) fueron pescados mensualmente, con cada barco usando 179 $km^2$*$mes^{-1}$ (±SD= 74). Las nasas se mueven de un área a otra dependiendo del mes, pero Green Moon es pescada todo el año. Las máximas áreas de Pesca fueron determinadas en Agosto, coincidiendo con el pico mayor de la reproducción. El área de pesca anual se extendió a 2,841 $km^2$*$year^{-1}$ (±SD=585). De los 6,227 $km^2$ del total del área de pesca, solo el 6% (1,060 $km^2$) fue considerada como zonas de alta densidad. La densidad de langosta disminuyó de 14.1 lobster.'lingada'$^{-1}$ en 1994 a solo 2.9 lobster.'lingada'$^{-1}$ en 2005. Se resalta la importancia de poder unir información de pescadores y de manejadores, compartir el conocimiento que cada grupo posee y ser capaces de manejar este recurso pesquero tan importante de una manera sostenible.


**Palabras claves:** Abundancia langosta, *Panulirus argus*, Archipiélago de San Andrés, langosta espinosa, participación pescadores.

## Introduction

Spiny lobsters from the San Andres archipelago, Colombia, have been heavily fished for over 25 years, and represented its most valuable fishery stock. The stock is comprised by one dominant species, *Panulirus argus* accounting for up to 95% of landings, and one less abundant species *P. guttatus* representing the remaining 5% [1]. This should be referenced. If it is a result of the study it should be reported in the resultsLobster fishing industry has been using series of trapsHow many traps? attached by a line ('lingadas') as the preferred fishing technique, however, lobsters are also fished by divers. Diving for lobsters at industrial level began in 1998 and has progressively increased since then, therefore fishing effort from trap fishers has declined from 96% in 1994 to 54% in 2003 [2,3]. Considering the multiple inconveniences of having divers fishing at industrial levels [4] it was finally banned as a legal fishing technique in 2007, and since then the use of traps is the only one permitted in the local fishing regulations.

Traps are deployed in remote and isolated reef complexes between 30 to 50m deep, particularly within the Nicaraguan rise shelf section that belongs to Colombia, locally known as Green Moon ('Media Luna') or The Corner ('La Esquina') as shown in figure 1. Additional reef atolls such as Quitasueño (QUEENA) and Serranilla (SERLL) have been also used as fishing grounds. At present, most of the fishing grounds lack high resolution bathymetry and habitat information, although there are sections of less shallow (less than 30m deep) insular shelves having detailed habitat maps [5]. Data acquired in this study make possible the identification of precise trap location around the San Andres archipelago extending over an area of 200,000 $km^2$. Unfortunately, the lack of complementary information such as benthic habitats and bathymetry made not possible to relate the high resolution trap position data to ecosystem functioning and connectivity. On the other hand, gathered information might be utilized to update available navigational charts.

The San Andres archipelago is Colombia´s most northern Colombian frontier and its insular shelves are composed of well-developed coral reefs in relatively good health conditions [5], with individual banks having their unique habitat characteristics and ecological interactions [6]. The archipelago, limiting with four countries (Nicaragua, Honduras, Jamaica and Costa Rica) and several reef atolls and oceanic environments are legally shared with United States of America and Jamaica by international treaties. As a consequence, marine resources, in particular the spiny lobsters are subject to heavy fishing pressures not only by Colombian enterprises, but also by international legal and illegal fishers. This unique situation increases challenges fishery managers the need to face local, national and international problematic, which in turn demands skills in solving permanent conflictive situations and demanding skills in political, cultural and socio-economic contexts.

