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The mangrove-fishery relationship: A local ecological knowledge perspective

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ABSTRACT

Mangroves, one of the major coastal ecosystems of tropical and subtropical regions, are critical habitats for fish and crustaceans, and provide a number of ecosystem services to people. While mangrove uses have been widely documented based on local ecological knowledge, seldom has this approach been used to analyse the mangrove-fishery relationship. By conducting semi-structured interviews (n = 82) with fishers in three different villages surrounding the Ciénaga Grande de Santa Marta, the most important lagoon system in the Colombian Caribbean because of its size and productivity, we evaluated fishing activity over time, mangrove use and mangrove-fishery linkage, and fishing and gear spatial distribution. Respondents believed that mangroves are critical habitats for fishery resources because they function as nurseries, food source and reproduction areas, and considered that the resource would be in jeopardy in the absence of mangroves. While fishing is the main activity in mangroves, they are also used for firewood, construction and to make fishing gear, but how fishers use mangroves varies across villages. Fishing is concentrated close to mangroves (< 20 m) and fishers' villages though there was some gear and species-dependent spatial variation across villages. Given that the system is highly degraded and conservation and fishery management plans are urgently required, we suggest combining scientific with local ecological knowledge in the planning and implementation of restoration and conservation plans to increase the chances of such programs being successful.

1. Introduction

Marine coastal ecosystems provide many ecosystem services [1], but have suffered considerable degradation [2,3] due to factors such as overfishing [4], habitat loss, pollution and climate change [5]. This degradation is exacerbated by a steady human population growth in coastal habitats [6,7].

In the tropics, many people rely on resources provided by mangrove-dominated estuaries, such as fish production [8] whereby catches are directly related to mangrove area [9,10], wood products [11], and protection against natural disasters [12]. Mangroves are critical habitats for fish and prawns: they are good nursery habitats [13,14], serve as feeding grounds, decrease predation risk for many fish species [15] and can enhance fish abundance of nearby coral reefs [16]. However, small-scale fishing in mangroves is rarely regulated and therefore fish size and fish diversity may decrease in high pressure fishing areas despite the presence of mangroves [17].

Although fishing is the major economic activity conducted by fishers to sustain their families in mangrove wetlands [18], other natural resources are exploited by locals, particularly wood-derived products from mangroves (e.g. Refs. [11,19]. Although these other activities are not conducted as intensely as fishing, they are important to satisfy critical needs such as construction materials and fuel [18]. While harvesting mangroves by locals may not be as detrimental as many other threats mangroves face [20,21], selective harvesting can considerably change forest structure and ecological processes [19,22].

Local ecological knowledge (LEK) can be an important source of information for conservation and management. LEK is the knowledge acquired during people's lifetime at a local scale and can be orally transmitted through generations about the relationship that humans have with the environment. As such, it is cumulative in nature and can be an important source of information for conservation and management [23]. Over the course of their lives, fishers spend many hours a day interacting intimately with their environment and therefore acquire

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valuable information about collecting resources efficiently, weather patterns, species' life history observations, and predator-prey relationships. LEK is extremely helpful in establishing conservation plans when integrated with scientific data, or on its own where no scientific data exist [23–28].

Given that fishers exploit multiple resources from the same area, they have vast knowledge about local ecological patterns. However, to date, studies including LEK in mangrove-dominated systems have focused primarily on ecosystem services provided by mangroves [11,19,29,30]. But detailed explanations of fishing activities, fishing gear or the spatio-temporal distribution of fishing from a mangrove perspective are still scarce. Fishers' knowledge about mangrove habitat gained through their fishing activities is therefore a key component of the mangrove-fishery linkage. While some authors have addressed mangrove fishery issues, explicitly interviewing fishers on the mangrove-fishery relationship by combining habitat knowledge, fishing gear and spatio-temporal fishing distribution questions has not been conducted. For example, Dahdouh-Guebas et al. [11] interviewed fishers in a mangrove delta in India in a protected area and an adjacent area to explore the ecosystem services provided by mangroves to these users. Similarly, a study in a lagoon system in the Sea of Cortez in Mexico, mapped the locations where fishers were engaged in fishing and estimated the mangrove distance at which the activity was carried out [31]. Santos et al. [32] interviewed fishers with respect to fishery resources and causes of decreased fishery yield, but lacked the spatio-temporal component and local perception on how fishing resources use mangroves. Recently, Hoque Mozumder et al. [34]; assessed the Sundarbans mangrove small scale fishery from a social-ecological perspective. Fishers' agreed that mangrove loss has caused a decline in the fishing resources.

The purpose of this study was to use fishers' LEK to understand their perceptions of the mangrove-fishery relationship in the Ciénaga Grande de Santa Marta (CGSM), a continental lagoon system located on the Caribbean coast of Colombia. We conducted semi-structured interviews with fishers who had fished there for more than 10 years. We asked three major questions that independently addressed different components of the mangrove-fishery linkage. a) what are the fishing gears used and species caught in the CGSM? b) what are the fishers' perceptions of the mangrove-fishery linkage in the CGSM? and c) what is the spatial distribution of fishing in the CGSM?

2. Methods

2.1. Study site

The CGSM is the largest lagoon estuarine system in the continental Colombian Caribbean with an approximate area of 1280 km^2 that includes a number of different water bodies such as swamps, channels and marine waters (Fig. 1). The lagoon system also supports a large mangrove forest that provides habitat for a high diversity of taxonomic groups [35]. Thus, the CGSM is a highly productive system that contributes about 35% of the fisheries catch in the Colombian Caribbean [36]. The estuary's hydrodynamics are controlled by a connection with the ocean in the northernmost part of the lagoon while freshwater is provided by rivers that drain from the Sierra Nevada de Santa Marta mountain range and from Colombia's main river, the Magdalena River [35,37]. Despite its importance, the system has been under constant anthropogenic pressure for over five decades for a number of reasons. Firstly, the sea-lagoon system connection was partially interrupted when a highway was constructed along the coastline in the 1950s. The freshwater flow to the system was also interrupted in the 1990s in order to prevent flooding in growing agricultural areas surrounding the CGSM [35,37]. As a consequence, the system experienced abnormally high salinity concentrations, eliciting massive mangrove and fish mortality. While a large restoration project was established to recover freshwater and marine inputs to the system by reopening freshwater channels [37], currently the CGSM is still under constant threat due to multiple stressors such as pollution, sedimentation, lack of fresh water entering the system which is deviated for agricultural purposes, human induced fires, and overfishing [38,40]. Nonetheless, the CGSM is an extremely important ecological system. As a result, a natural park (Isla Salamanca Natural Park) and a fauna and flora sanctuary were established in 1964 and 1977, respectively. It was also declared a RAMSAR site in 1998 and a Biosphere reserve in 2000.

