Spatial and temporal variation in the diet of the California sea lion (*Zalophus californianus*) in the Gulf of California, Mexico

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Abstract—Between June 1995 and May 1996 seven rookeries in the Gulf of California were visited four times in order to collect scat samples for studying spatial and seasonal variability California sea lion prey. The rookeries studied were San Pedro Mártir, San Esteban, El Rasito, Los Machos, Los Cantiles, Isla Granito, and Isla Lobos. The 1273 scat samples collected yielded 4995 otoliths (95.3%) and 247 (4.7%) cephalopod beaks. Fish were found in 97.4% of scat samples collected, cephalopods in 11.2%, and crustaceans in 12.7%. We identified 92 prey taxa to the species level, 11 to genus level, and 10 to family level, of which the most important were Pacific cutlassfish (*Trichiurus lepturus*), Pacific sardine (*Sardinops caeruleus*), plainfin midshipman (*Porichthys* spp.), myctophid no. 1, northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), anchoveta (*Cetengraulis mysticetus*), and jack mackerel (*Trachurus symmetricus*). Significant differences were found among rookeries in the occurrence of all main prey ($P \leq 0.04$), except for myctophid no. 1 ($P > 0.05$). Temporally, significant differences were found in the occurrence of Pacific cutlassfish, Pacific sardine, plainfin midshipman, northern anchovy, and Pacific mackerel ($P < 0.05$), but not in jack mackerel ($\chi^2=2.94$, df=3, $P=0.40$), myctophid no. 1 ($\chi^2=1.67$, df= 3, $P=0.64$), or lanternfishes ($\chi^2=2.08$, df=3, $P=0.56$). Differences were observed in the diet and in trophic diversity among seasons and rookeries. More evident was the variation in diet in relation to availability of Pacific sardine.

Manuscript approved for publication
9 October 2003 by Scientific Editor.

Manuscript received 20 October 2003
at NMFS Scientific Publications Office.

Fish. Bull. 102:47–62 (2004).

The population of the California sea lion (*Zalophus californianus*), in the Gulf of California numbers approximately 23,000 individuals, 82% of which inhabit the northern region of the gulf above latitude 28° (Aurioles-Gamboa and Zavala-González, 1994). In this region are found the most important reproductive areas and the highest pup production of the Gulf. Aurioles-Gamboa and Zavala-González (1994) suggested that the high concentration of animals in this region is related to high abundance of pelagic fish such as Pacific sardine (*Sardinops caeruleus*) (also known as South American pilchard, FAO), Pacific mackerel (*Scomber japonicus*), Pacific thread herring (*Opisthonema libertate*), and anchoveta (*Cetengraulis mysticetus*) (Cisneros-Mata et al., 1987[1]; Cisneros-Mata et al., 1991[2]; Cisneros-Mata et al., 1997[3]).

Despite the importance of the northern gulf region, feeding studies of the California sea lion at Gulf of California rookeries have been few and have been conducted at different time periods. Researchers have studied sea lion diet in Los Islotes (Aurioles-Gamboa et al., 1984; García-Rodríguez, 1995), Los Cantiles (Isla Angel de la Guarda), Isla Granito (Sánchez-Arias, 1992; Bautista-Vega, 2000), and Isla Racito (Orta-Dávila, 1988). These studies have shown that sea lions consume a variety of prey and that differences exist between the diet of sea lions found at different rookeries within the Gulf of California. At Los Islotes, the most important prey were cusk eel (*Aulopus bajacali*), bigeye bass (*Pronotogrammus eos*), threadfin bass (*Pronotogrammus multifasciatus*), and splitail bass (*Hemanthias* sp.) (Aurioles-Gamboa et al., 1984; García-Rodríguez, 1995). At Los Cantiles and Isla Granito important prey were lanternfish (*Diaphus* sp.), northern anchovy (*Engraulis mordax*), Pacific cutlassfish (*Trichiurus nitens*), shoulderspot (*Caelorinchus scaphopsis*), and Pacific whiting (*Merluccius productus*) (Sanchez-Arias, 1992; Bautista-Vega, 2000), whereas at Isla Racito, important prey were Pacific sardine (*Sardinops caeruleus*), Pacific mackerel (*Scomber japonicus*), grunt (*Haemulopsis* spp.), rockfish (*Sebastes*

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[1] Cisneros-Mata, M. A., J. P. Santos-Molina, J. A. De Anda M., A. Sánchez-Palafox, and J. J. Estrada. 1987. Pesquería de sardina en el noroeste de México (1985/86). Informe Técnico, 79 p. Centro Regional de Investigaciones Pesqueras de Guaymas. INP. SEPESCA. Calle 20 No. 605 Sur Col. La Cantera. Guaymas, Son. CP. 85400.

[2] Cisneros-Mata, M. A., M. O. Nevarez-Martínez, G. Montemayor-López, J. P. Santos-Molina, and R. Morales-Azpeitia. 1991. Pesquería de sardina en el Golfo de California de 1988/89–1989/90. Informe Técnico, 80 p. Centro Regional de Investigaciones Pesqueras de Guaymas. INP. SEPESCA. Calle 20 No. 605 Sur Col. La Cantera. Guaymas, Son. CP. 85400.

[3] Cisneros-Mata, M. A., M. O. Nevárez-Martínez, M. A. Martínez-Zavala, M. L. Anguiano-Carranza, J. P. Santos-Molina, A. R. Godínez-Cota, and G. Montemayor-López. 1997. Diagnosis de la pesquería de pelágicos menores del Golfo de California de 1991/92 a 1995/96. Informe Técnico, 59 p. Centro Regional de Investigaciones Pesqueras de Guaymas. INP. SEMARNAP. Calle 20 No. 605 Sur Col. La Cantera. Guaymas, Son. CP. 85400.

spp.), and Pacific whiting (*Merluccius* spp.) (Orta-Dávila, 1988).

Some California sea lion prey are important fisheries resources in Mexico. The Pacific sardine, for example, is the target of a fishery begun in 1967 and which, along with the northern anchovy, contributed to most of the volume of the catch (200,870 t during the 1995–96 season) obtained in the Gulf (Cisneros-Mata et al.[3]). The central and northern regions of the Gulf of California harbor the greatest abundance of sea lions and schooling fishes, such as the sardine and anchovy. Because of this, knowledge of sea lion feeding habits and their temporal and spatial variability is relevant to understanding the potential interaction between sea lions and fisheries in the area (Orta-Dávila, 1988; Sánchez-Arias, 1992; Bautista-Vega, 2000).

In this article, we present the results of concurrent diet studies conducted at various rookeries and haulout areas of sea lions in the northern rookeries of the Gulf of California to examine the prey consumed, and spatial and temporal variability in their diet.

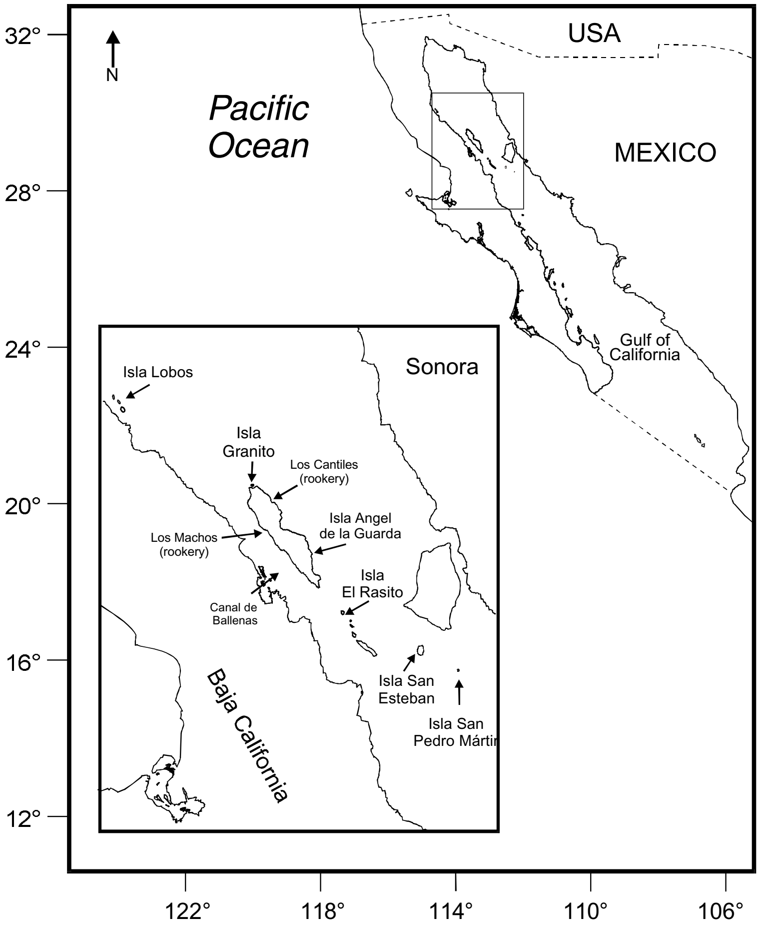

Figure 1

Map of Baja California showing location of California sea lion rookeries that were studied in the Gulf of California.

