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Stomach content analysis of juvenile, scalloped hammerhead shark *Sphyrna lewini* captured off the coast of Mazatlán, Mexico

Yassir Edén Torres-Rojas · Agustín Hernández-Herrera · Felipe Galván-Magaña · Vanessa Guadalupe Alatorre-Ramírez

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Abstract We quantified the diet of juvenile, scalloped hammerhead shark *Sphyrna lewini* in the area off Mazatlan, Sinaloa, Mexico, to understand their feeding ecology this shark. The prey species of *Sphyrna lewini* were identified and quantified from stomach content analysis. In addition, we determined the variations between genders. During two fishing seasons (2000–2001 and 2001–2002), we analyzed 232 stomachs, of which 85% contained food. The trophic spectrum was composed of three species of cephalopods, six of crustaceans and 19 species of fish from mainly pelagic and benthic habitats. According to the Index of Relative Importance (%IRI), the cephalopod *Loliolopsis diomedeae* with IRI = 18%, fish of the family Carangidae IRI = 25% and family Synodontidae IRI = 19% constituted the main prey in general. The trophic niche width was <0.4, which indicated that *S. lewini* juveniles in this area feed on a wide range of prey items, though they showed a preference for a few prey items.

Keywords Feeding habits · Specialist · Elasmobranchs · Gulf of California · Mexico

Y. E. Torres-Rojas (✉) · A. Hernández-Herrera · F. Galván-Magaña · V. G. Alatorre-Ramírez
Centro Interdisciplinario de Ciencias Marinas (CICIMAR-IPN), Av. IPN s/n Col. Playa Palo de Santa Rita, 23096 La Paz, B.C.S, México
e-mail: yassirtorres@yahoo.com.mx

Introduction

A predator's diet is a combination of availability of resources and foraging strategies (Spitz et al. 2006). It is commonly accepted that sharks are top predators in many marine communities, but until recently, there are just a few studies about their feeding habits and their trophic role in the ecosystem (Wetherbee and Cortes 2004). The diet of a shark determines many aspects of its life, including where it lives, the time of day that it is active, and the depths at which it can be found (Wetherbee and Cortes 2004). Analysis of stomach content allows us to determine its diet composition and understand more about its feeding habits and trophic role in the ecosystem (Cailliet et al. 1986).

Sphyrna lewini is known to feed on a mixture of fish and cephalopods, the proportions of which depend largely on the available food supply (Clarke 1971; Saucedo Barrón et al. 1982; Klimley 1983; Manjarrez Acosta et al. 1983). Duncan and Holland (2006) described Kāne'ohe Bay, Ō'ahu, Hawaii, as a protection area for *S. lewini*. The highest catch rates were observed during July, which indicates that a significant number of juvenile hammerhead sharks remain in Kāne'ohe Bay, Ō'ahu, for up to (or more than) 1 year, aggregating in the deep, turbid areas. Klimley (1983) described the habitat use of *S. lewini* in the Gulf of California based on feeding habits and found that juveniles feed mainly on benthic fish and epipelagic cephalopods, while adults feed on neritic and epipelagic fish and mesopelagic cephalopods. According to the number of prey items found, Klimley (1983) considered *S. lewini* a generalist-opportunistic predator. Some descriptive studies of the diet of *S. lewini* off the coast of Mazatlan, Sinaloa, identified fishes of the family Gerreidae (mojarras), Bothidae (Lefteye flounders), Scombridae (Mackerels, tunas, bonitos), Muraenidae (Moray eels), Mugilidae (Mullets), Urolophidae (Round rays), and crustaceans of the family Penaeidae (penaeid shrimps), but no reference of the contribution of each item to the diet has been made (Saucedo Barrón et al. 1982; Manjarrez Acosta et al. 1983).

