Feeding habits of the scalloped hammerhead shark, *Sphyrna lewini*, in Mazatlán waters, southern Gulf of California, Mexico

by

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ABSTRACT. - We studied the contents of 556 stomachs of scalloped hammerhead sharks, ranging from 48 to 160 cm TL, caught from off Mazatlán, southern Gulf of California, between October 2000 and April 2005: 449 stomachs had food contents, and 87 prey species were identified. The Index of Relative Importance (IRI) showed that the diet is mainly constituted of dart squids *Loliolopsis diomedeae* (IRI = 49%) and bony fishes: Carangidae (IRI = 26 %) and Gerreidae (IRI = 7%). According to the values of niche breadth (0.14) and diversity index (3.49), *Sphyrna lewini* should be a generalist and opportunistic predator, with unselective feeding behaviour: the type and amount of the food consumed are determined by its abundance and availability. The Morisita-Horn indices indicated high niche trophic overlap between sexes ($C\lambda = 0.95$), and low overlap between size classes ($C\lambda = 0.50$).

RÉSUMÉ. - Régime alimentaire du requin-marteau halicorne, *Sphyrna lewini*, dans les eaux de Mazatlan, golfe de Californie méridional, Mexique.

Nous avons étudié les contenus de 556 estomacs de requins-marteaux halicornes de 48 à 160 cm LT, capturés au large de Mazatlán, golfe de Californie méridional, entre octobre 2000 et avril 2005; 449 estomacs contenaient de la nourriture et 87 espèces-proies ont été identifiées. L'indice d'abondance relative (IRI) montre que le régime alimentaire est principalement constitué de calmars-fléchettes *Loliolopsis diomedeae* (IRI = 49%), et de poissons osseux : Carangidae (IRI = 26%) et Gerreidae (IRI = 7%). Selon les valeurs de la largeur de niche (0,14) et de l'indice de diversité (3.49), *Sphyrna lewini* serait un prédateur généraliste et opportuniste avec un comportement alimentaire non-sélectif : le type et la quantité de nourriture consommée étant déterminés par son abondance et sa disponibilité. Les indices de Morisita-Horn montrent un grand chevauchement des niveaux trophiques entre les deux sexes ($C\lambda = 0{,}95$), et un faible chevauchement entre les classes de tailles ($C\lambda = 0{,}50$).

Key words. - Sphyrnidae - *Sphyrna lewini* - Scalloped hammerhead shark - ISE - Gulf of California - Feeding habits.

The scalloped hammerhead shark *Sphyrna lewini* has circumtropical distribution, which includes the eastern Pacific Ocean from southern California to Ecuador. This species is an important resource for traditional and oceanic fisheries (Compagno *et al.*, 1995), representing approximately 50% of the shark catch obtained off the coast of Sinaloa, Mexico. *Sphyrna lewini* apparently changes its ontogenetic habitat: small sharks live in coastal waters and feed on benthonic and neritic fish, whereas the adults live in oceanic waters and feed on neritic and epipelagic fish, and cephalopods (Klimley, 1983).

Few studies on the biology of *S. lewini* have been done, so the main objective of this work was to analyze the feeding habits of the scalloped hammerhead shark off Mazatlán, Sinaloa, Mexico, and to compare the diet among sex and size groups.

MATERIAL AND METHODS

Sharks were obtained from the long line traditional fishing fleet operating in the fishing zone "Playa Sur" off Mazatlán, Sinaloa (Fig. 1), between October 2000 and April 2004. Scalloped hammerhead sharks were landed at the wharf, where they were identified.

No adult were obtained, but only juveniles with TL < 180 cm. They were sorted according to the two size classes defined by Soria- Quiroz (2004): immature sharks with TL < 100 cm and premature sharks with TL ranging from 100 to 180 cm.

The following data were recorded for each shark: total length (cm), weight (kg), sex, and maturity stage according to external characteristics (Soria-Quiroz, 2004). The stomachs were removed and frozen.