Materials and methods

Scat samples of California sea lions were collected at Isla San Pedro Mártir (SPM, 28°24′00″N, 112°25′3″W), Isla San Esteban (EST, 28°42′00″N, 112°36′00″W), Isla Rasito (RAS, 28°49′30″N, 112°59′30″W), Isla Granito (GRA, 29°34′30″N, 113°32′15″W), Isla Lobos (LOB, 30°02′30″N, 114°, 28′30″W), and at two colonies of Isla Angel de la Guarda known as Los Machos (MAC, 29°20′00″N, 113°30′00″W), and Los Cantiles (CAN, 29°32′00″N, 113°29′00″W, Fig. 1). The total number of California sea lions in these seven rookeries was approximately 15,000 animals (that were hauled out) of which about 12.2% inhabit San Pedro Mártir, 34.7% San Esteban, 2.8% El Rasito, 10.0% Los Machos, 8.7% Los Cantiles, 11.0% Isla Granito, and 20.6% Isla Lobos (Aurioles-Gamboa and Zavala-González, 1994). All the animals were spread out along the shoreline of each island, except at Isla Angel de la Guarda, where they were clustered within two areas: Los Cantiles, on the eastern shoreline and Los Machos on the western shoreline.

Scat samples were obtained at reproductive and nonreproductive haulout areas between June 1995 and May 1996. At El Rasito, sampling was done only at one reproductive area; fresh and dried samples were collected (Fig. 2). If for any reason a scat was not collected (because it was found in pieces or in poor condition), it was destroyed and the site was cleared to avoid collection during subsequent trips. All fresh and dried samples collected were pooled to represent each sampling period. We assumed that the diet information corresponded to a time period close to the collection trip, but some dried scats could have been deposited shortly after the last collection.

Scats were stored in plastic bottles and then dried shortly thereafter to prevent decomposition of fish otoliths and other hard parts (which were used in subsequent prey identification) until the scats could be processed at a later date. The samples were processed by soaking in a weak biodegradable detergent solution for 1 to 7 days before being sifted through nested sieves of 2.00-, 1.18-, and 0.5-mm mesh size. Fish bones and scales, eye lenses of fish and squid, otoliths, cephalopod beaks, and crustacean fragments were extracted from the samples. Cephalopod beaks were stored in 70% ethanol, and the other items were dried and stored in vials. Sagittal otoliths and cephalopod beaks were used to identify teleost fish and cephalopods, respectively. Identifications were made by using photographs and diagrams from Clarke (1962), Fitch (1966), Fitch and Brownell (1968), and Wolff (1984), as well as voucher specimen material from the 1) Center Interdisciplinario de Marinas Ciencias (CICIMAR), 2) Instituto Tecnólogico y de Estudios Superiores de Monterrey, Guaymas, 3) Los Angeles County Museum of Natural History, California, and 4) Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Baja California, Mexico. Prey species identifed to family level were coded by using

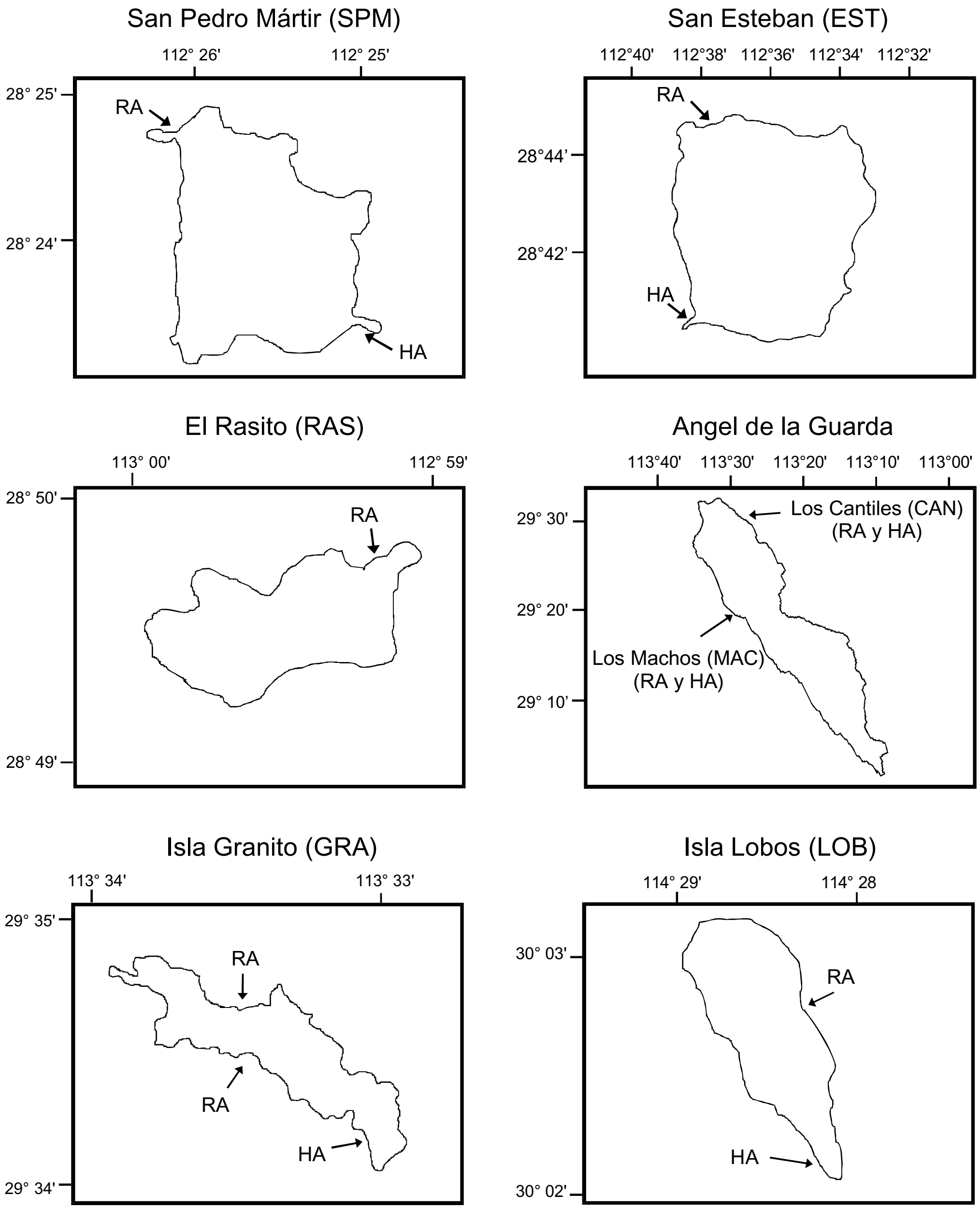

Figure 2

Location of sites where samples of California sea lion scats were collected at each island. RA = reproductive area; HA = haulout area.

the family name plus a sequential number. Otoliths from prey species that were not identified to species, genus, or family level were coded with "fish species" plus a number.