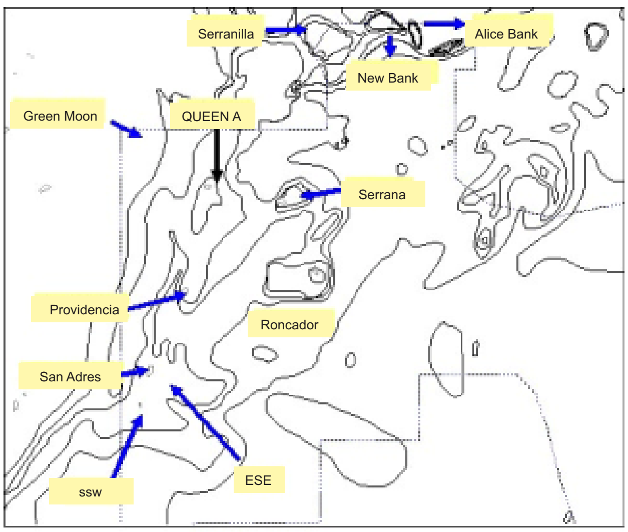


**Figure 1.** Geographic location of the San Andres archipelago identifying Colombia's boundaries (blue lines). 200 and 500 m in depth contours are highlighted to facilitate location of atolls shelves. Scale 1:4.000.000. Depth contours taken from [5].

For instance, each country has the fishing and effort database needed to make population analysis, but such information often: a) Is Incomplete/incorrect due to missing information in connection with real captures, b) Does not have measurements of appropriate fishing effort parameters, c) Does not have detailed information on fishing areas, d) Is affected by unknown levels of offshoreUnknown meaning in this context illegal lobster trade. Thus, data is being collected with high inaccuracy, limiting the power of the traditional fisheries statistics and the population models. Fishery management in one country will affect neighboring countries; therefore lobster fishing problems can be solved only by international cooperation and trust agreements among users and managers [7]. The data analyzed here was taken from the fishing log books kindly supplied by boat captains to fisheries managers for research purposes, thus constituting an example of the beginning of the cooperation level needed to build trust.

The main objective of this paper is to look for spatial and temporal patterns of lobster abundance resulting from the industrial trap fishery. More than 20,000 sites having geo-referenced trap positioning, number of traps and lobster abundance over a twelve year- period were analyzed to determine patterns of areas and seasons fished for lobsters, including identification of areas with the highest densities. Findings from this study are expected to increase the understanding on how fishers use the archipelago's fishing grounds and perhaps provide technical support to adjust fishing regulations based on mutual collaboration between managers and fishers. The lessons learned here, perhaps could be applied in other Caribbean countries.

## *Study Area*

Located in the Western Caribbean, but belonging to Colombia, The San Andres, Providencia and Santa Catalina Archipelago is located between 11° 30' to 16° 30'N and 78° 28' to 82°W (figure 1). The Archipelago includes three small inhabited islands - San Andres (SAI) and the island pair of Old Providence and Santa Catalina (PVA), How are these labled in Figure 1. Should be consistentas well as seven uninhabited keys and coral banks, with a total insular area of 57 $km^2$ and a marine area of around 200,000 $km^2$ surrounded by deep and oceanic environments (as deep as 5,000 m). The archipelago also includes a section of the Nicaraguan rise, known as Green Moon ('Luna Verde') or The Corner ('La esquina').

Atolls are lined up in a north-northeastern direction [8] and vary in shape, extension and separation among them (can be hundreds of kilometers apart) and have distinct habitats and productivity rates, thus conferring each one with unique ecological characteristics, despite their similarities. In general, reef complexes in the archipelago are characterized by the presence of barrier reefs and shallow and deep fore-reef on their windward side, a central reef lagoon with coral reef patches and slopes with different steepness on their leeward side.

Industrial fishing is allowed only on the northern reefsHow many countries fish these reefs and at some point please indentify if all countries participated in the data gathering, which comprises six atolls (Serrana, Roncador, Serranilla, Quitasueño, Bajo Nuevo and Bajo AliciaLables are not consistent with fig 1) as well as the section of the Nicaraguan rise. They are truly oceanic reefs and can be considered as one of the most isolated areas of the western Caribbean, being at its closest over a 240 km on the nearest continental land mass (Nicaragua), and 100 – 280 km from PVA and SAI islands respectively [8].

Around the archipelago there is a predominantly westward flow that mixes with an opposite one present in the south-west section of the Caribbean, thus generating the Colombia-Panama gyre. This gyre is present all year round with a mean velocity of 1 $m*s^{-1}$ [9-12] and might be the regional mechanism for larval retention and perhaps responsible for the high abundance and diversity seen in most of the archipelago's reefsNeed a reference to validate this idea unless ref 10 or 11 covers it.