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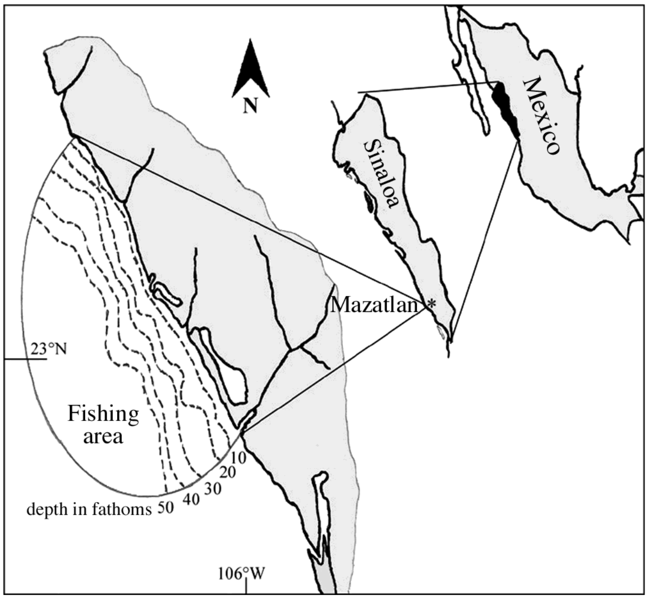

Figure 1. - Fishing area of the artisanal fishing fleet off Mazatlán, Mexico, where the specimens of *Sphyrna lewini* were caught. *[Zone de pêche de la flotte artisanale au large de Mazatlán, Mexique, où les spécimens de* Sphyrna lewini *ont été capturés.]*

Prey species were identified to the lowest taxonomic level possible, and separated for qualitative analysis. The following keys were used to identify the fishes: Clothier (1950), Monod (1968), Miller and Lea (1972), Miller and Jorgensen (1973), Allen and Robertson (1994), Fischer *et al.* (1995), and Thomson *et al.* (2000). Cephalopods were identified by their beaks according to Clarke (1962, 1986), Iverson and Pinkas (1971), and Wolff (1982, 1984). Crustaceans were identified using the keys in Fischer *et al.* (1995).

For analysis of prey composition in the diet, the index of relative importance (IRI) was used with the modification proposed by Stevens *et al.* (1982), who replaced the volume of food used by Pinkas *et al.* (1971) by the weight. Thus, for a particular category of prey, the value of the IRI_P is calculated as follows:

$$IRI_P = (\%N+\%W)\ \%F$$

where %N is the percentage of numerical composition, %W is the percentage in weight, and %F is the percentage of frequency of occurrence.

The Shannon-Wiener diversity index was used to calculate diversity (Pielou, 1975):

$$H' = -\sum (p_i)\ln(p_i)$$

where p_i is the proportion of each prey species.

Trophic niche breadth was estimated using Levin's (1968) standardized index, which takes values from 0 to 1:

$$B_i = 1/n - 1\{(1/\sum jP_{ij}^2) - 1\}$$

where B_i is Levin's index for predator i; P_{ij} is the proportion of the diet of predator i given by prey j, and n is the number of prey categories.

For our analysis, a value of B_i less than 0.6 was chosen to represent a specialist diet, which means that predator uses few prey resources and prefers specific prey, while a value over 0.6 was chosen to represent a generalist diet, which means that predator uses many resources without notable preference.

The Morisita-Horn index (Smith and Zaret, 1982) was used to evaluate dietary overlap between size classes and between sexes. This index ranges from 0, when the diets are completely different, to 1 when the diets are the same. Values exceeding 0.6 are considered to overlap significantly:

$$C\lambda = 2\frac{\sum_{i=1}^{n}(P_{xi}P_{yi})}{(\sum_{i=1}^{n}P_{xi}^2 + \sum_{i=1}^{n}P_{yi}^2)}$$

where $C\lambda$ is the overlap index between predator x and predator y; P_{xi} is the proportion of prey i of the total prey used by predator x; P_{yi} is the proportion of prey i of the total prey used by predator y, and n is the number total of prey.

RESULTS

A total of 556 specimens of *Sphyrna lewini* were examined: 300 males and 256 females. Total lengths ranged from 48 to 160 cm, with a polymodal frequency distribution. Small sharks with TL <100 cm were more frequent (Fig. 2).

Out of the 556 stomachs collected, 107 were empty (19%) and 449 contained food (81%). A total of 87 prey species were identified: 10 crustaceans, 5 cephalopods, and 72 fishes (Tab. I). For both size classes combined, the index of relative importance for the dart squid *Loliolopsis*

