Latin American Journal of Aquatic Research
E-ISSN: 0718-560X
lajar@ucv.cl
Pontificia Universidad Católica de Valparaíso
Chile

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Latin American Journal of Aquatic Research, vol. 39, núm. 3, 2011, pp. 449-460
Pontificia Universidad Católica de Valparaíso
Valparaiso, Chile

DOI: 10.3856/vol39-issue3-fulltext-6

Research Article

Daily food intake of *Kajikia audax* (Philippi, 1887) off Cabo San Lucas, Gulf of California, Mexico

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ABSTRACT. The daily food intake rates of the striped marlin, *Kajikia audax* (Perciformes: Istiophoridae), were estimated using qualitative and quantitative analyses of their trophic spectrum. We analyzed the stomach contents of 505 striped marlin caught by the sport fishing fleet off Cabo San Lucas, Baja California Sur, Mexico, sampled from October 1987 through December 1989. The most important preys were chub mackerel (*Scomber japonicus*), California pilchard (*Sardinops caeruleus*), and jumbo squid (*Dosidicus gigas*); together these represented ~55% of the striped marlin diet. The daily food consumption was estimated to be 2 kg per day, or ~3.6% of the mean body weight of *K. audax*. The total biomass of the prey consumed by the striped marlin during the 27 months of sampling around Los Cabos was estimated at 24.8 ton, of which the chub mackerel represented ~29% (7.2 ton), California pilchard just under 16% (3.9 ton), and jumbo squid ~10% (2.5 ton). The feeding habits of *K. audax* are discussed in terms of the distribution of the epipelagic (neritic and oceanic zones), demersal, and benthic prey, confirming that striped marlin migrate vertically and horizontally in search of their food.

Keywords: billfish, striped marlin, diurnal variation, consumption, Cabo San Lucas, Gulf of California, Mexico.

Tasa de consumo diario de alimento de *Kajikia audax* (Philippi, 1887) frente a Cabo San Lucas, golfo de California, México

RESUMEN. Se estimó la tasa de consumo diario de alimento del marlín rayado *Kajikia audax* (Perciformes: Istiophoridae), sobre la base de análisis cualitativos y cuantitativos de su espectro trófico. Se analizó el contenido estomacal de 505 ejemplares capturados por la flota deportiva frente a Cabo San Lucas, Baja California Sur, México muestreados de octubre 1987 a diciembre 1989. Las presas más importantes fueron la macarela del Pacífico (*Scomber japonicus*), sardina monterrey (*Sardinops caeruleus*) y calamar gigante (*Dosidicus gigas*), que en conjunto representaron aproximadamente el 55% de la dieta. La tasa de consumo de alimento fue estimado en 2 kg diarios, lo cual representó aproximadamente el 3,6% del peso corporal de *K. audax*. La biomasa total de presas consumidas por el marlín rayado durante los 27 meses muestreados en la zona de Los Cabos fue estimada en 24,8 ton, de las cuales la macarela del Pacífico representó alrededor del 29% (7,2 ton), la sardina monterrey poco menos del 16% (3,9 ton) y el calamar gigante aproximadamente el 10% (2,5 ton). Los hábitos alimentarios de *K. audax* se discutieron según la distribución de las presas epipelágicas (neríticas y oceánicas), demersales y bentónicas; lo cual confirmó la conducta migratoria (movimientos verticales y horizontales) del marlín rayado en busca de su alimento.

Palabras clave: picudos, marlín rayado, variación diurna, consumo, Cabo San Lucas, golfo de California, México.

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INTRODUCTION

Istiophorid billfishes are highly migratory species that inhabit the tropical and subtropical, epipelagic waters of the world's oceans, a large, relatively homogeneous environment that lacks significant physical barriers and most species spawn over broad geographic regions during a protracted season (Nakamura, 1995). They are targeted by both recreational and commercial fisheries all over the world. Yet despite this, there still remain large gaps in our knowledge of the biology and ecology of these species. Particularly, striped marlin *Kajikia audax* (Philippi, 1887) supports an important commercial catch in several regions of the world, while also forming the basis of important recreational fishing in the United States, Mexico, Ecuador, New Zealand, East Africa and Australia (Domeier, 2006). This species is highly prized as food (sashimi and smoked and frozen filet) for the excellent quality of its flesh and the high ratio of usable meat to body weight (Sosa-Nishizaki, 1998).