The area off the coast of Sinaloa has been described as a foraging ground for pelagic species such as Indo-Pacific sailfish (*Istiophorus platypterus*; Arizmendi-Rodríguez et al. 2006) and common dolphin fish (*Coryphaena hippurus*; Tripp-Valdez 2005). In this zone, shark catch is around 3,000 metric tons year^{-1} (Corro 1997, unpublished manuscript), of which 80% is scalloped hammerhead shark. *S. lewini* arrive in the fishing ground off Mazatlan at the end of autumn (October) and stay there until the end of the winter (March; Manjarrez Acosta et al. 1983). They usually range in length from 45 to 160 cm (Corro 1997, unpublished manuscript). Scalloped hammerhead sharks caught here are mainly juveniles since most are less than 212 cm, the estimated size at maturity (Compagno 1984).

The objectives of this study were to identify and quantify the relative importance of different food types for *S. lewini* and to test the hypothesis that stomach contents of juveniles of *S. lewini* differ by sex and seasonal aggregation of *S. lewini* off the coast of Mazatlan, Sinaloa, Mexico, could be associated with diet composition.

Materials and methods

Mazatlan, Sinaloa, is on the coast of the southern Gulf of California in Mexico (23°13′N; 160°24′38″W; Fig. 1). This is also a transition zone, where the California Current, the North Equatorial Counter Current, and the Mexican Coast Current converge (Kessler 2006).

Sample collection and processing

The artisanal shark fleet operates year round off Mazatlan with small boats, called pangas, 7 m long with 75-hp outboard motors. On each panga, two

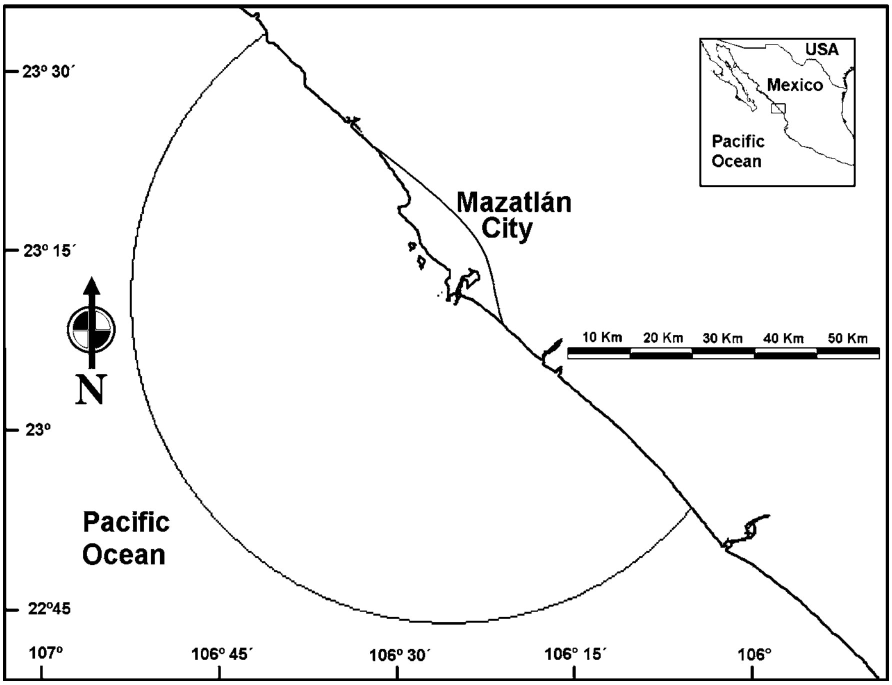

Fig. 1 Map showing the location of the study area. The *semicircle* indicates the area where the fishing fleet operates. It ranges from the coastline to 20 nautical miles seaward

fishermen use a depth longline with 600 hooks as fishing gear using fish of the family Ophichthidae as bait. The longline operates at 90–150-m depth. The fishing operations regularly start at dusk (18:30 h) and finish at dawn (05:30 h; Manjarrez Acosta et al. 1983).

Sharks were sampled monthly from the boats landing at the beach called Playa Sur after they returned from a night of fishing. *S. lewini* was sampled during two fishing seasons: December 2000 to February 2001 (Season I) and November 2001 to January 2002 (Season II). Each shark was identified. The total body length in cm (TL) was measured, and gender was determined. The stomachs were removed and kept frozen until further analysis in the fish laboratory at CICIMAR in La Paz,_Baja California Sur. The differences in gender composition (M:F) of the samples was evaluated using a χ^2 test.

