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The artisanal elasmobranch fishery of the Pacific coast of Baja California, Mexico

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ABSTRACT

Artisanal fisheries account for up to 80% of elasmobranch fishing activity in Mexican waters, yet details associated with fishing effort and species composition are generally unavailable. This paper describes a survey of the artisanal elasmobranch fishery of the Pacific coast of Baja California, Mexico from 2006 to 2008. The objectives were to determine the geographic extent, size, and targets of the artisanal fishery, and to describe the catch characteristics at Laguna Manuela, an artisanal camp where elasmobranchs are the primary target. For the latter, we used a combination of beach surveys and a novel survey method involving the identification of discarded carcasses. Forty-four artisanal fishing camps were identified, of which 29 (66%) targeted elasmobranchs at least seasonally, using primarily bottom-set gillnets and longlines. At Laguna Manuela 25 species of elasmobranchs were documented. Gillnetting accounted for 60% of fishing effort, and the most commonly captured species were *Rhinobatos productus*, *Zapteryx exasperata*, and *Myliobatis californica*. Longline fishing accounted for 31% of fishing effort, and the most commonly captured species were *Prionace glauca* and *Isurus oxyrhinchus*. Catch was composed of mainly juveniles for many species, indicating that the immediately surrounding area (Bahia Sebastian Vizcaino) may be an important elasmobranch nursery habitat. The results of this study will serve as a baseline for determining future changes in the artisanal fishery, as well as changes in species demography and abundance.

1. Introduction

Elasmobranchs have historically been an important food resource in Mexico, and exploitation of elasmobranchs can be traced back to the Aztecs and Olmecs, two of the most important Mexican pre-Hispanic cultures (Applegate et al., 1993). Written records for Mexican elasmobranch fisheries do not exist until the 1890s when shark fins were first exported to Asia from Baja California Sur. Since that time elasmobranch fisheries have increased dramatically in their size and geographical extent. Elasmobranchs are an important constituent of the Mexican diet and up to 90% of the Mexican harvest is consumed domestically (Bonfil, 1997). Elasmobranch fishing moreover provides both sustenance and income for some of the poorest sectors of Mexican society (McGoodwin, 1976).

Much of elasmobranch fishing in Mexico is dominated by artisanal fisheries (Castillo-Geniz, 1992). These are relatively small-scale operations in which 'pangas' (5–8-m long outboard-powered open boats) with a crew of (typically) three or fewer undertake one to two day fishing trips, setting and hauling the gear by hand. Elasmobranchs and other catch are brought back to a base camp on the beach where they are processed. In Mexico, an estimated 130,000 artisanal vessels annually harvest approximately 40% of the marine catch, and comprise up to 80% of the elasmobranch fishing effort (Arreguin-Sanchez et al., 2004; Bizzarro et al., 2007).

The well documented history for elasmobranch fisheries demonstrates that many are not sustainable (Walker, 1998). Compared to other important commercial taxa such as sardines, anchovies, and tunas, elasmobranchs grow slowly, require many years to reach sexual maturity, and have low reproductive rates. Therefore, elasmobranch populations are far less resilient to and are slower to recover from over-fishing (Smith et al., 1998). Declines in Mexican elasmobranch fisheries have been described for the Gulf of Mexico (Bonfil, 1997; Castillo-Geniz et al., 1998) and along the central Pacific coast (Perez-Jimenez et al., 2005). In addition, over-

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all Mexican elasmobranch landings have decreased substantially in recent decades, from 45,250 tons (t) in 1996 to an average of 35,264 t during the period 1997–2005, while effort has not declined (FAO, 2005). Currently, Mexico is ranked as one of the ten largest producers of shark landings worldwide (CONAPESCA, 2010).

Management of a sustainable elasmobranch fishery in Mexico has been hampered by a lack of reliable fisheries data. For example, historical elasmobranch landings data are grouped into five broad categories: tiburón (sharks greater than 1.5 m in length), cazón (sharks < 1.5 m), angelito (angel sharks), manta (batoids), and guitarra (guitarfishes) (SAGARPA, 2009), a reporting scheme that gives little information about species composition and ignores the distinction between small sharks and juveniles of large sharks. Moreover, historical landings probably greatly underestimate the actual take (Castillo-Geniz et al., 1998). In many remote areas, it is unknown how many artisanal camps exist, and what level of effort is directed towards elasmobranchs. In addition, species-specific information is unavailable for most artisanal elasmobranch fisheries, but is necessary for formulating effective management strategies (Bizzarro et al., 2009a).

This paper describes the artisanal elasmobranch fisheries of the Pacific coast of the Mexican state of Baja California (BC). Contrary to catch trends in other parts of Mexico, elasmobranch landings in BC have risen from an average of 1757 mt in the 1990s to an average of 4160 mt between 2000 and 2008, with an estimated economic value of 37 million pesos in 2008. In addition, BC accounted for 12.6% of Mexico's total elasmobranch capture during the period 2000–2008, with approximately 75% of these landings reported from the Pacific coast (CONAPESCA, 2010). Although recent studies have been published describing the artisanal elasmobranch fisheries along the Gulf of California (GOC) coast of BC (Bizzarro et al., 2009b; Smith et al., 2009), studies on the Pacific coast of BC are few and limited in scope. Holts et al. (1998) gave a brief general description of the rapidly growing artisanal fishery for pelagic sharks, and Gonzalez (personal communication) described the artisanal shark fishery near San Quintin. Andrade et al. (2005) surveyed the fishing activity and infrastructure of many artisanal camps in the region. However, no previous assessment specific to elasmobranch capture in the artisanal fishery has been conducted. The objectives of this study were to (1) survey the geographical extent, number of camps, and targets of the artisanal fishery, and (2) examine the catch characteristics at a representative artisanal camp where elasmobranchs are the primary target, and provide biological information for the most abundant species in landings.

2. Methods

2.1. Study area

The study area is the approximately 880 km of Pacific coastline of the Mexican state of Baja California (BC) (Fig. 1). BC is bordered on the north by the United States and on the south by the state of Baja California Sur. Much of BC is sparsely populated, with most of the approximately 2.8 million inhabitants (INEGI, 2007) concentrated in border cities such as Tijuana and Mexicali. The northern portion of the Pacific BC coastline (from the U.S. border to approximately 29°N latitude) is strongly influenced by the cold southward-flowing California Current, and is characterized by high primary productivity driven by coastal upwelling (Zaytsev et al., 2003). The continental shelf is narrow, extending from five to twenty km offshore. South of 29°N latitude the coastline transitions into Bahia Sebastian Vizcaino (BSV), a large embayment (35,678 km^2) where the continental shelf extends to as far as 140 km offshore (Figs. 1 and 2A). BSV is regarded as a temperate-tropical transitional zone, influenced by both the California Current

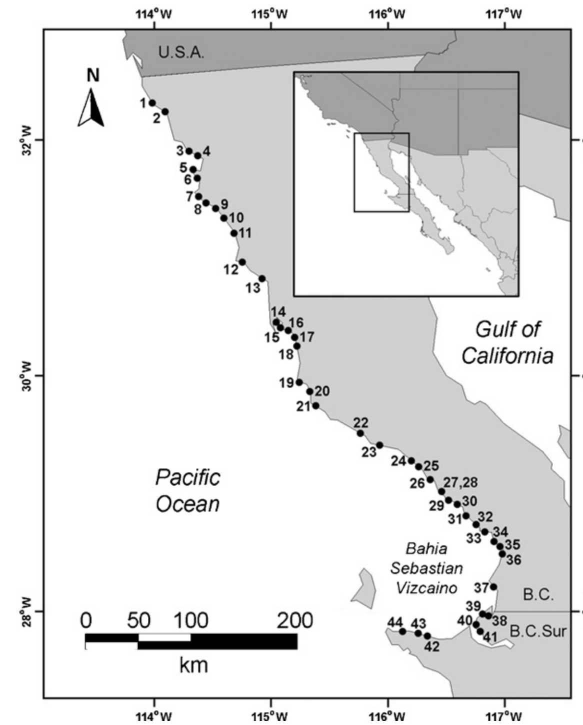


Fig. 1. Location of artisanal camps along the Pacific coast of the state of Baja California, Mexico. Numbers refer to map codes in Table 2. Inset shows the location of the study area relative to the United States and mainland Mexico.