Despite not having detailed bathymetry, it is expected that the presence of corals as well as sea mounts (elevations) and trenches (depressions) probably play a role in generating highly-variable small-scale circulation patterns, thus maintaining variable and high marine productivity [10-11].

## Methods

A total of 20,870 geographic positions of trap sets along with their lobster abundance were digitized from 26 fishing log books given by boats captains and three researches [9]. The data set contained the initial and end GPS positions of the trap set, the total number of lobsters caught, the total number of "lingadas" (groups of 25 traps attached by a line), date, boat name, company as summarized in table 1. Data was proofread before performing any spatial or temporal analysis.

**Table 1.** Summary of data set containing precise positioning of trap fishing lines (series of around 100 traps). Data during 1993-1995 taken from Medina [3], remaining information came from captains' log books.

| Year | No. Boats | No. Months | No. Entrances |
|---|---|---|---|
| 1993 | 3 | 3 | 97 |
| 1994 | 4 | 6 | 145 |
| 1995 | 2 | 2 | 115 |
| 1996 | 1 | 1 | 161 |
| 1997 | 2 | 4 | 379 |
| 1998 | 1 | 1 | 130 |
| 2000 | 2 | 2 | 4 |
| 2001 | 1 | 1 | 9 |
| 2002 | 2 | 2 | 11 |
| 2003 | 8 | 11 | 6546 |
| 2004 | 18 | 10 | 9405 |
| 2005 | 12 | 5 | 3868 |
| Total | 26 | | 20870 |

The trap fishery uses the same system utilized in Honduras, since most part of the fleet came from that country, and consisted on the deployment of four 'lingadas' 40 – 50 m apart, with each 'lingada' consisting of approximately 25 traps attached to a line (figure 2). Therefore, it was estimated that each set of traps represented approximately one kilometer of the seafloor.

Three different sets of fishing area maps were generated using the GIS Arc View version 3.2. The first series represented monthly displacements of fishing areas, the second series illustrated yearly changes in fishing areas, while the third series depicted only areas of highest lobster densities, understood as those sites having more than 15 lobsters, $'lingada'^{-1}$. This value was arbitrarily chosen from the density histogram, and accounted for the 6.4% of the data (1,341 points). Fishing areas in all cases were defined as one kilometer around every GPS position of the trap set initial point. To facilitate data analysis, maps attribute tables were manually associated with three major fishing areas: Green

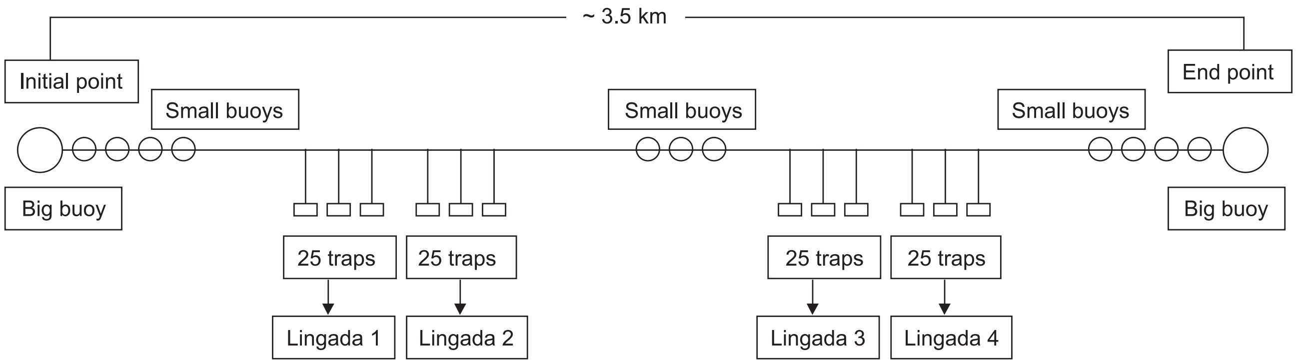


**Figure 2.** Scheme of trap arrangement fishing within the San Andres Archipelago.

Moon (the Colombian section of the Nicaraguan rise), QUEENA atoll and remaining atolls together (including SERLL and other isolated areas).