There are eleven communities surrounding the study area with a total population of about 400,000 people, half of which live in rural areas of the municipality [38] but around 25,000 people live in proximity to the lagoon [28]. Most of their population relies on the natural resources from the CGSM such as fisheries and mangrove products. Most people in these communities live subsistence livelihoods and have little or no education [36,37]. However, villages located close to larger municipalities (e.g. Ciénaga) or close to the highway connecting two large cities (i.e., Barranquilla and Santa Marta) have better conditions as they can market their catches more easily [36].

The fishery in the CGSM targets multiple different species and fishers use a variety of gears such as cast nets, gillnets, encircling gillnets, crab traps, longlines and handlines. Fishers typically own or rent small wooden canoes (3–9 m long) which are powered with small outboard engines or with oars or sails [36].

2.2. Semi-structured interviews

We conducted semi-structured interviews with fishers, who had fished for at least 10 years in the lagoon system, from three different fishing villages, Tasajera, Isla Rosario and Nueva Venecia. These sites were chosen because the Marine and Coastal Research Institute (INVEMAR) has conducted fishing surveys here over the years and thus a trust-based relationship has been built with local fishers. Also, fishers from other villages were not interviewed due to security issues related to Colombia's armed conflict. Tasajera and Isla Rosario are located next to the highway that connects both major cities; Nueva Venecia is a stilt village (Fig. 1). Interviews lasted between 45 and 60 min and were conducted by convenience sampling mainly at the landing sites. Field assistants, the same people who conduct fishery surveys for INVEMAR, conducted most of the interviews. Interviewers were trained and provided with an instructional document on how to conduct the interview. The lead author interviewed fishers with each assistant so they understood the procedure and until they felt confident about conducting interviews by themselves. A total of 82 interviews were conducted over a two-month period with fishers in the lagoon system (from June to August 2015): 19 in Nueva Venecia, 39 in Isla Rosario and 24 in Tasajera. Before a participant was interviewed, the project was explained and consent from each participant was obtained prior to proceeding. To maintain interviewer anonymity all the data were analyzed without using the participant's name. The ethics protocol was approved by the University of Victoria's Human Research Ethics Board under protocol number 15-013.

The interviews consisted of three parts, fishing questions (including spatial-temporal questions), mangrove questions, and mangrove-fishery linkage questions. We refer to non-spatial questions as questions about the fishing activity and mangrove relationship without a spatial component, which align with questions i and ii in the Introduction. Spatial questions refer to questions that include a spatial component (i.e. polygons) together with attributes from the non-spatial questions, and which align with question iii in the Introduction. First, fishers were asked about their fishing activity. We asked them to identify the most important species caught at different temporal scales (i.e., at present (2015), 5 years ago (2010) and 10 years ago (2005)), what fishing gear they used to catch the species, and their economic dependence on fishing activity. The state of the mangrove systems has not changed much over this time, and thus we hypothesized that fishing gears and species would also remain similar over time [38]. We also queried them

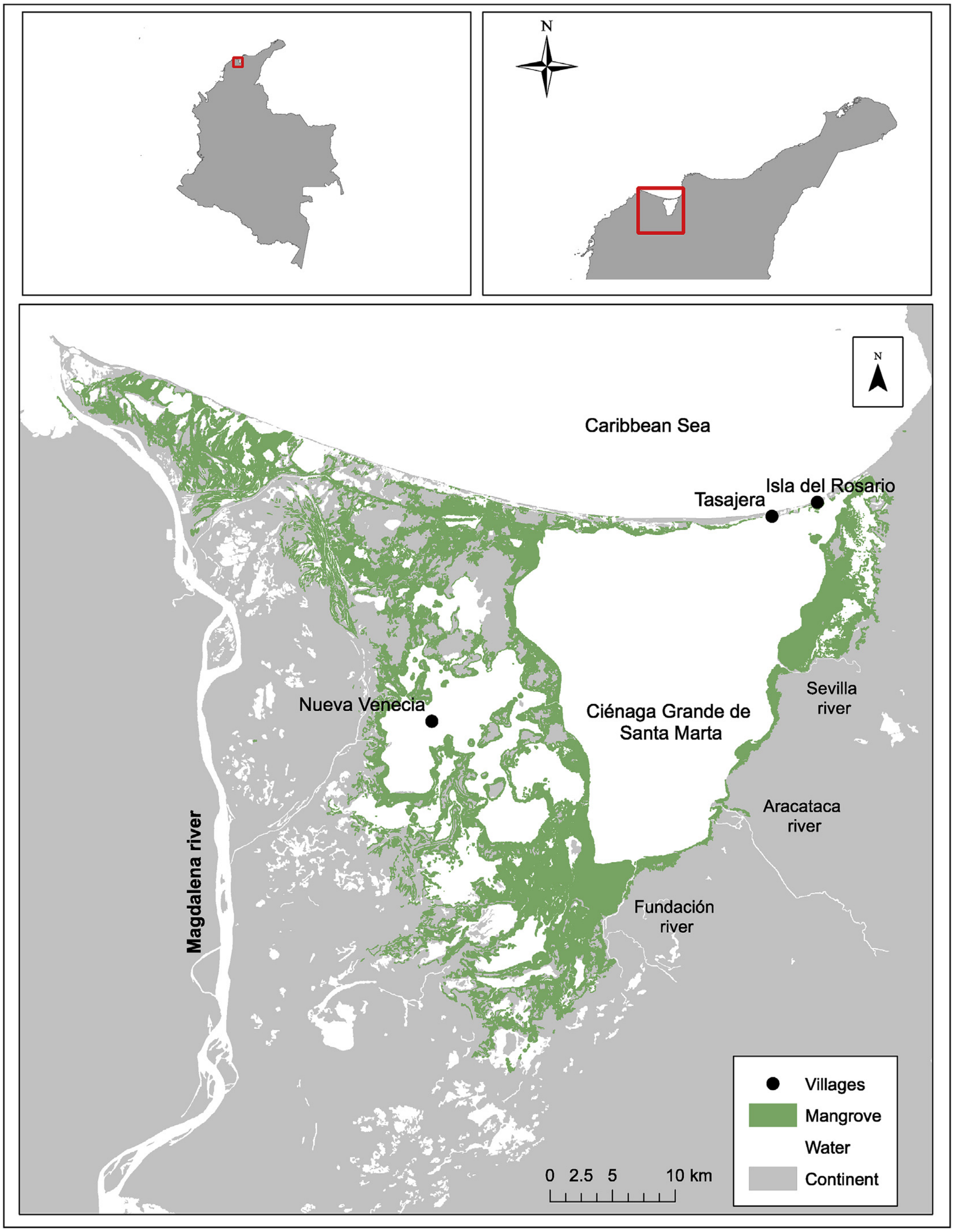

Fig. 1. Map of the Ciénaga Grande de Santa Marta showing the three fishing villages where interviews were conducted. Mangrove coverage shown is taken from 2014's mangroves coverage assessment by INVEMAR ([39]).

about their perception of both catch and size of species caught in 2010 and 2005 relative to 2015. For the spatial component, we asked fishers to draw polygons of their preferred fishing areas and the most frequent fishing gear used at the same temporal scales as above. This depiction allowed us to relate the spatial location of their catch with the species caught and the fishing gear used. Each fisher was presented with a 4 × 4 gridded map (Supplemental material) of the whole study area and was asked to show where their fishing area was on the map. After they had pointed to a specific grid (e.g. A4) the interviewer went to the zoomed-in, single page grid and asked the person to draw their preferred fishing area. This procedure was repeated three times, one for "at present" (2015), one for "5 years ago" (2010) and one for "10 years ago" (2005). The polygons were digitized as a single shape file in ArcGIS 10.4 with the Georeference tool using the gridded map described above as reference. These questions were aimed at gathering information about how fishers use mangroves in their daily activities, and their opinion on how the organisms they caught use the mangroves in the lagoon (i.e., the mangrove-fishery linkage).