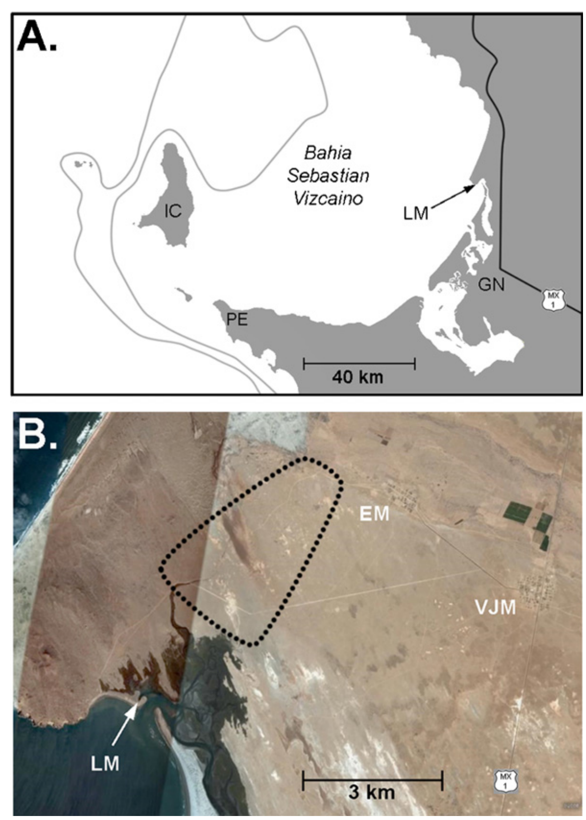


Fig. 2. (A) Bahia Sebastian Vizcaino. The extent of the continental shelf is indicated by the 100 m (inner) and 200 m (outer) bathymetry lines, in grey. Black line indicates the paved Transpeninsular Highway (MX 1). LM = Laguna Manuela; GN = Guerrero Negro; IC = Isla Cedros, PE = Punta Eugenia. (B) Detailed satellite image (Google Earth) of LM fishing camp and immediate surroundings. EM = Ejido Morelos, VJM = Villa Jesus Maria. Dotted black polygon indicates the area where carcass discard sites are located.

and warmer waters to the south. Punta Eugenia, at the southern extreme of BSV, represents the southern limit of the distribution of many fish taxa common to the San Diegan Province, and the northern limit of distribution for many fish species common to the tropical Panamic Province (Quast, 1968; Horn and Allen, 1978; Horn et al., 2006).

2.2. General survey of artisanal camps

A general survey of all artisanal fishing camps along the Pacific coast of BC was conducted in September 2006. Although the locations of some camps were previously reported by Andrade et al. (2005), the entire coastline was traveled by 4-wheel-drive vehicle to ensure that all camps were located. Informal, semi-structured interviews (Lindlof and Taylor, 2002) were conducted with fishers at each camp to determine the following information: (a) primary species or species groups targeted at each camp, (b) seasonal aspects of fishing activity, (c) fishing gear used and gear characteristics, (d) level of fishing effort (i.e., # of fishing vessels), (e) permanence or seasonality of camp, and (f) level of infrastructure. The location of each camp was determined with a global positioning system (GPS) unit. Most fishing camps were re-visited within the subsequent two year period to collect updated or additional information. For three camps where fishers were never available for interview, we used data from Andrade et al. (2005).

2.3. Laguna Manuela

2.3.1. Beach surveys

The artisanal fishing camp of Laguna Manuela (LM) is located within BSV, approximately 30 km from the border with BC Sur (Fig. 2A and B). Preliminary investigations identified LM as one of the most important elasmobranch fishing camps in BC, and thus it was selected for a detailed study of elasmobranch species composition and fishery characteristics. The camp, located on the inside of a sand spit at the entrance to the Laguna Manuela estuary, has no permanent structures, boat launch ramps, or electricity, and its access roads are unpaved and poorly maintained. Most fishers using LM live in the nearby villages of Ejido Morelos and Villa de Jesús María (7 and 10 km inland) (Fig. 2B).

Between September 2006 and December 2008, twenty-seven trips, ranging from 1 to 5 days in length, were made to survey the fishing activity at LM; the frequency of these trips was higher in summer when fishing activity increased and substantially lower in winter when it diminished (Table 1). During field visits, the catch of each vessel that fished that day was sampled. As fishers did not process their catch at sea, almost all specimens were identifiable to species level. In addition to recording the species and sex of all elasmobranchs, gear type was noted, and fishers were interviewed to determine ex-vessel price for elasmobranchs and other species.

Due to the high volume of total catch and limited time in which to collect data, measurements (to the nearest 0.5 cm) were recorded only for elasmobranchs, including total length (TL; using the 'natural' extension of the caudal fin) (Compagno, 2001) for shark species [except fork length (FL) for thresher shark, *Alopias vulpinus*], and disc width (DW) for batoids [except TL for guitarfishes (Genus *Rhinobatos* and *Zapteryx*)]. Although several species of the genus *Mustelus* were observed (*M. californicus*, *M. henlei*, and possibly *M. lunulatus* and *M. hacat*), these were grouped into the category *Mustelus* spp. due to the possibility of identification errors. In some cases, unambiguous identification was possible for *M. henlei*; these data are reported separately.

Catch per unit effort (CPUE) was calculated for each species within each major gear type; here the unit of effort is a single fishing trip (however, note that fishing effort was not standardized, in that vessels often fished with variable and unquantified numbers of hooks or nets). Histograms of sex-specific size distributions were plotted for each species, along with size-at-maturity data from Ebert (2003). Because of regional differences in size-at-maturity, this information is an approximation for our study area, and is shown for comparative purposes only. In cases where $n < 10$, only summary statistics (mean size ± SD) are given. For all species with ≥50 measured individuals, the difference in average size between females and males was compared using a linear mixed-effects ANOVA model (Pinheiro and Bates, 2004), with a trip effect (random effect) to capture variability among trips (in a number of cases multiple sharks were measured from the same trip) and sex as a fixed effect. Histograms showing the percentage of total trips relative to CPUE values were plotted for species where $n > 50$. The assumption of equal sex ratios (1:1) within the landings was tested using chi-square analysis with Yate's correction for continuity (Zar, 1996; Bizzarro et al., 2009c). Seasonal aspects of elasmobranch species composition and fishery activity could not be analyzed due to the sharp decline in elasmobranch fishing and survey effort from October through March. For all statistical tests, a p value of <0.05 was considered significant.