In the laboratory, stomachs were thawed and prey items were identified to the lowest taxonomical level possible. For each stomach, the percentage of fullness was determined according to Stillwell and Kohler (1982), where 0 = empty, 1 = 1–25% of fullness, 2 = 26–50% of fullness, 3 = 51–75% of fullness, and 4 = 76–100% of fullness. To compensate for digested food items, we separated four levels of digestion according to Galván-Magaña (1999) and used different identification keys for each level. Digestion level 1 included recently consumed items identified using Allen and Robertson (1994), Fischer et al. (1995), and Thomson et al. (2000). Digestion level 2 was characterized by food items with little to no skin remaining but still containing muscle, whereas digestion level 3 was characterized by fish skeletons. For levels 2 and 3, we used taxonomic keys based on vertebrae characteristics such as number of vertebrae, position, and form (Clothier 1950). We also compared diet items with complete skeletons of organisms captured in the area.

Digestion level 4 was characterized by hard structures such as fish otoliths, crustacean remains, and cephalopod beaks and identified using Fitch and Brownell (1968), Brusca (1980), Wolff (1984), and Clarke (1986). Because fisherman used Ophichthids as bait, fish of the family Ophichthidae were excluded from the diet analysis when they showed regular forms (as if they were cut by a knife) and when they were recently consumed.

Dietary data analysis

To determine that the number of stomachs collected were enough to represent the diet of *S. lewini*, species accumulation using the Clench function (Eq. 1) was fitted (Jiménez-Valderde and Hortal 2003). First, we randomized (100 times) the observed data matrix of the number of stomachs (unit effort) versus accumulated prey items to obtain an "ideal curve" of species accumulation (EstimateS program). Then we exported the data of the "ideal curve" to Statistica® (StatSoft 2001) to estimate the goodness of fit by the simplex and Quasi-Newton nonlinear estimations using the Clench function. Finally, as an indicator of the quality of the diet, we used the parameters of the Clench function to estimate the slope of the curve (Eq. 2). A slope value less than 0.1 indicates a good representation of the diet (Soberón and Llorente 1993).

$$\mathrm{Sn} = a \times n/(1 + b \times n) \quad (1)$$

$$\text{Slope at } n = a/(1 + b \times n)^2 \quad (2)$$

where a = the rate of increase of new species at the start of the inventory, b = parameter related to the shape of the curve.

Diet data from *S. lewini* were expressed as percentage composition in each stomach by number (%N), percentage composition in each stomach by wet weight (%W), and the frequency of occurrence of each item in the diet (%F). The index of relative importance (IRI; Eq. 3, Pinkas et al. 1971) measures the importance of each prey item relative to other prey items by taking into account both the weight and number of each prey item and the frequency at which each occurs in the diet. IRI was calculated for prey items using the equations

$$\mathrm{IRI} = (\%N + \%W)\%F \quad (3)$$

where %N = percentage of a certain food organism, %W = percentage of food weight, %F = percentage of frequency of occurrence.

The values of IRI are reported as a percentage (Eq. 4, Cortés 1997)

$$\%\mathrm{IRI} = \frac{100\mathrm{IRI}_i}{\sum_{i=1}^{n} \mathrm{IRI}_i} \quad (4)$$

where n = total number of food categories considered at a given taxonomic level.

To determine if there are differences in the diet between genders, the similarities were analyzed using permutation–randomization methods in the similarity matrix (ANOSIM, PRIMER 6 v. 6.1.6). The global rank similarity R ($0 \leq R \leq 1$) is a useful comparative measure of the degree of separation. When R is about zero, Ho is true, i.e., there is no separation between groups (Clarke and Warwick 2001).