Striped marlin in Mexican waters and particularly in Cabo San Lucas at the southern tip of the Baja California Peninsula forms the core of sport fishing. The southern Gulf of California is a migration zone for striped marlin (Squire & Suzuki, 1990; Abitia-Cárdenas *et al*., 1998), where fish longer than 200 cm postorbital length (modal PL) are feeding and storing energy in preparation for reproduction (Abitia-Cárdenas *et al*., 2002). Its larvae (2.8-30.5 mm total length) have been collected in near shore waters south of Los Cabos, suggesting that spawning occurs in the lower Gulf of California when water temperature is ≥ 27.0°C (González-Armas *et al*., 1999).

There are several general studies on the feeding habits of striped marlin in the Pacific Ocean (Hubbs & Wisner, 1953; De Silva, 1962; Evans & Wares, 1972; Eldrige & Wares, 1974; Abitia-Cárdenas *et al*., 1997, 1998). Abitia-Cárdenas *et al*. (2002) estimated seasonal total energy storage (kcal g^{-1} wet weight) as well as energy storage in muscle and gonadal tissue of a limited number of female striped marlin from the Los Cabos region. However, there are no published estimates of their daily food consumption. An ecosystem approach to fisheries management requires an understanding of the impact of predatory fish on the most important prey species and that the measured rates of food consumption by apex predators lay the ground work for gaining insight into the role of predators in the food web of the marine ecosystem (Olson & Galván-Magaña, 2002). The goal of this study was to estimate the daily biomass consumption of the main prey species of striped marlin in the Los Cabos, Mexico area based on qualitative and quantitative analysis.

MATERIALS AND METHODS

Stomach samples were collected from the striped marlin catch by the sport fishing fleet, trolling with live bait or jigs in the area of Los Cabos (22°53'N, 109°54'W) from October 1987 through December 1989 (Fig. 1). In order to study the influence of the size of the fish, the data was grouped in 12 size classes (from 111-221 cm postorbital length) (Ponce-Diaz *et al*., 1991). The postorbital length (eye-fork length) and weight of each fish was measured and the stomach was preserved in formalin. Stomachs were weighed, food was removed, and the contents were weighed and stored according to the digested prey and its degree of digestion. Vertebral characteristics (*e.g*., number and position) were used to identify fish using taxonomic keys (Miller & Jorgensen, 1973) whereas, for undigested fish, we used (Miller & Lea, 1972; Allen & Robertson, 1994; Fischer *et al*., 1995). Crustaceans were identified using (Brusca, 1980; Fischer *et al*., 1995) and cephalopods were identified from the mandible (beaks) using (Wolff, 1982; Clarke, 1986).

Recognizable prey items were divided into major taxonomic categories. Prey were quantified and expressed as a percentage of volume (mL) (Hyslop, 1980): V (%) = (v/vT)×100; where v is volume displaced by a prey species and vT is volume displaced by all prey. A multivariate analysis of variance (MANOVA) of percent volume values was used to examine differences in prey consumed related to sex and size class.

The theoretical maximum capacity of the stomach (Stillwell & Kohler, 1982) was used to quantify the degree of stomach fullness. Stomach fullness was recorded according to an estimated fourth-point scale as percentages of total fullness: 0-25% full, 26-50% full, 51-75% full, and 76-100% full.

Estimates of mean daily and annual food consumption were made from the stomach contents of all striped marlin collected (applying the conversion 1 mL = 1 g) (Stillwell & Kohler, 1985). The values were extrapolated to fish hooked by the eight fishing fleets in Cabo San Lucas (Klett-Traulsen *et al*., 1996) to estimate the relative contribution of prey biomass (metric tons, ton) consumed by striped marlin.

Food evacuation time was estimated based on the type of prey (Olson & Boggs, 1986). For example, scombrids (mackerel) are evacuated in 5.29 h on average, whereas cephalopods take 2.24 h. Given the lack of information on the time-course for evacuation, the mean evacuation time of 5.29 h calculated for yellowfin tuna *Thunnus albacares* was used (Olson & Boggs, 1986). It was assumed that the evacuation time

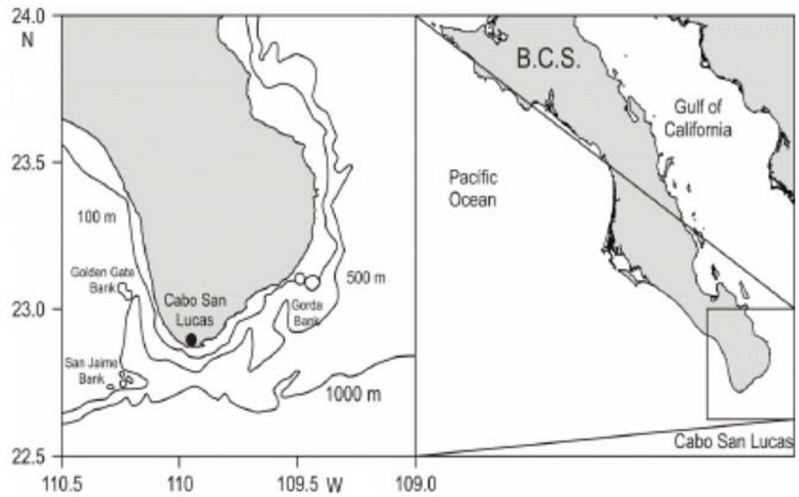

Figure 1. Location of study area off Cabo San Lucas, Mexico.