Table 1
Sampling dates and number of pangas sampled per trip at Laguna Manuela artisanal fishing camp.

Year	Date(s)	Days	Pangas
2006	September 25	1	2
2007	March 12–16	5	14
	April 18–19	2	2
	May 22–24	3	19
	June 13–14	2	5
	June 21–22	2	4
	June 27–28	2	4
	July 23–26	4	17
	September 3–5	3	11
	September 21	1	8
	November 6–7	2	7
	November 21	1	2
	December 18–20	3	6
2008	February 10	1	3
	March 11–13	3	8
	April 6–8	3	5
	April 29–30	2	22
	May 13–15	3	24
	June 11–13	3	22
	June 17–19	3	33
	July 2–4	3	27
	July 22–24	3	32
	August 11–13	3	34
	August 27–29	3	34
	October 6	1	10
	October 14–16	3	17
	December 4–5	2	15
Total		67	387

2.3.2. Carcass discard site survey

In addition to the beach surveys, elasmobranch species composition in the LM artisanal fishery was assessed by identifying discarded elasmobranch carcasses. Because local regulations prohibit the dumping of processed carcasses into the LM estuary, fishers typically discarded elasmobranch heads and offal at several 'carcass discard sites' inland from LM (Fig. 2). The high heat and low humidity of the desert quickly desiccated these remains and preserved them in a state resembling mummification (Fig. 3). Discard sites were located and mapped with GPS, and the total combined area was calculated using Arcview GIS 3.2. All elasmobranch carcasses in the discard sites were counted and identified to the lowest possible taxon level, using physical characteristics such as chondrocranial, tooth, and spine morphology.

Fig. 3. View of carcass discard site in vicinity of LM artisanal fishing camp.

3. Results

3.1. General survey of artisanal camps

Forty-four artisanal camps were located along the Pacific coast of BC (Fig. 1). Camps ranged from seasonal and very small with no permanent structures or electricity (e.g., Punta Colonet), to permanent locations featuring high year-round fishing effort that supported entire villages (e.g., Santa Rosaliita). Table 2 details comparative characteristics of the camps.

Elasmobranchs were the primary target at 5 of the 44 camps and were targeted secondarily at 25 additional camps. Coastal elasmobranchs (mainly batoids and small sharks) were targeted using bottom-set gillnets deployed on the continental shelf. These nets are monofilament with lengths of 100–500 m, depths of up to 5.5 m, and stretched mesh sizes of 6–12 cm. Multiple gillnets, either strung together or set in various locations, were often deployed for a 24 h (h) period before retrieval. The maximum number of gillnets in use simultaneously by one vessel was eight. Pelagic sharks were targeted with longlines ranging from 3 to 4.5 km in length, with highly variable hook counts (range 200–500), and set depths of 5–10 m. 'J'-style hooks of 6–10 cm length were commonly used, whereas the use of circle hooks was rare. Fishers usually set longlines before sunrise and left them in the water for eight to twelve h, regularly checking them to remove ensnared sharks and re-bait hooks. Lines were retrieved by late afternoon, and fishers generally returned to camp near sunset. Although most longline trips did not exceed one day, the maximum observed trip duration was 3 days.

Teleosts were the primary target at 19 of the 44 artisanal fishing camps, and were targeted secondarily at 17 additional camps. Although most often fished with bottom-set gillnets (of the same configuration as those used to target elasmobranchs), trap and hook-and-line fishing were also used to target teleosts. It is important to note that elasmobranchs were an incidental, and often major, bycatch of teleost-directed gillnet fishing.

Invertebrates were an important component of the artisanal fishery, and one or more of these groups were the primary target at 17 of the 44 camps, and secondarily targeted at 9 additional camps. Although quantification of invertebrate catch is beyond the scope of this paper, the high fishing effort and ex-vessel prices for invertebrates (urchin: 100 pesos kg^{-1}; abalone: 300–500 pesos kg^{-1}; lobster: 150–250 pesos kg^{-1}; bivalves: 120–200 pesos kg^{-1}; crab: 20–30 pesos kg^{-1}; snail: 50 pesos kg^{-1}; octopus: 50 pesos kg^{-1}; sea cucumber: 30 pesos kg^{-1}) indicate their economic importance. However, because most invertebrate fishing methods are highly species-specific and characterized by low bycatch, their impact on elasmobranchs is considered negligible, and they are not considered further in this paper.