Three indices were used to describe the diet of sea lions. Percent number (PN) represents the percentage of the number of individuals for each prey taxon over the total number of individuals found in all scat samples. Percent of occurrence (PO) represents the percentage of scats having a given prey taxon and indicates the percentage of the population that is consuming a particular prey species. The third index, index of importance (IIMP) incorporates PN and PO and is defined as

$$\mathrm{IIMP}_i = \frac{1}{U}\sum_{j=1}^{U}\frac{X_{ij}}{X_j}, \qquad (1)$$

where x_i = number of individuals of taxon i in scat j;
X_j = total number of individuals from all taxa found in scat j; and
U = total number of samples with prey.

The IIMP, developed for scat analysis (García-Rodríguez, 1999), was used to determine the importance of prey species, their spatial and temporal variation in the diet, diversity of prey estimates, and measures of similarity among rookeries. Crustaceans were not incorporated into the IIMP index because it was not possible to quantify the number of individuals in the samples.

We used the IIMP Index because it is less sensitive to changes in the number of prey in an individual scat compared to PN. For example, if a scat contains a single prey taxon, the IIMP does not change regardless of the number of individuals of that taxon, in that scat. However, as one increases the number of individuals of a given prey taxon in the scat, the PN will also increase for that prey. The IIMP allows each scat to contribute an equal amount of information, whereas PN can be dominated by a few scats with a large number of a single prey-taxon otoliths. In this manner the IIMP is similar to the split-sample frequency of ocurrence (SSFO) index, developed by Olesiuk (1993), where each scat is treated as a sampling unit and does not assume, as does PN, that the distribution of prey hard parts between scats is uniform. However, with the SSFO index, each prey taxon in a given scat is given an equal weight for that scat. If only one species occurs in a sample, its occurrence is scored as 1, if two species occur, each occurrence is scored as 0.5, and so forth (Olesiuk, 1993). The IIMP index incorporates more information than the SSFO index, regardless of the number of individuals of each taxon in the scat.[4]

Percent number (PN) was used only to show differences between broad prey groups (fishes and cephalopods) and PO was used to review the temporal and spatial changes from each main prey (those with average IIMP of at least 10% at any rookery). For all estimations, a single otolith (right or left) or single cephalopod beak (upper or lower) represented one individual prey. We tested the hypothesis that the occurrence of the main prey was independent of the rookery and of the date collection using contingency tables and an estimator of chi-square (χ^2) (Cortés, 1997).

Total length of the otoliths (mm) and the linear equation obtained by Alvarado-Castillo[5] were used to estimate the length of the Pacific sardine (total length mm=7.41+(47.24 × otolith length mm); r=0.85, n=2740). Insufficient data did not allow estimating the size of specimens from May. All estimated lengths were transformed using log10, followed by an ANOVA among sampling periods. The size of Pacific sardine consumed by California sea lion was compared to those caught in the commercial fishery. We chose to estimate the size of Pacific sardines because of the broad information available concerning age and growth and other aspects about the fishery and because we found many sardine otoliths in good condition.

Spatial and temporal correlation in composition of diet was compared by using the Spearman rank correlation coefficient (R_S) (Fritz, 1974). Pairs of IIMP values were used for each prey taxon in a pair of sampling events (rookeries or sampling dates) to examine the correlation among them. This analysis was limited to prey that had an IIMP value of 10% or more. Cluster analysis of average IIMP data for the seven rookeries was used to assess the similarity of the diet among rookeries. The dendrogram for the cluster analysis was based on relative Euclidean distances and unweighted pair-grouping methods (UPGMA) strategy (Ludwig and Reynolds, 1988). We included only prey that, for at least one occasion, had IIMP values ≥10%.

Trophic diversity was evaluated by using diversity curves (Hurtubia, 1973) developed from IIMP index data. For each date and colony, the cumulative diversity was calculated for increasing numbers of sequentially numbered (but we assumed randomly deposited and collected) scat samples. The diversity curves also allowed us to evaluate sample size (Hurtubia, 1973; Hoffman, 1978; Magurran, 1988, Cortés, 1997) by identifying the point at which the curve flattens. The diversity was estimated by using the Shannon index:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i, \qquad (2)$$

where H' = trophic diversity;
S = total number of prey taxa; and
P_i = $IIMP_i$, and represents the relative abundance of taxon i obtained from each scat and pooled from scat 1 up to the total number of scats collected.

The values of trophic diversity were then plotted against the number of pooled scats.

Results

Identification of prey

The 1273 scat samples collected during June 1995 through May 1996 (Table 1) yielded fish remains in 97.4% of the samples, cephalopod remains in 11.2%, and crustacean remains in 12.7%. Fish and cephalopods represented 95.3% and 4.7%, respectively, of the 5242 individual prey (excluding crustaceans). The occurrence and number of these prey groups changed temporally and spatially (Fig. 3). We identified 92 prey taxa to the species level, 11 to the genus level, and 10 to family level from 851 scats (Table 2). Remaining scats had damaged prey structures in a condition that prevented us from identifying species to the genus or family level.

We found nine main prey with IIMP average values ≥10% (Table 3): the Pacific cutlassfish (*Trichiurus lepturus*), the Pacific sardine (*Sardinops caeruleus*), the plainfin midshipman (*Porichthys* spp.), myctophid no. 1, the northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), the anchoveta (*Cetengraulis mysticetus*), jack mackerel (*Trachurus symmetricus*), and the lanternfish (unid. myctophid).

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[4] García-Rodríguez, F. J., and J. De la Cruz-Agüero. In prep. An index to measure the specie prey importance of California sea lion (*Zalophus californianus*) based on scat samples.

[5] Alvarado-Castillo, R. Unpubl. data. Departamento de Biología y Pesquerías, Centro Interdisciplinario de Ciencias Marinas. Avenida IPN S/N Col. Palo Playa de Santa Rita, La Paz, Baja California Sur, México 23070.

Table 1

Number of scats collected at each rookery for each sampling period.

	June 1995	September 1995	January 1996	May 1996	Total
San Pedro Mártir (SPM)	22	33	88	29	172
San Esteban (EST)	50	66	91	67	274
El Rasito (RAS)	11	56	58	25	150
Los Cantiles (CAN)	20	58	47	35	160
Isla Granito (GRA)	24	20	41	19	104
Los Machos (MAC)	39	32	36	0	107
Isla Lobos (LOB)	72	139	72	23	306
Total	238	404	433	198	1273

Spatial and temporal variability of the main prey

The importance (IIMP) of the Pacific cutlassfish was greater in Los Cantiles (28.4%), Isla Lobos (20.8%), and Isla Granito (48.5%) than at other sites (Fig. 4). The Pacific sardine was the dominant prey at Los Machos and to the south. There was a significant correlation across the seasons between Los Machos and El Rasito (r=0.998, P=0.04), but not between Los Machos and Isla Granito (r=0.602, P=0.59). The IIMP of sardine was also correlated between El Rasito and San Esteban (r=0.95, P=0.04). The plainfin midshipman did not show a clear pattern, but its presence in the diet increased northeastward from Isla Angel de la Guarda. Lanternfishes, especially myctophid no. 1, were the dominant prey at San Pedro Mártir, San Esteban, and El Rasito. The presence of Pacific mackerel was positively correlated with the presence of the Pacific sardine. The anchoveta was only found at Isla Lobos, and jack mackerel at El Rasito, San Pedro Mártir, and Isla Granito.

The changes in the PO of the main prey coincided with the variations of the IIMP. The occurrence of Pacific cutlassfish, Pacific sardine, plainfin midshipman, northern anchovy, Pacific mackerel, and jack mackerel was significantly different (P<0.04) among rookeries. Myctophid no. 1 showed no significant difference in ocurrence (χ^2=11.04, df=6, P=0.09); but when all lanternfishes were pooled, their occurrence among rookeries was significantly different (χ^2=11.13, df=6, P=0.04). We found significant temporal differences in the occurrence of Pacific cutlassfish, Pacific sardine, plainfin midshipman, northern anchovy, and Pacific mackerel (P<0.05), but no significant differences were found among seasons in the occurrence of jack mackerel (χ^2=2.94, df=3, P=0.40), myctophid no. 1 (χ^2=1.67, df=3, P=0.6428), or lanternfish (χ^2=2.08, df=3, P=0.5562).