Data for years 2003 and 2004 were the those which had the most complete information (76% of the data base), thus they were used to estimate the number of lobsters fished by trappers by multiplying the mean number of lobsters fished per boat per month times the total number of fishing boats during the same period of timeWere your time periods two months? As listed below YES. The monthly number of fishing boats was obtained from the landings monitoring database available at the Fishing and Agriculture Department. Data was grouped every two months because this is the normal duration of a fishing trip.

## Results and Discussion

### Monthly variations

On average the trap fishery is using around 1,750 km$^2$ (±SD=1,025) per month to catch spiny lobsters, with Green Moon accounting for up to 68% (1,188 km$^2$, ±SD= 667), and QUEENA representing another 14% (244 km$^2$, ±SD= 189). Fishing areas within Green Moon were seen over a broad section of the shelf, ending in what could be a particular depth contour not known yet, but expected to represent the 30 or 50 m one based in what was found for QUEENA (figures 3 and 4). Indeed, Medina et al [3] taken data on board of trap boats in Green Moon during 1993-1995 reported that traps were deployed at depths ranging from 10.3 to 48.2 m with a mean of 32.4 m (SD= 6.1). Most fishing areas in QUEENA were located at the south end of the bank, and along its protected side.

Unexpectedly, it was found that the majority of the remaining 18% (318 km$^2$, ±SD=246) of the fishing areas were located between Green Moon and QUEENA, forming clusters of fishing areas presently charted to be at 500 to 8000 m in depth. The existence of these small areas are believed to belong to deep reefs (Seamounts, gayestDo you mean guyots?) which have not been identified in nautical charts, but known by certain fishers who used them as fishing grounds. Few trap boats appear to be fishing within the insular shelf of Serranilla, and in fact fishing areas there were registered before year 2000. Fishers mentioned that nowadays SERLL is not used because usually divers empty their traps, since they are using hookahs (air compressors).

When fishing areas are observed at detailed spatial scales ($\leq$ 1:100.000), it is easy to observe that traps are set in pairs or triplets, and in some cases they form quadrants, and are perpendicular to the insular shelves. It was interesting to find that traps are also set aligned along east-west transects (30 to 50 km in length), usually in pairs that are about 3 km apart. Long transects usually begin or end over the small areas suspected to be deep reefs. These transects may indicate how captains locate fishing grounds in absence of good bathymetry.

Despite archipelago's shelves are fished all year round, results showed that traps are being displaced from one area to another depending on the month (figure 3), and in addition, fishing areas extension are varying on a monthly basis (figure 4). In fact, two months (August and February) were identified as those ones being extensively fished. The peak in August was more important for areas within Green Moon and deep reefs, while February-March peak was noticed mainly for areas within QUEENA. Overall reductions in fishing areas were found from April to July, which can be associated to a small

