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Integrating the spatial and temporal dimensions of fishing activities for management in the Northern Gulf of California, Mexico

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ABSTRACT

Fishers' knowledge collected through a rapid appraisal process that involved semi-structured interviews in 17 fishing communities in the Northern Gulf of California, Mexico, was used to understand the spatial and temporal scales at which small-scale fisheries operate. This study identifies 43 main target species and group of species and the fishing gear preference(s) for the harvest of each. The reported spatial and temporal patterns associated with the target species were used to evaluate use of existing marine protected areas (MPAs), the distance traveled to reach fishing areas, and the timing and locations of fishing activities. MPAs were found to be important fishing areas for multiple communities with 79% of the total area within MPAs being actively utilized. Five communities stand out in their capacity to travel up to 200 km to reach their fishing grounds. The results also show a clear a seasonal differentiation in species and areas targeted as well as fishing gear and methods used. A systematic incorporation of information related to spatial and temporal scales in fishing activities provides additional opportunities for the sustainable management of fisheries, both for the Mexican government and local interests. The incorporation of local knowledge helped building a source of information that can provide insights for regulatory agencies in the development of spatially explicit management measures in the Northern Gulf of California, Mexico.

1. Introduction

The collapse of many of the world's fisheries (Jackson et al., 2001; Myers and Worm, 2003; Worm et al., 2006) and a corresponding decline in the sea's capacity to provide essential ecosystem services (MEA, 2005) has led to the search for management approaches to prevent further failure (Worm et al., 2009). Among these, a focus on ecosystem-based approaches (Pikitch et al., 2004) has led to a paradigm shift towards place-based ecosystem management (i.e., marine spatial planning, ocean zoning, marine protected areas) (Cicin-Sain and Belfiore, 2005; Hooker and Gerber, 2004). Place-based ecosystem approaches acknowledge the benefits that appropriate boundaries around resources and those entitled to use them bring to management (Ostrom, 1990). The definition and establishment of clear boundaries can also enhance conservation efforts by eliminating spatial and temporal fragmentation of space among users (Commission, 2003). However, the definition of these boundaries requires the understanding of the spatial and temporal dimensions of human activities and the ecosystem in order to define the scale required for their assessment and management (Berkes and Folke, 1998; Hilborn et al., 2005). Once the different levels of scale (e.g., spatial and temporal) are understood, it is possible to capture the relationship between users and the ecosystem, providing analytical dimensions (i.e., management units) for decision-making (Glaser, 2006). These relationships have come to be recognized as central to coastal and marine management (Folke et al., 2007; Hilborn et al., 2005; Orensanz et al., 2006).

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Research on the spatial and temporal heterogeneity of ecosystems and the different scales of management has typically focused on biological processes of the environment. Meeting the challenge of place-based ecosystem management will, however, require an improved understanding of the human use patterns in the marine environment by highlighting areas of intense use or areas where multiple activities are occurring. This process can illustrate inequalities in resource use and access, and reveal the progressive expansion of fishing activities to larger scales (e.g., roving bandits) (Berkes et al., 2006). In this quest for more and better information, researchers and decision-makers have recently turned their attention towards the accumulated local knowledge (LK) of users to bring a detailed representation of human activities in space and time into management process resources (St. Martin and Hall-Arber, 2008).

Increasing evidence has been assembled to support the view that LK is fundamental to understanding the needs and impacts that users bring into management of marine species (Berkes, 1993; Johannes, 1989; Neis and Felt, 2000). In addition to providing much needed data, LK inherently incorporates the spatial component into resource management (Johannes, 1993). The inclusion of LK can be enhanced through the use of geospatial tools such as geographic information systems (GIS) (Anuchiracheeva et al., 2003; Close and Hall, 2006; Riolo, 2006). With advances in GIS and the inclusion of LK, new opportunities for accessing and understanding data with spatial and temporal characteristics have become available. Examples of local knowledge incorporation using GIS include: (1) the design of marine protected areas (MPAs) (Aswani and Hamilton, 2004; Aswani and Lauer, 2006); (2) the understanding of sea tenure systems distribution (Mohamed and Ventura, 2000); (3) the contribution to improving knowledge on marine resources (Carter and Nielsen, 2011; Le Fur et al., 2011; Sáenz-Arroyo et al., 2005); and (4) designing and implementing fisheries management strategies (Anuchiracheeva et al., 2003; Close and Hall, 2006; De Freitas and Tagliani, 2009; Zukowski et al., 2011). These examples demonstrate the impact of incorporating local knowledge and GIS into research through a cost-effective strategy for obtaining essential data, which would otherwise take years to collect. Other authors have also argued that integrating LK into GIS in support of spatially explicit planning can help coordinate and plan future activities and potentially reduce the costs of fishing effort and overharvesting (Close and Hall, 2006; Hall and Close, 2007; St. Martin, 2004).

A recent publication by Moreno-Báez et al. (2010), presented an approach to collect, integrate and validate fishers' LK to address the problem of accessing and understanding basic data related to small-scale fishing activities at a regional scale. The research took place in the Northern Gulf of California (NGC), Mexico, providing an example of how key LK can be incorporated and corroborated during the data-collection process. The LK was collected not only at a local level, but also across regional scales involving large areas used by multiple, distant, and yet interconnected fishing communities and their highly diverse fishing activities. The present article presents the results collected during the same period and using the same methodology to portray the spatial and temporal dynamics of small-scale fishing fleets in the NGC by: a) identifying main target species and the methods used to capture them, b) tracking the use of MPAs by communities, c) comparing the distances traveled by fishers from different communities to reach their fishing grounds, and d) capturing the spatial and temporal dimension of fishing distribution and convergence of fishing activity and communities. Results provide further evidence supporting the need to integrate LK and GIS to map small-scale fishing activities at a regional scale. Regional analysis can provide information on how fishing fleets operate in space and time and highlight the progressive expansion of fishing activities to larger scales. These results provide insights for the development of place-based assessments and management strategies.

1.1. The Northern Gulf of California

Our analysis is centered on the small-scale fishing activities of the NGC, an area covering approximately 3000 km of coastline from south of Bahía de Kino, Sonora to El Barril, on the Baja California peninsula (including islands) (Fig. 1), Mexico. In this area alone, there are over 3500 fishers working on a regular basis out of 17 permanent small-scale fishing communities and several other temporary fishing camps. In aggregate, the extent of their fishing activities covers at least 89% of the coastline and 60% of the open sea (Moreno-Báez, 2010). Small-scale fishing is the most prevalent type of fishing activity taking place in the region (Cudney-Bueno and Turk-Boyer, 1998; Moreno et al., 2005) and is characterized by the use of locally owned and operated skiffs called *pangas*, which are small (6–8 m) fiberglass fishing skiffs (2–3 fishers/boat) used throughout the region, usually operating with 55–150 hp outboard motors, and multiple types of fishing.

The number of small-scale pangas operating in the NGC is estimated to be over 1600 (unpublished results, Pangas Project) and the small-scale fishing fleet targets over 80 species of fish, mollusks, crustaceans and echinoderms on a regular basis (Cisneros-Mata, 2010; Cudney-Bueno and Turk-Boyer, 1998). Multi-sector activities also take place in the region including industrial fishing (e.g., sardine fishery using purse-seine nets and shrimp fishery using bottom trawls), recreational sport fishing and tourism. Additionally, small-scale fishing, as a sector, has experienced significant growth in Mexico since the 1980s (Hernández and Kempton, 2003), and both abundance and diversity of marine resources have been impacted by present multi-sectoral activity (Sagarin et al., 2008) resulting in "fishing down the food web" (Sala et al., 2004). Appropriately, conservation and management efforts have led to, among other things, the creation of MPAs, and various community-based fisheries management initiatives (Aburto-Oropeza and López-Sagástegui, 2006; CONANP, 2009; Cudney-Bueno et al., 2009) (Fig. 1). Inevitably, the high diversity of conservation and management measures and intensity of fishing activities in this region has resulted in a rapid evolution of institutional change and development of numerous territorial conflicts over access to marine resources (Cinti et al., 2010a; Cudney-Bueno, 2000; Cudney-Bueno and Basurto, 2009).

While place-based ecosystem management in Mexico has not been formally instituted, *ad hoc* environmental policy tools that incorporate spatial and temporal dimensions have been employed. Examples of these include fisheries ordinance plans (programas de ordenamiento pesquero), management plans (planes de manejo pesquero), fishing concessions and permits (permisos y concesiones pesqueras), refuge zones (zonas de Refugio) and, closed seasons (Bezaury-Creel, 2005). Moreover, with the passage of a new national fishing law in Mexico (Ley general de pesca y acuacultura sustentables, LGPAS) (DOF 2007), the fisheries administration for the first time has called for an explicit definition of spatial and temporal management measures (i.e., fisheries ordinance plans) that also require inclusion of social, economic and environmental values in support of decision-making.

Delineating spatially explicit measures in a region where fishing activity is highly dynamic represents a big challenge. If these management measures are to occur, their success will heavily rely on the availability and quality of spatial data concerning the human use of coastal and marine resources, and the scales at which fishing fleets operate (i.e., spatial and temporal dimension). However, access to information is particularly complicated and commonly