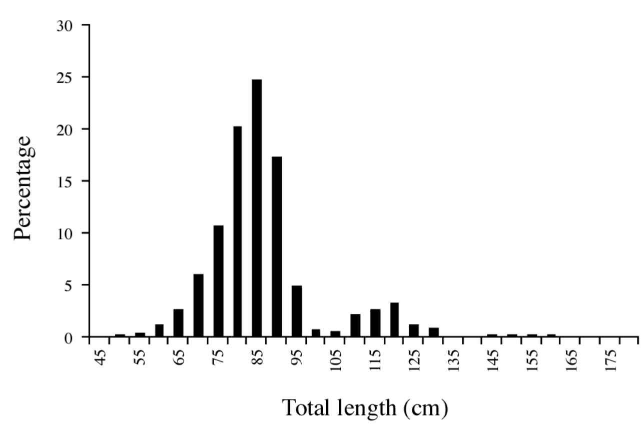

Figure 2. - Total length frequency distribution of *Sphyrna lewini* from off Mazatlán, Mexico. *[Distribution de la fréquence de taille des spécimens de* Sphyrna lewini *pris au large de Mazatlán, Mexique.]*

Table I. - Prey species found in the stomachs of *Sphyrna lewini* juveniles from off Mazatlán, Sinaloa, Mexico; results expressed in absolute numbers, in numerical (N), and gravimetric (G) percentages, in frequency of occurence (F), and as index of relative importance (IRI). *[Proies trouvées dans les estomacs de jeunes* Sphyrna lewini *pris au large de Mazatlán, Sinaloa, Mexique; résultats exprimés en nombres absolus, en pourcentages numériques (N) et gravimétriques (G), en fréquences de présence (F) et en indices d'abondance relative (IRI).]*