To evaluate the trophic-width niche of *S. lewini*, we used the Levin standardized index "Bi" (Eq. 5; Krebs 1999). Data were pooled and separated by gender. Index values range from 0 to 1, with low values (<0.6) indicating diet dominated by few prey items (specialist predator) and higher values (>0.6) indicating generalist diets (Labropoulou and Eleftheriou 1997).

$$\mathrm{Bi} = \frac{1}{n-1\left\{\left(1/\sum P_{ij}^2\right)-1\right)\right\}} \tag{5}$$

where Bi = niche breadth, $\sum P_{ij}^2$ = Proportion of jth prey item in predator i's diet, n = total number of prey species.

Results

We collected 232 stomachs, 73 during Season I (2000–2001) and 159 during Season II (2001–2002). Juvenile sharks ranged in size from 48 to 165 cm TL with a mean size of 89.8 cm (14.8 SD). The gender ratio did not significantly differ from 1:1 (M:F; χ^2; $P > 0.05$). The analysis of similarities of diet composition by gender (ANOSIM, PRIMER 6 v. 6.1.6) showed no differences ($R = 0.002$, $P = 0.001$). We therefore combined the genders for the subsequent analyses. Of the stomachs collected, 198 (85%) contained food and 34 (15%) were empty. In both seasons, the largest number of samples were collected during December (160 with food, 33 empty), followed by January (20 with food, 0 empty), November (12 with food, 1 empty), and February (6 with food, 0 empty; Fig. 2).

In the stomach-fullness analysis, we found 48% in category 1, 33% in category 2, 12% in category 3, and 7% in category 4 (Fig. 3a). For the level of digestion, 2% of prey items were at level 1, 10% at level 2, 25% at level 3, and 63% at level 4 (Fig. 3b).

The prey species accumulation curve showed enough samples to characterize the diet of *S. lewini*

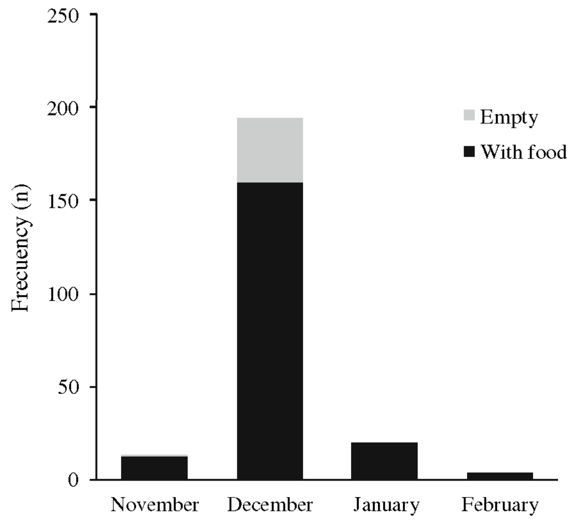

Fig. 2 Sample size by month in Mazatlan, Sinaloa (2000–2002)

($S_{obs} = 28$; $R^2 = 0.999$, $a/b = 33.03$, slope at 28 = 0.027; Fig. 4). The trophic spectrum (Table 1) was composed of 3 cephalopod species belonging to 3 families, 6 species of crustaceans from 3 families, and 19 species of fish from 14 families. According to the percentage of the index of relative importance (%IRI), *S. lewini* feed mainly on fish of the family Carangidae (25%), Synodonthidae (19%), the cephalopod *Loliolopsis diomedeae* (18%) and Crustacea *Pleuroncodes planipes* (6%). The diet breadth value was less than 0.4 (Table 1).