Size of Pacific sardine consumed by sea lions

The estimated size of the Pacific sardine found in scat was between 101.8 mm and 179.7 mm (mean length of 150.4 mm ±13.7 mm). Significant differences were found among sampling periods (F=4.79, df=2, P=0.01), specifically between June and January (Newman-Keuls test; P=0.04) and between September and January (Newman-Keuls test; P=0.01). The average size was 147.4 mm (±16.1 mm) in June, 151.7 mm (±13.0 mm) in September, and 136.5 mm (±13.7 mm) in January (Fig. 5). A similar pattern was found in Los Cantiles, Los Machos, and Isla Granito.

Spatial and temporal correlation in diet

We identified 25 prey taxa that had an IIMP index value of ≥10% (Table 3) for a given collection. The Spearman rank correlation coefficient of IIMP between any pair of rookeries during June, September, January, and May was not significant (P>0.08). There was no positive correlation among any pair of sampling periods for any rookery (P>0.14), except between January and May at San Pedro Mártir (R_S=0.64, P<0.05) and El Rasito (R_S=0.66, P<0.05) and between January and June as well as between January and May at Isla Lobos (R_S=0.56, P=0.05; and R_S=0.59, P=0.05, respectively).

The similarity in diet was related to the distance between rookeries. A clustering for the seven rookeries was obtained from these 25 prey taxa (Fig 6). We arbitrarily used a "cutoff" distance of 0.3 and 0.4 on the dendrogram as reference points for identifying clusters. The group obtained by using the first distance (0.3) showed four feeding areas: one located in the south (area I: San Pedro Mártir, San Esteban, and El Rasito), another in Canal de Ballenas (area II: Los Machos) and two in the north (area III: Los Cantiles and Isla Lobos; and area IV: Isla Granito). When the second distance (0.4) was used, the seven rookeries grouped into two clusters: 1) the southern region and Canal de Ballenas, and 2) the region north of Angel de la Guarda.

Spatial and temporal variability in trophic diversity

Temporal variability in trophic diversity was evident between the rookeries (Fig. 7). In general, two patterns could be differentiated: one in which the diversity varied little throughout the year and the other in which diversity was high in January and low in September. The rookeries San Pedro Mártir and Isla Lobos showed the first pattern and Los Machos and Isla Granito (and to a lesser extent, San Esteban and El Rasito) showed the second pattern. In September, when diversity was low, the dominant prey at

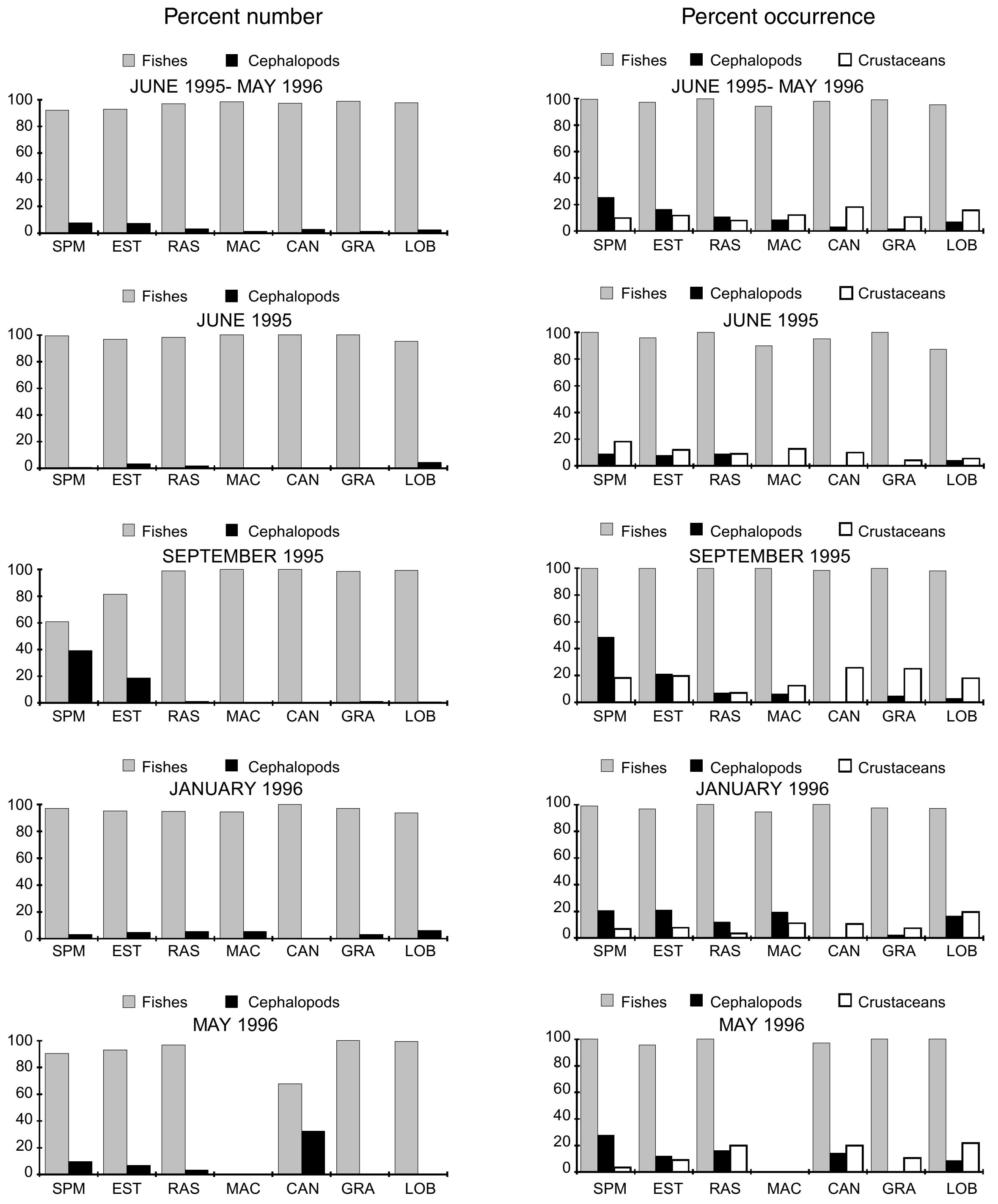

Figure 3

Percent number (PN) and percent occurrence (PO) index values for fishes, cephalopods, and crustaceans found in samples of California sea lion scats collected at seven rookeries in the Gulf of California, Mexico, for all sampling periods combined and for each sampling period.

San Esteban, El Rasito, and Los Machos was Pacific sardine, whereas at Isla Granito, it was Pacific cutlassfish (Fig. 4). The curves obtained for Los Cantiles showed a clear pattern of diversity only in September, although the trend in the January curve would suggest a higher diversity in January than in September.

Table 2

Prey of California sea lion identified from scat samples collected at Isla San Pedro Martir, Isla San Esteban, Isla El Rasito, Los Cantiles, Isla Granito, Los Machos and Isla Lobos from June 1995 through May 1996. *n* ind. = number of individuals in the sample; PN = percent number; n occurr = number of occurrences; PO = percentage of occurrence; IIMP = index of importance.