Prey item			N	%N	G	%G	F	%F	IRI	%IRI
MOLLUSCA Cephalopoda	Enoploteuthidae	*Abraliopsis affinis*	56	8.235	1.090	0.015	23	5.180	42.740	3.826
	Ommastrephidae	*Dosidicus gigas*	4	0.588	0.040	0.001	4	0.901	0.530	0.047
		Sthenoteuthis oualaniensis	2	0.294	0.020	0.000	2	0.450	0.133	0.012
	Loliginidae	*Loliopsis diomedeae*	145	21.324	52.480	0.739	95	21.396	472.050	42.253
	Argonautidae	*Argonauta* spp.	3	0.441	0.030	0.000	1	0.225	0.099	0.009
	Subtotal Mollusca Cephalopoda		210	30.882	53.660	0.8	-	-	515.552	46.1
CRUSTACEA Decapoda	Squillidae	*Squilla mantoidea*	7	1.029	31.760	0.447	7	1.577	2.328	0.208
	Sicyoniidae	*Sicyonia disdorsalis*	3	0.441	8.670	0.122	3	0.676	0.381	0.034
	Processidae	*Processa peruviana*	1	0.147	2.070	0.029	1	0.225	0.040	0.004
	Penaeidae	Peneids	11	1.618	20.340	0.286	11	2.477	4.717	0.422
		Farfantepenaeus californiensis	6	0.882	60.170	0.847	6	1.351	2.337	0.209
		Litopenaeus stylirostris	1	0.147	9.180	0.129	1	0.225	0.062	0.006
		Penaeus spp.	1	0.147	35.300	0.497	1	0.225	0.145	0.013
		Trachypenaeus spp.	2	0.294	23.000	0.324	2	0.450	0.278	0.025
		Trachypenaeus pacifica	8	1.176	46.310	0.652	7	1.577	2.882	0.258
		Xiphopenaeus riveti	1	0.147	2.170	0.031	1	0.225	0.040	0.004
	Galatheidae	*Pleuroncodes planipes*	28	4.118	97.670	1.375	28	6.306	34.636	3.100
	Portunidae	*Callinectes bellicosus*	1	0.147	1.760	0.025	1	0.225	0.039	0.003
	Subtotal Crustacea Decapoda		70	10.294	338.400	4.8			47.884	4.3
TELEOSTEI Anguilliformes	Muraenidae	Muraenids	14	2.059	117.200	1.649	14	3.153	11.693	1.047
	Ophichthidae	*Ophichthus* spp.	2	0.294	19.690	0.277	2	0.450	0.257	0.023
		Ophichthus triserialis	2	0.294	158.000	2.224	1	0.225	0.567	0.051
Clupeiformes	Clupeidae	Clupeids	4	0.588	42.390	0.597	4	0.901	1.067	0.096
		Sardinops spp.	1	0.147	16.640	0.234	1	0.225	0.086	0.008
		Sardinops caeruleus	6	0.882	156.090	2.197	5	1.126	3.467	0.310
		Opisthonema spp.	1	0.147	7.270	0.102	1	0.225	0.056	0.005
	Engraulidae	Engraulids	9	1.324	14.550	0.205	8	1.802	2.754	0.246
		Anchoa spp.	4	0.588	13.470	0.190	4	0.901	0.701	0.063
Aulopiformes	Synodontidae	Synodontids	2	0.294	90.000	1.267	2	0.450	0.703	0.063
		Synodus spp.	1	0.147	9.740	0.137	1	0.225	0.064	0.006
		Synodus scituliceps	11	1.618	138.450	1.949	9	2.027	7.229	0.647
Ophidiiformes	Ophidiidae	Ophidiids	1	0.147	0.500	0.007	1	0.225	0.035	0.003
		Lepophidium spp.	2	0.294	20.770	0.292	2	0.450	0.264	0.024
		Lepophidium pardale	1	0.147	13.130	0.185	1	0.225	0.075	0.007
		Lepophidium prorates	3	0.441	72.550	1.021	3	0.676	0.988	0.088
Beloniformes	Hemiramphidae	*Hyporhamphus unifasciatus*	2	0.294	34.380	0.484	2	0.450	0.350	0.031
Beryciformes	Holocentridae	*Myripristis* spp.	1	0.147	2.690	0.038	1	0.225	0.042	0.004
Perciformes	Centropomidae	Centropomids	1	0.147	19.040	0.268	1	0.225	0.093	0.008
	Serranidae	Serranids	3	0.441	33.190	0.467	3	0.676	0.614	0.055
		Diplectrum spp.	1	0.147	13.660	0.192	1	0.225	0.076	0.007
		Diplectrum labarum	1	0.147	50.010	0.704	1	0.225	0.192	0.017
		Diplectrum pacificum	2	0.294	79.470	1.118	2	0.450	0.636	0.057
		Hemanthias signifer	4	0.588	93.640	1.318	4	0.901	1.717	0.154
	Malacantidae	*Caulolatilus affinis*	1	0.147	14.330	0.202	1	0.225	0.079	0.007
	Carangidae	Carangids	68	10.000	677.050	9.529	58	13.063	255.103	22.834
		Caranx spp.	7	1.029	99.750	1.404	7	1.577	3.836	0.343
		Caranx caballus	2	0.294	112.320	1.581	2	0.450	0.845	0.076
		Caranx caninus	1	0.147	24.030	0.338	1	0.225	0.109	0.010
		Caranx sexfasciatus	2	0.294	53.470	0.753	2	0.450	0.471	0.042
		Chloroscombrus orqueta	12	1.765	203.100	2.858	11	2.477	11.454	1.025
		Decapterus spp.	12	1.765	230.860	3.249	11	2.477	12.421	1.112
		Selar crumenophtalmus	11	1.618	247.920	3.489	9	2.027	10.352	0.927
		Selene peruviana	3	0.441	82.500	1.161	3	0.676	1.083	0.097
	Coryphaenidae	*Coryphaena* spp.	2	0.294	99.290	1.397	1	0.225	0.381	0.034
	Gerreidae	Gerreids	36	5.294	376.750	5.302	31	6.982	73.984	6.622
		Eucinostomus spp.	11	1.618	162.890	2.292	11	2.477	9.687	0.867
		Eucinostomus argenteus	8	1.176	340.580	4.793	8	1.802	10.756	0.963
		Eucinostomus currani	1	0.147	37.750	0.531	1	0.225	0.153	0.014
		Eucinostomus gracilis	5	0.735	172.930	2.434	5	1.126	3.569	0.319