Next, fishers were asked general questions about mangroves to validate their understanding about these habitats. We then queried participants on how they use mangroves in their daily life. Finally, we explicitly asked them if they thought that there was a relationship between mangroves and their fishing activity, and if so, asked them to explain what the relationship was.

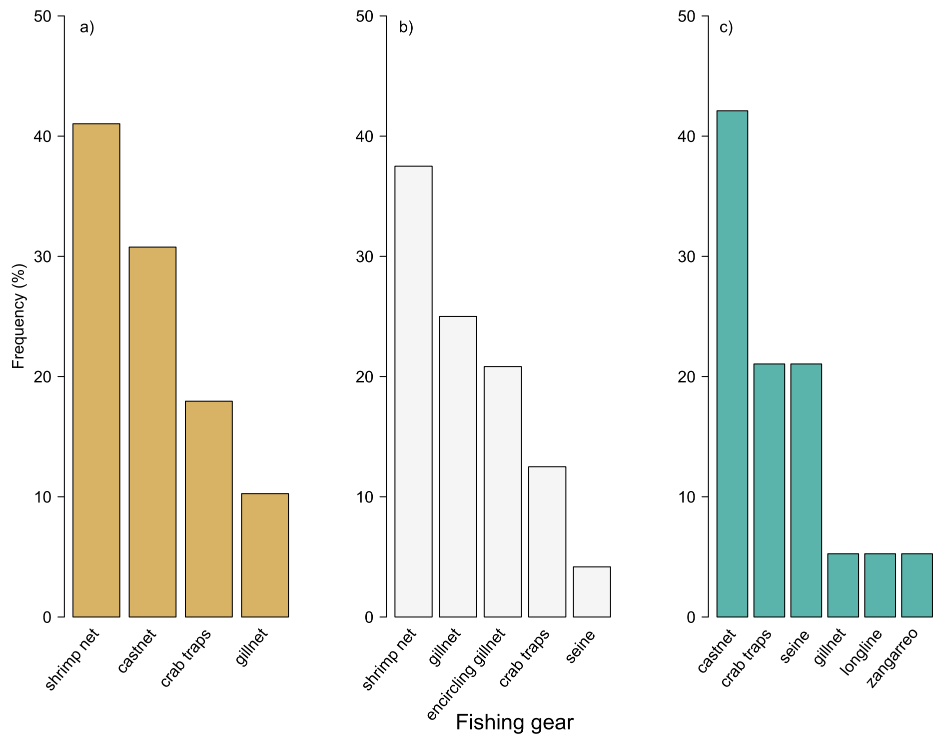

Fig. 2. Frequency (in percentage) of fishing gear used in a) Isla Rosario; b) Tasajera and c) Nueva Venecia. Zangarreo is a fishing method whereby the fisher gets in the water and sets a small mesh size entangling net bordering the mangrove roots.

2.3. Data analysis

2.3.1. Non-spatial interview questions

We created contingency tables for each question to tally fishers' responses and determine interactions between categorical variables, such as time (2005, 2010 and 2015), fishers' village, most frequent gear used, and species caught. Tables were constructed with two or three categories depending on the specific question. For the relationship between the most frequent fishing gear used and the village where the fisher was from we constructed tables tallying the number of responses in both categories. Similarly, the answers for the most caught species were cross-tabulated for both fishing village and time period, and responses tallied across these three categories. To analyse fishers' perception on whether catch had gotten better, worse or stayed the same at present relative to 2010 and 2005, we tallied fishers' answers based on time periods, their perception (better, same or worse) and their fishing village. The same three categories were used to summarize fisher's perception on how the size of the fishing resources caught had changed over time using 2015 as the reference point.

For mangrove questions, we also tallied fishers' responses based on categories. For the question on the fishery relationship with mangrove habitat, we summarized the different responses by tabulating different habitat uses (e.g. nursery) and villages. Similarly, we tallied the responses on what would happen to the fishing resources in the absence of mangroves by using these responses as a category together with fishing village. Finally, interviewees' responses were summarized based on the village and the answers given on how they exploited mangroves (e.g. firewood).

These tables allowed us to run log-linear models where a saturated model (i.e. no degrees of freedom) was fitted first and then the highest interaction was removed. To determine if the interactions were significant, we carried out partial Chi-square tests between the two models [41]. If the interactions were not significant, we concluded that the response for any given category was independent. A significant interaction suggested that the answers were not independent and therefore, there was an association between the variables measured. All statistical analyses were conducted in R [42].

2.3.2. Spatial analysis

Distance to mangrove was calculated by locating the centroid of each polygon drawn by the participant and measuring the distance to the closest mangrove area. Calculated distances were grouped by fishing villages, the three time periods, and by fishing gear to analyse differences in distances across villages and time, and between different fishing gears with two separate general linear models. To determine the spatial distribution of the main fishing areas, fishing gear used, and most important species caught in each fishing village and all villages combined, we counted the number of overlapping polygons by villages over time, fishing gear, and by most important species caught. For example, if two different fishers from the same village drew a polygon, and these overlapped, the count would be two. Next, we created a raster dataset from the output shape file with a cell size of 100 m. This resolution was chosen to allow for potential biases in the drawn polygons [43]. Thus, high-count values (i.e. high polygon overlap) represented a higher area used, while lower values represented areas used by fewer fishers. Finally, we applied a filter in order to smooth the raster dataset and have a cleaner representation of the fishing area.

3. Results

Respondents had fished in the lagoon system for an average of 33.7 years, ranging from 10 years to 55 years. The time that fishers from Isla Rosario had fished (mean = 39.82 years ± SD = 10.99 years) was ~10 years greater than in Tasajera (28.04 years ± SD = 10.63 years) or Nueva Venecia (28.58 years ± SD = 10.56 years). All of the income from respondents from Tasajera and Nueva Venecia depended on their catch, compared to 84.6% of the fishers in Isla Rosario. This means that 15.4% of the fishers in Isla Rosario had additional income outside of fishing despite most of their income relying on their daily catch.