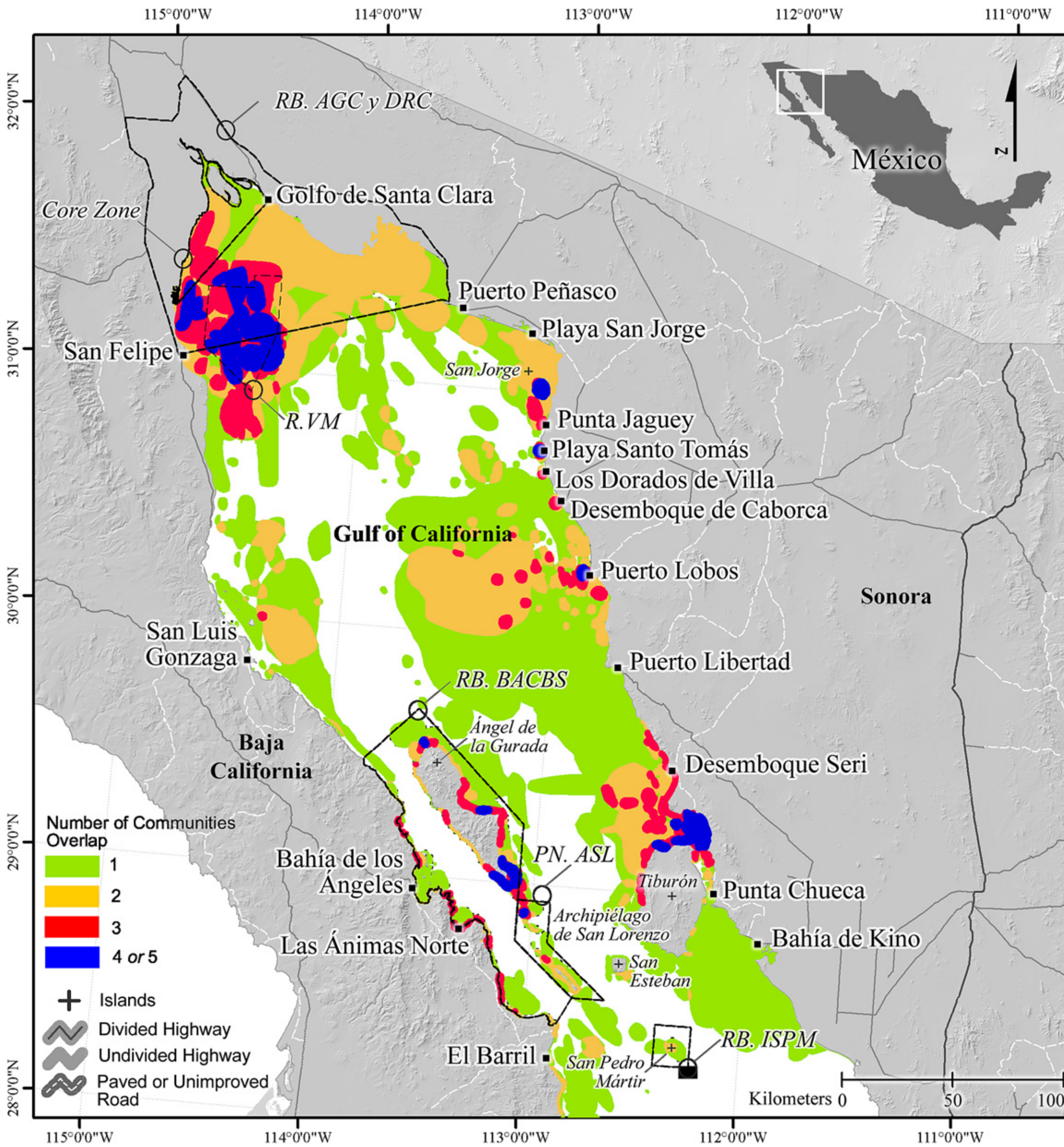

Fig. 1. Map of the Northern NGC. The MPAs present in the area are indicated as follows: Reserva de la Biósfera (Biosphere reserve) Alto Golfo de California y Delta del Río Colorado (RB.AGC y DRC), the Refugio (Refuge) de la Vaquita Marina (R.VM) which is partially encompassed in the RB.AGC y DRC, the Reserva de la Biósfera (Biosphere Reserve) Bahía de los Ángeles, Canales de Ballenas y Salsipuedes (RB. BACBS), Parque Nacional (National Park) Archipiélago de San Lorenzo (PN. ASL) and Reserva de la Biósfera (Biosphere Reserve) Isla San Pedro Mártir (BR. ISPM). Square markers indicate the 17 fishing communities included in this study. Midriff islands: Isla Ángel de la Guarda, Isla Tiburón, Archipiélago San Lorenzo, Isla San Esteban and Isla San Pedro Mártir.

fishing effort and production reported at the local and regional level by fishers in Mexico lack adequate historical data (Lluch-Cota et al., 2007; Ramírez-Rodríguez, 2011). Moreover, the location where the product comes from is frequently unknown (Cinti et al., 2010b).

It is crucial to understand the progressive expansion of fishing activities for providing management recommendations (Berkes et al., 2006). Our study provides a baseline describing the distribution of fishing activities in the NGC by characterizing spatial and temporal data for small-scale fishing activities and presenting how these uses and communities relate to the complex natural systems in which they are embedded. The information provided by the fishers has the potential to fill a critical information gap where human activities and natural systems intersect that must be filled in order to provide a preliminary baseline to inform and guide the development of environmental policy tools that incorporate spatial and temporal dimensions being promoted in Mexico.

2. Methods

2.1. Interview and data collection

The central component to documenting the spatial and temporal dimension of small-scale fishing activities was captured through fisher's LK. A rapid appraisal (Beebe, 1995; Chambers, 1994) to collect LK was implemented across 17 fishing communities in the NGC (Fig. 1). The methodology entailed aggregating LK of a representative set of individual fishers (captains) through semi-structured interviews conducted between December 2005 and

July 2006 regarding what, where, when and how they fish. The unit of analysis was based on boat captains, given that captains are generally the most experienced and knowledgeable fishers and those who tend to make the decisions about where and when to fish. Accordingly, the universe for sampling was the number and names of existing captains of active boats. Stratified random sampling was used to calculate the sample size for each community as established by Krejcie and Morgan (see Bernard, 1995: 77–78), ensuring a 95% probability sample with at least a 10% confidence interval for each fishing community sampled. All captains were interviewed for fishing communities with 10 pangas or fewer.

The interview was composed of two main parts: 1) general information regarding fishing activities along with the identification of species commonly fished and, those species that are considered to be target[1] species; and, 2) spatial and temporal distribution of fishing activities based on selected target species that involved the use of a variety of printed maps. During the first part of the interview, a list of 54 different species (and in some cases, a group of species[2]) that researchers already knew were fished in the region, were provided to the interviewee. The fishers then identified which of these species they fished, with an option to add any that were not mentioned on the list. Next, a more refined selection to indicate which of the species mentioned were considered target species was requested to the interviewees. The second part of the interview focused on identifying the three most important target species or groups of species for that interviewee. Questions were focused on the spatial and temporal distribution of fishing activities for each one of the three target species selected.

The map design for mapping the fishing distribution included basic information such as the coastline (INEGI 1:50,000 topographic maps), bathymetry, and general landmarks and their local names. Maps were printed at six different scales ranging from 1:800,000 to 1:15,000 and were tested with a small group of researchers and fishers to identify the best design prior to the main data-collection exercise. By using these maps in the field, questions were asked to draw the three primary fishing grounds (most frequently visited) and three or more secondary fishing grounds (less or rarely visited) for each of the three target species or group of species selected. For the temporal distribution, fishing seasons for the target species in question were identified by the interviewee by separating the fishing calendars in two ways: the total season (all the months in which the species is harvested) and main season (months the fisher concentrated fishing effort on that particular species). Each month of the year was divided in 'early' stage (e.g., early January) or 'late' stage (e.g., late January) in order to capture more detail about the fishing seasons. Total and main fishing seasons were captured for primary and secondary fishing grounds in order to identify detailed geographical seasonality for fishing activities. Additional notes about fishing grounds and seasons were provided by fishers when necessary. Finally, questions regarding depth, gear type utilized and the reasons why they fish in specific places and times were also applied. LK was recorded based on their assessment of current and past (no older than five years) conditions.

2.2. Data assembly and analysis

A total of 376 fishers were interviewed and a total of 769 basemaps representing fishing distribution were produced (Moreno-Báez, 2010). The data collected regarding fishing activities (first section of the interview) were captured in a spreadsheet database. This database contains general information about fisheries, the species commonly fished and, those selected as target species. The second part of the interview containing specific information and fishing calendars of the three selected target species, were also captured in spreadsheets but coded to be integrated with the spatial information. The fishing areas drawn by fishers onto the individual paper maps were integrated in a digital format using on-screen digitizing. The 769 maps were digitized, georeferenced, and integrated into a GIS shapefile using ArcGIS 9.2 (ESRI, 1999–2008). The location-based data individually (i.e., interview, primary or secondary fishing zone, target species and, fishing gear) was coded and joined with associated attributes representing additional information from the interviews into the GIS database in preparation for spatial integration and analysis. After preliminary analysis, internal data validation focus groups were conducted to crosscheck the information among fishers. The necessary adjustments were applied prior to the overall data analysis (Moreno-Báez et al., 2010). Along with the identification of more than 80 species commonly fished, fishers selected 58 target species or group of species in the first part of the interview. In the second part of the interview and based on the three most important target species chosen, 43 species or group of species were selected for which fishers provided detailed spatial and temporal information (Table 1).

To capture fishing activity in spatial and temporal scales, the spreadsheet containing the fishing calendar attributes month by month were joined with the attribute table of the shapefile using ArcGIS™ 9.2 (ESRI, 1999–2008). The next step was to use GIS to link the cartographic spatial dataset of fishing grounds with the temporal information with non-spatial attribute data. To link the data sets in the GIS, a compound code made with the interview code, species code and fishing zone code was used. This process allowed joining the information for a particular fishing ground and its associated fishing season. Through topological map overlay, maps aggregated by species and fishing activity were created across the respondents. Simple and complex standard query commands were used to generate seasonal maps by group of species using the attribute table of a shapefile. Those maps aided in the visualization of the distribution and overlap of fishing activity by communities and representative species for different fishing methods.

2.3. Use of marine protected areas and travel distances

The geographical limits of actual MPAs (CONANP, 2009) (Fig. 1) were overlaid in order to understand who (e.g., the number of communities) was using these areas. For this analysis the 43 species and group of species (Table 1) identified in the second section of the interview were included in order to calculate the overlap of communities working in common fishing grounds within MPAs. With this information a matrix of communities' convergence for each MPA in the study region was created. The total area being use within MPAs was calculated for each community and, by means of queries, selection and union functions using ArcGIS™ 9.2, the target species being fished within each MPA were identified.

To understand the expansion of fishing activities, the distance traveled by each community to the fishing grounds was calculated. This analysis was classified by community and fishing method. The total area of fishing activity and the distance traveled by community was computed by: 1) using standard query commands based on the community's name and fishing method to separate each communities' fishing grounds; 2) dissolving all polygons corresponding to a particular community and fishing method in order to acquire an area; 3) calculating the geometry to obtain the total fishing area by community and fishing method; and 4) calculating the maximum and mean distance traveled by community using the

[1] Species that require a dedicated fishing trip.

[2] In some cases (e.g. some large sharks, flounders) fishers don't target a specific species but rather a group of similar species and, thus, were lumped as one.

Table 1
List of target species selected as the most important in the NGC.