Scientific name	Common name	*n* Ind.	PN	*n* Occurr.	PO	IIMP
Trichiurus lepturus	Pacific cutlassfish	306	5.837	128	15.041	16.392
Sardinops caeruleus	Pacific sardine	358	6.829	88	10.341	10.020
Porichthys spp.	midshipman	456	8.699	95	11.163	9.297
Myctophid no. 1	lanternfish	714	13.621	119	13.984	7.901
Engraulis mordax	northern anchovy	430	8.203	43	5.053	5.199
Scomber japonicus	Pacific mackerel	103	1.965	42	4.935	3.403
Cetengraulis mysticetus	anchoveta	410	7.821	15	1.763	2.404
Loliolopsis diomedeae	squid	77	1.469	35	4.113	2.399
Trachurus symmetricus	jack mackerel	111	2.118	41	4.818	2.273
Merluccius spp.	Pacific whiting	55	1.049	25	2.938	2.206
Pontinus spp.	scorpionfish	61	1.164	26	3.055	1.842
Enoploteuthid no. 1	squid	95	1.812	23	2.703	1.754
Caelorinchus scaphopsis	shoulderspot	65	1.240	25	2.938	1.728
Octopus sp. no. 1	octopus	24	0.458	17	1.998	1.614
Sebastes macdonaldi	Mexican rockfish	42	0.801	18	2.115	1.496
Citharichthys sp no. 1	sanddab	120	2.289	23	2.703	1.220
Fish species no. 1	—	49	0.935	25	2.938	1.153
Haemulopsis leuciscus	white grunt	176	3.357	21	2.468	1.093
Peprilus snyderi	salema butterfish	163	3.110	33	3.878	1.025
Prionotus spp.	searobin	12	0.229	9	1.058	0.855
Prionotus stephanophrys	lumptail searobin	53	1.011	14	1.645	0.814
Argentina sialis	Pacific argentine	19	0.362	13	1.528	0.754
Fish species no. 2	—	55	1.049	27	3.173	0.737
Hemanthias peruanus	splittail bass	60	1.145	22	2.585	0.602
Fish species no. 3	—	9	0.172	6	0.705	0.592
Micropogonias ectenes	slender croaker	13	0.248	9	1.058	0.547
Lepophidium spp.	cusk-eel	9	0.172	3	0.353	0.532
Fish species no. 4	—	10	0.191	3	0.353	0.511
Sebastes exsul	buccanner rockfish	15	0.286	10	1.175	0.505
Cranchiid no. 2	Squid	20	0.382	12	1.410	0.501
Haemulon flaviguttatum	yellowspotted grunt	11	0.210	3	0.353	0.468
Selar crumenophthalmus	bigeye scad	24	0.458	12	1.410	0.431
Fish species no. 5	—	33	0.630	19	2.233	0.384
Paralabrax sp. no. 1	sea bass	9	0.172	5	0.588	0.373
Synodus sp. no. 3	lizardfish	10	0.191	3	0.353	0.341
Lepophidium prorates	prowspine cusk-eel	5	0.095	4	0.470	0.335
Fish species no. 6	—	9	0.172	5	0.588	0.324
Synodus sp. no. 1	lizardfish	25	0.477	10	1.175	0.324
Octopus sp, no. 2	octopus	8	0.153	7	0.823	0.308
Gonatus berryi	squid	5	0.095	5	0.588	0.274
Mugil cephalus	striped mullet	1	0.019	1	0.118	0.265
Paranthias colonus	Pacific creole-fish	1	0.019	1	0.118	0.265
Balistes polylepis	finescale triggerfish	13	0.248	4	0.470	0.245
Physiculus nematopus	charcoal mora	30	0.572	12	1.410	0.244
Hemanthias spp.	sea bass	9	0.172	6	0.705	0.234
Fish species no. 7	—	10	0.191	8	0.940	0.233
Uroconger varidens	conger eel	8	0.153	5	0.588	0.189
Larimus spp.	drum	8	0.153	6	0.705	0.174
Apogon retrosella	barspot cardinalfish	5	0.095	4	0.470	0.173
Dosidicus gigas	squid	8	0.153	5	0.588	0.171

continued

Table 2 (continued)

Scientific name	Common name	*n* Ind.	PN	*n* Occurr.	PO	IIMP
Merluccius productus	Pacific whiting	1	0.019	1	0.118	0.167
Fish species no. 8	—	2	0.038	2	0.235	0.159
Synodus sp. no. 2	lizardfish	12	0.229	5	0.588	0.132
Scorpaena sonorae	Sonora scorpionfish	2	0.038	1	0.118	0.130
Eucinostomus spp.	mojarra	13	0.248	5	0.588	0.129
Fish species no. 9	—	3	0.057	3	0.353	0.127
Cynoscion reticulatus	striped weakfish	23	0.439	7	0.823	0.124
Fish species no. 10	—	10	0.191	1	0.118	0.122
Caulolatilus affinis	bighead tilefish	4	0.076	3	0.353	0.114
Paralabrax auroguttatus	goldspotted sand bass	18	0.343	4	0.470	0.110
Fish species no. 11	—	3	0.057	2	0.235	0.102
Cranchiid no. 5	squid	1	0.019	1	0.118	0.097
Bodianus diplotaenia	mexican hogfish	1	0.019	1	0.118	0.087
Prionotus sp. no. 1	searonbin	2	0.038	2	0.235	0.087
Strongylura exilis	california needlefish	1	0.019	1	0.118	0.083
Synodus spp.	lizardfish	6	0114	5	0.588	0.146
Fish species no. 12	—	3	0.057	3	0.353	0.074
Fish species no. 13	—	2	0.038	1	0.118	0.065
Fish species no. 14	—	3	0.057	1	0.118	0.060
Fish species no. 15	—	2	0.038	1	0.118	0.058
Fish species no. 16		2	0.038	2	0.235	0.056
Porichthys sp. 1	midshipman	1	0.019	1	0.118	0.052
Fish species no. 17	—	5	0.095	3	0.353	0.049
Calamus brachysomus	Pacific porgy	5	0.095	2	0.235	0.043
Fish species no. 18	—	1	0.019	1	0.118	0.042
Fish species no. 19	—	5	0.095	2	0.235	0.041
Ophididae no. 1	—	1	0.019	1	0.118	0.040
Fish species no. 20	—	5	0.095	3	0.353	0.039
Sebastes sinesis	blackmouth rockfish	2	0.038	1	0.118	0.039
Symphurus spp.	tonguefish	3	0.057	1	0.118	0.038
Fish species no. 21	—	2	0.038	1	0.118	0.036
Pronotogrammus multifasciatus	threadfin bass	8	0.153	2	0.235	0.029
Fish species no. 22	—	2	0.038	2	0.235	0.027
Fish species no. 23	—	2	0.038	1	0.118	0.021
Orthopristis reddingi	Bronze-striped grunt	16	0.305	1	0.118	0.020
Fish species no. 24	—	2	0.038	1	0.118	0.020
Fish species no. 25	—	1	0.019	1	0.118	0.016
Cranchiidae no. 4	squid	2	0.038	2	0.235	0.014
Fish species no. 26	—	2	0.038	2	0.235	0.014
Histioteuthis heteropsis	squid	1	0.019	1	0.118	0.014
Scorpaenidae no. 1	—	1	0.019	1	0.118	0.011
Fish species no. 27	—	3	0.057	2	0.235	0.011
Fish species no. 28	—	1	0.019	1	0.118	0.010
Fish species no. 29	—	1	0.019	1	0.118	0.008
Cranchiidae no. 3	squid	1	0.019	1	0.118	0.006
Bollmannia spp.	goby	1	0.019	1	0.118	0.006
Fish species no. 30	—	1	0.019	1	0.118	0.005
Cranchiidae no. 1	squid	1	0.019	1	0.118	0.004
Paralabrax maculatofasciatus	spotted sand bass	1	0.019	1	0.118	0.003
Ophidion scrippsae	basketweave cusk-eel	1	0.019	1	0.118	0.003
Physiculus spp.	cod, codling, mora	2	0.038	1	0.118	0.003
Ophididae no. 2	—	4	0.076	1	0.118	0.002
Unid. Carangidae	jacks	8	0.153	3	0.353	0.141

continued

Table 2 (continued)

Scientific name	Common name	*n* Ind.	PN	*n* Occurr.	PO	IIMP
Unid. Engraulidae	anchovies	1	0.019	1	0.118	0.248
Unid. Haemulidae	grunts	13	0.248	11	1.293	0.509
Unid. Labridae	wrasses	1	0.019	1	0.118	0.005
Unid. Mycthophidae	lanternifishes	216	4.121	71	8.343	4.895
Unid. Ophididae	cusk-eel	2	0.038	1	0.118	0.098
Unid. Scianidae	drums	13	0.248	9	1.058	0.643
Unid. Scorpaenidae	scorpionfishes	30	0.572	18	2.115	1.078
Unid. Serranidae	sea bass	13	0.248	6	0.705	0.176
Unid. Triglidae	searobins	1	0.019	1	0.118	0.002
	Unid. fishes	39	0.744	16	1.880	1.819
	Unid. cephalopods	4	0.076	4	0.470	0.373
	Unid. fishes (very eroded)	381	7.268	231	27.145	
	Remains of cephalopods			14	1.645	
	Remains of crustaceans			162	19.036	

Discussion

Stomach acids attack otoliths, affecting their size and number and consequently the estimate of prey occurrence and importance. Erosion of otoliths during digestion has been analyzed in studies of pinnipeds in captivity. Bowen (2000) reviewed nine studies that estimated the proportion of otoliths recovered in scat samples to obtain a prey-number correction factor (NCF). He found that NCF is greater than 1.0 because many prey species are not recovered in the scat samples. Additionally, the erosion level can be significantly different among prey species (Bowen, 2000) because of differences in the shape and microstructure of otoliths. Therefore, estimates of biomass based on scat analysis should be carefully interpreted because the consumption of some prey species can be under- or overestimated. Correction factors are needed to compensate for differential erosion for the prey species of each pinniped.