3.1. Non-spatial questions

In general, shrimp nets were the most important fishing gear used, followed by cast nets and crab traps. Shrimp nets were most commonly used in both Isla Rosario (41.03%) and Tasajera (37.5%), while cast nets were more commonly used in Nueva Venecia (42.11%). Although crab traps and gillnets were the only two gear types shared across the three villages, their use frequency differed across the communities (Fig. 2); however, we found no association between fishing gear and villages ($\chi^2 = 6.59$, df = 5, p = 0.25) suggesting that the fishing gear choice is independent of where fishers live.

Shrimp (family Penaeidae), crabs (*Callinectes* sp.) and striped mojarra (*Eugerres plumieri*) were the most caught taxa across all villages and throughout the three time-points (Supplemental material). However, there were no differences over time across villages with respect to the species caught ($\chi^2 = 13.48$, df = 30, p = 0.9). Nonetheless, when removing the three-way interaction from the model, we observed that villages select for different species ($\chi^2 = 211.5$, df = 26, $p < 0.001$). For example, shrimp, crabs and striped mojarra were the most important species caught in Isla Rosario, whereas shrimp, ladyfish (*Elops saurus*) and striped mojarra were the most important species in Tasajera. Conversely, tilapia (*Oreochromis niloticus*), crabs and a mullet (*Mugil incilis*) were the most targeted species in Nueva Venecia. Similarly, catch diversity (i.e. number of species) was highest in Isla Rosario (9 species) followed by Tasajera (8 species) and Nueva Vencia (5 species). Although some variation was observed across time periods, there were no statistical differences ($\chi^2 = 7.76$, df = 15, p = 0.9) suggesting that fishers selected the same species over time (Fig. 3).

The three-way interaction for fishers' catch perception, that is if catches were better, same or different over time (catch perception X village X time), was not significant ($\chi^2 = 7.76$, df = 4, p = 0.1), but both catch perception X village ($\chi^2 = 39$, df = 4, $p < 0.01$) and catch X time ($\chi^2 = 19.83$, df = 2, $p < 0.01$) interactions were significant. Thus, the catch perception differed across villages, particularly in 2010 when most fishers (66.6%) from Tasajera considered catches to be the same as in 2015. However, fishers from all three villages agreed that catches were worse in 2015 compared to 2005 (Fig. 4a and Fig. 4b).

We also asked fishers to determine whether fishery resource size was different in 2015 relative to 2010 or 2005. Size perception of their catch differed across villages ($\chi^2 = 12.25$, df = 4, p = 0.01); fishers in Tasajera (62.5%) and Nueva Venecia (52.63%) considered that size of individuals caught in 2010 compared to 2015 were similar, while respondents in Isla Rosario considered that individuals were smaller (56.41%) in a higher proportion compared to the other two villages (Fig. 4c). Fisher's size perception also differed over time ($\chi^2 = 4.29$, df = 1, p = 0.038). While fishers considered that the size was similar and in some cases larger in 2010, the perception for 2005 changed to a majority of respondents in the three villages considering that individuals were either smaller or similar in size compared to 2015 (Fig. 4d).

3.1.1. Mangroves uses and fishery relationship

Although all fishers agreed that there is a mangrove-fishery relationship in the CGSM, interviewees from different villages differed in their opinion on the specific ecosystem function provided by mangroves ($\chi^2 = 26.73$, df = 10, p = 0.029). The most uniform responses across villages were that fish and crustaceans use mangroves as feeding areas and habitat in general. A high number of interviewees from Tasajera (57.14%) and Isla Rosario (39.28%) compared to Nueva Venecia (3.57%) considered that mangroves are important nursery areas for the species' they catch. The importance of mangroves as refuge was also mentioned by fishers in all three villages, but was more prevalent in Isla Rosario (55%) and Nueva Venecia (35%). The use of mangroves as breeding areas was only mentioned by fishers in Isla Rosario (83.3%) and Nueva Venecia (16.6%), while the use of mangroves as spawning areas was only mentioned in Isla Rosario (Fig. 5b).

When fishers were asked what would happen to fishery resources in the absence of mangroves, all of their responses suggested a negative impact on the resource, although the reasons differed across villages ($\chi^2 = 78.73$, df = 18, $p < 0.001$). Fishers in Isla Rosario showed the most diverse suite of responses ranging from death from a given cause (e.g., warmer water) to lack of reproduction. Respondents from

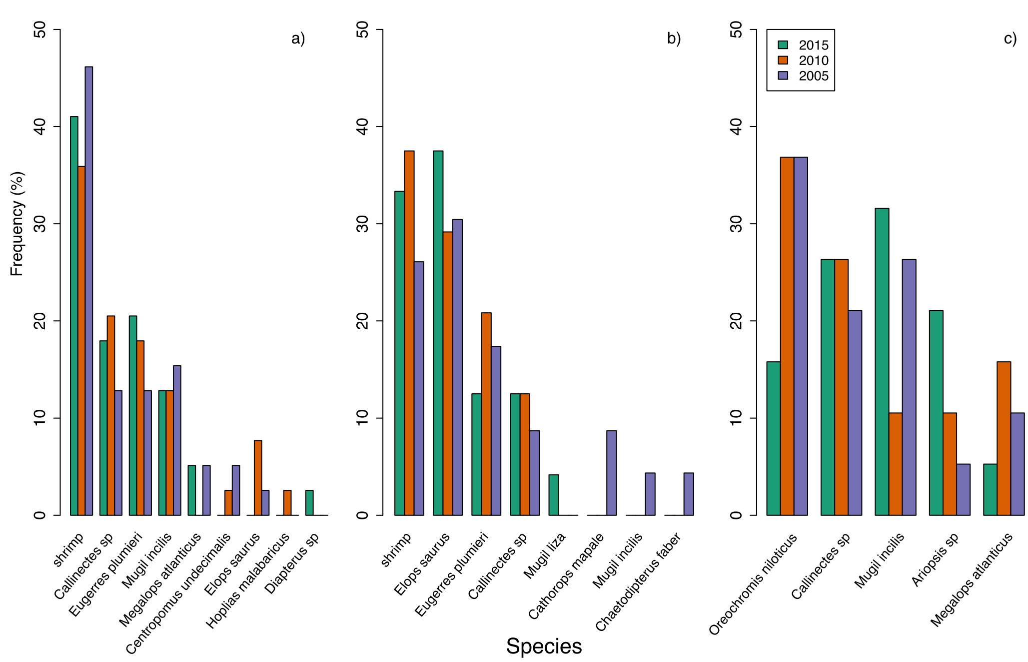

Fig. 3. Frequency (percentage) of the most abundant species caught at three different time periods (2015, 2010 and 2005) in a) Isla Rosario b) Tasajera and c) Nueva Venecia according to the fishers' responses in each village.