Spp. Id.	Scientific name	Common name (English)	Fishing method[a]	Communities[b]
Cartilaginous fishes				
1	*Carcharhinus limbatus*	Blacktip shark	G	PLO, SFE
2	*Carcharhinus* spp.	Shark	G	BDA, BKI, DDS, EBA, GSC, PCH, PLI, PLO, PPE, SFE, SLG
3	*Dasyatis dipterura*, spp.	Diamond stingray	G	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
4	*Gymnura marmorata*	Butterfly ray	G	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
5	*Mustelus californicus, lunulatus or henlei*	Smoothhound shark	G, L	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
6	*Myliobatis californica or longirostris*	Bat ray or longnose eagle ray	G	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
7	*Rhizoprionodon longurio*	Pacific sharpnose shark	G	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
8	*Rhinobatus* (mainly *R. productus*)	Shovelnose guitarfish	G	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
9	*Sphyrna* spp.	Hammerhead shark	G	BDA, BKI, DDC, DDS, EBA, GSC, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
10	*Squatina californica*	Pacific angel shark	G	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
Ray-finned fishes				
11	*Atractoscion nobilis*	White sea bass	G	BDA, BKI, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
12	*Cynoscion othonopterus*	Gulf corvina	G, H	GSC, SFE
13	*Cynoscion parvipinnis*	Shortfin corvina	G	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
14	*Caranx* spp. and *Seriola lalandi*	Jack	H	EBA, LAN
15	*Epinephelus acanthistius*	Gulf coney	L	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
16	*Epinephelus niphobles*	Star-studded grouper	L	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
17	*Epinephelus analogus*	Spotted cabrilla	D, H	BDA, BKI, DDC, DDS, EBA, GSC, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
18	*Balistes polylepis*	Finescale triggerfish	D, H, T	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
19	*Mycteroperca jordani*	Gulf grouper	D, G, L, H	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
20	*Mycteroperca prionura*	Sawtail grouper	D, H	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
21	*Mycteroperca rosacea*	Leopard grouper	D, H	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
22	*Paralabrax auroguttatus*, spp.	Goldspotted sand bass	L, T	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SLG, STO
23	*Paralabrax maculatofasciatus*	Spotted sand bass	D, T, H	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
24	*Stereolepis gigas*	Giant sea bass	H	BDA, BKI, DDC, DDS, GSC, PCH, PLI, PLO, PPE, SFE, SJO
25	*Hoplopagrus guentherii*	Barred pargo	G, D, H	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
26	*Lutjanus argentiventris* or *novemfasciatus*	Yellow snapper or Pacific dog snapper	G, D, H	BDA, BKI, DDC, DDS, EBA, GSC, PCH, PLI, PLO, PPE, SFE, SJO, SLG
27	*Lutjanus peru*	Pacific red snapper	D, H	BDA, BKI, DDS, EBA, PLI
28	*Micropogonias megalops*	Gulf croaker	G	BDA, BKI, DDC, DDS, GSC, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
29	*Mugil* spp.	Mullet	G	BDA, BKI, DDC, DDS, GSC, LAN, LDV, PCH, PLI, PLO, PPE, SFE, SJO, SLG, STO
30	*Paralichthidae*/*Pleuronectidae* (*P. aestuarius*)	Flounders	G, H	BDA, BKI, DDC, DDS, EBA, GSC, LAN, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
31	*Scomberomorus* spp.	Sierra	G	BDA, BKI, DDC, DDS, GSC, LDV, PCH, PLI, PLO, PPE, SFE, SJO, SLG
Arthropods, Mollusks and Echinoderms				
32	*Callinectes bellicosus* and *arcuatus*	Swimming crab	T	BDA, BKI, DDC, DDS, GSC, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG
33	*Litopenaeus stylirostris*	Blue shrimp	G	BKI, DDC, GSC, LDV, PCH, PJA, PLI, PLO, PPE, SFE, SJO, SLG, STO
34	*Panulirus inflatus*	Spiny lobster	D	BDA, BKI, GSC, PCH, SFE
35	*Atrina tuberculosa*	Tuberculate pen shell	D	BKI, DDS, PCH, PLI, PLO, PPE
36	*Dosinia ponderosa*	Giant dosinia clam	D	BDA, BKI, DDS, GSC, PCH, PLI, PLO, PPE, SLG
37	*Hexaplex* (*Muricanthus*) *nigritus*	Black murex snail	D	BKI, DDC, DDS, GSC, PCH, PLI, PLO, PPE, SFE, SJO, SLG
38	*Octopus* spp. (possibly *O. hubssorum*) or *bimaculatus*	Octopus	D, T	BDA, BKI, DDC, DDS, EBA, GSC, LAN, PCH, PLI, PLO, PPE, SFE, SJO, SLG
39	*Panopea generosa*	Goeduck clam	D	DDS, PCH, SFE, SJO
40	*Phyllonotus erythrostoma*	Pink murex	D, T	BDA, BKI, DDC, DDS, GSC, PCH, PLI, PLO, PPE, SFE, SJO, SLG

(continued on next page)

Table 1 (*continued*)

Spp. Id.	Scientific name	Common name (English)	Fishing method[a]	Communities[b]
41	*Pinna rugosa*	Rugose pen shell	D	BDA, BKI, DDS, PCH, PLI, PLO, PPE, SJO
42	*Spondylus calcifer*	Rock scallop	D	BDA, BKI, DDS, PCH, PLI, PLO, PPE, SFE, SJO, SLG
43	*Isostichopus fuscus*	Sea cucumber	D	BDA, BKI, LAN, PCH, PLI, SFE

[a] Fishing methods: D) diving; G) gillnets; L) longline; T) traps; H) hand fishing line.
[b] Communities: Bahía de los Ángeles (BDA); Bahía de Kino (BKI); Desemboque de Caborca (DDC); Desemboque Seri (DDS); El Barril (EBA); Golfo de Santa Clara (GSC); Las Ánimas (LAN); Los Dorados de Villa (LDV); Punta Chueca (PCH); Punta Jaguey (PJA); Puerto Libertad (PLI); Puerto Lobos (PLO); Puerto Peñasco (PPE); San Felipe (SFE); San Jorge (SJO); San Luis Gonzaga (SLG); Santo Tomas (STO).

location of the community and fishing method with a ArcGIS Spatial Analyst Euclidean distance tool.

2.4. Spatial and temporal dynamics of fishing activities

For the purpose of this publication we selected a subset of 18 target species (Table 2) which were reported by the interviewees as the most representative species or group of species (i.e., number of base-maps interviews) during the second part of the interview. This subset of data was then classified based on fishing gear. In some cases, specific information on the fishing gear use for each species was not obtained in the initial interview. However, internal data validation workshops and researchers involved in the process addressed this data gaps (Moreno-Báez et al., 2010). For example, some species such as groupers (groupers *Mycteroperca* spp.) can be captured using different fishing methods such as longline, diving and sometimes gillnets. If the fisher specified the fishing method used for a particular species, the fishing grounds were then classified based on the specific fishing method. Overall, four main categories were identified as the most commonly used within the interviews: (1) gillnets (2) longline (3) traps and, (4) diving. The information can be delineated by fishing community but the fine-grained data remain confidential. The complete project database and maps are housed at the University of Arizona, the base of the PANGAS project.[3]

The spatial representation of fishing grounds varied across fishing methods due to the difference in the use of space among the different fishing gears. Consequently, for the spatial and temporal analysis, a vector-grid map was created consisting of 5630 cells (2.8 km $\times$ 2.8 km spatial resolution) to standardize and represent the spatial units (i.e. fishing grounds). Each cell was used as the standard unit of analysis throughout the study area. By means of selection by attributes and location, presence and absence of fishing activity by one or more communities was depicted and represented in the vector-grid map created by month and group of species. A series of analyses were conducted to define and combine different group of species and seasonality. The selection process by attributes and location for these analyses was defined using the following attributes: a) species or group of species (Table 2); b) fishing community; and c) month. Based on the described selection and using the vector-grid map, each cell was assigned the value of 1 (presence of fishing activity by community) or 0 (absence of fishing activity by community) on a monthly basis. The presence or absence of fishing activity and the number of communities overlapping throughout the study area was depicted by means of classification (i.e., number of communities' overlap).

[3] PANGAS stands for "Pesca Artesanal del Norte del Golfo de California – Ambiente y Sociedad" (Small-scale Fisheries in the Northern Gulf of California – Environment and Society). It is an interdisciplinary alliance of six institutions conducting ecosystem-based research.

3. Results

The 43 species and groups of target species selected as the most important are presented in Table 1. From this list, 10 communities harvest more than 41 different species and 16 of these species are targeted using two or more different gear options. Fig. 1 shows the overlap of community fishing activity in the NGC including the MPAs, utilizing the information provided for all 43 species presented in Table 1. Based on this spatial information for the region of the NGC (33,528 km^2), 29% of the fishing area is used by at least two communities, 6% is used by three communities and 2% is used by four or five communities.

3.1. Use of marine protected areas and travel distances

Convergence of fishing activity by up to five different communities was found in all five MPAs. Table 3 shows that 79% of the grand total area established for a natural protected areas in the NGC, is being utilized by a total of 10 communities for fishing activities. These results also show that 25 of the 43 different target species selected as important are regularly harvested in the Reserva de la Biósfera del Alto Golfo de California y Delta del Río Colorado (RB.AGC y DRC), 12 are harvested within the Refugio (Refuge) de la Vaquita Marina (R.VM), 13 in Reserva de la Biósfera (Biosphere Reserve) de Bahía de los Ángeles, canales de Ballenas y Salsipuedes (RB.BACBS), 7 in Parque Nacional (National Park) Archipiélago de San Lorenzo (PN.ASL) and, 3 within the Isla San Pedro Mártir (RB.ISPM). Within the RB.AGC y DRC and the R.VM, ray and shark fisheries represent 30% and 50%, respectively, of the total species targeted. Within the other three marine reserves, fisheries focused on other species of ray-finned fishes, arthropods, mollusks and echinoderms.

Travel distances are presented by community and classified by fishing method (Fig. 2). In general, 13 communities travel more than 50 km on a regular basis to reach their fishing grounds with four communities traveling distances greater than 150 km. Bahía de Kino reported the longest distances to reach fishing grounds for traps, gillnets and diving fisheries. Fishers from Bahia de Kino reported traveling distances between 180 and 200 km when targeting sierra, leopard grouper and spiny lobster. Other communities such as Desemboque de Caborca travel 180 km for targeting Gulf coney (i.e., longline fishery), which according to fishers comments, requires high investment capital due to the fuel cost to travel to and from the fishing grounds. The community of Puerto Libertad travels long distances to the midriff islands to target smothhound shark and San Felipe reaches distances up to 180 km to reach the same species. Most of the communities targeting smothhound shark, mentioned the high fishing competition in the sharks and ray fishery. Finally, communities such as Puerto Peñasco and San Luis Gonzaga can travel more than 140 km for the shrimp fishery, which is located mainly within the RB.AGC y DRC. Los Dorados de Villa, Punta Chueca, Punta Jagüey and San Jorge remain under the 50 km range or less when traveling to their fishing grounds. However,

Table 2
Species selected for the spatial and temporal analysis and the description of the fishing method utilized.