Discussion

The fishing season of the juvenile scalloped hammerhead shark off the coast of Mazatlan is short and well-defined. The presence or absence of *S. lewini* seems to be associated with seasonal migrations along the northwest Mexican coast (Corro 1997, unpublished manuscript). Off Mazatlan, the diet of *S. lewini* included prey from pelagic and benthic habitats. Klimley (1983) reported scalloped hammerhead juveniles feeding mainly on benthic fish and pelagic cephalopods in the Gulf of California. According to Manjarrez Acosta et al. (1983) and Saucedo Barrón et al. (1982), off Mazatlan, Sinaloa, *S. lewini* have similar preferences for functional groups (benthic fish and pelagic cephalopods) but are different species composition. Our results indicate

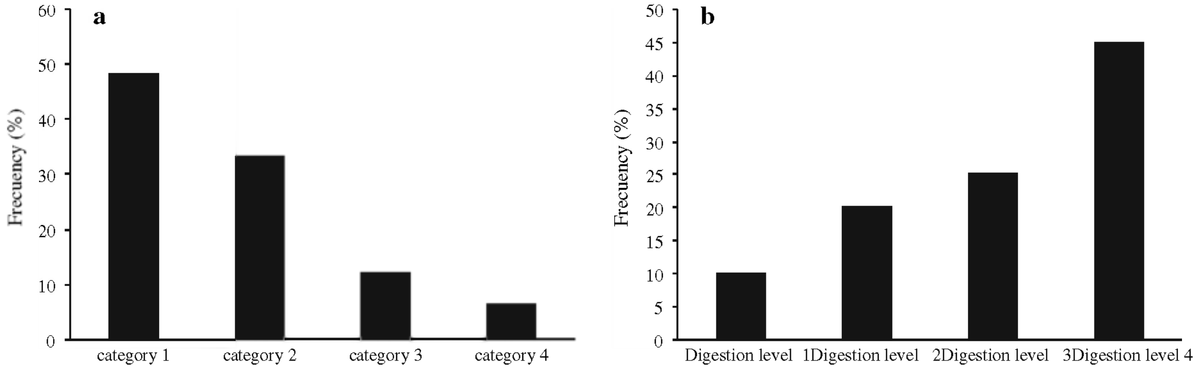

Fig. 3 Percentage of fullness (**a**) and digestion level (**b**) observed in the stomachs of *S. lewini* from Mazatlan, Sinaloa

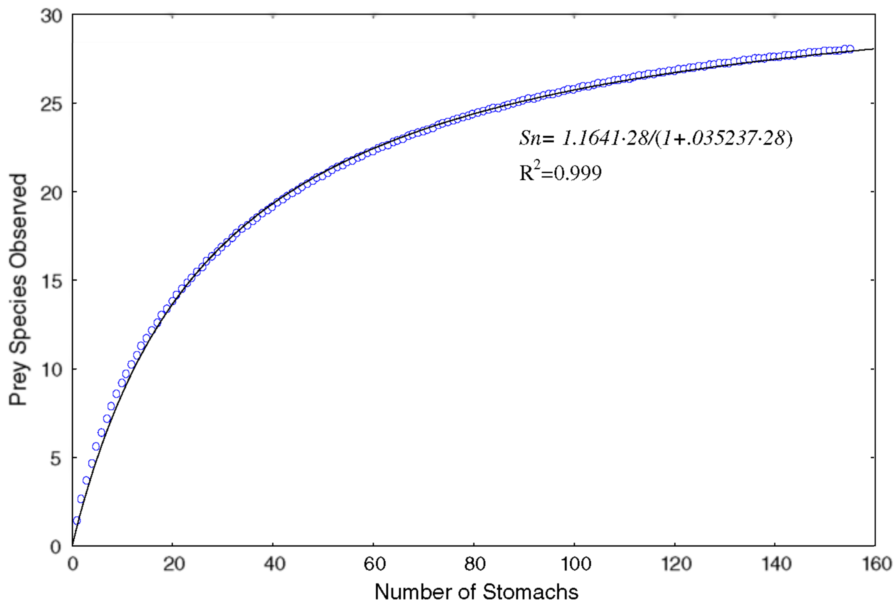

Fig. 4 Prey species accumulation curve fitted by Clench function (*dots*, observed data; *solid line*, expected data)

that independent of the location, juveniles of *S. lewini* could maintain a similar trophic niche.

Cortés (1997) mentioned that the analysis of stomach contents from shark catch with longlines can result in a large number of empty stomachs; however, we found a large number of stomachs with food even though they were obtained from the artisanal longline-fishing fleet from Mazatlan. This is because the fishermen check the fishing gear for catch on a daily basis.