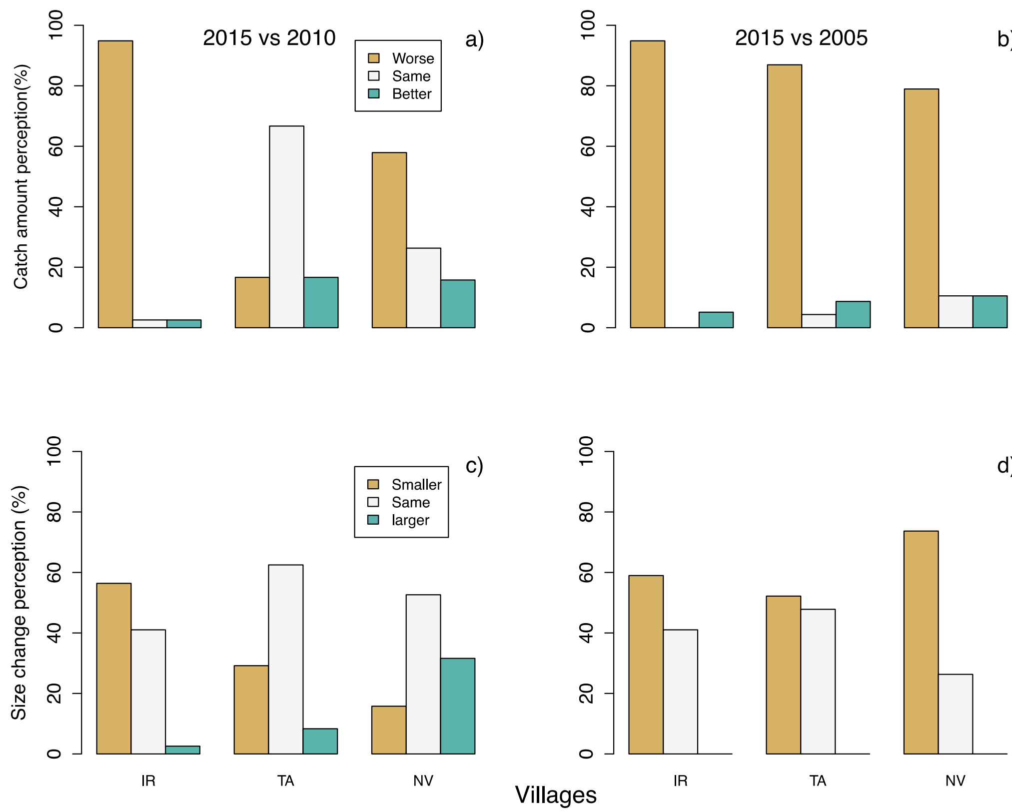

Fig. 4. Frequency of fishers' perception in 2015 relative to 2010 (a and c) and 2005 (b and d) for catch (a and b) and fishery resource size (c and d) of the most abundant species caught in the three time periods for the three fishing villages where interviews were conducted. IR = Isla Rosario, TA = Tasajera and NV = Nueva Venecia.

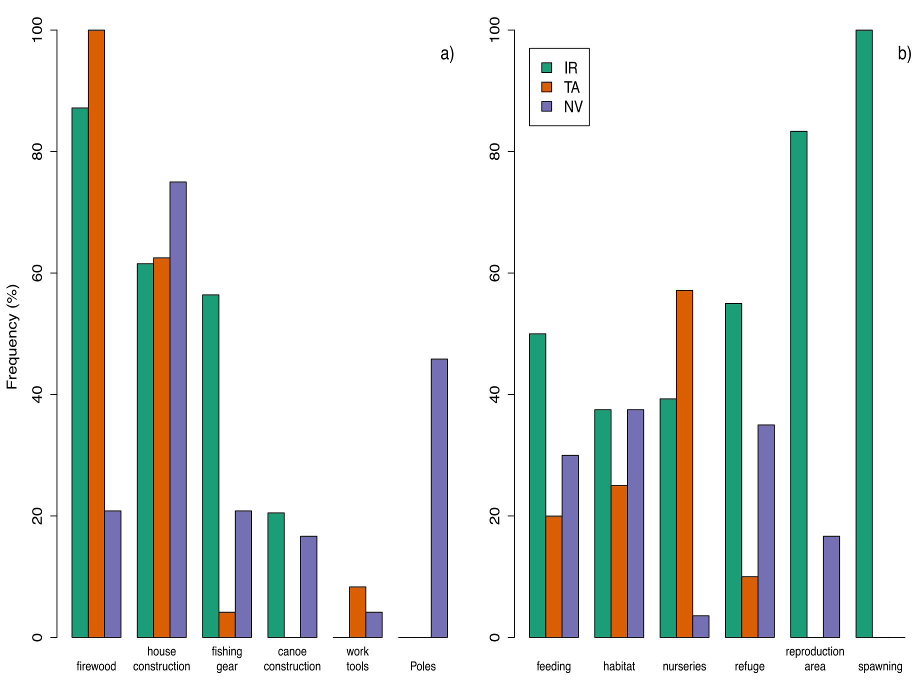

Fig. 5. Frequency (percentage %) of mangrove uses by a) fishers and b) crustaceans and fish according to respondents from three fishing villages. IR = Isla Rosario, TA = Tasajera and NV = Nueva Venecia. In a) Most respondents mentioned more than one use and thus the percentages are calculated based on the number of individuals in each fishing village who mentioned each given category.

Table 1
Frequency (percentage) of responses on possible outcomes in the hypothetical absence of all mangrove coverage in the CGSM for each village. IR = Isla Rosario, TA = Tasajera and NV = Nueva Venecia.

	IR	TA	NV
Catch decline	7.69	4.17	0
Die	7.69	91.67	52.63
Die-water warm up	23.08	0	0
Move to ocean	17.94	0	0
Move to river or ocean	10.26	0	0
Move to rivers	5.13	0	0
Move to similar habitat	23.08	4.17	47.37
Stop reproducing	5.13	0	0

Tasajera and Nueva Venecia provided less descriptive answers and mostly stated that fish would die (Table 1).

In the CGSM, fishers from the three villages exploited mangroves for different purposes ($\chi^2 = 70.10$, df = 10, $p < 0.01$). Mangroves were used for firewood by all fishers in Tasajera and by 87.18% of fishers in Isla Rosario, but minimally used in Nueva Venecia (26.32%). However, harvesting mangroves to construct houses and used as poles (herein defined as a tool used to move a canoe) was greater, and unique in Nueva Venecia compared to Isla Rosario and Tasajera. Fishing gear derived from mangroves, such as posts for stationary gillnets, was higher in Isla Rosario (56.41%) than in Tasajera (4.17%) and Nueva Venecia (26.32%). Less frequently, mangroves were also used for canoe construction and for work tools among the interviewed fishers in the three villages (Fig. 5a).