Spp. Id[a]	Species	No. base-maps interviews	Description of fishing methods
Cartilaginous fishes			
3	Diamond stingray	97	Gillnets made of monofilament nylon nets.
4	Butterfly ray		Mesh sizes range from 3 inches to 10 inches.
5	Smoothhound shark		One *panga* can carry 1 or 2 gillnets with lengths
6	Bat ray or longnose eagle ray		that range from 700 m to 2700 m. The community
7	Pacific sharpnose shark		of Bahía de Kino harvest Smoothhound shark
8	Shovelnose guitarfish		using longline from August to October.
10	Pacific angel shark		
Ray-finned fishes			
12	Gulf corvine	56	Gillnets made of monofilament and multifilament nylon nets. Mesh sizes ranged from 5 inches to 6 inches.
15	Gulf coney	45	Longline with 300 or 350. Fishers also might use between 1 or 2 lines. However, some fishers reported the use of 3 lines in one *panga*.
31	Sierra	71	Gillnets made of monofilament nylon nets. Mesh sizes range from 2 2/3 inches, 3 inches, 3 1/4 inches and 3 1/2 inches depending on the season. Alternatively, in some communities, few fishers use hand fishing line.
Arthropods, Mollusks and Echinoderms			
32	Swimming crab	58	Modified version of the Chesapeake Bay crab trap.
33	Shrimp	119	Gillnets made of monofilament nylon nets. Mesh sizes ranged from 2 to 1/2 inches to 2–3/4 inches. Cast nets and bottom trawl (small-scale) can also be used but are not as common.
34	Spiny lobster	60	Different diving methods: 1) Free diving using snorkel; 2) Use
37	Black murex		of a 'hookah' with an air compressor connected to a modified beer keg
38	Octopus		as the reserve air tank and with one or two 100 m hoses attached to a tank
42	Rock scallop		with air regulators.
43	Sea cucumber		They use hooks, knifes and a bag to collect the harvest. The use of traps are common in communities such as Bahía de los Ángeles for octopus.
Total of maps = 769		506	

[a] See Table 1 for species identification (Spp. Id.).

some of these communities are utilized as base-camps for other communities that travel long distances for the shrimp fishery. In general, the overall mean distance traveled per community is 40 km, with 38 km for gillnets, 47 km for longline, 31 km for traps and 30 km for diving.

3.2. Spatial and temporal convergence of fishing activity

Although maps and the total and main fishing seasons were obtained for the 43 target species and group of species, we selected the 18 species listed in Table 2 to present the spatial and temporal results in Figs. 3–9. The data allowed characterizing the activity and the inactivity of each community throughout the year. Fishing grounds for ray and shark fisheries presented in Fig. 3 illustrate the geographic fluctuations and the communities' convergence. According to fishers' notes, the exact location of fishing grounds may vary from year to year hence fishers drew broad polygons on the maps. Convergence of multiple communities is found all year-round mainly around the midriff islands. Different temporal patterns for all 7 species were found in the fishing calendars. Bahía de Kino is the community that harvests five of the six species selected and indicated a year-round activity for diamond stingray, bat ray or longnose eagle ray and Pacific angel shark. Puerto Peñasco and San Luis Gonzaga also present year-round activity for shovelnose guitar and Pacific sharpnose shark respectively. In general, for ray and shark fishery, fishing calendars show convergence of different communities' activity for total and main fishing season.

Fig. 4 presents the spatial and temporal fishing patterns for Gulf corvina, one of the most important fisheries in the northernmost part of the region (Erisman et al., 2010; Rodríguez-Quiroz et al., 2010). This fishery has an official season closure that runs from May to August (NOM-063-PESC-MX) (D.O.F. 25 August 2005). According to notes provided by fishers, they understand that the Gulf corvina arrives to the upper Gulf during the spawning season coming in large aggregations between February and April and thus their fishing effort is concentrated during this timeframe (Fig. 4). From February to May, the two communities that reported activity in this MPA overlap in their fishing grounds. Also, fishing activity occurs within the RB.AGC y DRC and its core zone. The main fishing

Table 3
Community convergence and target species captured in MPAs in the NGC.

Marine protected area	Total area (ha)	Use %	Communities	Target species[a]
Alto Golfo de California y Delta del Río Colorado	546,063	100%	DDC, GSC, PPE, SFE, SLG	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 19, 22, 25, 28, 29, 30, 31, 32, 33, 37, 38, 41, 42
Area de Refugio de la Vaquita Marina	123,924	100%	DDC, GSC, PPE, SFE, SLG	2, 3, 4, 6, 7, 8, 10, 12, 15, 28, 31, 33
Bahía de los Ángeles, Canales de Ballenas y Salsipuedes	384,801	83%	BDA, BKI, EBA, LAN, PLI, SLG	5, 7, 10, 15, 18, 22, 29, 30, 31, 34, 38, 42, 43
Archipiélago de San Lorenzo	58,083	38%	BDA, BKI, EBA, LAN, PLI	10, 14, 21, 22, 34, 38, 43
Isla San Pedro Mártir	29,938	74%	BKI, EBA	14, 22, 43

[a] See Table 1 for species (Spp. Id.) and community identification.

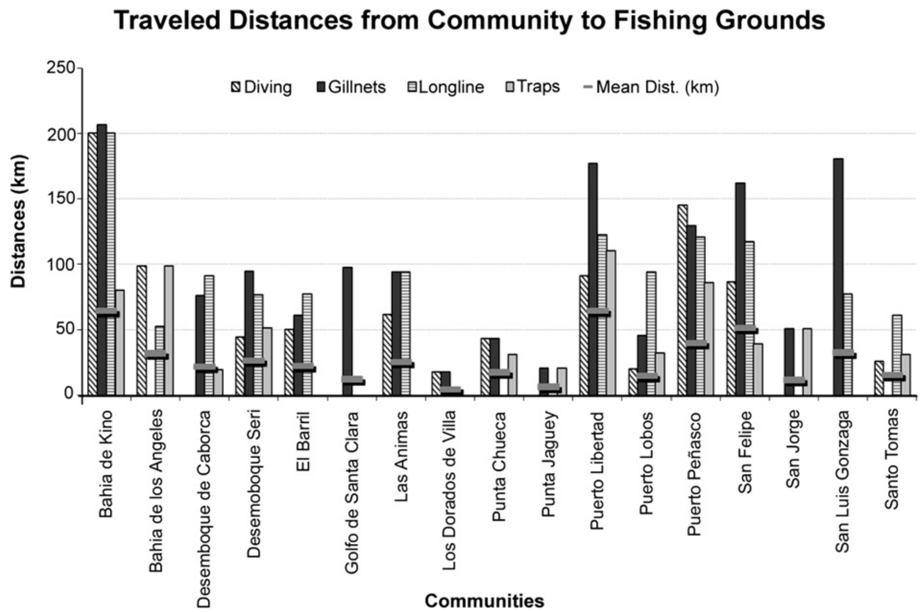

Fig. 2. Maximum distance traveled from the community to fishing grounds by fishing method and total mean distance.

season for Gulf corvina corresponds with its annual spawning event (Erisman et al., 2010; Rowell et al., 2005).

Fig. 5 presents the fishing grounds for Gulf coney, which are distributed in large areas throughout central area of the Gulf of California. Three communities overlap in their fishing grounds from December to April. Fishing activities in the NGC for Gulf coney occur far away from the coastline and in different depths ranging from 64 m to 230 m. Gulf coney fishery is possibly the most dangerous and demanding for fishers due to the distance traveled and the depths where fishers work (Cudney-Bueno and Turk-Boyer, 1998). The fishing season includes two months of inactivity generally occurring in July and August. In general, the fishing season is similar for the 7 communities that provided information. The community of Puerto Libertad was the only one that presented the longest total and main fishing season for this species that runs for 8 months while the rest of the communities presented longer total fishing seasons and shorter main fishing seasons.

Fig. 6 shows the spatial distribution of fishing activity for the sierra fishery. Fishing grounds are shared by up to five communities from February to May and from September to November around the midriff islands. According to Cudney-Bueno and Turk-Boyer (1998) there are two different sierra species (i.e., *Scomberomorus sierra* and *Scomberomorus concolor*). The fishing season for sierra is known as “la corrida de la sierra” (the sierra run), which elucidates the migration of this species. All communities except Puerto Libertad presented short periods of fishing activity for the sierra fishery. The northernmost communities of El Golfo de Santa Clara and Puerto Peñasco concentrate their fishing efforts between April and October. The southernmost communities of Bahía de Kino, Desemboque de los Seris and, Punta Chueca, identified two total and main fishing seasons: 1) between February and May; and, 2) between September and December. Fishers provided some specific notes about this fishery, indicating that “during summer, the fish are large but in winter season, the individual fish are smaller”.

Fig. 7 presents the spatial and temporal distribution of fishing activity for swimming crab, which represents one of the most important fisheries for the communities in the NGC (Bourillón-Moreno, 2002; Rodríguez-Quiroz et al., 2010). This species has a recommended season closure for the state of Sonora (also called administrative season closure) (INAPESCA, 2010) during its reproductive period, which runs from April to June (NOM-039-PESC-2003). The highlight of this information is how the fishing activity diminishes in some areas during the administrative season closure (from April to June). From July to November as many as three communities converge in the northernmost part of the Gulf close to the community of Puerto Peñasco. In the southernmost part of the study area, within the Seri territory (Bourillón-Moreno, 2002), up to three communities converged during 2 different periods: 1) March and April and, 2) August and September. The total and main fishing calendars show this dissimilarity as well. The southern communities such as Bahía de Kino, Desemboque de Los Seris and Punta Chueca present similarities in inactivity (i.e., indicating the closure of the season) while Puerto Peñasco, one of the northernmost communities, shows some activity from April to September.