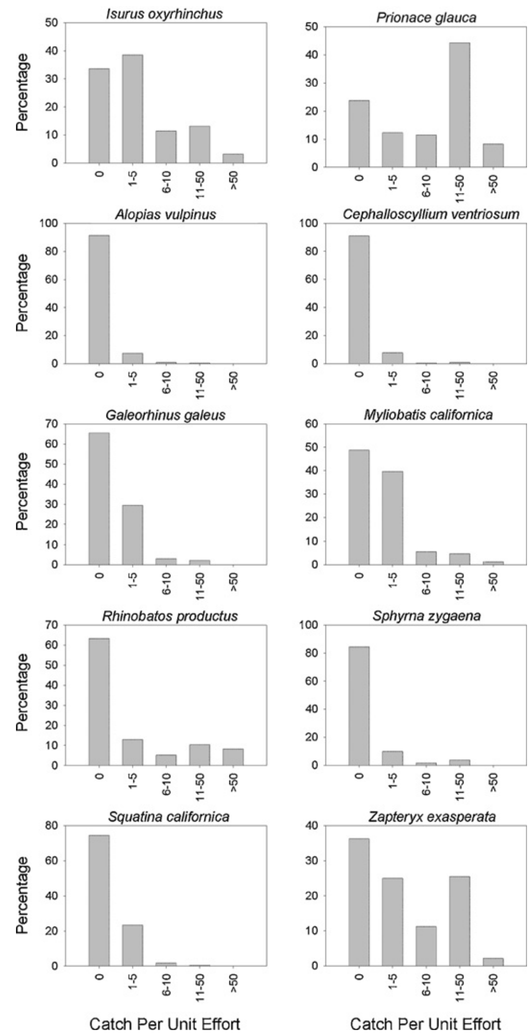


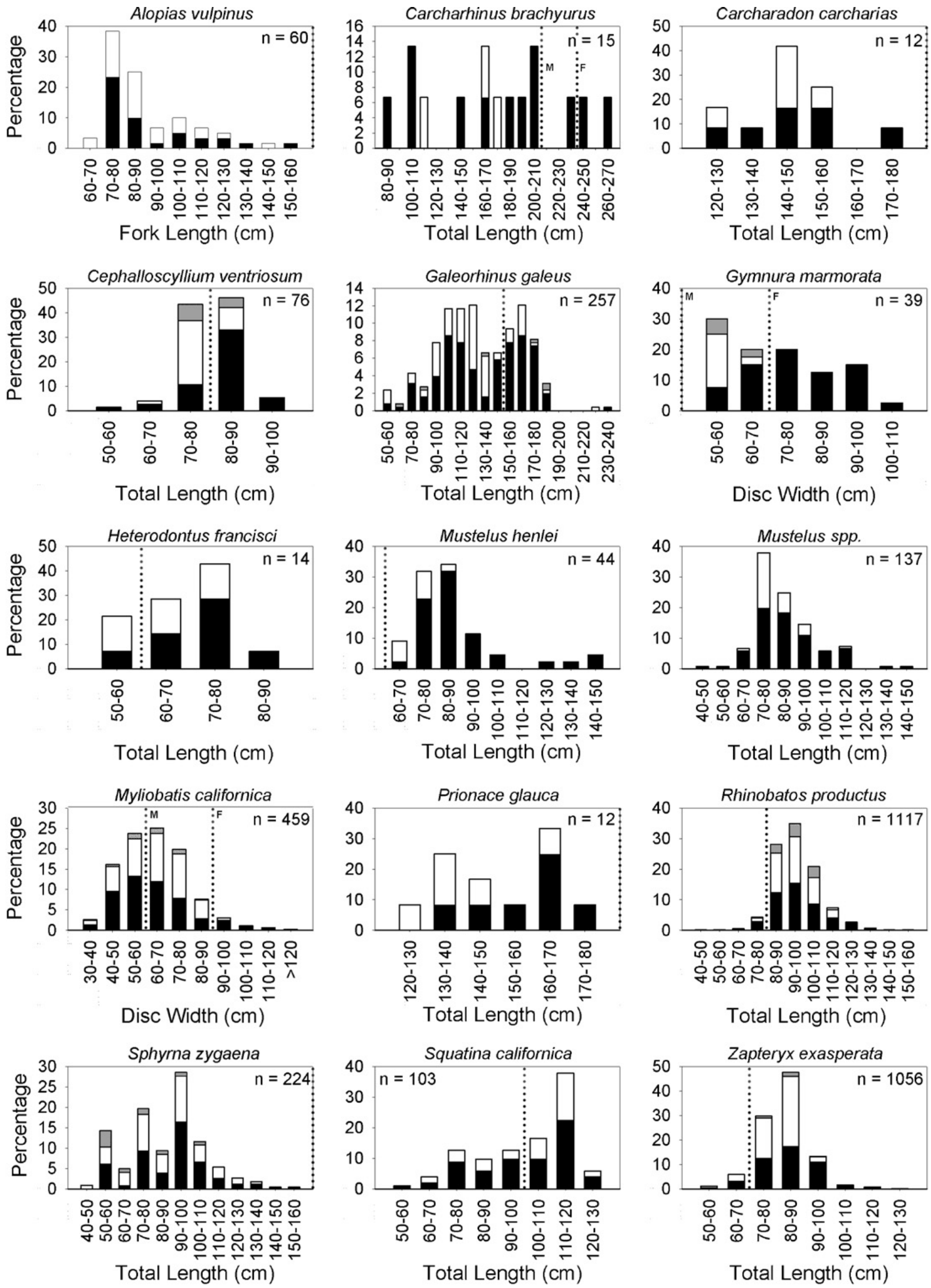
Fig. 4. Histograms showing the percentage of total trips with varying CPUE values for species where $n > 50$.

3.2. Laguna Manuela

3.2.1. Beach surveys

A total of 67 days was spent sampling at LM, during which the mean (±SD) number of vessels fishing day^{-1} was 7.35 ± 3.93. A maximum of 15 vessels day^{-1} was observed working simultaneously in summer, while inclement weather during winter months occasionally reduced effort to zero. The beach surveys covered 387 panga trips that captured 10,595 elasmobranchs.

Three fishing methods – gillnet, longline, and trap – accounted for the entire catch observed during the study period. Gillnets were used by 232 of the 388 pangas (60% of fishing trips) and the primary target was elasmobranchs (7518 individuals from 24 species; Table 3). The three most abundant elasmobranchs taken by gillnet were the shovelnose guitarfish (*Rhinobatos productus*, 46.1%; CPUE = 14.9), banded guitarfish (*Zapteryx exasperata*, 27.9%; CPUE = 9.0), and California bat ray (*Myliobatis californica*, 9.4%; CPUE = 3.1). Banded guitarfish showed the highest tendency to be captured in large numbers (Fig. 4). Of the eleven species caught in numbers greater than 50, there were significant, sex-specific differences in size distribution for two. *Cephaloscyllium ventriosum* females (81.8 ± 6.9 cm TL) were significantly larger than males (77.6 ± 4.5 cm TL), and *Zapteryx exasperata* females (83.4 ± 10.0 cm TL) were significantly larger than males (79.9 ± 6.9 cm TL). Two of these eleven species had a significantly larger proportion of



Species	cm	s.d.	msmnt	*n*
Dasyatis dipterura	47.1	14.2	DW	5
Notorhynchus cepedianus	152.5	34.6	TL	2
Platyrhinoidis triseriata	52.3	3.8	TL	5
Raja inornata	36.9	3.7	DW	8
Squalus acanthias	111	1	TL	3
Triakis semifasciata	132.3	12.4	TL	3
Urobatis halleri	33	---	DW	1

Fig. 5. Sex-specific size frequency distributions of elasmobranchs sampled from the gillnet fishery at Laguna Manuela. *n* refers to the number of measured individuals upon which size histograms are based, and not necessarily the total number captured. Females are depicted in black, males in white, sex unknown in grey. Dotted lines indicate approximate size at maturity (Ebert, 2003). In cases where a substantial difference in size at maturity exists between sexes, lines are labeled M (male) or F (female). Dotted lines on the left or right *y* axis indicate that size at maturity is either less than or greater than the scale shown. Tabular data at the bottom provides summary statistics for species where $n < 10$. cm is mean size ± SD (standard deviation) for the specified measurement (msmnt) taken for that species.

Table 2

Characteristics of surveyed artisanal camps. Pangas = number of fishing vessels present during surveys (or minimum/maximum in cases of seasonal fluctuations in effort). Where camp names are followed by [A], data shown are from Andrade et al., 2005. Target refers to the species complexes targeted at each camp, in order of fishing effort. Codes for this category are: CE(G): coastal elasmobranchs (gillnet); PE(L): pelagic elasmobranchs (longline); T: teleosts; I: invertebrates (A: abalone; L: lobster; C: crab; G: gastropod; B: bivalves; U: urchin; H: sea cucumber; O: octopus); K: kelp. Perm refers to whether a camp is P (permanent) or T (temporary/seasonal). Structures refers to the number of structures related to fishing activity at each camp. These are divided into: S (Simple—rudimentary or temporary constructs), P (Permanent—strongly constructed or concrete), or V (Village—the camp is incorporated into a larger village or infrastructure that is not necessarily supported solely by fishing). NA: Data not available.