3.2. Spatial questions

In general, fishing activity across villages occurred close to mangroves. Although there were differences across villages (ANOVA, F = 72.93, df = 2, $p < 0.05$), the distance to mangroves for fishing activity had not changed through time (ANOVA, F = 0.84, df = 2, p = 0.43). While fishers in Tasajera fished on average 13.74 m ± 6.69 m away from the mangroves, fishers from Isla Rosario (6.21 m ± 6.29 m) and Nueva Venecia (4.08 m ± 3.45 m) fished closer to the mangroves. Although gillnet and encircling gillnets were used further away from mangroves compared to the other fishing gears (ANOVA, F = 9.00, df = 7, $p < 0.05$), all gears were always used on average, under 20 m from the closest mangrove area, suggesting a strong relationship between fishing and mangrove habitats.

Overall, the most common fishing areas were located in the northern part of the CGSM, although a large area used by fewer fishers was observed in the southwestern area of the CGSM (Supplemental material). The most common fishing grounds of the three villages were close to their landing site, suggesting short travel distances. However, in 2005 some fishers from Isla Rosario were fishing in the southern part of the CGSM. Similarly, the areas used by fishers in Nueva Venecia were more widespread and further from their village in 2005 compared to 2015 (Fig. 6).

We found interesting spatial patterns related to the different gears used. For example, shrimp nets, encircling gillnets and gillnets were mainly used in the north. Shrimp nets were used along the whole northern border while encircling gillnets were limited to one specific area. Conversely, seine nets were mainly limited to the southwestern area of the lagoon system and their use was more widely distributed than other gears. Similarly, cast nets covered a large area although they were mostly used at the mouth of the lagoon (Fig. 7).

Shrimp and crab catch distribution within the lagoon system resembled the two fishing methods that target such groups. The spatial catch patterns for fish species were a function of the village and the gear used. Striped mojarra, for example, was highly caught where fishers drew polygons for encircling gillnets, but were also caught in the mouth of the lagoon system. However, striped mojarra catches had a small area relative to the whole system represented. In contrast, *M. incilis* was caught over a wider area across the system although it was not as highly targeted as *E. plumieri*. *O. niloticus*, which was only targeted by fishers in Nueva Venecia showed the most southern distribution and had some area overlap with *M. incilis* and *Ariopsis* sp. (Fig. 8).

4. Discussion

The mangrove-fishery linkage has been well documented from an ecological stand point in both local [44] and global settings [10]. However, our study is the first to conduct an in-depth analysis of the mangrove–fishery linkage from a LEK perspective by interviewing the major stakeholders in the system and obtaining fishing gear and spatio-temporal fishing information from a human perspective, and explicitly querying fishers on the mangrove-fishery relationship. In general, we found that fishing occurs close to mangrove habitats (typically under 20 m) and to their home villages. There is a consensus among fishers that mangroves support their fishing activity. Indeed, many of the species caught in the CGSM are mangrove-dependent and similar species or genera have been reported in other mangrove areas in different geographical settings [32]. Our findings suggest that LEK is an alternative and powerful tool to gain insights into ecosystem function and the mangrove-fishery linkage because fishers' knowledge has proven to be a useful and trustful source [45,46].

The most commonly used fishing grounds (i.e. where more polygons overlapped) were at short distances from mangroves (< 20 m) for all fishing gears, although some gears, such as encircling gillnets or gillnets, are used at further distance to mangroves. Fishing activity close to mangroves (i.e. less than 20 m away) has also been reported for multiple fishing gears and was also gear dependent in a sub-tropical lagoon system in the Sea of Cortez in Mexico [31]. Similarities in two different geomorphological lagoon systems suggest that fishing is best at a close distance from mangroves. This can be explained based on the high productivity of mangroves due to two main energy pathways, prey availability, due to the nursery function, and a detritus-based food web which can attract a higher abundance of larger organisms than adjacent habitats [13]. Although fishers are not familiar with these ecological mechanisms, a high percentage of them believe that the species they target use the mangroves to feed. Similarly, two other common responses among interviewees were that mangroves were important habitat and reproduction grounds for fish and crustaceans. As a result, based on their knowledge of fish and crustacean movement, feeding patterns, and reproductive cycles, they fish close to where these organisms are. Torres-Guevara et al. [28] also found by conducting interviews that artisanal fishers fish close to nursery areas in the CGSM. However, fishers consider this practice unsustainable. Nonetheless, they continue to do it because in many cases it is the only source of food and/or income available to them [35].

Previous LEK study respondents have mentioned that mangroves are important for fishing productivity 11 [11,19,32,32,33], but our work is the first to include specific questions inquiring about the importance of mangroves for their fishing activities. The fundamental role of mangroves to support fisheries was not in doubt for the fishers interviewed in the CGSM. Though the perception of services that mangroves provide for fish and crustaceans differed by village, all the categories mentioned by fishers have been the subject of scientific research. For example, the role that mangroves play as nursery grounds for reef species on Caribbean islands is widely accepted and understood [14,47]. Similarly, field experiments have demonstrated that mangroves support high densities of juvenile fish as the structural complexity of the roots decrease predation risk and create good refuge areas [15]. Fishers always identified negative impacts for fisheries in the hypothetical scenario of total or partial loss of mangrove forests. In a similar study in a river estuary in Brazil, Santos et al. [32] found that fishers reported decreases in catches due to mangrove loss caused by aquaculture and fishing