Fig. 8 presents fishing activity for shrimp in the northernmost part of Gulf of California with greater overlap of communities from September to December. There are two common shrimp species harvested in the Gulf of California (i.e., blue and brown shrimp) but fishers clarified that blue shrimp is what they target the most because of its higher value and because it is found in shallower waters. The shrimp fishery is one of the most important fisheries in Mexico in terms of income and employment (Lluch-Cota et al., 2007; Rodríguez-Quiroz et al., 2010). The shrimp fishery has a formalized regulation under the NOM-002-PESC-1993 (DOF, 1993, 2007), which establish a spatio-temporal closure, with regulation on the fishing effort and other specifications regarding the fishing equipment and gear. This guidance is included in the management plan for the RB.AGC y DRC (1995). This regulation established that shrimp fishery for all small-scale and large-scale vessels should take place within the period from September to March (Cisneros-Mata, 2010).

Finally, Fig. 9 presents spatial distribution of fishing activity for five different benthic species usually found in rocky reef ecosystems and commonly fished by diving (Table 2). Diving is widely used in the Gulf of California for the extraction of benthic species (Cinti et al., 2010b) and takes place close to the shore in depths that range from 2 to 36 m deep. However, in some communities such as Bahia de Los Angeles, traps are also used (Torreblanca Ramírez,

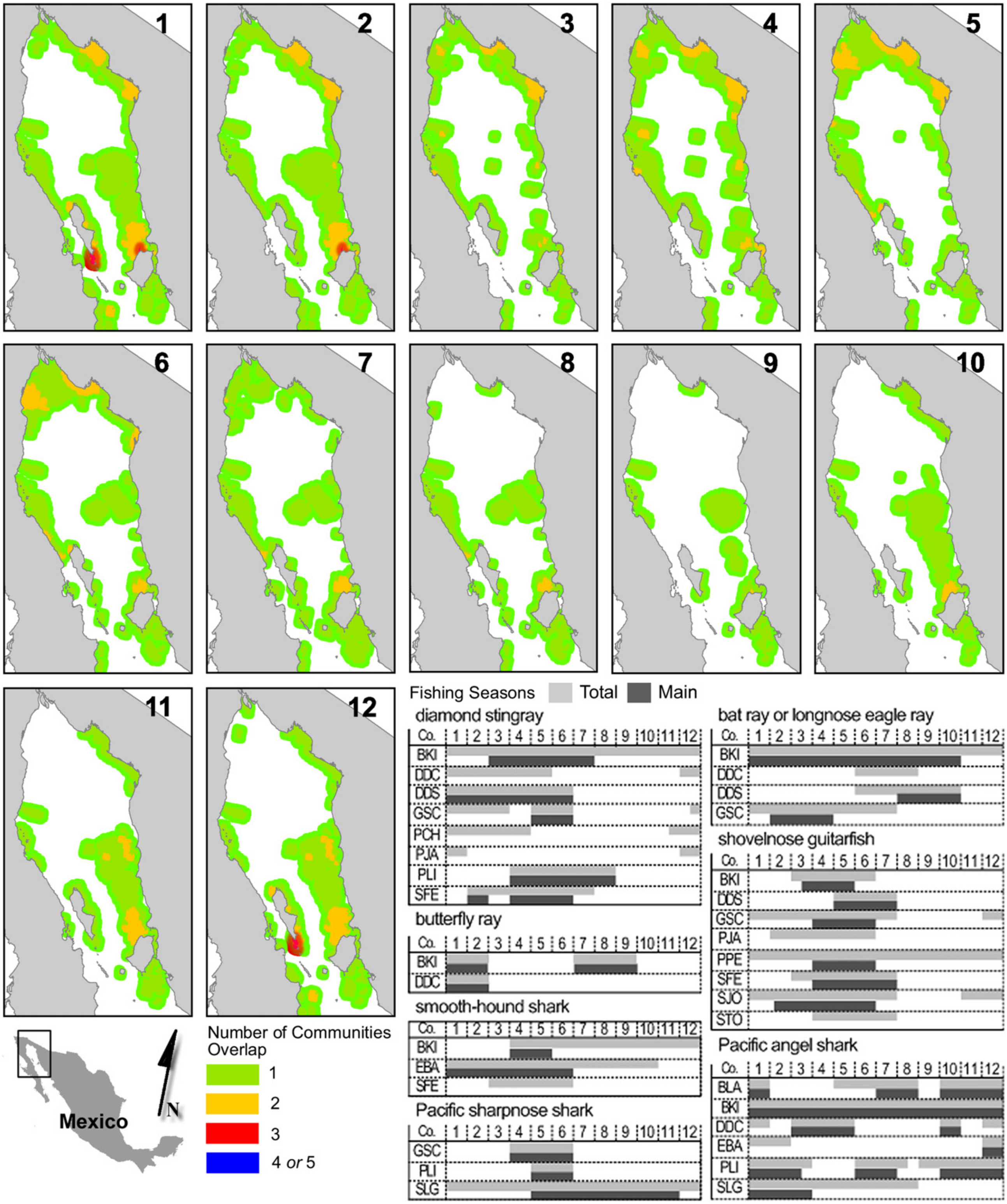

Fig. 3. Monthly distribution of fishing grounds and number of communities working coincidently for ray and shark fishery including: diamond stingray, butterfly ray, smoothhound shark, bat ray or longnose eagle ray, pacific sharpnose shark, shovelnose guitarfish, hammerhead shark and, pacific angel shark. Months: January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) December (12). Communities included: BDA, BKI, DDC, DDS, EBA, GSC, PCH, PLI, PLO, PPE, SFE, SJO, STO and, SLG (See Table 1, for communities' code).

2008) for the octopus fishery. In the octopus fishery, some the communities have a year-round total fishing season. This can be attributed to the importance of the fishery for these communities, fishing gear utilized (e.g., traps) or the possibility of targeting two different species of octopus (possibly *Octopus bimaculatus* and *Octopus hubssorum*) (Cudney-Bueno and Turk-Boyer, 1998). Fig. 9 shows up to 5 communities converging throughout the year around the midriff islands but the highest community overlap

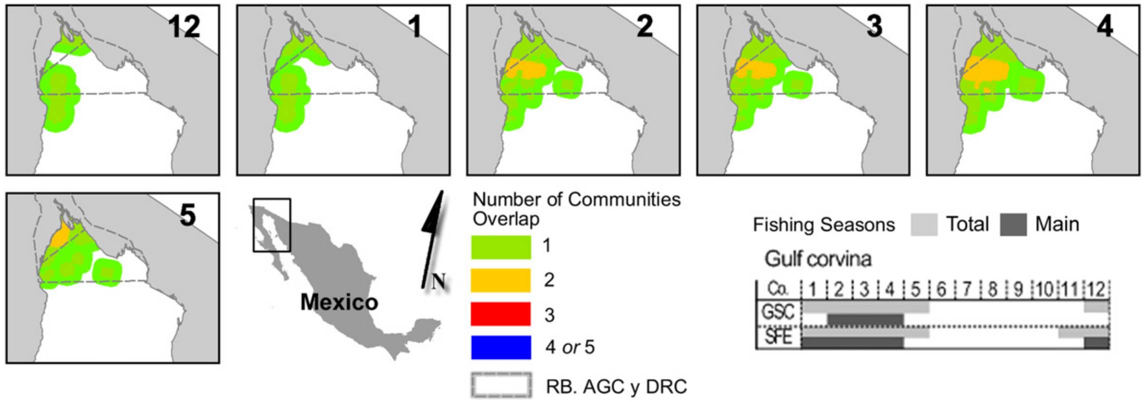

Fig. 4. Monthly distribution of fishing grounds and number of communities working coincidently for Gulf corvina fishery. January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) December (12). Communities included: GSC, SFE (See Table 1, for communities' code). The MPA present in the area is indicated as follows: Reserva de la Biósfera (Biosphere reserve) Alto Golfo de California y Delta del Río Colorado (RB.AGC y DRC).

along the region takes place from January to April. One of the most important communities for diving fishing activities is Bahía de Kino, Sonora (Moreno et al., 2005). From the list of benthic target species, only three have an existing regulation. Sea cucumber and rock scallop are under the NOM-059-ECOL-1994. Lobster is under the NOM-006-PESC-1993, which was selected by Bahía de Kino as an important target species, presenting a year-round total fishing season. For black murex, the main fishing season is from May to