Figura 1. Ubicación geográfica del área de estudio frente a Cabo San Lucas, México.

of yellowfin tuna is adequate for estimating daily rations of striped marlin because chub mackerel is one the most important elements in the diet of both the marlin and tuna predators. It was assumed that this rate of evacuation is unaffected by predator size, prey size, and sea temperature (Stillwell & Kohler, 1985).

RESULTS

Mean postorbital length was 176.81 ± 11.47 cm (± 1 SD) and mean weight was 56.14 ± 10.95 kg. Of 505 striped marlin that were sampled, 452 had food in their stomachs (89.6%), 27 had empty stomachs (5.3%), and 26 had regurgitated (5.1%). Taxonomic work identified 42 taxa (31 fishes, 6 cephalopods, and 5 crustaceans) belonging to 21 families and 35 genera (Table 1).

Stomach contents displaced a total volume (mL) of 231l, of which 87.6% were fish, 11.5% cephalopods, and 0.9% crustaceans. The main species were chub mackerel *Scomber japonicus* (29%), California pilchard *Sardinops caeruleus* (15.8%), jumbo squid *Dosidicus gigas* (10%), and the redeye round herring *Etrumeus teres* (8.5%). The postorbital length frequency distribution in the 505 striped marlin was 120 to 221 cm, with the 171-180 cm size class (36%) most prevalent (Fig. 2). The largest number of empty stomachs occurred in marlin ranging from 151-200 cm, with only one empty stomach in marlin ranging from 121-140 cm.

Prey consumption also varied with size (Table 1). MANOVA revealing significant differences in consumption patterns for the size classes ($P < 0.0001$), with Tukey's test (Sokal & Rohlf, 1981) indicating that striped marlin ≤180 cm PL consumed a more diverse group of fish (n = 30) compared to marlin >180 mm PL (n = 15; Table 1). In contrast, for cephalopod and crustacean prey, no significant differences ($P > 0.05$) were noted between size classes (11 *vs* 6 prey species, respectively) (Table 1).

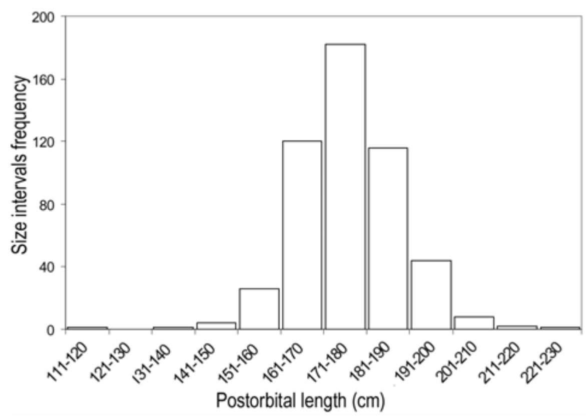

Figure 2. Frequency of postorbital length (cm) of striped marlin collected between 1987-1989 off Cabo San Lucas, Mexico.

Figura 2. Distribución de clases de talla (longitud postorbital en cm) para marlín rayado capturado en el periodo 1987-1989 frente a Cabo San Lucas, México.

Of the sample, there were 297 females (58.8%) and 208 males (41.2%), a sex ratio of 1.4:1. MANOVA revealed highly significant differences ($P < 0.0001$) in diet based on sex (Table 2) and Tukey's test showed that females consumed twice as much fish as males. In

Table 1. Summary of food categories in stomachs (n = 452) of striped marlin from the southern of Gulf of California, Mexico expressed as absolute values and percentages of the volumetric values (V).

Tabla 1. Resumen de las categorías alimentarias encontradas en contenidos estomacales (n = 452) de marlín rayado en la boca del golfo de California, México los resultados están expresados en valores absolutos y porcentuales en términos del volumen de las presas (V).