The prey species in the stomachs were at different levels of digestion indicating that *S. lewini* feed continuously during the day. According to gastric evacuation rates measured in *S. lewini*, the fish digest food within 5–22 h (Bush and Holland 2002). However, some authors (Springer 1960; Clarke 1971; Klimley 1983; Klimley et al. 1988; Duncan and Holland 2006) have mentioned that *S. lewini* is more active at night, which is corroborated by the habitat and behavior of the main prey consumed by this shark in the southeastern Gulf of California. The cephalopod *Loliolopsis diomedeae* is a neritic cephalopod that is probably more active during the night when it is caught by shrimp trawlers close to Mazatlan. However, there is no information on behavior on this cephalopod species. A similar species from the same family (*Loligo opalescens*) feeds more during the daylight and less during the night (Recksiek and Frey 1978). The synodontids have a preference to prey on small fish during the night in the benthic area of soft bottoms (Fischer et al. 1995).

Table 1 Index of Relative Importance (IRI) and niche breadth value (Bi)

Prey item			*N*	%*N*	*G*	%*G*	*F*	%*F*	IRI	%IRI
Cephalopoda	Enoploteuthidae	*Abraliopsis affinis*	19	4.703	0.110	0.004	7	3.5354	16.6390	0.9556
	Loliginidae	*Loliolopsis diomedeae*	**77**	**19.059**	**1.430**	**0.046**	**32**	**16.1616**	**308.7663**	**17.7320**
	Argonautidae	*Argonauta* spp.	3	0.743	0.030	0.001	1	0.5051	0.3755	0.0216
Crustacea	Squillidae	*Squilla mantoidea*	5	1.238	8.100	0.258	3	1.5152	2.2658	0.1301
	Sicyoniidae	*Sicyona disdorsalis*	2	0.495	2.870	0.091	2	1.0101	0.5923	0.0340
	Peneidae	*Farfantepenaeus californiensis*	3	0.743	8.000	0.255	2	1.0101	1.0072	0.0578
		Trachypenaeus spp.	2	0.495	23.000	0.732	2	1.0101	1.2394	0.0712
		Trachypenaeus pacifica	12	2.970	23.050	0.734	6	3.0303	11.2238	0.6446
		Pleuroncodes planipes	**30**	**7.426**	**86.000**	**2.737**	**19**	**9.5960**	**97.5202**	**5.6004**
	Rest of crustacean	Crustaceans	0	0.000	0.460	0.015	1	0.5051	0.0074	0.0004
Teleostei	Muraenidae	Muraenids	10	2.475	89.630	2.852	6	3.0303	16.1444	0.9272
	Ophichthidae	*Ophichthus triserialis*	2	0.495	158.000	5.028	1	0.5051	2.7895	0.1602
	Clupeidae	*Sardinop caeruleus*	8	1.980	122.960	3.913	4	2.0202	11.9057	0.6837
	Engraulidae	*Anchoa* spp.	2	0.495	8.400	0.267	1	0.5051	0.3850	0.0221
	Synodontidae	Synodontids	**68**	**16.832**	**213.440**	**6.793**	**27**	**13.6364**	**322.1488**	**18.5006**
		Synodus scituliceps	18	4.455	138.450	4.406	9	4.5455	40.2796	2.3132
	Carangidae	Carangids	**49**	**12.129**	**459.290**	**14.617**	**32**	**16.1616**	**432.2467**	**24.8233**
		Decapterus spp.	18	4.455	230.860	7.347	11	5.5556	65.5688	3.7655
		Selar crumenophthalmus	18	4.455	247.920	7.890	8	4.0404	49.8800	2.8645
	Sciaenidae	Sciaenids	9	2.228	54.540	1.736	5	2.5253	10.0086	0.5748
	Mugilidae	*Mugil cephalus*	8	1.980	245.910	7.826	8	4.0404	39.6206	2.2754
	Paralichthyidae	*Etropus crossotus*	4	0.990	51.490	1.639	3	1.5152	3.9829	0.2287
	Bothidae	Bothids	12	2.970	149.840	4.769	8	4.0404	31.2680	1.7957
	Labridae	Labrids	7	1.733	63.720	2.028	5	2.5253	9.4962	0.5454
	Scombridae	*Auxis* spp.	5	1.238	97.170	3.092	2	1.0101	4.3737	0.2512
		Euthynnus lineatus	5	1.238	111.610	3.552	3	1.5152	7.2569	0.4168
		Thunnus spp.	1	0.248	3.750	0.119	1	0.5051	0.1853	0.0106
	Stromateidae	*Peprilus snyderi*	4	0.990	44.490	1.416	3	1.5152	3.6454	0.2093
	Balistidae	*Balistes polylepis*	3	0.743	134.210	4.271	2	1.0101	5.0643	0.2908
	Unidentified teleosts	Fishes	0	0.000	363.530	11.569	42	21.2121	245.4043	14.0932
		Total	**404**	**100**	**3142.26**	**100**	**198**[a]	**129.2929**	**1741.2918**	**100**
		Bi values	**0.33**							