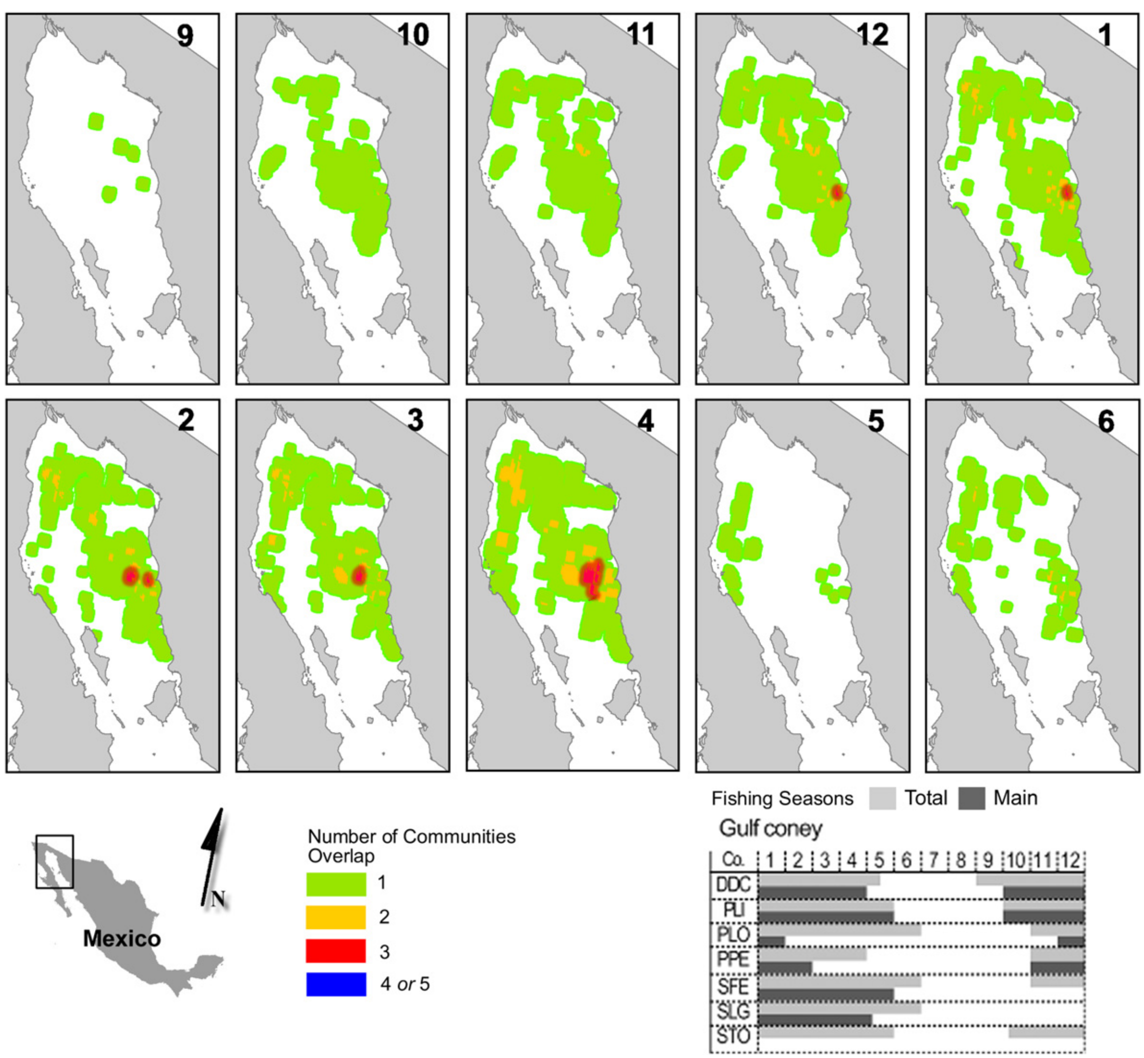

Fig. 5. Monthly distribution of fishing grounds and number of communities working coincidently for Gulf coney fishery. January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) December (12). Communities included: DDC, PLI, PLO, PPE, SFE, SLG, STO (See Table 1, for communities' code).

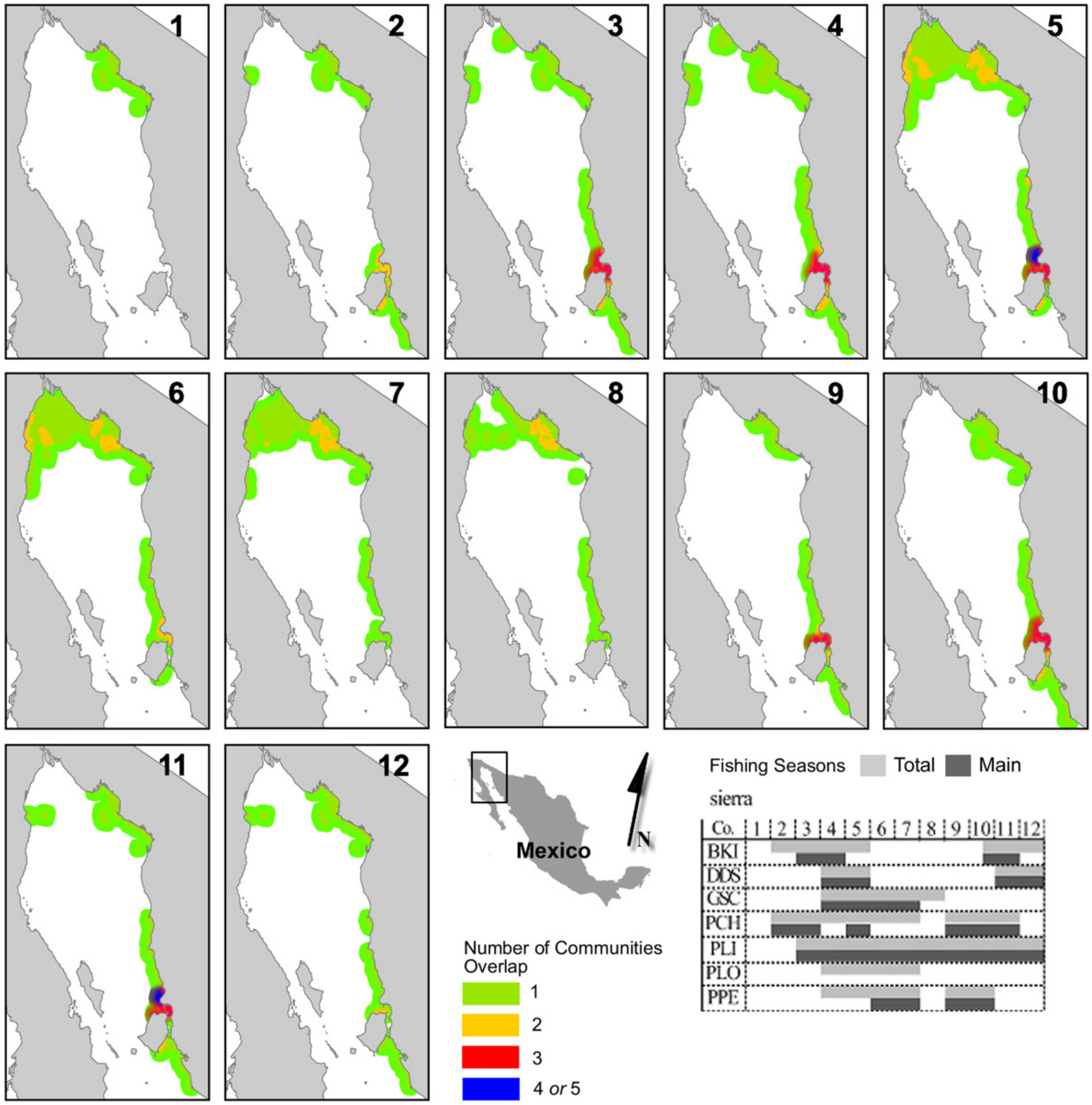

Fig. 6. Monthly distribution of fishing grounds and number of communities working coincidently for sierra fishery. January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) December (12). Communities included: BKI, DDS, GSC, PCH, PLI, PLO, PPE, SFE (See Table 1, for communities' code).

August and the breeding aggregations of black murex in the area of Puerto Peñasco occur from early April to September which indicate a close relationship between fishing seasons and reproductive and/or spawning seasons (Cudney-Bueno et al., 2008).

4. Discussion

The collection of LK regarding the spatial and temporal distribution of small-scale fishing activities helped to understand spatial and temporal patterns, heterogeneity and interaction within complex natural systems. This information was used to establish a comprehensive baseline of fishing activities in the NGC by integrating the information using GIS. In the Gulf of California, fishers normally target more than 80 different species (Cisneros-Mata, 2010) and our results suggest that more than 50% of the 17 fishing communities focus their fishing effort on more than 40 different target species and group of species using a variety of fishing gear and methods. MPAs are often used by fishing communities to target different species with some traveling long distances to reach the MPAs. Our results showed differences in activity along portions of the coast of Sonora and Baja California and also differences between communities from the uppermost and the lower part of the NGC. These results suggest that there is a clear seasonal differentiation in species and target areas as well as fishing gear and methods used. Given that the NGC is a main spawning ground for numerous species and that fishers often target breeding aggregations, our results can aid in the identification of spawning seasons and locations for various species.

4.1. Fishing activities in marine protected areas

The results showed that 79% of the total area established for MPAs is used by multiple communities year-round. One example of fishing activity convergence between different communities is within the RB.AGC y DRC and its no-take zone. At the time this study was conducted (2005–2006), this no-take zone was clearly an important and highly used fishing ground, with multiple fisheries taking place in the area, including ray, shark, shrimp and

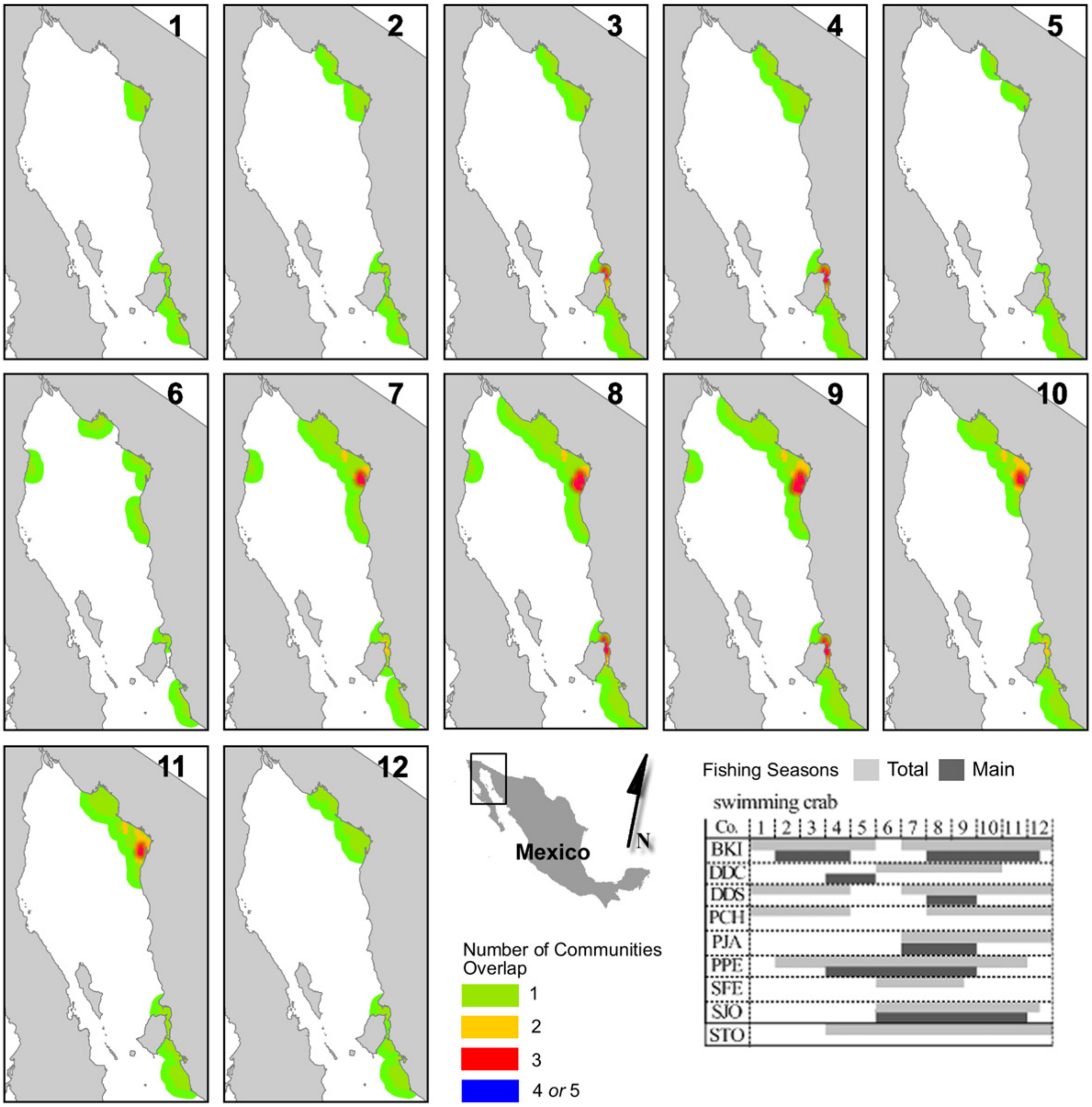

Fig. 7. Monthly distribution of fishing grounds and number of communities working coincidently for swimming crab fishery. January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) December (12). Communities included: BKI, DDC, DDS, PCH, PJA, PPE, SFE, SJO, STO (See Table 1, for communities' code).

corvine fisheries (Fig. 1; Table 3). Nevertheless, activities in the no-take zone are intended (by law) to be limited to research, small-scale shellfish harvesting and low-impact ecotourism. The management program for the RB.AGC y DRC (CONAPESCA-INP, 2004; DOF, 2009) states that one of the constraints to understanding the spatial distribution and fishing effort within the reserve, is the lack of reliable data reported by local fishing communities. With the information collected in this study, it is possible to provide managers with essential data such as fishing activity distribution in space and time and, species harvested. This information can be used to understand the local and regional demand for the resource and intensity of use.