Item prey	V (mL)	% V
Cephalopoda		
Teuthoidea		
Enoploteuthidae		
Abraliopsis affinis	1474.20	0.64
Ommastrephidae		
Dosidicus gigas	23136.84	10.01
Stenoteuthis oualaniensis	1.67	< 0.01
Octopoda		
Octopodidae		
Octopus spp.	131.23	0.06
Japetella heathi	0.41	0.00
Argonautidae		
Argonauta spp.	1809.99	0.78
Crustacea		
Amphipoda	13.50	0.01
Isopoda	3.00	0.00
Stomatopoda		
Squillidae		
Squilla spp.	15.10	0.01
Euphausiacea	11.00	< 0.01
Decapoda		
Galatheidae		
Pleuroncodes planipes	1937.00	0.84
Osteichthyes		
Clupeiformes		
Clupeidae	3206.00	1.39
Etrumeus teres	19681.00	8.52
Opisthonema libertate	4985.00	2.16
Sardinops caeruleus	36492.00	15.79
Gadiformes		
Merlucciidae		
Merluccius productus	16619.00	7.19
Exocoetidae		
Exocoetus spp.	0.10	< 0.01
Belonidae		
Strongylura exilis	11.30	< 0.01
Syngnathiformes		
Fistulariidae		
Fistularia corneta	5092.00	2.20
Scorpaeniformes		
Triglidae		
Prionotus spp.	45.00	0.02
Uranoscopidae		
Kathetostoma averruncus	5.00	< 0.01
Perciformes		
Serranidae	8365.00	3.62
Diplectrum spp.	226.50	0.10
Carangidae	2399.80	1.04
Caranx caballus	1988.50	0.86
Caranx hippos	769.00	0.33
Chloroscombrus orqueta	54.20	0.02
Decapterus muroadsi	14460.00	6.26
Naucrates ductor	68.00	0.03
Trachinotus rhodopus	6.50	< 0.01
Selar crumenophthalmus	5017.00	2.17
Coryphaenidae		
Coryphaena hippurus	185.00	0.08
Mugilidae		
Mugil curema	700.00	0.30
Sphyraenidae		
Sphyraena ensis	680.00	0.29
Scombridae		
Auxis spp.	8201.50	3.55
Euthynus lineatus	70.00	0.03
Katsuwonus pelamis	13.30	0.01
Scomber japonicus	67055.50	29.01
Tetraodontiformes		
Balistidae		
Balistes polylepis	5721.00	2.48
Xanthichthys mento	115.00	0.05
Lagocephalus lagocephalus	135.00	0.06
Diodontidae		
Diodon holocanthus	68.00	0.03

contrast, consumption of cephalopods and crustaceans were not significantly ($P > 0.05$) different between genders.

Mean maximum capacity of striped marlin stomachs was 2.5 L, which is ~4.4% of the weight of the average striped marlin. Of 452 stomachs with prey, 261 (57.7%) had a fullness status of 0-25%; 120 (26.5%) had 26-50%; 48 (10.6%) had 51-75%; and 23 (5.1%) had 76-100% (Table 3). Stomach fullness in all seasons there was a tendency for fuller stomachs in larger striped marlin (Table 4).

Since chub mackerel was the main food for striped marlin near Los Cabos, calculation of the daily biomass consumption included mean gastric evacuation time of 5.3 h and a mean daily consumption of 0.51 kg per striped marlin. The latter value corresponds to the mean amount of food consumed by 452 striped marlin, which was equivalent to 1% of the mean weight (56.1 kg) of the striped marlin sampled.

Based on the assumption that predicted striped marlin need 5.29 h to evacuate food (21.16 h), it was marlin feed four times daily. When multiplying this by the mean biomass consumed (0.51 kg), daily

Table 2. Trophic spectrum of the 12 size interval (cm) of striped marlin expressed in absolute values of the volumetric method: n = total stomach examined.

Tabla 2. Composición alimentaria de 12 intervalos de talla consecutivos (cm) de marlín rayado, expresados como valores absolutos en términos del volumen de las presas, donde n corresponde al número de estómagos analizados para cada intervalo de talla.