Table I. - Continued. *[Suite.]*

Prey item			N	%N	G	%G	F	%F	IRI	%IRI
Perciformes	Sciaenidae	Sciaenids	30	4.412	387.920	5.459	29	6.532	64.474	5.771
		Bairdiella spp.	1	0.147	22.180	0.312	1	0.225	0.103	0.009
		Bairdiella armata	1	0.147	49.730	0.700	1	0.225	0.191	0.017
		Cynoscion spp.	1	0.147	59.97	0.844	1.00	0.23	0.223	0.020
		Cynoscion parvipinnis	1	0.147	2.280	0.032	1	0.225	0.040	0.004
		Cynoscion reticulatus	1	0.147	44.360	0.624	1	0.225	0.174	0.016
		Odontoscion spp.	1	0.147	59.970	0.844	1	0.225	0.223	0.020
		Odontoscion xanthops	8	1.176	190.050	2.675	7	1.577	6.072	0.543
	Mullidae	*Pseudupeneus grandisquamis*	2	0.294	74.620	1.050	2	0.450	0.606	0.054
	Mugilidae	Mugilids	1	0.147	13.680	0.193	1	0.225	0.076	0.007
		Mugil spp.	5	0.735	72.640	1.022	5	1.126	1.979	0.177
		Mugil cephalus	9	1.324	253.670	3.570	9	2.027	9.919	0.888
		Mugil curema	5	0.735	172.100	2.422	3	0.676	2.133	0.191
	Labridae	Labrids	6	0.882	71.150	1.001	6	1.351	2.546	0.228
	Sphyraenidae	*Sphyraena lucasana*	1	0.147	28.160	0.396	1	0.225	0.122	0.011
	Scombridae	Scombrids	5	0.735	156.040	2.196	5	1.126	3.301	0.295
		Auxis spp.	13	1.912	189.170	2.662	12	2.703	12.362	1.107
		Euthynnus lineatus	4	0.588	126.600	1.782	4	0.901	2.135	0.191
		Scomber japonicus	2	0.294	37.890	0.533	2	0.450	0.373	0.033
		Thunnus spp.	1	0.147	3.750	0.053	1	0.225	0.045	0.004
	Stromateidae	*Peprilus snyderi*	3	0.441	44.490	0.626	3	0.676	0.721	0.065
Pleuronectiformes	Paralichthyidae	*Paralichthyids*	8	1.176	18.010	0.253	7	1.577	2.254	0.202
		Etropus crossotus	3	0.441	51.490	0.725	3	0.676	0.788	0.071
	Bothidae	Bothids	11	1.618	194.160	2.733	11	2.477	10.778	0.965
	Pleuronectidae	Pleuronectids	6	0.882	41.760	0.588	6	1.351	1.987	0.178
	Achiridae	Achirids	4	0.588	14.410	0.203	3	0.676	0.534	0.048
		Achirus mazatlanus	3	0.441	20.990	0.295	3	0.676	0.498	0.045
	Cynoglossidae	*Symphurus elongatus*	1	0.147	25.900	0.365	1	0.225	0.115	0.010
Tetraodontiformes	Balistidae	*Balistes polylepis*	2	0.294	134.210	1.889	2	0.450	0.983	0.088
	Subtotal Osteichthyes		400	58.823	6713.390	94.5	-	-	553.766	49.6
TOTAL			680	100	7105	100	-	-	1117	100

diomedeae was highest (49%), followed by fishes of the families Carangidae (26%), Gerreidae (7%), and Sciaenidae (6%).

Food was found in the stomach of 211 females, out of the 256 obtained. The diet composition consisted of 59 species: 6 crustaceans, 3 cephalopods, and 50 species of fish, as well as unidentified species of the families Paralichthyidae, Carangidae, Penaeidae, Labridae, Gerreidae, and Muraenidae. For females of both size classes combined, the IRI of the dart squid *Loliolopsis diomedeae* was the highest (40%), followed by fish of the family Carangidae (27%), and the pelagic red crab *Pleuroncodes planipes* (4%).

Food was found in the stomach of 238 males, out of the 300 obtained. The diet composition consisted of 73 species: 11 crustaceans, 4 cephalopods, and 58 fishes, as well as unidentified species of the families Carangidae, Muraenidae, and Paralichthyidae. For males of both size classes combined, the IRI of *Loliolopsis diomedeae* was the highest (48%), followed by fishes of the family Carangidae (21%) and Gerreidae (11%).

Immature sharks (TL <100 cm) fed mainly on *Loliolopsis diomedeae* (IRI 46.7%), carangid fishes (17.9%), gerreid fishes (8.9%), *Pleuroncodes planipes* (2.9%), and *Abraliopsis affinis* (0.7%). Premature sharks (TL 100-180 cm) fed on *Loliolopsis diomedeae* (IRI 8.5%), carangid fishes (30.6%), *Pleuroncodes planipes* (1.5%), and *Abraliopsis affinis* (33.9%) (Fig. 3).

The diet of *S. lewini* in Mazatlán waters had high species diversity (H' = 3.42), but niche breadth was low (*Bi* = 0.15). The diets of males (H' = 3.39, *Bi* = 0.17) and females (H' = 3.27, *Bi* = 0.20) were similar.