A similar case is the R.VM also located in the northernmost part of the Gulf (Fig. 1), established in December 2005 (DOF, 2005) to protect and recover the population of the endangered 'Vaquita' porpoise (*Phocoena sinus*). Within the R.VM, the shrimp gillnet fishing activity (i.e., shrimp fishery) is represented by five communities (Table 3). It is important to mention that the information presented here was collected just as the decree of the R.VM was established. Since then, the Mexican government has established a strategy to stop the use of gillnets and has spent an unprecedented amount of resources in enforcing management guidelines for this area. However, these measures are still the subject of conflicts due to the historically high number of users involved in these fisheries (Nava, 2009).

The establishment of MPAs can be seen as an opportunity to secure access rights to fishery resources and preferential use of fishing grounds (Cudney-Bueno et al., 2009). However, our results suggest that the various MPAs of the NGC were being utilized not only by local communities within the MPAs but also, distant from the MPAs. These results support the importance of incorporating, as part of any spatial planning process, spatial data in which fishing fleets operate in order to avoid potential conflicts over resources access (Douvere, 2008). In addition, this information may help in defining the geographic scale and seasons at which available legal tools in Mexico can be implemented in support of sustainable

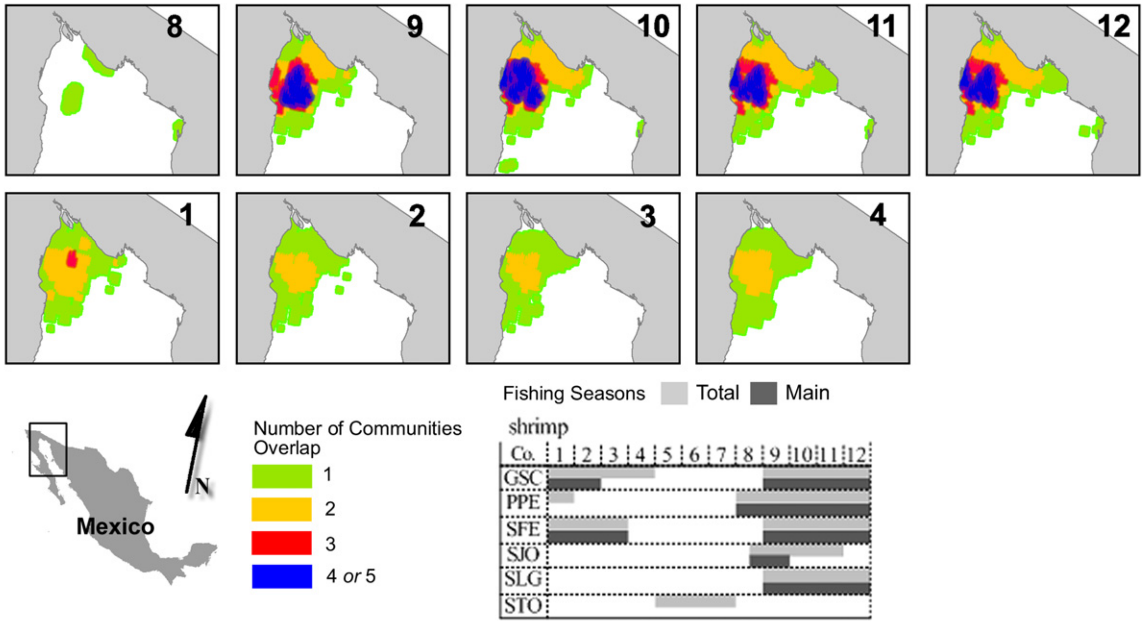

Fig. 8. Monthly distribution of fishing grounds and number of communities working coincidently for shrimp fishery. January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) December (12). Communities included: GSC, PPE, SFE, SJO, SLG (See Table 1, for communities' code).

management. By understanding how communities utilize MPAs and the 'which method, when, where and by whom' for the main species being harvested, it is possible to provide guidance to managers including areas visited by multiple communities, areas that may be depleted due to frequency of use, and concerns over sensitivities in the timing of fishing. Additionally, the opportunities for strategically suggesting or avoiding boundary rules can be better identified and we can strive to achieve a balance between various user groups and interests (Russ and Zeller, 2003). For example, the definition of access rights based on geographic boundaries may cause problems for fisheries concentrating on migratory species (Wilson et al., 2006) but it is recommended for sedentary resources (Hilborn et al., 2005), which are mainly harvested by commercial divers or using traps (mainly for swimming crab). For mobile species, other management tools such as catch shares or season closures may play a more viable and effective role than the establishment of territorial use rights or even forms of spatially explicit harvest refugia.

4.2. Travel distances

Managing access rights to resources is an ongoing challenge in small-scale fisheries due to the spatial expansion of fishing activities resulting from depletion of local or regional resources (Berkes et al., 2006). Our results demonstrated that at least five communities stand out in their capacity to travel long distances to reach their fishing grounds (up to 200 km) (Fig. 2). Results related to the distance traveled may suggest the communities' "interest" or "apathy" in their use of fishing grounds. For example, of the communities studied, Bahía de Kino showed traveled distances up to 200 km for diving, gillnets and longline fisheries. These results also suggest that the most important near shore fishing grounds are used by swimming crab fishers (i.e., traps fishery), which reach up to 60 km from the shore. There may be multiple reasons for Bahía de Kino fishers traveling such distances. For example, Bahía de Kino is the oldest fishing town (ca. 1930s) located in the study area, and it is likely that intense harvesting over the years has resulted in depleted nearby fishing grounds for some species. Hence, fishers may need to travel longer distances to fish. Other reason may be the access to better infrastructure, consequently they are able to travel longer distances. Bahía de Kino is located near a major city, Hermosillo, the capital of the state of Sonora, and is approximately 400 km from the USA-Mexico border with relatively easy access to major transportation routes, all suggesting a higher market demand. Other communities that travel long distances to reach their fishing grounds, such as Puerto Peñasco and Puerto Libertad, also have good access to major roads due to major tourism activities or other revenue sources such as the Comisión Federal de Electricidad (Federal Commission of Electricity). Access to major roads provides these communities with access to major markets in Mexico City, the United States, and a number of countries in Asia. More research needs to be address on the specific issue of access to infrastructure and its influence on the expansion of fishing activities in the NGC. However, incorporating this information into the design of management measures may help on both understanding and addressing economic and safety issues in management (Norse, 2010). This analysis also illustrates that fishing production reported by fishers does not necessarily derive from local fishing grounds, but at least in part is sourced from other jurisdictions. Distance traveled can be an indicator of the condition of local fishing grounds (i.e., overfishing) or an indicator of good or bad access to infrastructure. Additionally, travel distances can provide managers the opportunity to calculate what may be the economical investment needed to travel long distances across land or sea in order to access different fishing grounds and to develop indicators to measure the fishing grounds condition or stress.

4.3. Spatial and temporal distribution of fishing activities

The collective degree of fishing activity can be the result of different social and biological factors embedded in the system. For example, many fishers base their decisions on knowledge about spawning seasons and this is reflected in the fishing calendars and maps for several target species. Our results on spatial and temporal distribution of fishing activity suggest that this is the case for the shark and rays fishery (Fig. 3). The spatial and temporal distribution