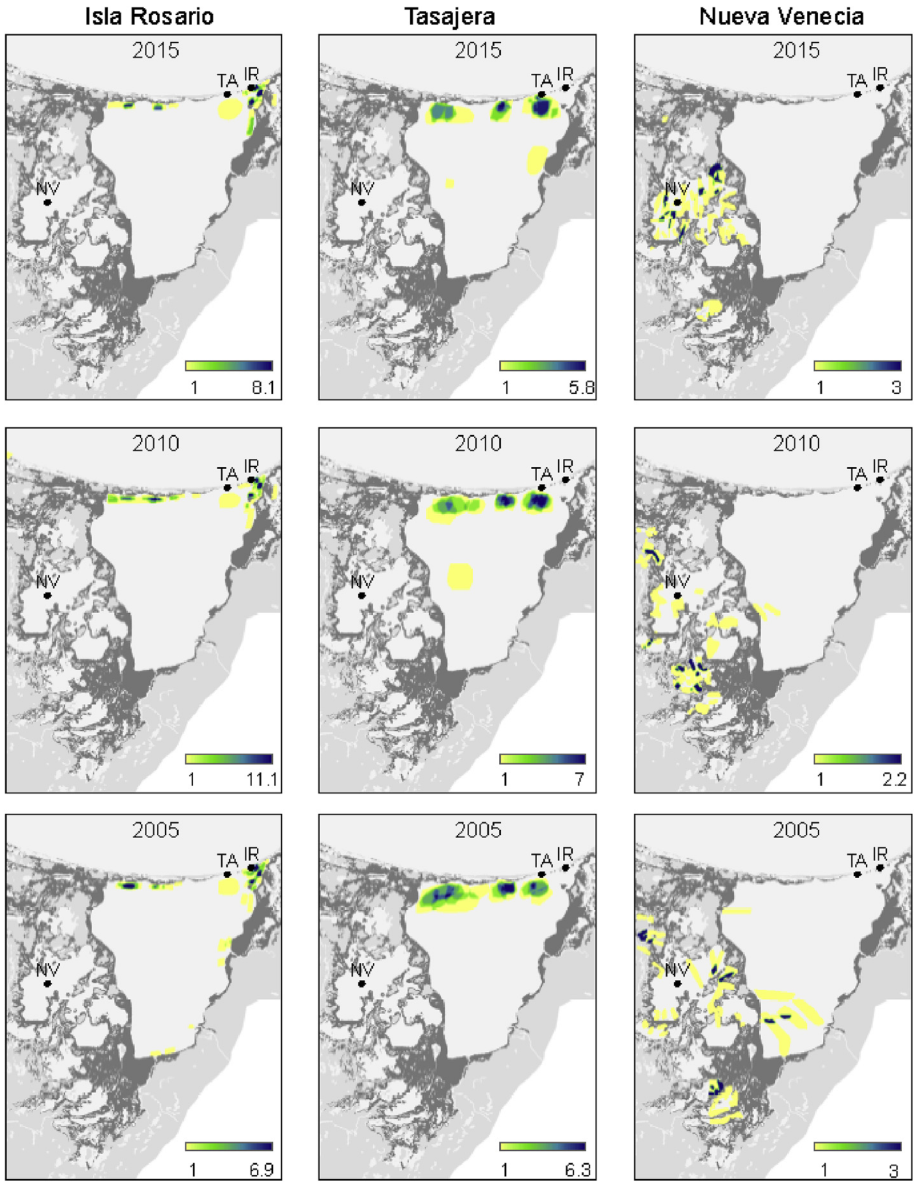

Fig. 6. Maps showing fishing areas across villages and over three time periods, recent (2015), 5 years ago (2010) and 10 years ago (2005). In the legend, yellow colours represent no polygon overlap (low fishing density) whereas blue represents high polygon overlap (high fishing density in the area). Each map has its own scale as the number of overlapping polygons differs across all combinations. In total 82 fishers were interviewed (n = 39 in Isla Rosario (IR), n = 24 in Tasajera (TA) and n = 19 in Nueva Venecia (NV). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

pressure. In contrast, Dahdouh-Guebas et al. [11] found that fishers perceive fishing pressure as a major threat for their resources, but not habitat loss. In many cases, fishers' concerns concur with local studies that have explored the mangrove-fishery relationships in similar lagoon systems [31], and at a global scale whereby mangrove-fishery relationships have shown a positive trend [10].

Most respondents considered that catches had declined in 2010 and 2015 relative to 2005. Catch records for the whole system suggest that there has been a general decline in fish catches from 2005 to the present. However, crustacean catches were similar in 2005 and 2010, but have only shown a negative trend since 2012 [38]. While fishers' catch perception is not an exact representation of the past, other studies have shown that there are similarities between fishers' perception and landing records in other locations [45,48]. The perception of smaller individual sizes in 2005 relative to 2015 was consistent as respondents from all three villages agreed that size of fish had declined over time. Studies in British Columbia (Canada), and Brazil agree with these findings whereby fishers' perception of size shows a negative trend over time mostly caused by high fishing pressure [45,48]. Records show that high fishing pressure and high juvenile catches [38], coupled with a deteriorated ecosystem, such as sedimentation, eutrophication, high salinity concentration due to lack of fresh water, and mangrove mortality [35], have led to a decrease in catch and size of the resources in the CGSM. Although fishers acknowledged the fishery resource depletion based on our findings and other LEK studies in the area, they considered that their fishing behaviour (i.e. gear used and hours of fishing) was not highly detrimental to the system, likely because this is the only income source that fishers have. Rather, fishers think that the actual degraded state of the lagoon is the government's responsibility [28].

Many of the species targeted by the interviewees over the years have been reported as mangrove-dependent in other studies. For example, prawn landings have been reported to increase with mangrove area locally [31,49] and globally [10]. In Brazil, similar fish species to the ones fished in CGSM have also been determined to be mangrove-dependent and crucial for fishers' subsistence [32]. Mullets (Mugilidae)

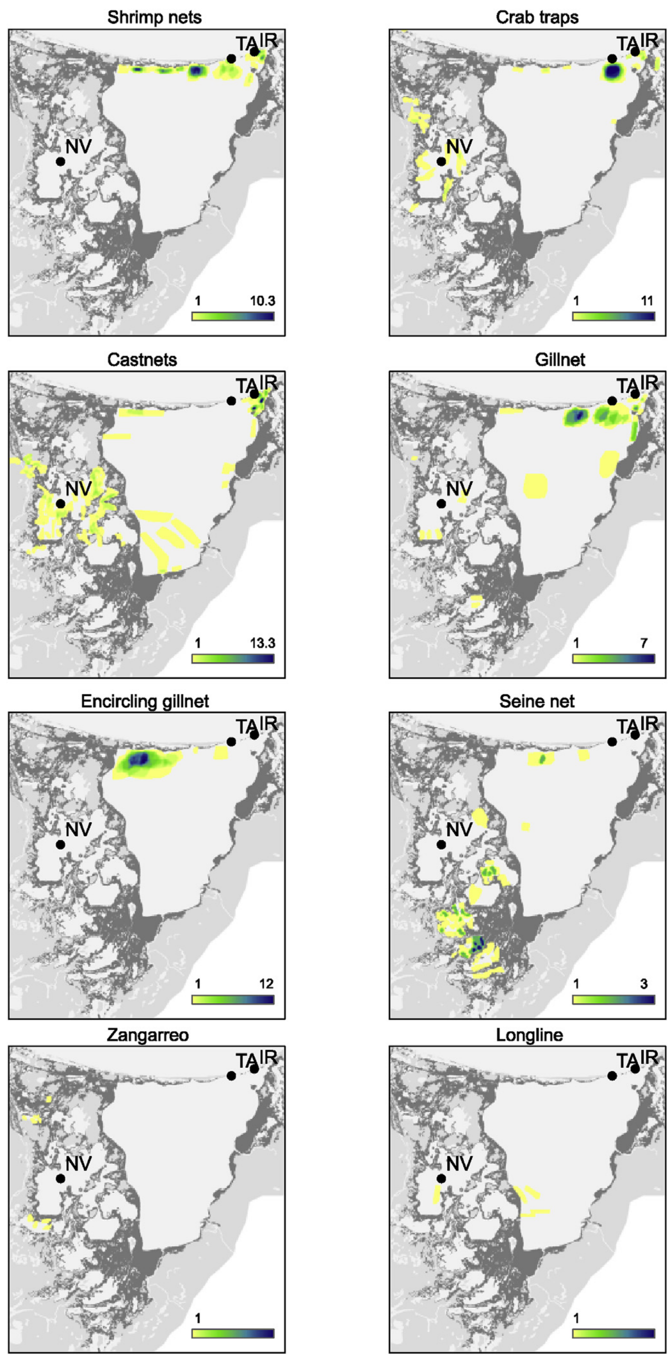

Fig. 7. Maps showing the spatial distribution of the different fishing gears combined for all villages used by fishers interviewed in IR (Isla Rosario, n = 39), TA (Tasajera, n = 24) and NV (Nueva Venecia n = 19). In the legend, yellow represents low (no polygon overlap) while blue represents high (many polygons overlapping) occurrence. Each map has a unique scale because the polygon count was done separately for each gear and thus is related to the number of respondents. There are no upper limits for zangarreo and longline use as there were no overlapping polygons. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

have been classified as mangrove-dependent in Africa [50,51], Gerreidae have been linked to mangroves in Florida [52] and catfish (*Ariopsis* sp) have been found to depend on mangroves in Colombia [53].