In this study the most important prey of California sea lions were pelagic fish with small, thin, and fragile otoliths (Nolf, 1993). The lanternfish also have small otoliths—perhaps smaller than those of any other prey taxa found in the scats. Their true importance in California sea lion feeding may be underestimated because of erosion caused by stomach acids (Da Silva and Neilson, 1985; Murie and Lavigne, 1985; Jobling and Breiby, 1986; Jobling, 1987; Tollit et al., 1997). Similarly, the presence of cephalopods may have been underestimated because their jaws are composed of chitin, which is harder to digest, and frequently are regurgitated (Pitcher, 1980; Hawes, 1983). However, the high resistence to digestion of cephalopod beaks allows recovery of them in good shape. Thus they are a good choice to use in such diet analyses (Lowry and Carretta, 1999).

A numerical index of prey species importance may over- or underestimate the dominance of prey species in the diet because it does not consider the weight of the prey. For IIMP, a numerical index that assumes a similar weight for all prey species, the true importance of the individual large prey in the diet can be underestimated and the importance of individual small prey can be overestimated. This problem is also present when the PO, PN, and the SSFO index are used because these are all based only upon the number and occurrence of otoliths and cephalopods beaks. As when using PN, and the SSFO, the IIMP does not work for species that cannot be enumerated, such as crustaceans.

Given the tendencies of the trophic diversity curves, the sample size was suitable in almost all cases. However, at San Pedro Mártir a few more samples would have been useful to fully depict the diet. At Los Cantiles, except during September 1995, the samplings should have been more intense because the flattened portion of the diversity curves are not clear. The information, therefore, that comes from those samples could be biased. However, the number of scats that we analyzed contained a high percentage of the consumed species, especially the main prey.

The results of this study indicate that the California sea lion consumed mainly fish and some crustaceans and cephalopods. According to the PN index, fish were more important than cephalopods in the diet of sea lions. In addition, fish were more frequent (PO) than crustacean and cephalopods.

Crustaceans were represented in a similar manner in scats from all rookeries. Cephalopods, however, were more important at San Pedro Mártir and San Esteban, probably because they are more common towards the southern gulf. Species of the suborder Oegopsida, which includes oceanic species (Roper and Young, 1975), were most commonly found in scats from these rookeries. Orta-Dávila (1988) and Sánchez-Arias (1992) have also noted the low consumption of cephalopods at the northern rookeries. Fish were the most diverse and commonly eaten prey. In contrast to cephalopods, fish were slightly less important in the southern region.

The availability and abundance of the various prey resources influenced the diet of the sea lions in the Gulf

Table 3

Prey of California sea lions having IIMP index values ≥10% in at least one sampling period for seven rookeries in the Gulf of California, Mexico. Blank indicate that species were not recorded in diet; "—" means unavailable data.

	Prey species	June 1995	September 1995	January 1996	May 1996	Average
San Pedro Martir	*Engraulis mordax*	29.7		2.1	0.5	8.1
	myctophid no. 1	29.0	10.5	9.0	20.5	17.3
	Porichthys spp.	11.2	2.0	6.8	15.5	8.9
	Prionotus stephanophrys	0.6	3.3	3.3	10.9	4.5
	enopleoteuthid no.1		27.3	0.8		7.0
	Sebastes macdonaldi		10.4			2.6
	Haeumulopsis leuciscus			16.7	6.0	5.7
San Esteban	*Trichiurus lepturus*	24.9	3.4		3.0	7.8
	Sardinops caeruleus	10.0	34.1		4.2	12.1
	unid. Myctophidae	13.79	3.4	4.3	10.9	8.1
	myctophid no. 1	2.8	11.8	8.9	18.8	10.6
	enopleoteuthid no. 1		16.9			4.2
	Sebastes macdonaldi		2.1	9.7	1.4	3.3
	fish species no. 1			1.7	11.0	3.2
El Rasito	*Porichthys* spp.	26.2	4.0	2.3		8.1
	unid. Myctophidae	16.4	1.5	8.1	16.4	10.6
	Scomber japonicus	13.8	3.2	3.7	2.5	5.8
	Pontinus spp.	11.5	5.1	4.1	10.9	7.9
	Octopus sp. no.1	11.5		2.9	7.7	5.5
	myctophid no. 1	6.6	5.1	21.4	6.8	10.0
	Sardinops caeruleus	1.6	40.1	0.9	7.3	12.5
	Trachurus symmetricus		22.0	5.0	23.4	12.6
	Caelorinchus scaphopsis		3.6	13.5	10.5	6.9
Los Machos	*Sardinops caeruleus*	21.0	64.1	16.8	—	34.0
	Scomber japonicus	19.0		10.9	—	10.0
	Merluccius spp.	15.4		8.2	—	7.9
	Trichiurus lepturus	11.7	5.4		—	5.7
	Sebastes macdonaldi	1.8		11.3	—	4.4
Los Cantiles	*Porichthys* spp.	66.7	15.5			20.6
	Trichiurus lepturus	22.2	38.2		53.1	28.4
	Engraulis mordax	3.7	0.4	14.3		4.6
	myctophid no. 1		17.6	4.8		5.6
	Sardinops caeruleus		6.8	19.0		6.5
	fish species no. 3		0.9	14.3		3.8
	unid. fishes		0.9	19.0		5.0
	unid. Scianidae			14.3		3.6
	Lepophidium spp.			14.		3.5
	Loliolopsis diomedeae				21.1	5.3
Isla Granito	*Engraulis mordax*	49.3	7.8			14.3
	Trichiurus lepturus	22.0	70.1	2.0	100.0	48.5
	unid. myctophidae	1.7	1.1	12.6		3.9
	Sardinops caeruleus	0.9		18.7		4.9
	Porichthys spp.	0.5	18.2	4.6		5.8
	Citharichthys sp. no. 1			21.7		5.4
Isla Lobos	*Cetengraulis mysticetus*	32.7	0.1	6.8	27.8	16.9
	Trichiurus lepturus	25.2	27.7	15.8	14.3	20.8
	Porichthys spp.	9.0	10.3	23.2	35.5	19.5
	Loliolopsis diomedeae	4.9	2.2	11.6	3.5	5.6
	Peprilus snyderi		23.5	5.2		7.2