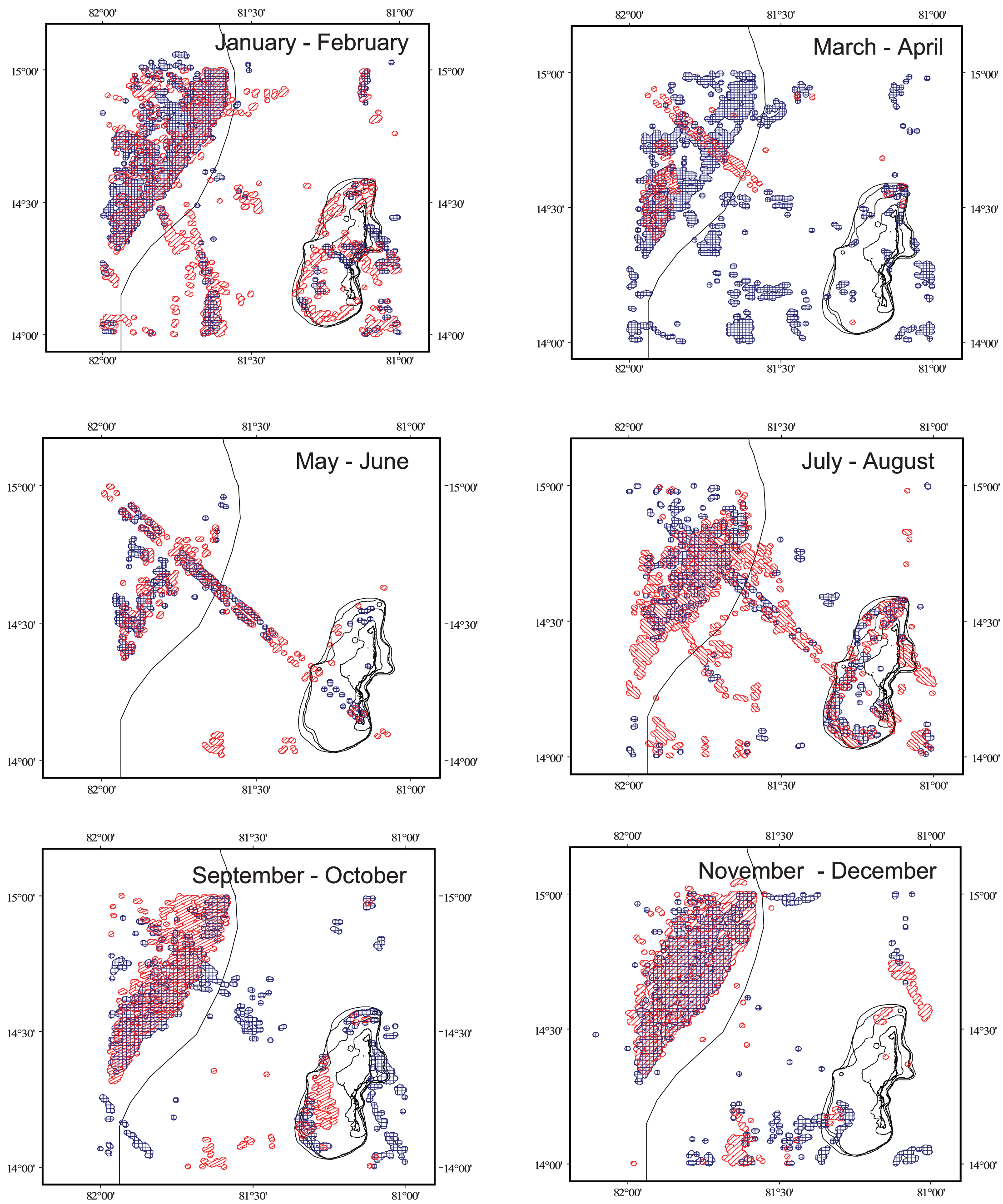


**Figure 3.** Series of thematic maps illustrating monthly displacements of fishing areas. Green areas identified the first month while the blue areas identified the second month. Scale 1:800.000. Data from 26 fishing log books and Medina et al (1996). N=20,870.

number of data entriesIs this the same meaning you intended?, but perhaps it may indicate real reductions in fishing efforts, roughly 50% of the fishing fleet in 2003 and 2004 (but it was almost 100% for 2005).