Map	Camp Name	Pangas	Target	Perm	Structures	N Lat	W Long
1	Popotla	6/30	T, I(L, C, U), CE(G)	P	V	32.282	117.034
2	Puerto Nuevo	6	I(L, C), T, CE(G)	P	V	32.243	116.936
3	El Sauzal	6/20	I(L, U, S), T, CE(G), PE(L)	P	V	31.894	116.706
4	Ensenada	4/7	PE(L), T	P	V	31.859	116.632
5	Rincon de Ballenas	7	T, CE(G)	P	S(4)	31.718	116.671
6	Arbolitos[A]	12	I(U, B, H)	T	S(1)	31.702	116.685
7	Puerto Santo Tomas	10/15	I(U, G), T	P	P(20), S(10)	31.554	116.681
8	Punta San Jose	2/12	T, CE(G)	P	P(1), S(1)	31.467	116.600
9	Campo de Enmedio	2/6	T, CE(G)	T	S(6)	31.450	116.533
10	San Juan de las Pulgas	2	T, CE(G)	T	S(2)	31.408	116.500
11	Erendira	8/10	T, I(B), CE(G), K	P	V	31.285	116.400
12	Punta Colonet	3	T	T	S(1)	30.970	116.280
13	Camalu	14	T, CE(G)	P	S(2)	30.935	116.237
14	Punta Azufre (San Quintin)	4/6	T, PE(L), I(B)	P	S(2)	30.389	115.986
15	El Chute (San Quintin)	6/8	T, PE(L), I(B)	P	P(3), S(6)	30.436	115.987
16	El Pabellon	4/6	T	P	None	30.373	115.852
17	El Socorro	2/8	T, PE(L)	P	None	30.310	115.820
18	El Tranquilo	4/6	T, CE(G)	T	None	30.281	115.803
19	Punta Baja	15/25	I(U,C,B, H, G), T, PE(L)	P	P(28), S(3)	29.950	115.811
20	Campo Nuevo	2/4	I(L,U,A), T	P	S(1)	29.698	115.602
21	Punta San Carlos	15	T, CE(G), I(L,C)	P	P(11), S(11)	29.627	115.478
22	Puerto Catarina	6/20	I(C), T, CE(G)	P	S(15)	29.525	115.270
23	Puerto Canoas	6	T, I(L), CE(G)	P	P(2), S(10)	29.420	115.120
24	Faro de San Jose	5/8	CE(G), T, I(A,L,C,G)	P	P(3), S(6)	29.286	114.877
25	El Cuchillo	4	CE(G), T, PE(L), I(C)	T	S(3)	29.242	114.834
26	Bahia Blanca[A]	NA	I(L,C,B), T	P	S(4)	29.113	114.678
27	Punta Cono South	3	T, CE(G), PE(L)	P	S(4)	28.975	114.580
28	Punta Cono North	3/6	I(L)	T	S(6)	28.973	114.591
29	Bahia Maria	6	T, CE(G), PE(L), I(L)	P	S(6)	28.934	114.510
30	El Cardon	1	T	T	None	28.911	114.452
31	El Marron	4	I(L,O), T, CE(G), PE(L)	P	P(5)	28.814	114.375
32	Puerto San Andres	NA	NA	NA	NA	28.707	114.287
33	Santa Rosaliita	6/20	T, CE(G), I(L), PE(L)	P	V	28.667	114.217
34	Punta Rosarito[A]	NA	CE(G), T, PE(L),	T	S(1)	28.570	114.160
35	Campo Esmeraldas	1/10	T, PE(L)	T	P(1), S(1)	28.515	114.068
36	El Tomatal	3/6	I(L), T	T	P(1)	28.486	114.067
37	Laguna Manuela	10/25	CE(G), PE(L), T, I(L)	P	S(1)	28.247	114.084
38	Puerto Carranza (La Isla)	8/16	I(B), T, CE(G)	P	S(1)	28.037	114.119
39	Puerto Viejo	6/8	I(B)	P	P(4)	28.016	114.118
40	Las Casitas	15/80	I(B, C, G), T, CE(G), PE(L)	P	P(6)	27.851	114.158
41	El Datil	NA	NA	T	None	27.796	114.176
42	El Queen	4/6	I (A, L, B, H, O)	P	P(3)	27.801	114.720
43	Malarrimo	9	I (A, L, B, H, G, O), T, CE(G)	P	P(15), S(10)	27.801	114.720
44	El Chevo/Campito	6/8	I(L,O), T, CE(G)	P	P(17), S(4)	27.823	114.852

females: *G. galeus* (females: 165, males: 86) and *Squatina californica* (females: 64, males: 37). Fig. 5 summarizes the sex and size-frequency data for gillnet caught elasmobranchs, and shows sample sizes for comparisons made above. The observed size ranges suggest that specimens of *A. vulpinus*, *Carcharhinus brachyurus*, *Carcharodon carcharius*, and *Sphyrna zygaena* were likely juveniles, while specimens of other species were primarily mature, or a mix of juveniles and adults (Fig. 5).

The ex-vessel value of elasmobranchs captured with gillnets at LM ranged from six to sixteen pesos kg^{-1}. Five elasmobranch species had no commercial value but were occasionally retained as bait for trap fishing; these accounted for only 1.2% of the catch. The fins of seven elasmobranch species had ex-vessel values ranging from 800 to 1000 pesos kg^{-1} dry weight (Table 3).

Gillnet fishing was opportunistic and commercially valuable teleosts were often targeted when abundant. These included Pacific halibut (*Paralichthys californicus*; ex-vessel price: 20–40 pesos kg^{-1}), white seabass (*Atractoscion nobilis*; 40–60 pesos kg^{-1}), yellowtail jack (*Seriola lalandi*; 10–15 pesos kg^{-1}), black seabass (*Stereolepis gigas*; 30–40 pesos kg^{-1}), and fantail sole (*Xystreurys liolepis*; 15–25 pesos kg^{-1}). These species also consituted the majority of bycatch when elasmobranchs were targeted. Other minor bycatch species included barred sandbass (*Paralabrax nebulifer*), Pacific bonito (*Sarda chiliensis*), Pacific chub mackerel (*Scomber japonicus*), California scorpionfish (*Scorpaena guttata*), and Pacific barracuda (*Sphyraena argentea*).

Longline fishing was done by 121 of the 388 pangas sampled (31% of fishing trips), and the primary target was elasmobranchs (3111 individuals from 8 species; Table 3). The most commonly caught species was the blue shark (*Prionace glauca*, 68.2%; CPUE = 17.4), followed by the mako shark (*Isurus oxyrhinchus*, 28.3%; CPUE = 7.2). Blue sharks were most often caught in groups of 11–50 individuals (Fig. 4). Female blue sharks (150.5 ± 29.1 cm TL) were significantly larger than males (132.7 ± 22.2 cm TL), and were also present in significantly larger proportion (n = 679) than males (n = 348). The size range of blue and mako sharks suggest juvenile status, while specimens of *G. galeus* were likely a mix of juveniles and adults, and all *Pteroplatytrygon violacea* were likely mature (Fig. 6).

The carcass values of longline-captured elasmobranchs ranged from 12 to 16 pesos kg^{-1}, with fin values of 800–1000 pesos kg^{-1}; the exception was *P. violacea*, with a carcass value of 7 pesos kg^{-1}

Table 3
Elasmobranch species taken by gillnet and longline at Laguna Manuela between September 2006 and December 2008, with number (n) of individuals documented, and percentage (%) of catch composed of that species. CPUE refers to mean catch per trip. S.E. = standard error. Carcass and Fins refers to ex-vessel price paid to fishers (in Mexican pesos kg^{-1}). (Note: during the time frame of this study, the peso was equivalent to approx. $0.09 in U.S. currency.).