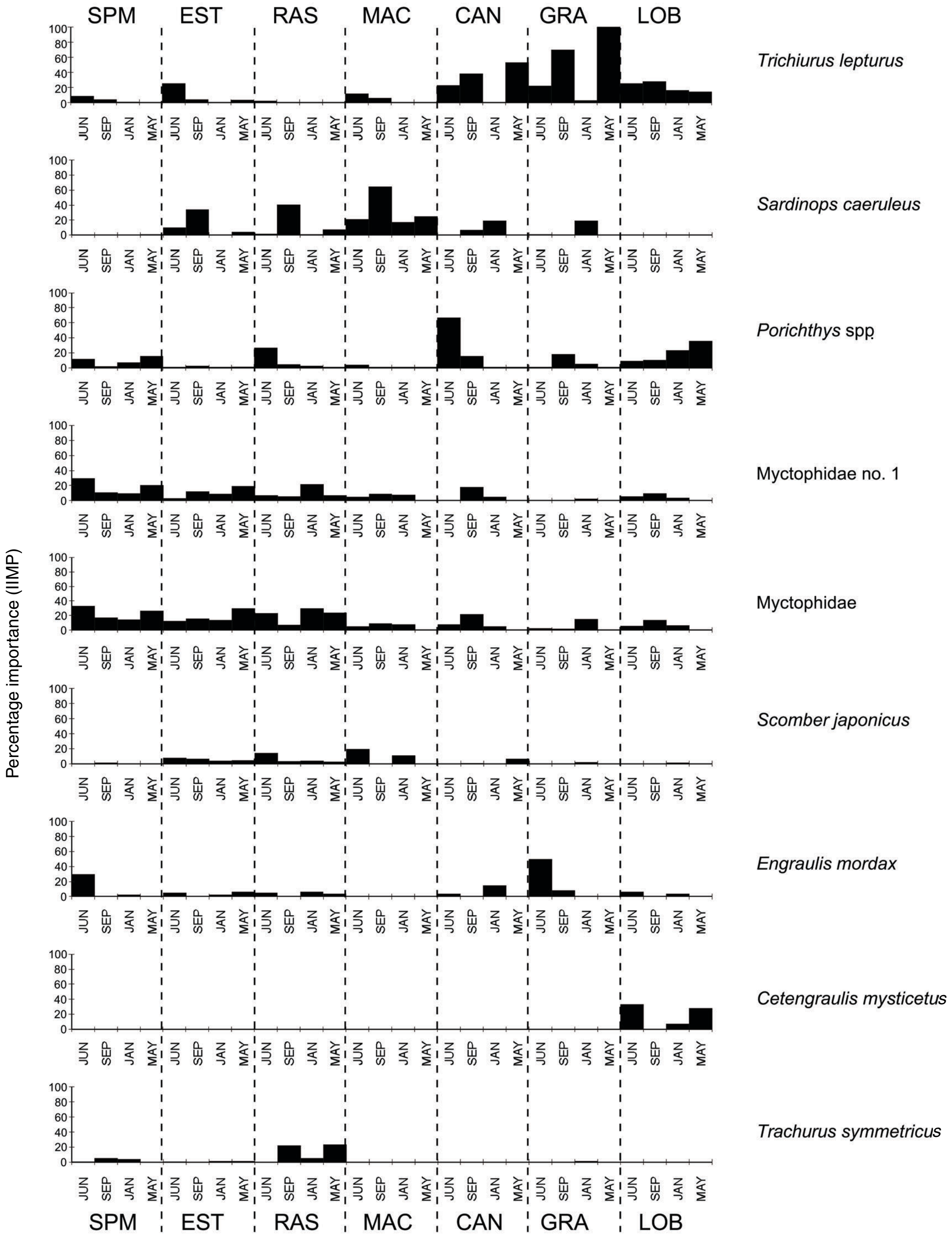

Figure 4

Index of importance (IIMP) for nine prey species identified from samples of California sea lions scats collected at seven rookeries in the Gulf of California, Mexico, during June and September 1995, and January and May 1996.

of California. The distribution pattern of Pacific sardine closely agrees with its importance in the sea lions diet. The Pacific sardine occurred in high concentrations around Angel de la Guarda and Isla Tiburon during the summer and along the coast of southern Sonora during the winter, where spawning occurs (Cisneros-Mata et al.[3]). Sardines were consumed in the Canal de Ballenas region during the summer (September), when they are very abundant. Larger size Pacific sardines were consumed by sea lions most frequently during the summer when adult sardines occur more frequently in the Canal de Ballenas. As adult sardine left Canal de Ballenas (Cisneros-Mata et al., 1997), the proportion of young individuals in the diet of sea lions increased. The fish eaten by sea lions were apparently smaller than those captured by the commercial fisheries. The average estimated size of the sardines consumed was 150.4 mm, whereas the average size of commercially caught fish during the 1995–96 season was 162.4 mm (Cisneros-Mata et al.[3]). This 7% difference in size may have been caused by an underestimation of otolith size because of digestive erosion (Jobling and Breiby, 1986). If this is so, then the size of Pacific sardines consumed by sea lions is similar to the size of those captured by the fishery.

Isla Lobos was the only rookery where Pacific sardine was not consumed. This finding differs from those of Cisneros-Mata et al.[3] which show the Pacific sardines present as far north as Isla Lobos. However, their study period was during the 1991–92 El Niño episode, whereas our study occurred during normal oceanographic conditios in 1995–96.

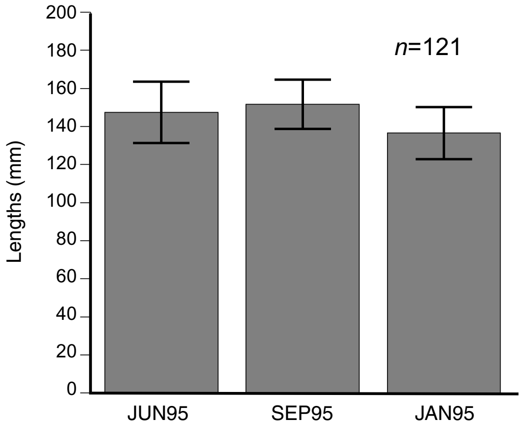

Figure 5

Size of Pacific sardine (*Sardinops caeruleus*) estimated from otoliths found in California sea lions scats collected in Isla San Esteban, El Rasito, Granito, Los Cantiles, and Los Machos. One standard deviation is indicated from each mean.

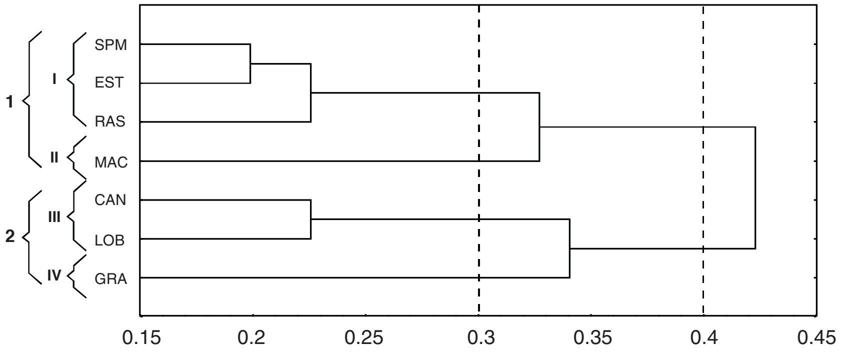

Figure 6

Dendrogram of cluster analysis of seven rookeries determined with Euclidean distance (computed from the IIMP of the 25 prey that had on at least one occasion a value ≥10%) and the UPGMA (unweighted pair-grouping methods) strategy. The vertical lines represent the points of references to delimit the groups.

Less is known about the spatial and temporal availability of other important prey. As with commercial captures (Arvizu-Martinez, 1987), Pacific mackerel occurred together with Pacific sardine. Similar variations in occurrence for both species have been noticed from stomach content analyses of the giant squid (*Dosidicus gigas*) (Ehrhardt, 1991). Lanternfishes were abundant north of Isla Angel de la Guarda (Robison, 1972); however they were not important in the diet of the California sea lion in this region. Their greater importance in the diet at southern rookeries was probably due to the absence of more preferred prey such as Pacific sardine, Pacific cutlassfish, or anchoveta. The consumption of northern anchovy tended to be less important towards Canal de Ballenas, where Pacific sardine reached its maximum importance. The low spatial overlap of these two species has also been noted in other studies. The anchoveta was present only at Isla Lobos. This is an estuarine-lagoon species, typical of coastal lagoons of northern Sinaloa and Sonora (Castro-Aguirre et al., 1995). The presence of this prey in Isla Lobos is possibly due to the sandy coast (Walker, 1960), which is similar to that of the Sinaloa-Sonora coast.