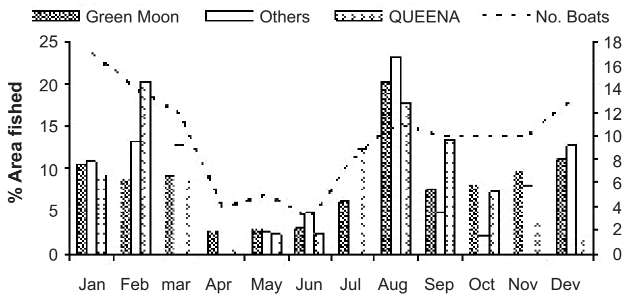


**Figure 4.** Monthly variation of fishing areas per trap boat, referenced to total number of boats fishing.

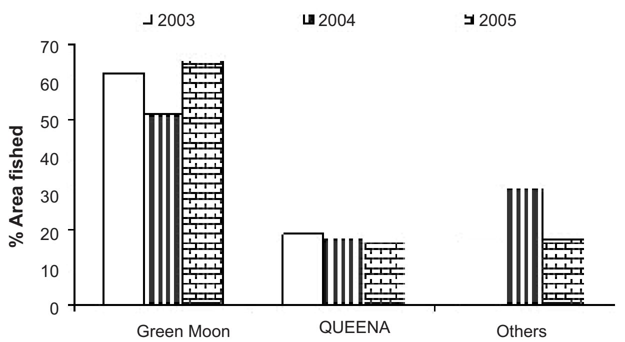


**Figure 5.** Yearly variations in fishing areas within the San Andres Archipelago. (analysis only considered 2003, 2004 and 2005 accounting for 92% of the data).

A three month close season (April to June) was established by the first time in Colombia during 2004, but it has been in place for more than ten years in Honduras, thus chances are that the reduction in fishing areas could be real. Up to now, there is not a clear understanding why fishers move their traps with time; it can be simple logistics, but it could also respond to biological reasons (i. e: following lobster migration, knowledge of areas with lobster aggregations, etc).

**Annual variations**

When data was rearranged to analyze changes at annual scales, it became clear that spatial distribution of fishing grounds can be extracted from data after 2003 having the majority of the entries. Annual average of lobster areas fished with traps was estimated in 2,841 $km^2$ (±SD=585), with the potential to be larger because gathered data represented roughly 50% of the fishing fleet in 2003 and 2004 (but it was almost 100% for 2005). However, increases in fishing areas are not expected to be much higher, because fishing grounds are limited to certain depths and habitat types. Boat captains suggested that all available areas are being presently fished.

Spatial distribution of fishing areas by years denoted the same arrangements Do you mean the same methods were used described for monthly variations, with Green Moon being the predominantly used area (figure 5). Similarly, deep reefs were more important fishing grounds than areas around QUEENA shelf. As number of boats in this fishery increased, fishing grounds became more limiting, thus forcing to explore additional areas. For instance, it was in 2005 when a number of fishing boats were using further reefs such as New Bank. Fishing in SERLL was observed only for 1993-1994 when divers fishing for lobsters were not common (figure 6).

**Highest Abundances**

Total area fished by trappers was estimated in 6,227 $km^2$, however areas with the highest lobster densities (greater or equal to 15 lobsters.'lingada'$^{-1}$) represented only 6 % of the data set (1,060 $km^2$), with 52.8 % located at Green Moon (figure 8) seems to indicate that almost all lobster densities over 15 were prior to 1993. Please confirm that lobster fishing locations in 2003-05 are ot being compared to lobster density prior to 1995. True. Areas expected to be over isolated reefs were found to be important sites for concentrating lobsters, accounting for 33.8% of the total areas. QUEENA sites represented only 13.6% of the highest density areas (figure 7).

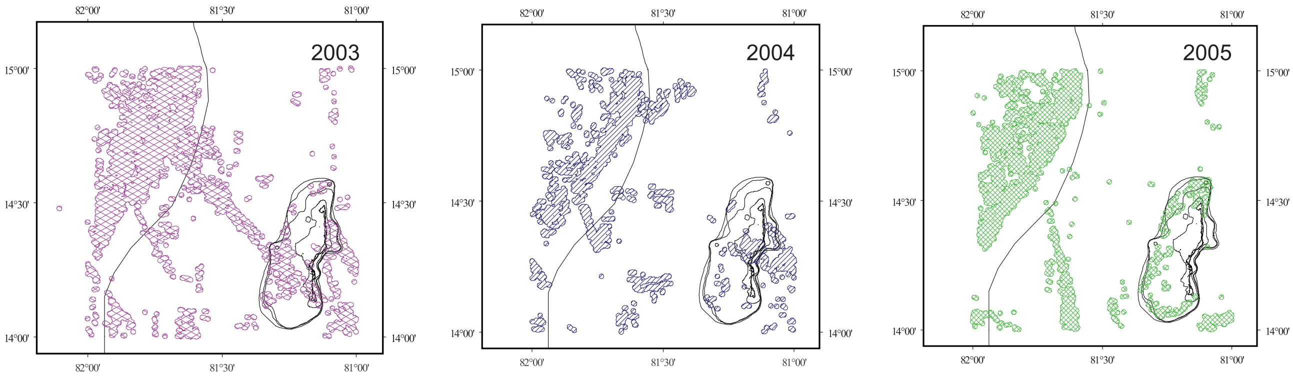


**Figure 6.** Series of thematic maps illustrating yearly displacements of fishing areas. Scale 1:800.000. Data from 26 fishing log books and Medina et al (1996). N=20,870.