Method	Species	n	%	CPUE	S.E.	Carcass	Fins
Gillnet	*Alopias vulpinus*	64	0.85	0.28	0.10	16	≤800
	Carcharhinus brachyurus	19	0.25	0.08	0.03	12	≤ 1000
	Carcharodon carcharias	12	0.16	0.05	0.02	12	≤1000
	Cephalloscyllium ventriosum	75	1.00	0.32	0.13	None	None
	Dasyatis dipterura	5	0.07	0.02	0.01	8–12	None
	Galeorhinus galeus	274	3.64	1.18	0.24	12–16	≤800
	Gymnura marmorata	53	0.70	0.23	0.06	6–10	None
	Heterodontus francisci	14	0.19	0.06	0.02	6–10	None
	Isurus oxyrhinchus	12	0.16	0.05	0.02	14–16	≤1000
	Mustelus henlei	54	0.72	0.23	0.06	12–14	None
	Mustelus spp.	191	2.54	0.82	0.32	12–14	None
	Myliobatis californica	710	9.44	3.06	0.66	8–12	None
	Narcine entemedor	2	0.03	0.01	0.01	None	None
	Notorhynchus cepedianus	2	0.03	0.01	0.01	8–12	None
	Platyrhinoides triseriata	6	0.08	0.03	0.01	None	None
	Prionace glauca	1	0.01	0.00	0.00	6–10	≤800
	Raja inornata	8	0.11	0.03	0.02	None	None
	Rhinobatos productus	3464	46.08	14.93	3.42	10–12	None
	Sphyrna zygaena	306	4.07	1.32	0.37	12–16	≤1000
	Squalus acanthias	3	0.04	0.01	0.01	12–14	None
	Squatina californica	140	1.86	0.60	0.11	12–14	None
	Triakis semifasciata	5	0.07	0.02	0.01	12–14	None
	Urobatis halleri	1	0.01	0.00	0.00	None	None
	Zapteryx exasperata	2097	27.89	9.04	1.08	6–10	None
Subtotal		7518	100				
Longline	*Alopias vulpinus*	5	0.16	0.04	0.03	14–16	≤800
	Carcharhinus brachyurus	1	0.03	0.01	0.01	12	≤1000
	Carcharodon carcharius	3	0.10	0.02	0.02	12	≤1000
	Galeorhinus galeus	74	2.38	0.61	0.33	12–16	≤800
	Isurus oxyrhinchus	881	28.32	7.22	1.58	14–16	≤1000
	Prionace glauca	2120	68.15	17.38	1.92	6–10	≤800
	Pteroplatytrygon violacea	17	0.55	0.14	0.04	7	None
	Sphyrna zygaena	10	0.32	0.08	0.03	12–16	≤1000
Subtotal		3111	100				

and no fin value. Bycatch consisted almost entirely of Humboldt squid (*Dosidicus gigas*), which had no ex-vessel value and was retained only for personal consumption.

Nine percent of the sampled vessels fished with traps. During the summer these targeted the barred sandbass (*Paralabrax nebulifer*), which spawns in the area at that time (Allen and Hovey, 2001). Traps were usually deployed for 2 day periods and catch rates were as high as 100–800 kg per vessel, with an ex-vessel price of 6–10 pesos kg^{-1}. Bycatch was low (<5% by number), consisting primarily of small numbers of ocean whitefish (*Caulolatilus princeps*) and California sheephead (*Semicossyphus pulcher*). Elasmobranch bycatch was not observed.

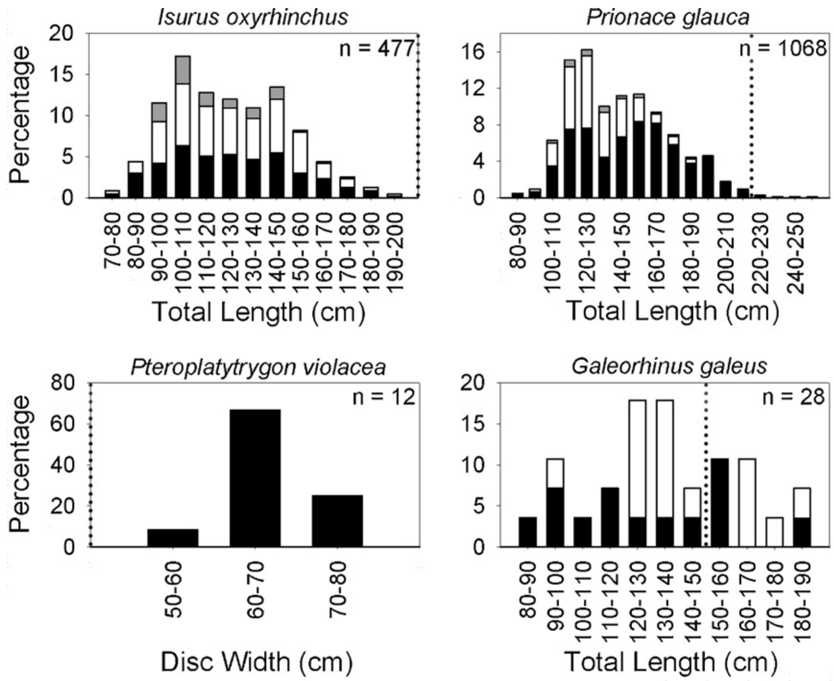
Trap fishing targeted spiny lobster (*Panulirus interruptus*) during the legal season (September 15 to February 15), and lobster trapping was the dominant activity at LM during December and January. This was an important supplemental income fishery at LM, with ex-vessel value for lobster as high as 150–250 pesos kg^{-1}. The unloading of lobster traps was not observed, as this was done at sea, but interviews with fishers indicate that elasmobranch bycatch in this fishery is negligible.

3.2.2. Carcass discard sites

Seventeen carcass discard sites were located, covering a total area of 90,520 m^2. Within these sites 31,860 elasmobranch carcasses were located and identified, from at least 22 different species (Table 4). Species composition was nearly identical to that of beach surveys, except that neither *Urobatis halleri* nor *Raja inornata* were found in discard sites, while 1 specimen of *Mobula japanica* was observed in carcass discard sites but not beach surveys.

Table 4
Elasmobranch species identified in carcass discard sites outside of LM artisanal fishing camp, with number (n) of individuals documented, and percentage (%) composed of that species.

Species	n	%
Prionace glauca	10608	33.29
Rhinobatos productus	8018	25.17
Isurus oxyrinchus	6091	19.12
Zapteryx exasperata	3842	12.06
Galeorhinus galeus	731	2.29
Squatina californica	620	1.95
Sphyrna zygaena	374	1.17
Pteroplatytrygon violacea	260	0.82
Myliobatis californica	208	0.65
Mustelus henlei	207	0.65
Cephaloscyllium ventriosum	187	0.59
Mustelus spp.	168	0.53
Heterodontus francisci	157	0.49
Alopias vulpinus	137	0.43
Carcharodon carcharias	76	0.24
Carcharhinus brachyurus	75	0.24
Gymnura marmorata	44	0.14
Narcine entemedor	26	0.08
Triakis semifasciata	15	0.05
Squalus acanthias	9	0.03
Dasyatis dipterura	4	0.01
Notorynchus cepedianus	3	0.01
Mobula japanica	1	<0.01
Total	31861	100



Species	cm	s.d.	msmnt	*n*
Alopias vulpinus	158.6	27.6	FL	5
Carcharhinus brachyurus	86.0	---	TL	1
Carcharodon carcharias	166.8	5.0	TL	3
Sphyrna zygaena	119.9	29.1	TL	8

Fig. 6. Sex-specific size frequency distributions of elasmobranchs sampled from the longline fishery at Laguna Manuela. *n* refers to the number of measured individuals upon which size histograms are based, and not necessarily the total number captured. Females are depicted in black, males in white, sex unknown in grey. Dotted lines indicate approximate size at maturity, from Ebert, 2003. In cases where a substantial difference in size at maturity exists between sexes, lines are labeled M (male) or F (female). Dotted lines on the left or right *y* axis indicate that size at maturity is either less than or greater than the scale shown. Tabular data at the bottom provides summary statistics for species where $n < 10$. cm is mean size ± SD (standard deviation) for the specified measurement (msmnt) taken for that species.