Item prey	Size interval (cm)											
	111-120 (n = 1)	121-130 (n = 0)	131-140 (n = 1)	141-150 (n = 4)	151-160 (n = 26)	161-170 (n = 120)	171-180 (n = 182)	181-190 (n = 116)	191-200 (n = 44)	201-210 (n = 8)	211-220 (n = 2)	221-230 (n = 1)
Abraliopsis affinis					417	297	458.2	302				
Dosidicus gigas	0.84			750	1429	7400	7146.5	2412.5	1304	1270	1124	300
Stenoteuthis oualaniensis						0.42	0.61	0.64				
Octopus spp.					27		104.23					
Japetella heathi						0.2	0.21					
Argonauta spp.				44		513.5	802	236		214.49		
Amphipoda						1.5	12					
Isopoda							1.9	1.1				
Squilla spp.							15.1					
Euphausiacea						4.3	6.7					
Pleuroncodes planipes	1.9			81	340	338	443.5	307.5	225.10	200		
Clupeidae	125					774	1600	707				
Etrumeus teres					4345	4075	5092	4055	1768	346		
Opisthonema libertate						1357.5	1120	2507.5				
Sardinops caeruleus	210			303	2869	6324.5	18010	4226.5	2958	1077	514	
Merluccius productus						6000	4032.5	2101.5	3200	1285		
Exocoetus spp.							0.1					
Strongylura exilis							11.3					
Fistularia corneta					2003	1672	873	211	333			
Prionotus spp.							45					
Kathetostoma averruncus							5					
Serranidae	136				684	1410.5	2700.5	1125	1658.5	650.5		
Diplectrum spp.							226.5					
Carangidae					998.5	487	385	105.5	63.8		360	
Caranx caballus					345	504.5	420	315.5	403.5			
Caranx hippos						245.5	356	111.5	56			

Item prey	Size interval (cm)											
	111-120 (n = 1)	121-130 (n = 0)	131-140 (n = 1)	141-150 (n = 4)	151-160 (n = 26)	161-170 (n = 120)	171-180 (n = 182)	181-190 (n = 116)	191-200 (n = 44)	201-210 (n = 8)	211-220 (n = 2)	221-230 (n = 1)
Chloroscombrus orqueta						20.5	33.7					
Decapterus muroadsi				770		7123	3850.5	1359.5	875.5	481.5		
Naucrates doctor					68							
Trachinotus rhodopus							6.50					
Selar crumenophthalmus				235	1020	1320	1090	834	318	200		
Coryphaena hippurus						70	115					
Mugil curema						247	453					
Sphyraena ensis					680							
Auxis spp.				274		2053.5	2364	1325.5	2184.5			
Euthynus lineatus							70					
Katsuwonus pelamis					13.3							
Scomber japonicus				1301	10323.5	7568.5	26512.5	8123.5	4525.5	5025	3023	653
Balistes polylepis				201	1099	904.5	1002	1367	1147.5			
Xanthichthys mento							115					
Lagocephalus lagocephalus							135					
Diodon holocanthus				12.56		55.44						

Table 3. Summary of food categories of female (n = 279) and male (n = 173) striped marlin from the southern Gulf of California, Mexico, expressed as absolute values and percentages of the volumetric values (V).

Tabla 3. Composición de categorías de presa encontradas en hembras (n = 279) y machos (n = 173) de marlín rayado en la boca del golfo de California, México expresado como valores absolutos y porcentuales con base al volumen de las presas (V).

Item prey	Female		Male	
	V (mL)	%V	V (mL)	%V
Abraliopsis affinis	615.50	0.44	858.70	0.94
Dosidicus gigas	16030.68	11.46	7106.16	7.78
Stenoteuthis oualaniensis	1.00	< 0.001	0.67	< 0.001
Octopus spp.	131.13	0.09	0.10	< 0.001
Japetella heathi	0.31	< 0.001	0.10	< 0.001
Argonauta spp.	909.72	0.65	900.27	0.99
Amphipoda	13.50	0.01	0.00	0.00
Isopoda	2.10	< 0.001	0.90	< 0.001
Squilla spp.	15.10	0.01	0.00	0.00
Euphausiacea	5.80	< 0.001	5.20	0.01
Pleuroncodes planipes	1035.08	0.74	901.92	0.99
Clupeidae	2299.00	1.64	907.00	0.99
Etrumeus teres	8394.90	6.00	11286.10	12.36
Ophistonema libertate	2867.40	2.05	2117.60	2.32
Sardinops caeruleus	20457.10	14.63	16034.90	17.57
Merluccius productus	7246.50	5.18	9372.50	10.27
Exocoetus spp.	0.10	< 0.001	0.00	0.00
Strongylura exilis	11.30	0.01	0.00	0.00
Fistularia corneta	3523.40	2.52	1568.60	1.72
Prionotus spp.	20.00	0.01	25.00	0.03
Kathetostoma averruncus	5.00	< 0.001	0.00	0.00
Serranidae	8365.00	5.98	0.00	0.00
Diplectrum spp.	0.00	0.00	226.50	0.25
Carangidae	1009.18	0.72	1390.62	1.52
Caranx caballus	839.80	0.60	1148.70	1.26
Caranx hippos	461.70	0.33	307.30	0.34
Chloroscombrus orqueta	54.20	0.04	0.00	0.00
Decapterus muroadsi	7824.00	5.60	6636.00	7.27
Naucrates doctor	4.00	< 0.001	64.00	0.07
Trachinotus rhodophus	6.50	< 0.001	0.00	0.00
Selar crumenophthalmus	2931.90	2.10	2085.10	2.28
Coryphaena hippurus	5.00	< 0.001	180.00	0.20
Mugil curema	223.20	0.16	476.80	0.52
Sphyraena ensis	680.00	0.49	0.00	0.00
Auxis spp.	6011.30	4.30	2190.20	2.40
Euthynus lineatus	70.00	0.05	0.00	0.00
Katsuwonus pelamis	0.00	0.00	13.30	0.01
Scomber japonicus	43807.10	31.33	23248.40	25.47
Balistes polylepis	3649.60	2.61	2071.40	2.27
Xanthichthys mento	115.00	0.08	0.00	0.00
Lagocephalus lagocephalus	0.00	0.00	135.00	0.15
Diodon holocanthus	46.00	0.03	22.00	0.02