The diet of California sea lions differed among rookeries, probably due to differences in feeding sites and prey availability. Antonelis et al. (1990) studied the foraging characteristics of the northern fur seal (*Callorhinus ursinus*) and the California sea lion at San Miguel Island and found differences between foraging areas among species. The northern fur seal was found most frequently foraging in oceanic water within 72.4 km from the island, whereas Califorinia sea lions forgaged more often in the shallower neritic zone, within 54.2 km from the island. Different foraging distances in California sea lions from San Miguel Island were found by Melin and DeLong (1999). During the nonbreeding season a higher percentage of foraging locations occurred at distances less than 100 km, whereas during the breeding season most of the foraging locations occurred at distances greater than 100 km. These differences are probably due to the increased California sea lion population in San Miguel; this increase in population forces sea lions to exploit new areas as a density-dependent response to population

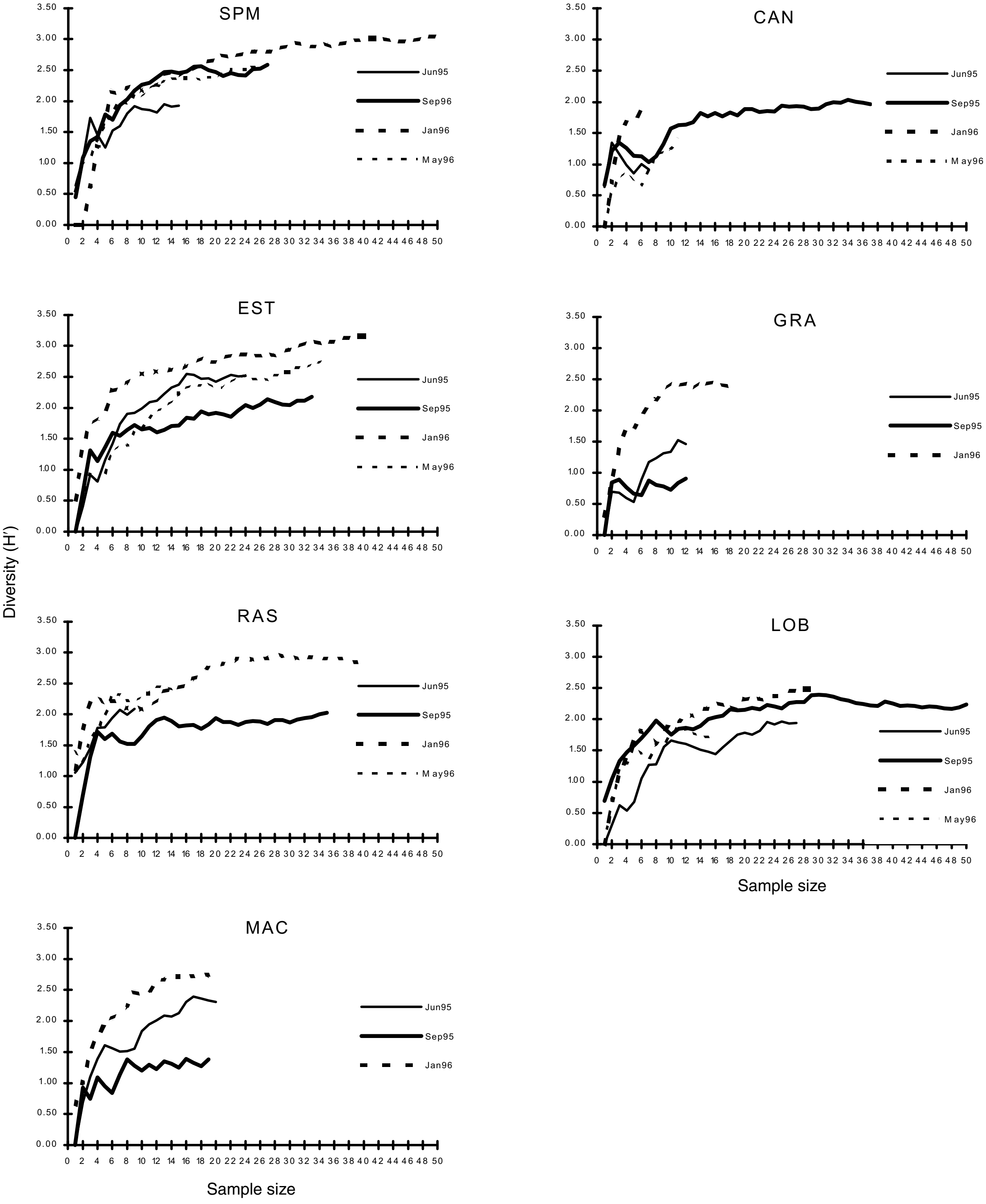

Figure 7

Trophic diversity curves for California sea lions determined from scat samples collected at seven rookeries in the Gulf of California, Mexico. SPM = San Pedro Mártir; EST = San Esteban; RAS = Isla Rasito; MAC = Los Machos; CAN = Los Cantiles; GRA = Isla Granito; LOB = Isla Lobos.

growth. Although, these differences could also be due to variability in the distribution of prey (Melin and DeLong, 1999), as suggested by Antonelis and Fiscus (1980), foraging areas might change with season and annual variations in prey availability and abundance.

Foraging areas in the Gulf of California could lie closer to rookeries than those recorded for San Miguel Island sea lions because the diet was different among rookeries in spite of the shorter distance between them (54.2 km). At Los Islotes, Baja California Sur, adult females fed within 20 km of the colony (Durán-Lizárraga, 1998). Kooyman and Trillmich (1986a, 1986b) reported similar data in sea lion colonies of the Galapagos Islands. In the northern region of the Gulf of California, feeding range could be shorter than that at Los Islotes because of the higher concentration of food at high nutrient concentrations (phosphate, nitrate, nitrite, and silicate) in Canal de Ballenas that is associated with strong tidal mixing (Alvarez-Borrego, 1983).

Four foraging zones were discerned from dietary differences in sea lions from the seven rookeries studied. Zone I, which included San Pedro Mártir, San Esteban, and El Rasito, was characterized by the consumption of lanternfish; zone II, which included Los Machos was characterized by the consumption of Pacific sardine and Pacific mackerel; zone III, which included Isla Granito, by the consumption of Pacific cutlassfish and the northern anchovy; and zone IV, Los Cantiles and Isla Lobos, was characterized by the consumption of the plainfin midshipman and the Pacific cutlassfish. These four zones may indicate differences in habits used by sea lions or may indicate different oceanographic conditions exploited by sea lions. The eastern coast of the Gulf of California displays high photosynthetic pigment concentrations, associated with upwelling induced by winds from the northwest in the winter. These conditions may make Canal de Ballenas one of the most important for the distribution of Pacific sardine during the summer.

Trophic diversity varied spatially and temporally. San Pedro Mártir and Isla lobos sea lions seem to depend on a more stable feeding areas compared to sea lions at rookeries on Isla Granito and Los Machos, where changes in diversity of consumed species indicated that sea lions feed on fewer species during certain times of the year. Similar results in relation to the changes in diversity were also noticed in the rookeries of the Channel Islands and Farallon Islands, California (Bailey and Ainley, 1982; Antonelis et al., 1984; Lowry et al., 1990; Lowry et al., 1991). Perhaps the tendency to have the highest values of diversity and little seasonal variation at San Pedro Mártir is the result of this rookery being located in a zone of transition between two biogeographical areas. This geographical position confers greater environmental heterogeneity and greater ecological diversity (Walker, 1960).

California sea lions in the upper region of the Gulf of California obtain the main portion of their diet from a relatively small number of species. The decrease in abundance of any of these food resources can seriously affect the population, particularly at Isla Granito and Los Machos because sea lions from these rookeries depend on a few species.

Acknowledgments

We wish to thank Secretaria de Marina, Armada de Mexico, for its great support during the field activities, and the Consejo Nacional de Ciencia y Tecnologia (CONACYT) for funding this study under grant number 26430-N. The Secretaria de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP) provided permits for field work (DOO.-700-(2)01104 and DOO.-700(2).-1917). We would like to thank Robert Lavenberg and Jeff Siegel for allowing us the use of otoliths from the collection at the Natural Museum History of Los Angeles County and also Lawrence Barnes for his logistical support during the stay of first author at Los Angeles; we also thank Manuel Nava for allowing us the use of otoliths from the collection in Tecnologico de Monterrey, Campus Guaymas. We are also grateful to Unai Markaida for his assistance in prey identification based on the examination of cephalopods beaks. We thank Mark Lowry for commenting on an earlier draft of the paper, Norman Silverberg for reviewing the manuscript in English, and two anonymous reviewers for their valuable suggestions and criticism. The first author would like to thank Centro Interdisciplinario de Ciencias Marinas-IPN for a scholarship (PIFI, Programa Institucional para la Formación de Investigadores) assigned for postgraduate studies.

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