The values in bold represent the four most important prey items in the diet of the shark

[a] Number of stomachs with content

Bush (2003) mentions that hammerhead shark neonates in Kāne'ohe Bay, Ō'ahu, remain in turbid areas for protection during the day and move at night to reef areas to feed. Possibly *S. lewini* in the southeastern Gulf of California make similar daily migrations, moving from protected and shallow waters to deep waters to feed on cephalopods.

Sphyrna lewini captures a relatively large number of prey items (28 species), confirming that the ocean off Mazatlan, Sinaloa, is a good foraging ground for the juvenile *S. lewini*, as was described for other pelagic species in the same area, such as sailfish (Arizmendi-Rodríguez et al. 2006) and dolphinfish (Tripp-Valdez 2005). Juvenile *S. lewini* prefer specific prey items that reduce the niche-breadth index to low values and can therefore be classified as a specialist (Bush 2003; Aguilar-Castro 2003). Bush (2003) suggests that the juvenile *S. lewini* off Ō'ahu, Hawaii, are generalist feeders and that Kāne'ohe Bay appears to be a suboptimum foraging habitat.

In addition, Klimley (1983) classified *S. lewini* from the Gulf of California area as a generalist-opportunist predator because this species consumes a great number of prey species and because it is encountered in several habitats. We believe that the low values found of trophic-width niche in our research (Bi = 0.4) could be related to an opportunistic feeding behavior of *S. lewini*, which is probably associated with the abundance and availability of the different prey items. However, this still needs analysis relating stomach contents and abundances of prey species off the coast of Mazatlan. We found no differences in diet composition of males and females. Therefore, we suggest that all juvenile hammerhead sharks move and feed in the same habitat. This behavior has previously been observed in juveniles in the Bahia de La Paz (Aguilar-Castro 2003; Pittenger 1984). However, Klimley (1983) reported gender segregation during the night among adults of *S. lewini* in the Gulf of California, probably associated with feeding behavior and suggesting an ontogenic shift in the diet.

The international Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) recognizes the vulnerability of sharks to detrimental long-term commercial fishing. It also emphasizes the need for international coordination in the management of both the direct and indirect catch of sharks given their wide-ranging distribution, long migrations, and habitat requirement (FAO 1999). This study on the stomach contents allowed us to identify Mazatlan as a possible feeding area, where juveniles of both sexes feed on similar prey. We also note that even though the number of preys is apparently high, the diet is restricted to only some of them. We do not know if this is caused by preferences for particular prey or because *S. lewini* is opportunistic. To infer food preferences and quantify energetic contributions, future studies should consider aspects such as prey abundance in the foraging zone and the weight and caloric content of each. What is true is that the coast of Mazatlan is an area where *S. lewini* return each year and there is a fishery exploiting juveniles. It is important that any management strategy or resource conservation should consider these results to infer the behavior and interaction of *S. lewini* with other species.

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