Table 4. Seasonal frequency by size interval (cm), sex ratio (F: female, M: male), mean volume of the stomach contents and degrees of fullness (1: 1-25%; 2: 26-50%; 3: 51-75; 4: 76-100%).

Tabla 4. Variación estacional por intervalo de talla (cm), proporción de sexos (F: hembra, M: macho), volumen promedio del contenido estomacal y grado de llenado (1: 1-25%; 2: 26-50%; 3: 51-75% y 4: 76-100%).

Season	Size interval (cm)	Number of stomach	Sex ratio	Mean volume content (mL)	Degree of fullnes
Fall (1987)	151-160	1	1 Male	636.50	2
	161-170	8	1.35 : 1	600.43	2
	171-180	11	0.83 : 1	158.41	1
	181-190	9	3.5 : 1	662.27	2
	191-200	3	0.5 : 1	32.30	1
	221-230	1	1 Female	857.77	2
Winter (1988)	151-160	4	0.33 : 1	419.50	1
	161-170	9	0.88 : 1	444.28	1
	171-180	17	1.28 : 1	632.56	2
	181-190	12	5 : 1	222.87	1
	191-200	2	2 Females	1657.50	4
Spring (1988)	141-150	1	1 Male	552.40	1
	151-160	2	1 : 1	1375.30	3
	161-170	25	1.27 : 1	464.87	1
	171-180	31	1.38 : 1	478.37	1
	181-190	16	4.33 : 1	278.75	1
	191-200	5	4 : 1	731.80	2
Summer (1988)	151-160	2	2 Males	1366.55	3
	161-170	8	0.6 : 1	178.55	1
	171-180	13	1.17 : 1	505.36	1
	181-190	7	1.33 : 1	476.33	1
	191-200	2	1 : 1	249.80	1
	201-210	1	1 Female	1825.30	4
	211-220	1	1 Female	2035.50	4
Fall (1988)	111-120	1	1 Male	473.74	1
	151-160	2	1 : 1	995.45	2
	161-170	23	0.53 : 1	332.16	1
	171-180	32	1.67 : 1	562.08	1
	181-190	26	2.71 : 1	638.56	2
	191-200	7	6 : 1	508.18	1
	201-210	1	1 Female	2200.20	4
Winter (1988)	151-160	1	1 Male	538.30	1
	161-170	10	1 : 1	450.66	1
	171-180	16	0.77 : 1	367.89	1
	181-190	15	1.14 : 1	449.50	1
	191-200	13	2.25 : 1	752.74	2
Spring (1989)	201-210	1	1 Male	962.80	2
	141-150	2	1 : 1	1015.60	2
	151-160	2	2 Female	745.35	2
	161-170	5	4 : 1	244.18	1
	171-180	29	1.9 : 1	306.29	1
	181-190	16	1.67 : 1	309.01	1
	191-200	10	4 : 1	609.43	2
	201-210	3	3 Females	1913.73	3
Summer (1989)	151-160	1	1 Female	592.00	1
	161-170	1	1 Female	512.72	1
	171-180	6	2 : 1	420.82	1
	181-190	2	1 : 1	921.75	2
	191-200	1	1 Female	1501.80	3
Fall (1989)	141-150	1	1 Female	1532.96	3
	151-160	5	4 : 1	1198.74	2
	161-170	18	3.5 : 1	501.91	1
	171-180	10	9 : 1	330.94	1
	181-190	1	1 Female	2174.80	4

consumption of an adult marlin was ~2.04 kg, ~3.6% of mean weight. By extrapolating the calculated daily consumption over the estimated capture of 12,166 striped marlin hooked by eight sport fleets from Cabo San Lucas over 27 months (Klett-Traulsen *et al*., 1996), it was estimated 24.8 ton of prey were consumed or an annual consumption rate of 11.02 ton.