4. Discussion

This study provides the first description of the geographical extent, size, gear characteristics, and target species of the artisanal fisheries along the Pacific coast of BC, with an emphasis on profiling artisanal fishery impacts on elasmobranchs. It also reports details for a 26 month study of elasmobranch catch composition at Laguna Manuela fishing camp, providing new information about the relative abundance and size distribution of elasmobranchs taken by artisanal fisheries in Bahia Sebastian Vizcaino (BSV).

4.1. Survey of artisanal camps

The 44 artisanal fishing camps located along the Pacific coast of BC varied considerably in size, effort level, target species, and fishing methods. The total number of artisanal camps is similar to other comparably-sized areas along the Pacific coasts of BC Sur and mainland Mexico (Bizzarro et al., 2009a,c; D. Cartamil unpublished data), but is substantially lower than along the Gulf of California (GOC) coast of BC Sur (Bizzarro et al., 2009b). Nevertheless, the Pacific coast of BC has a larger number of artisanal fishing camps than the GOC coast of BC (Smith et al., 2009), which has received far more attention in regards to declines in elasmobranchs and other large predators (Saenz-Arroyo et al., 2005; Lercari and Chavez, 2007; Montes et al., 2008). Although elasmobranchs are not the primary target in all camps, they were targeted on some level in 68% of the camps, indicating that artisanal fisheries likely have a substantial impact on elasmobranch populations.

This study is a 'snapshot' of the artisanal fishery during a specific period (September 2006 through December 2008). Although the lack of historical data from artisanal fisheries of the Pacific coast of BC precludes comparisons with past status of the fishery, these data provide a base-line for future comparisons. In this regard, the information contained in Table 2 will be useful to determine the magnitude of changes in the number and size of artisanal fishery camps, their effort levels, and species targeted.

4.2. Laguna Manuela

4.2.1. Fishery characteristics

Laguna Manuela proved to be an ideal site for a detailed study of catch composition because of the high volume of elasmobranchs captured, constancy of fishing effort, and the high level of cooperation received from fishers. Although alternative target species were taken, elasmobranchs dominated the total catch at this camp. Gillnet-captured teleosts commanded a higher ex-vessel price than most elasmobranchs, but were not as abundant or reliably caught. Trap fishing for barred sand bass required a relatively low fuel expenditure and minimal at-sea work; however, the low market value for this species, in combination with the long processing time for the small carcasses made it a less attractive activity for many fishers. Conversely, ex-vessel value for trap-caught lobster was substantially higher than for any elasmobranch (Table 3). However, because of the limited season of this fishery, it served only to supplement income from elasmobranch fishing at LM.

4.2.2. Biological data

Twenty-five species of elasmobranchs were recorded at LM, which is lower than what has been reported for other areas along the Pacific coast of Mexico. Bizzarro et al. (2009c) registered 43 species off the GOC coast of Sonora, while Smith et al. (2009) registered 32 species of elasmobranchs along the GOC coast of BC. This comparison likely reflects lower elasmobranch species diversity on the Pacific coast of BC relative to the GOC, although our sample sizes were also generally lower due to differences in magnitude of catch at some GOC camps.

The number of species encountered in the survey did not increase after the first year, and thus likely represents the actual species composition of the region. Nevertheless, additional species would likely be encountered during unusual oceanographic conditions such as El Niño/La Niña events (Lea and Rosenblatt, 2000; Rojo-Vazquez et al., 2008). Smaller size classes (including neonates) of many species may be absent or under-represented due to selectivity for larger animals by fishing gear (Marquez-Farias, 2005), while species with little or no market value (e.g., *Urobatis halleri*, *Raja inornata*, *Platyrhinoidis triseriata*) were often discarded at sea, and thus are also under-represented by catch data.

Female dominated sex ratios were noted for *P. glauca*, *G. galeus*, and *S. californica*. This may indicate sexual segregation, a relatively common phenomenon in elasmobranchs (Sims et al., 2005) which has been reported previously for *P. glauca* (Nakano and Seki, 2003; Mucientes et al., 2009). Skewed sex ratios were reported for *G. galeus* in California waters (Ebert, 2003) and *S. californica* off Sonora, Mexico (Bizzarro et al., 2009c). For elasmobranchs inhabiting the continental shelf, skewed sex ratios may indicate the migration of gravid females into nearshore waters for pupping (Marquez-Farias, 2005). Although this is a possibility, a large percentage of the captured females of these two species were immature. We also detected significant sex-specific differences in size for *C. ventriosum* and *Z. exasperata*. However, these differences were very small and probably lack biological significance. Fig. 4 shows that CPUE values were often high for both blue shark and banded guitarfish, which may indicate that these species are particularly susceptible to fishing activity due to aggregating behavior.

The capture of large numbers of elasmobranchs of a size range suggesting sexual immaturity at LM indicates that the surrounding area (i.e., continental shelf waters of BSV) may serve as important juvenile habitat for numerous elasmobranch species. Many shark species that are pelagic as adults [e.g., *S. zygaena*, *A. vulpinus*, and *C. carcharias* (Buencuerpo et al., 1998; Weng et al., 2007; Cartamil et al., 2010a)] were represented only by small individuals captured over the BSV shelf. In addition, the capture of substantial numbers of *A. vulpinus* extends the known juvenile habitat for this species southward from southern California waters (Cartamil et al., 2010b). Although some gillnet-caught elasmobranchs, such as *R. productus* and *Z. exasperata* were represented primarily by adults, the morphology of these species is such that juveniles often escape entanglement in gillnets (Marquez-Farias, 2005). There are also extensive estuarine and lagoonal systems connected to BSV that are difficult or illegal for fishers to access, and these may serve as juvenile habitat for various species. Elasmobranch nursery areas are critical to the sustainability of adult populations (Branstetter, 1990), and future research should focus on identifying nurseries within the BSV complex.

According to interviews with fishers at LM, this camp has existed for over 35 years and apparently sustained consistently high elasmobranch catch rates. However, fishers in other areas of western BC described declines in elasmobranch abundance over the same period. Several factors likely contribute to these regional differences. The extremely wide continental shelf in BSV provides a correspondingly large habitat (35,678 km^2) that can support a higher biomass of elasmobranchs than the narrower shelf areas found offshore of the northern portion of western BC. The amount of fishing pressure per area is reduced because the surrounding coastline is sparsely populated with few artisanal camps. BSV also has a higher productivity than adjacent coastal areas throughout the year (Lluch-Belda, 2000; Morales-Zarate et al., 2000).