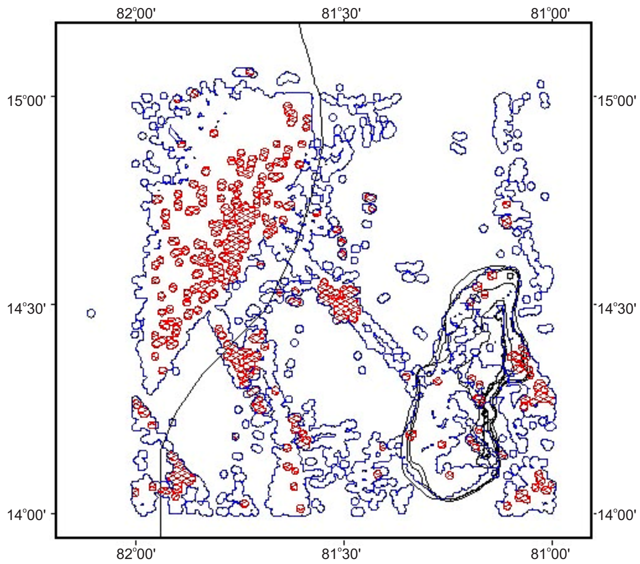


**Figure 7.** Map denoting spatial distribution of areas of highest lobster densities ($\geq$ 15 ind/'lingada'). Scale 1:800,000. Data from 26 fishing log books and Medina *et al* (1996). N=1,341.

traps per set), and production went down. Then fishers decided to use four 'lingadas' (~400 traps per set) and have been using this amount since 2000. But, lobster abundances have not yet responded positively to the diminishing in number of traps.

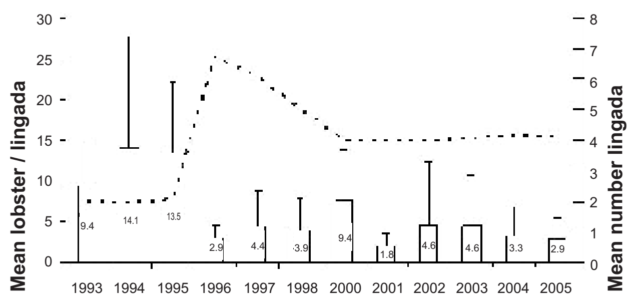


**Figure 8.** Negative trends in annual mean lobster density ($\geq$ 15 ind/'lingada'). Vertical bars indicated one standard deviation. For comparison mean number of 'lingadas' is plotted over density values.

It was found a clear negative trend in lobster density with time. Present values of lobster density was on average 2.9 lobster.'lingada'$^{-1}$ (±SD=2.6), which is 1.3 times lower than values estimated between 2001-2004, 1.6 times lower tan values during 1996-2000, and 2.8 times lower than values during 1993-1995 (figure 8). At the beginning of the fishery (1993-1995), fishing boats using only two 'lingadas' (~200 traps per set) were having good lobster production, thus, they decided to triple this amount (around 800

The fact that lobster production has not been recovered despite reducing number of traps per set, and, on the contrary, lobster production continues diminishing, can be understood as strong evidence of over-fishing. Indeed, Prada and Castro [2] and Chiquillo et al [13] have reported additional signs of over fishing, such as: a) Reduction of CPUE from 41.82 tail kg*day$^{-1}$ during 1990-1995 to 30 tail kg*day$^{-1}$ during 2000-2003, b) Only slight increments in CPUE from 3 to 4 tail kg*diver*day$^{-1}$ between 200-

2003 despite increment in number of divers in 30%, I do not understand thisc) Reduction in tail length from 18.1 cm in 1998 to 16.2 cm in 2004. Therefore fisheries managers need to look into additional regulations, greater reductions in fishing efforts and improvement in enforcement and surveillance in order to achieve lobster recovery.