To estimate the biomass of the main prey species consumed by striped marlin, the percent volume for each food type was calculated and converted to biomass: chub mackerel 29% (7.2 ton); California pilchard 15.8% (3.9 ton); jumbo squid 10% (2.5 ton); redeye round herring 8.5% (2.1 ton); Pacific hake *Merluccius productus*, 7.2% (1.8 ton); the carangid *Decapterus muroadsi* 6.3% (1.6 ton); and the scombrid *Auxis* spp. 3.6% (0.9 ton) (Fig. 3).

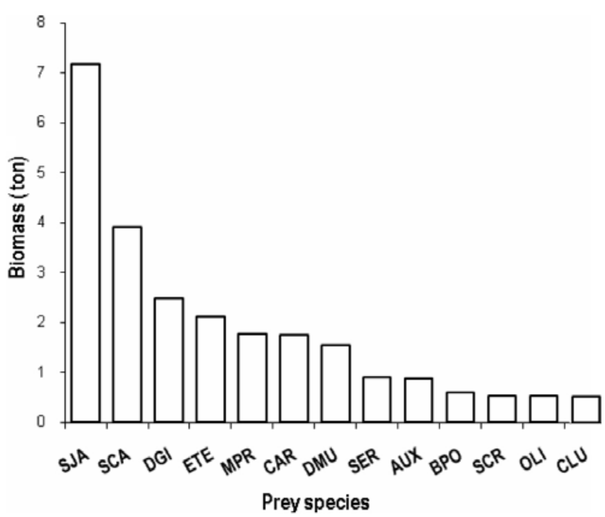

Figure 3. Plot of the biomass (ton) of the most important prey of striped marlin. SJA: *Scomber japonicus*, SCA: *Sardinops caeruleus*, DGI: *Dosidicus gigas*, ETE: *Etrumeus teres*, MPR: *Merluccius productus*, CAR: Carangidae, DMU: *Decapterus muroadsi*, SER: Serranidae, AUX: *Auxis* spp., BPO: *Balistes polylepis*, SCR: *Selar crumenophthalmus*, OLI: *Opisthonema libertate* and CLU: Clupeidae.

Figura 3. Contribución en términos de biomasa (ton) de las presa principales consumidas por el marlín rayado: SJA: *Scomber japonicus*, SCA: *Sardinops caeruleus*, DGI: *Dosidicus gigas*, ETE: *Etrumeus teres*, MPR: *Merluccius productus*, CAR: Carangidae, DMU: *Decapterus muroadsi*, SER: Serranidae, AUX: *Auxis* spp., BPO: *Balistes polylepis*, SCR: *Selar crumeno-phthalmus*, OLI: *Opisthonema libertate* y CLU: Clupeidae.

DISCUSSION

All billfishes are considered epipelagic (Block *et al*., 1992a; Nakamura, 1995). Striped marlin are found in more temperate waters than others istiophorids, with strong preferences for waters 20-25°C (Ueyanagi, 1965; Domeier, 2006). Tracking of horizontal and vertical movements show that striped marlin spend most of the time in surface waters (10 m), but dive to depths of 170 m, suggesting that their vertical movements are strongly influenced by water temperature (Brill *et al*., 1993). In general, telemetry tracking of billfish revealed that species, such as striped marlin and blue marlin (*Makaira nigricans*), make short vertical migrations to moderate depths, while swordfish (*Xiphias gladius*) dive deeper and longer (Block *et al*., 1992a, 1992b; Sedberry & Loefer, 2001; Takahashi *et al*., 2003).

In waters surrounding Cabo San Lucas, BCS, Mexico, striped marlin mainly consume epipelagic prey in the neritic zone, and to a lesser extent, prey from deeper waters. Common prey was chub mackerel, California pilchard, and jumbo squid, which are important components of the commercial harvest in the eastern Pacific Ocean (Ehrhart *et al*., 1986; Gluyas-Millan & Quiñonez-Velazquez, 1996; Felix-Uraga *et al*., 1996), with the jumbo squid also preying on the other two former species. On the other hand, epipelagic (neritic and oceanic zones), demersal, and benthic species in the diet of striped marlin suggest it migrates vertically and horizontally to feed.

A high number of top predators eat the most abundant prey found in their environment (Olson & Galván-Magaña, 2002; Young *et al*., 2006; Arizmendi-Rodríguez *et al*., 2006). Migrating habits of striped marlin might also reflect a reproductive strategy that includes searching for water masses with adequate conditions for growth and survival of their larvae and prey for their juveniles and immature adults. Several authors consider these migrations as behavior to ensure favorable reproduction conditions (Radakov, 1973; Lagler *et al*., 1977).