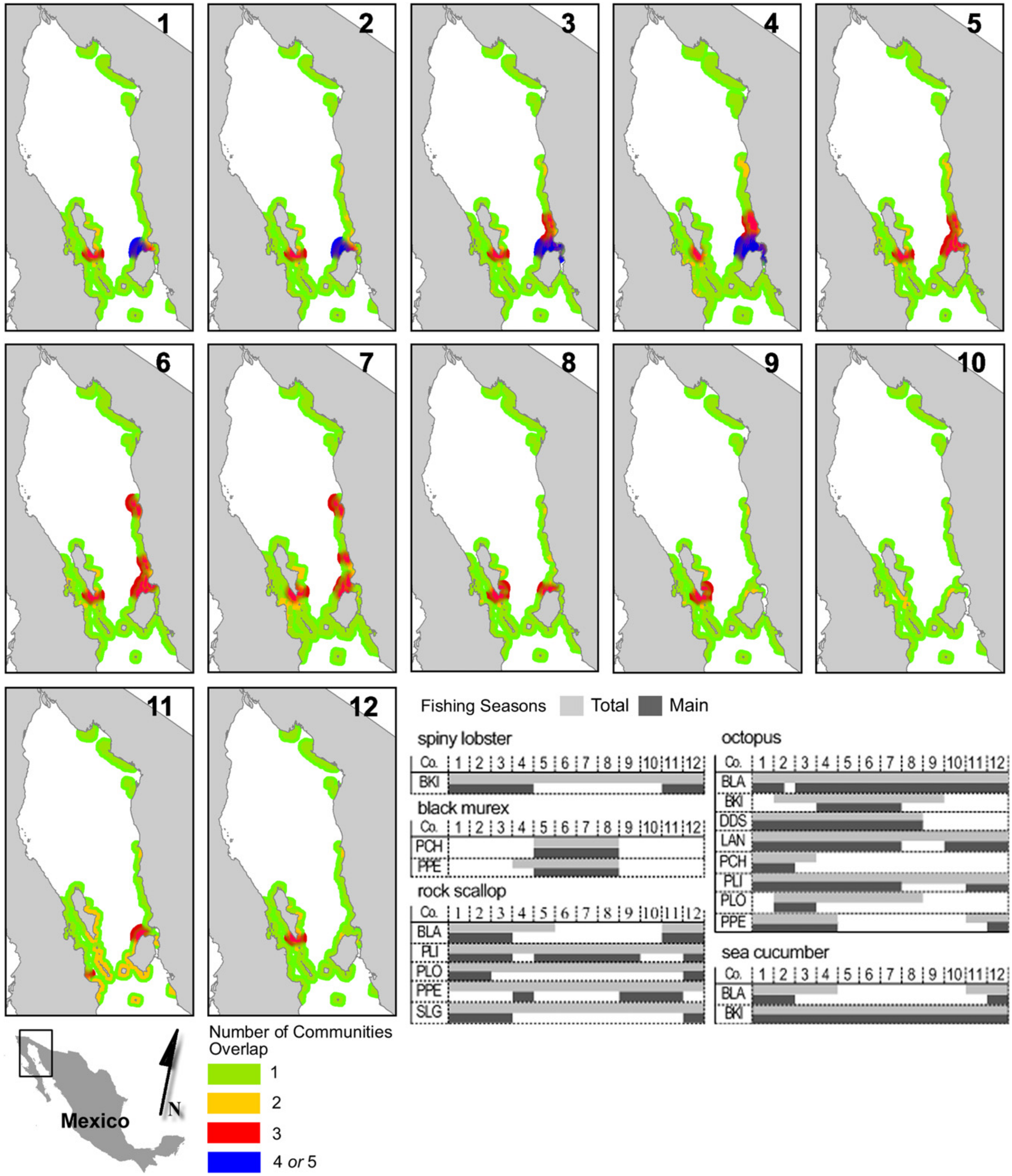

Fig. 9. Monthly distribution of fishing grounds and number of communities working coincidently for rocky reef benthic species fishery (mollusk, arthropods and echinoderms) including: spiny lobster, black murex, octopus, rock scallop and, sea cucumber fishery. January (1), February (2), March (3), April (4), May (5), June (6), July (7), August (8), September (9), October (10), November (11) December (12). Communities included: BDA, BKI, DDS, EBA, LAN, PCH, PLI, PLO, PPE (See Table 1, for communities' code).

of this fishery shows patterns that may be linked to regional differences in the migration and reproductive periods of various sharks and rays. However, the existing Mexican regulatory instruments for shark and ray fisheries did not distinguish any spatial or temporal heterogeneity in the fishery until recently. Life history information for most of these species is unknown and the need for spatial and temporal information can be crucial for the fisheries management agenda (CONAPESCA-INP, 2004).

The swimming crab, an important fishery for the NGC in terms of economic value and number of people participating in the fishery, is another example of an activity driven by its spawning season. INAPESCA (2010) recommended a season closure for this species during its reproductive period. However, fishers from northern Sonora assert that the reproductive season of swimming crab in the northern part of the state is different than in the south, and preliminary field observations suggest this is the case (Loaiza-Villanueva et al., 2009). In all, at least 40% of the 43 target fisheries selected are captured primarily during their reproductive season (Cudney-Bueno et al., 2008; Cudney-Bueno and Turk-Boyer, 1998; Erisman et al., 2010; Rowell et al., 2005). This information may help with the establishment of suitable spatially explicit management measures or season closures where the need to incorporate reproductive patterns of species is crucial.

Fishers' knowledge associated with repeated observations or experience may be established through the existence of a large number of accounts of the same event (e.g., good fishing seasons or sites). For example, Fig. 9 suggest that the rocky reef fishing activity along the midriff islands and in the northernmost part of the coast of Sonora is prevalent year-round with multiple communities using the same fishing grounds. Fishers suggested through notes that they return to those fishing grounds based on previous experiences and repeated observations of different events such as spawning aggregations events (e.g., black murex) and good fishing grounds for certain species. Understanding of the ecosystem and repetitive human interactions with species and habitats, including the knowledge that resource users have accumulated historically is an important asset to incorporate in management.

Fishers' decisions can be driven by factors such as social and economic needs as influenced by market demand and rational thinking to maximize profit, and constrains of resource availability and pressures from *de facto* open access (Cinti et al., 2010a). In the Gulf coney fishery, one of the large predatory fishes, the fishing season can occur from October until late June. However, the peak season, where more communities overlap in their fishing grounds, varies between January and March. The Gulf coney fishing activities diminish for some communities as soon as the shrimp fishery season starts (Cudney-Bueno and Turk-Boyer, 1998). This change is driven by the market demand for shrimp, which is one of the most economically important fisheries for the uppermost communities in the Gulf. This behavior shows how the market may also influences in fishing activity.

The implications of this information for conservation and management efforts are significant, providing critical insights into how space should be allocated to specific uses, how market influences in fishing activity and where resources availability fluctuates due to *de facto* open access in the NGC. In order to address conservation and management planning, it is important to understand how people are already using the marine environment in space and time, which in turn makes it possible to capture the collective use of natural resources, their potentially competing interests, and other facets and interactions of small-scale fishing activity under various scenarios. For example the Gulf corvine fishery, which takes place within the boundaries of the RB.AGC y DRC (Fig. 4) is mainly the providence of two communities, Golfo de Santa Clara and San Felipe. By understanding the fishing dynamics for this species, it is possible to have a prognosis of what management measures may work when multiple communities are using the same resource. By identifying these dynamics at a spatial and temporal scale, it is possible to make sound decisions on when to develop, implement, and enforce management strategies such as boundary rules, catch shares or season closure (Wilson, 2006).

The results presented in this study highlight the value of the vast knowledge that local users have in terms of the ecological processes, as related to the spatial and temporal dimension of fishing activities amassed from repeated observations. Based on the results obtained within this study and in previous work (Cudney-Bueno and Turk-Boyer, 1998; Moreno-Báez et al., 2010), local knowledge has helped document previously undocumented but essential spatial-temporal variables for the sustainable management of marine resources across a large, interconnected marine ecosystem in the NGC. However, this large-scale perspective comes at the sacrifice of finer-scale resolution and specificity that might come from other ethnographic approaches. For example, LK was obtained through single interviews, rather than, for example, longer term observation and the associated capacity to highlight misunderstandings, contradictions, or bias more readily identified over time. One potential source of discrepancy was the generalization or differences in language (i.e., species names) used by the fishers from different communities. It is possible that for certain migratory species such as sierra and Gulf corvina, the results were generalized for more than one species (Cudney-Bueno and Turk-Boyer, 1998). These differences may not be always picked up during interviews or in subsequent analyses. Furthermore, the success of the interpretation may be enhanced by the skills of the experts capturing and analyzing the data. Another limitation of the method to collect the data used in our study was the use of printed maps during the interviews, which may also be a source of bias in the quality of the data provided, given the diverse fishing methods, specialization, experience to read maps and knowledge about the fishery. The impact of these biases was minimized by working closely with local experts from the communities and by the two internal data validation workshops organized in two main fishing communities (Moreno-Báez et al., 2010). However, the collection of information through focus group requires a much greater effort and might bring other kind of bias to the study, such as generalization of information, the selection of adequate participants and the potential unidentified number of focus groups that should be organized (Stewart et al., 2007).

An additional benefit to a research approach centered on LK is a sense of ownership. When fishers are involved in the research and decision-making process, management guidelines are more likely to be effective because confidence of both fishers and managers can be increased (Anuchiracheeva et al., 2003; Berkes et al., 2001; Cudney-Bueno and Basurto, 2009; Johannes et al., 2000). Likewise, including fishers' LK could ultimately help empower stakeholders by bringing recognition to their experience, while promoting the cooperation among fishers, managers, and scientists that is ultimately essential for successful management of coastal and marine resources. The approach outlined here allowed a much fuller understanding of the potential implications and cumulative effects of management plans and policies at different scales. The collection and analysis of LK as presented here is therefore intended to complement, and not replace, scientific research and the more detailed analyses that are possible at individual sites and local scales.

5. Conclusions

Capturing the spatial and temporal dynamics and the heterogeneity in the NGC's small-scale fisheries is an important first step for the characterization of the overall marine ecosystem for the development of more appropriate management. Our results help portray the system dynamics relative to spatial and temporal information that influences fishers' decisions, helping answer key questions such as 'What is the spatial distribution of fishing activity?' 'Where and by what fishing method are the different species being fished?' 'Which communities are actively involved in which fisheries?' 'Where and when are the fishing activities concentrated?' Management decisions require information across multiple spatial and temporal scales, something that is made possible by incorporating the information provided by fishers to characterize the activity and the inactivity of each fishery by community. The understanding of the social and biological factors influencing a fishery, the mismatches among fishing activities, and management guidelines that take these spatio-temporal factors into account can be important for improving policies that not only help manage a fishery more sustainably, but also help reduce negative socio-economic risks and impacts on the different communities that target the fishery. Furthermore, scientific research building off of this information will allow the evaluation of future scenarios for management by considering different options and priorities including change, adaptability, contingency and uncertainty to ensure ecological sustainability while promoting economic development. Because data are collected and evaluated at a regional scale, other data on natural or social systems can be integrated into the equation with relative ease. The benefits of assembling such data and developing spatial and temporal analyses are to understand the dynamics of fishing activity, the spatial scale of organization, and the spatial and temporal variability of species distribution at a regional scale.

Planning at a spatial and temporal scale provides new opportunities for the management of fisheries, both for the Mexican government and local interests. Future studies might include the integration of other sectors at a regional scale (e.g., industrial fishing, recreational sport fishing and tourism) to support, for example, efforts towards the implementation of place-based ecosystem management (e.g., ordinance plans) and informing marine spatial planning (Douvere, 2008; Halpern et al., 2008). Recommendations by the new national fishing law (LGPAG, 2007) on incorporated spatially or temporally explicit management tools represent an opportunity for sustainable fisheries management in Mexico. Including the spatial and temporal dynamics of human activities should be a part of a continuing evaluation process, not a static end. This allows for the linking of information from local and regional scales and provides the analytical dimensions necessary not only for decision-making, but also the establishment of guidelines for spatial planning. While this study focuses on the NGC, the approach for characterizing small-scale fishing activities in coastal and marine waters can be applied to other coastal ecosystems.

Ethical statement

This is to confirm that the conduct of this research involved no significant ethical issues, and that the normal protocols of good scholarship were followed throughout.

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