Elasmobranch species composition at LM is similar to that of the other artisanal camps located within BSV, but is not necessarily representative of the entire western coast of BC. Species composition at camps farther north will likely be more similar to the temperate fauna found in southern California. There are also many differences in species composition between the present study and that reported for the Pacific coast of BC Sur by Villavicencio-Garayzar and Abitia-Cardenas (1994). These authors summarized elasmobranch capture data for artisanal fisheries in Laguna San Ignacio and Bahia Magdelena (approximately 200 and 500 km south of LM, respectively) and documented many species that did not occur at LM, including *Heterodontus mexicanus*, *Galeocerdo cuvier*, *Sphyrna mokarran*, and *Myliobatis longirostris*. Similarly, Bizzarro et al. (2007) reported *Rhinoptera steindachneri* near Bahia Magdelena, another species not documented at LM. These observations support the assertion that BSV (or more precisely, Punta Eugenia) delineates the limits of latitudinal distribution for many fish species (Quast, 1968; Horn and Allen, 1978; Horn et al., 2006).

Elasmobranch species composition exhibits some latitudinal trends in comparison with previous studies in the region. For example, species composition in the artisanal fisheries of Sinaloa overlaps very little with the present study, reflecting the tropical coastal fauna of mainland Mexico (Bizzarro et al., 2009a). However, farther north in the upper GOC (i.e., the Sonoran and eastern BC coasts), species composition reported by Bizzarro et al. (2009c) and Smith et al. (2009) shows greater overlap with the present study for the more abundant species, particularly some batoids (such as *R. productus* and *M. californica*) and the mustelid sharks. Perhaps surprisingly, there is less overlap with elasmobranch fauna on the eastern (GOC) coast of BC Sur, although *P. glauca* begins to be a more commonly caught pelagic shark species in this area (Bizzarro et al., 2009b). A preliminary study along the western coast of BC Sur indicates that *P. glauca* and *R. productus* are major components of the artisanal fisheries in this region (Cartamil unpublished data). Bizzarro et al. (2007) observed targeted effort for *R. productus* in a western BC Sur artisanal fishery, as did Salazar-Hermoso and Villavicencio-Garayzar (1999). Thus, the importance of *R. productus* in so many northwestern Mexican artisanal fisheries may indicate a need for increased management consideration.

4.2.3. Carcass discard site survey

The discard site survey proved to be a novel and relatively rapid method of assessing elasmobranch species composition at the LM artisanal fishery. Although we observed differences in the relative proportions of some elasmobranch species as compared to beach surveys, this was expected as the discard site survey represents fishery catch over a substantially longer period (we estimate that carcasses may take 5 y or longer to decompose, but this has not been verified). Only one species (*Mobula japanica*, $n = 1$) was noted in the discard site survey but not beach surveys. BSV is north of the typical range of *M. japanica* (Notarbatolo-di-Sciara, 1988) and it is probable that this specimen was captured during a warm-water year.

This is the first example we are aware of where a carcass discard site was examined to quantify species composition of an ongoing artisanal fishery. This type of analysis is well suited for elasmobranch remains, which contain large and easily identifiable elements that resist decomposition, including jaws, chondrocrania, and spines. Although discard surveys provide little information on sex, seasonality or size distribution of catch (but see Santana-Morales, 2008), they may prove valuable in the future to quickly assess fishery target species. For example, other discard sites were noted at the El Marron artisanal camp (Fig. 1) and at El Barril on the GOC coast (Santana-Morales, unpublished data).

4.3. Management implications

Although no base-line data comparable to the present study exist in western BC, interviews with older fishermen suggest that both the abundance and average size of elasmobranchs have declined significantly in recent decades off the western coast of BC. Many of these declines have been exacerbated by a historic lack of governmental regulation. However, several steps have recently been taken to manage elasmobranch fisheries in Mexican waters. For example, the Mexican National Institute of Fisheries recommended a moratorium on the issuance of new elasmobranch-fishing permits in 1993 (Castillo-Geniz et al., 1998), which was implemented in 1998 (Sosa-Nishizaki et al., 2008). This was followed in 2007 by NOM-029-PESCA-2006 (DOF, 2007), a major piece of legislation that includes regulations specific to artisanal fisheries.

Some general predictions as to how NOM-029 will affect artisanal Pacific BC fishers can be made based upon the present study. Artisanal longline fishers in BC typically deploy up to 500 hooks, while elasmobranch gillnet fishers use multiple gillnets per vessel with mesh sizes of 6–12 cm. NOM-029 guidelines limit artisanal longline fishers to a maximum of 350 hooks, and limit gillnet fishers to the use of one gillnet per vessel with a minimum mesh size of 15 cm. Most longline fishers will not have to dramatically modify fishing practices to conform to NOM-029. Indeed, NOM-029 may be beneficial to artisanal longliners in that it restricts larger commercial longline vessels to waters 20 nautical miles (nm) or more from shore, thus reducing competition with artisanal vessels, which are restricted to only 10 nm from shore. However, gillnet fishers will not only have to greatly reduce the number of gillnets deployed, but the larger mesh size required will result in reduced catch rates of smaller fish. Although NOM-029 may have a negative economic impact on artisanal gillnetters, it represents an important step towards the conservation of elasmobranchs in Mexico. However, very few fishers interviewed in the survey fully understood the NOM-029 guidelines, and less were in compliance with them (e.g., the mandatory completion of logbooks).

The declines in elasmobranch abundance noted in many parts of Mexico (Bonfil, 1997; Castillo-Geniz et al., 1998; Perez-Jimenez et al., 2005) perhaps justify a decrease in elasmobranch-directed fishing effort by artisanal fisheries. Given the higher ex-vessel prices for most teleost and invertebrate species harvested by BC artisanal fishers, a shift in effort to these more sustainable resources may be warranted. Vieira and Tull (2008) determined that the cessation of elasmobranch fishing by artisanal fishers in Indonesia did not result in substantial economic hardship, as fishing could be directed towards alternative species. For example, the Humboldt squid is a major longline bycatch that was viewed as a plague by fishers because it would become hooked before sharks but had no ex-vessel value. This species potentially represents a major alternative target for artisanal fishers (Ehrhardt et al., 1983), and an export market is currently in development (Jara, personal communication).

Further studies are necessary to assist management of artisanal elasmobranch fisheries along the Pacific coast of BC. A continuous monitoring program that provides location-specific catch data is needed to provide realistic estimates of total elasmobranch landings. Biological studies detailing aspects of age and growth, diet, reproduction, and spatial dynamics are required to conduct stock assessments and evaluate sustainability of the most heavily exploited shark and ray species (Gallucci et al., 1996). Socioeconomic surveys would be useful to identify social and cultural drivers of fishing pressure, and monitor changes in the economic conditions of fishers over time (Bunce et al., 2000; Cinner and McClanahan, 2006; Battaglia et al., 2010). In addition, alternative avenues of management should be explored, such as the expansion of a limited-access fishing cooperative system, which has been shown to encourage sustainable stewardship of coastal resources (Young, 2001; Basurto, 2005).

The status of elasmobranchs in Mexico is also of concern to U.S. fisheries management, as elasmobranchs are a shared resource of ecological and economic importance to both countries. Many commercially valuable pelagic shark species, such as the blue, the common thresher, and the mako, have geographical ranges that expose them to fisheries in both the U.S. and Mexico (Hanan et al., 1993; Obrien and Sunada, 1994; Gonzalez, 2008; Escobedo-Olvera, personal communication). Though less understood, the movement patterns of many coastal sharks and batoids likely span the international border as well (Ebert, 2003). Ultimately, binational management strategies will be required that take into account mortality introduced through the activities of fisheries in both countries to calculate acceptable harvest levels.

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