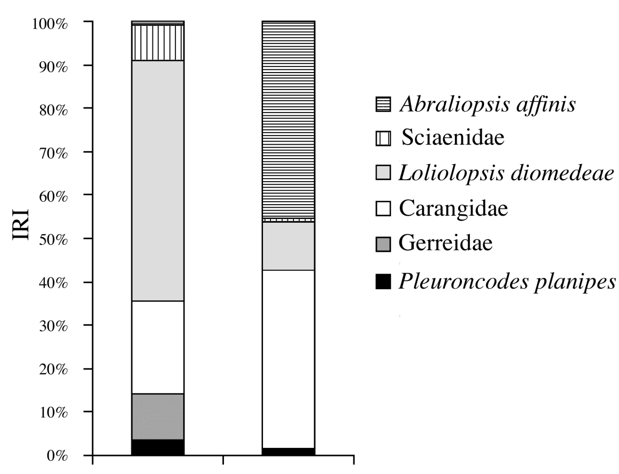

Figure 3. - Index of Relative Importance (IRI) by sizes classes of *Sphyrna lewini* from off Mazatlán, Mexico. *[Indice d'abondance relative (IRI) par classe de taille des spécimens de* Sphyrna lewini *capturés au large de Mazatlán, Mexique.]*

The Morisita-Horn index of overlap between sexes was high for both size classes combined ($C\lambda$ = 0.95), but low overlap was found for the diet between size classes ($C\lambda$ = 0.50).

DISCUSSION

Although sampling effort spanned the whole year, the traditional fishing fleet of Mazatlán catches the majority of *Sphyrna lewini* from October to March. According to the size ranges and external characteristics observed, all captured sharks were juveniles. Our study revealed lengths close to those observed by Klimley (1983), who found juveniles of less than 87.5 cm in the bay of La Paz in the Gulf of California, and by Torres-Huerta (1999), who reported juveniles from 45.4 to 186 cm TL caught by gillnet in the same area. The modal groups in total length frequency distribution were similar to those observed by Soria-Quiroz (2004), but in this study sharks of less than 100 cm TL were more frequent. The catch of juveniles in the fishing ground close to Mazatlán, indicates that this might be a pupping area (Castro, 1983), where they find refuge from predators (Allen and Robertson, 1994).

Sphyrna lewini of both size classes combined in the area off Mazatlán fed on fishes (55.6%), cephalopods (30.2%), and crustaceans (14.1%). Similar diets (cephalopods and fishes) were described previously for scalloped hammerhead sharks from Kaneohe, Oahu, Hawaii (Clarke-Thomas, 1971), Kwazulu-Natal, South Africa (Smale and Cliff, 1988) and Gulf of California (Klimley, 1983).

The presence of mesopelagic and neritic prey in the diet of *S. lewini* in Mazatlan may be related to forays these sharks make to depths of 50-450 m, which were more frequent at night (Klimley *et al*., 1993). Our results show that juveniles of *S. lewini* consumed more neritic (Loliginidae) than oceanic cephalopods, but in South Africa, adults of *S. lewini* consumed more oceanic than neritic cephalopods (Smale and Cliff 1988).

The high diversity index value coincides with the high number of different items consumed by *S. lewini* (87 prey species). The low niche breadth index value classified juvenile scalloped hammerhead sharks as specialists because they consume more on few prey. Klimley *et al.* (1983) classify to scalloped hammerhead as an opportunistic-generalist predator in the Gulf of California; however he found more adults than juveniles, and the feeding behavior in adults is different than that of juveniles, because they consume more on epipelagic and mesopelagic cephalopods (Galvan *et al.* 1989). The overlap index showed no difference between sexes, so we inferred that both male and female juveniles feed on similar prey from October to March. However, Galván *et al.* (1989), mentioned sex segregation, in which males of *S. lewini* were more common than females during the spring season, and the catch frequencies of both sexes were the same during summer. Also they found seasonal differences in *S. lewini* length (190 to 240 cm of total length). Klimley (1983), mentioned sex segregation in this shark species throughout the year in the Gulf of California, with a high percentage (47%) of adult and juvenile females feeding offshore on pelagic prey, while males were caught in coastal areas (15%), where the incidence of benthic prey was higher. Even the main prey species of both size classes were largely the same. Differences in proportion of prey do not cause overlaping. This result could be explained by a greater home range of larger sharks, as reported by Klimley (1983), and Smale and Cliff (1988), who found that the juveniles of *S. lewini* stay in coastal waters (mainly in bays) for some time, and that, with grow, they move toward oceanic areas during the night to feed, and return to the coast during the day.

In summary, the population of *S. lewini* off Mazatlán consist mainly of juveniles of less than 160 cm TL. They are specialist predators with similar diets for both sexes, but showing some variations between size classes.

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