The sizes recorded (111-221 cm postorbital length) in this study match those reported for other striped marlin sport fisheries, but not matching the longline Japanese commercial fishery records that have both smaller and larger sizes. For example, the length of striped marlin in the longline Japanese commercial fishery is 80-240 cm (Shingu *et al*., 1974; Miyabe & Bayliff, 1987) while the offshore areas of Mazatlan and Sonora yield marlin ranging from 110-204.5 cm (Wares & Sakagawa, 1974), and Buenavista and Los Cabos, B.C.S. range from 107.5-225.5 cm (Wares & Sakagawa, 1974; Ponce-Diaz *et al*., 1991). The range of striped marlin postorbital length size classes in our study is wide because of the selectivity of the fishing methods and the spectrum of sizes in the waters near Los Cabos. Thus, our data reflects the length of striped marlin throughout much of its range.

Striped marlin exhibited significant ontogenetic and sex differences in diet. Striped marlin with size ≤180 cm PL fed on a larger number of fish species and consume greater biomass, while striped marlin >180 cm PL, which consume fewer fish species and biomass. Additionally, female marlin had a larger percentage of filled stomachs and consuming twice the fish biomass of males.

Estimating daily consumption of this apex predator in their environment is difficult because several factors, such as size of fish and their food, water temperature, and digestion and evacuation rates play a major role. Studies of several species of teleostean fish and sharks to determine stomach evacuation rates and daily ratio have been done (Stillwell & Kohler, 1985; Olson & Boggs, 1986; Olson & Mullen, 1986; Olson & Galván-Magaña, 2002). However, studies for billfishes are lacking because direct measurements on these fish are not possible because of logistic constraints, including their pelagic habitat, large size, and wide-roving behavior, and the technology for maintaining these large marine fishes in optimal conditions in the laboratory or in a natural enclosure in the sea, has not been developed.

In our study, only approximate calculations can be made of daily consumption by employing gastric evacuation rates of species with similar characteristics of standard metabolic rates and high-performance physiology, such as tuna and dolphin fishes (Brill, 1996; Olson & Galván-Magaña, 2002). Considering the mean weight of the stomach content of 452 striped marlin and the mean gastric evacuation rate of yellowfin tuna (5.29 h), we estimated that striped marlin eat 2.04 kg prey each day, approximately 3.6% of their mean weight. This value seems reasonable and is comparable with estimates made for other predator species. For example, an estimate of 0.3% of body weight for the shark *Ginglymostoma* spp. (Clark, 1963), 5.6% of body weight of common dolphinfish *Coryphaena hippurus* (Olson & Galván-Magaña, 2002) and 10% of body weight for blue fin tuna *Thunnus thynnus* (Butler & Mason, 1977). For billfish, the only previously published estimate of daily consumption is for the swordfish *Xiphias gladius*, which consumed 0.93 kg of prey, representing 1.6% of mean body weight (Stillwell & Kohler, 1985).

Indirectly, this study on the feeding habits of striped marlin provides an assessment of the relative abundance of the main prey species in their diet. Chub mackerel represented 28.9% (7.2 ton); California pilchard, 15.8% (3.9 ton); and jumbo squid 10% (2.5 ton) of the overall diet. Extrapolating the estimated daily consumption (2.04 kg) to an estimated 12,166 striped marlin hooked by the sport fishing fleet of Cabo San Lucas from October 1987 through December 1989 (27 months) suggests 24.8 ton of prey consumed and an annual food consumption rate of 11.02 ton. It needs to be stressed that these estimates should be considered as minimums because 84.2% of the stomachs were less than 50% of estimated maximum capacity.

Striped marlin are apex predator in the pelagic food web in the southern Gulf of California and the results support the assumption that billfish and others large pelagic fish may be of keystone predators in the marine ecosystem (Hinman, 1998; Kitchell *et al*., 2006). Additionally, these results provide key data for implementing ecosystem analysis based on food web models (Kitchell *et al*., 2006).

ACKNOWLEDGEMENTS

We wish to thank the Instituto Politécnico Nacional (COFAA, EDI) and the Centro de Investigaciones Biológicas del Noroeste for their support. Thanks Consejo Nacional de Ciencia y Tecnología (CONACyT) and Sistema Nacional de Investigadores (SNI). Finally thanks to Ira Fogel for editing the English-language text and Ing. Armando Hernandez-Lopez for the edition of figures and tables.

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Received: 20 October 2010; Accepted: 28 September 2011

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