With the improvement in the GPS technology, captains did not continue the detailed annotation in the logbooks after 2005, thus estimates about the degree of over-fishing in recent years using density variables could not be assessed.

It is expected that total number of lobsters fished at industrial level could significantly increase if total captures can be considered. For instance, it might double if lobsters fished by divers are included. However, unknown levels of illegal fishing hindered the possibility to estimate real fishing volumes.

It became clear that fishers regulate themselves trying to keep sustainable fisheries by shifting fishing areas and controlling number of 'lingadas'. Spatial and temporal patterns in lobster abundances were available because fishers shared data and information with managers, increasing trust between the two groups, which are working towards similar objectives, been able to maintain healthy lobster populations, while maximizing production.

There is hope that the recent establishment of a system of marine protected areas within the archipelago will allow stock recovery while protecting ecosystem biodiversity and function. Under this new approach, fishing grounds in QUEENA and Roncador as well as large sections of the Serrana Bank will be not allowed to industrial fishers. Reduction in available fishing areas will be then introduced when the lobster global quota has been established, and thus it will result in an important reduction in fishing effort.

During the last two years, lobster stock assessment has presented the spiny lobster in the San Andres Archipelago as stable resource which maintains a healthy condition referenced to international standards [14]. An increasing lobster biomass is the result of having adaptive fishery management that integrates all available information including scientific monitoring data, fishers log books and information given through interviews towards reduction of fishing effort. The recent global economic crisis has also contributed to reduce the international market lobster value, which in turn produced a net reduction in fishing trips not only in Colombia, but also in most Caribbean productive countries [15].

This work is a good example of the active involvement between scientists and fishers collecting and analyzing baseline data to generate new knowledge, one of the key processes in the fishery co-management [16]. The new information is then utilized in the preparation of development and management plans and strategies, for decision-making, for monitoring and evaluation and for process documentation. The participatory research process is important also raising awareness and education of other community members about their natural resources, as well as being useful in the formulation of potential solutions. Participatory research, which is conducted using a mix of scientific and rapid-appraisal methods, includes the collection of traditional and indigenous knowledge.

## *Findings*

The detailed information gathered from the industrial trap fishers allowed the verification that the Colombian section of the Nicaraguan rise (Green Moon), is the most fished zone by trappers, and in general can be considered as an area of particularly high lobster densities. In addition, areas within QUEENA shelf were identified to be important fishing grounds, particularly at the south end of the bank. Surprisingly, small clusters of areas over uncharted areas were seen to be of common use and to support high lobster densities, even higher than some areas in QUEENA.

More distant insular shelves are not commonly fished. Serranilla was found to be important fishing ground at the beginning of the fishery that was abandoned once lobster divers increased. A new insular shelf (New Bank) was identified to be fished only during 2005, denoting the necessity of fishing grounds as a consequence of increasing in number of fishing boats.

However, incomplete data set may underestimate the use of these more remote atolls for the trap fishery.

Having many years of experience, fishers nowadays have knowledge not only about location of high lobster abundances areas, but also on lobster movements or other biological reasons that resulted in good production. As a consequence, traps are being displaced throughout the fishing grounds on monthly (and annually) basis, concentrating fishing efforts on selected areas while trying to keep steady costs.

A clear negative progressive trend of lobster density was determined, with actual levels of production diminished from 14.1 lobster*'lingada'$^{-1}$ in 1994 to only 2.9 lobster*'lingada'$^{-1}$ in 2005. The reduction in lobster density persisted because potential reduction in number of 'lingadas' per boat is counteracted by the increase in number of fishing boats (particularly with lobster divers). In addition, lack of appropriate fishing regulations and enforcement hindered the recovery of this valuable stock.

This paper illustrates the importance of bringing fishers and managers together in order to share the knowledge that each group possesses and to be able to manage a valuable fishery resource in a sustainable way. As more information becomes available, better understanding about spatial and temporal patterns of the lobster abundance in the archipelago will be advantageous to both users and managers.

## Acknowledgments

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