The spatial distribution of three of the most economically important species (*M. incilis, E. plumieri* and *C. mapale*) in the CGSM were previously modelled by using kriging interpolation, based on fishery

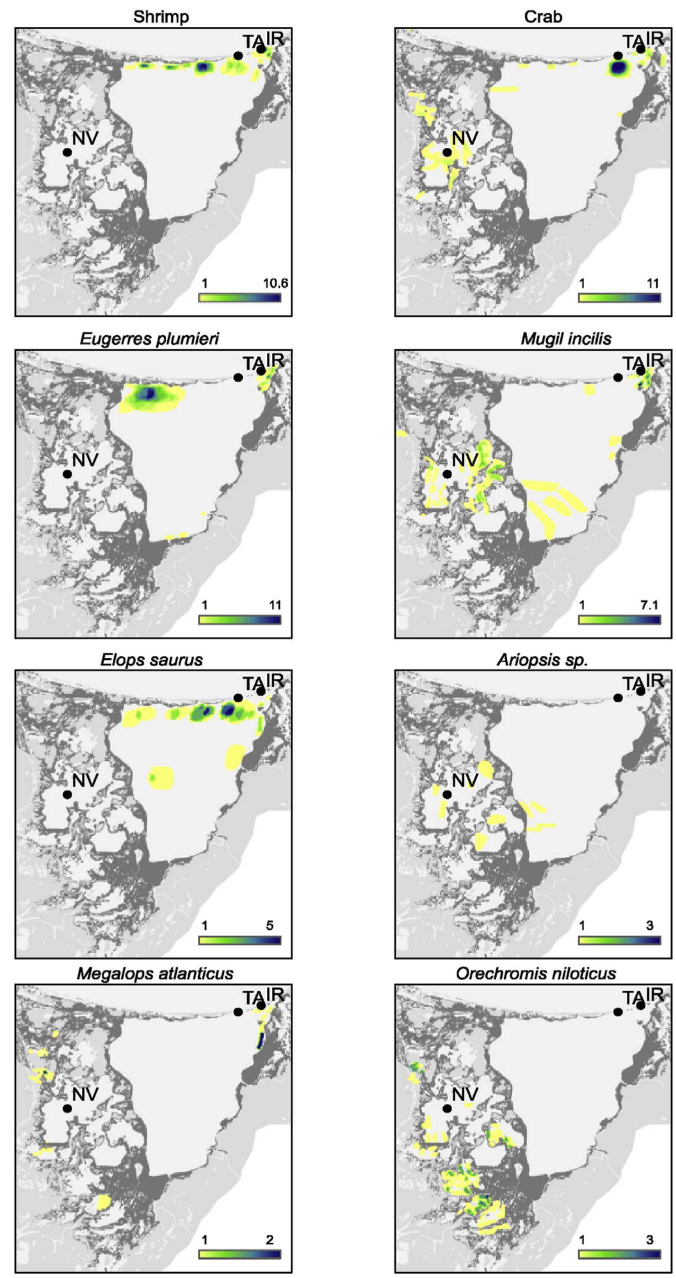

Fig. 8. Map showing the spatial distribution of catches of the most frequent species caught by fishers interviewed in IR (Isla Rosario, n = 39), TA (Tasajera, n = 24) and NV (Nueva Venecia, n = 19). In the legend, yellow represents low (no polygon overlap) while blue represents high (many polygons overlapping) occurrence. Each map has a unique scale because the polygon count was done separately for each species and thus is related to number of respondents. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

independent data [54]. Our results, based on the fishers' responses for two of these species (*M. incilis* and *E. plumieri*), show similar patterns to the modelled distributions. It is possible that if fishers from southern villages were included, more species would resemble the distributions obtained from the models described. In north-eastern England a lobster fishery spatial distribution was assessed by fishing patrols with GPS on board that sighted fishing vessels and semi-structured interviews, and found a high frequency of overlap between both datasets [43]. Both our study and this one concur on the importance and accuracy of perceived spatial distribution of fishery resources in different ecosystems. The similarities between the scientific findings and fisher perception are remarkable, and when incorporated into scientific research can provide better management plans [24].

In addition to potentially better management, our findings also have important conservation implications. Fishers' knowledge with respect to catch decline, was consistent with systematic monitoring programs [38,55]. However, fishery management in coastal lagoon systems such as the CGSM is extremely challenging because their fisheries are commonly multi-gear and multi-species [35,56], and the jurisdiction is unclear as estuaries are located in the transition zone between sea and land [27,57]. Although fishers are the major resource users, they are rarely included in fishery management planning, which has often contributed to ineffective management [25]. In Colombia, managers' and fishers' perception of adequate management differs in scale because managers have a national perspective while fishers identify issues in their fishing grounds. These differing perspectives lead to poorly managed fisheries because of the broad management strategies used by the government without taking into account fishers' local knowledge [27]. These management issues are exacerbated in the CGSM because managers and fishers have different opinions about fishing in the system [28]. In contrast, more robust management plans have been implemented when including fishers and their knowledge elsewhere [24]. In addition to the fishery issues, mangrove use by locals (e.g. wood and fuel) in CGSM has not been accounted for in monitoring programs despite the ecological effects that it can induce in the ecosystem [19]. We suggest that by incorporating how the mangrove forest is changing based on the resource exploitation together with mangrove coverage loss, the overall understanding of the system will become more robust and conservation plans can be enhanced.

5. Conclusions

We have found convincing evidence of the mangrove-fishery linkage from a LEK perspective in the CGSM by combining fishing, mangrove-fishery, and spatial questions. Fishers' knowledge about the system is remarkable and in many cases concurs with findings based on biological science approaches. As a consequence, LEK combined with biological science may improve ecosystem management and conservation [25,58]. However, at present, the CGSM is under extreme anthropogenic pressure and highly deteriorated. Fishery resources are decreasing and mangrove mortality has increased while mangrove density has decreased [38]. Given the importance of the lagoon system, the Colombian government has announced important funding to restore the system. Thus, including fishers in the conservation plans that are underway must be a priority for restoration to be successful.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2019.103656.

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