FILTERING APPARATUS AND FEEDING OF THE PACIFIC MACKEREL (*SCOMBER JAPONICUS*) IN THE GULF OF CALIFORNIA

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ABSTRACT

The filtering apparatus and the stomach contents of 350 Pacific mackerel (*Scomber japonicus*) were examined from sizes ranging between 80 and 280 mm standard length (SL). Fish were collected in the Gulf of California in 1993 and 1994. Analysis of the filtering apparatus showed that the adults of the species employ filter feeding because they have a small gill-raker gap, and that juveniles, which have the greatest gill-raker gap, are particle-feeders. Analysis of the stomach contents with the index of relative importance (IRI) showed that the most meaningful prey categories were fish larvae (*Engraulis mordax* and *Sardinops caeruleus*) followed by crustacean larvae (brachyurans and stomatopods), as well as calanoid copepods (*Calanus pacificus*, *Acartia* sp., and *Paracalanus* sp.). This study shows that the Pacific mackerel is a facultative carnivore that prefers zooplanktonic and micronektonic prey whose variability depends on seasonal changes. Because of its feeding habits, the fish is placed on the third and fourth trophic levels in the epipelagic environment of the Gulf of California.

INTRODUCTION

The Pacific mackerel, *Scomber japonicus* Houttuyn 1782, is a cosmopolitan species distributed in tropical and subtropical waters of the Atlantic, Indian, and Pacific Oceans, as well as in their marginal seas (Collette and Nauen 1983).

In the Eastern Pacific, the most important population is distributed in the California Current System, including the Gulf of California, where it is associated with marginal, nearshore upwelling. In the Gulf of California, the fish is distributed in the central and southern provinces in nearshore waters (Roedel 1948; Walker 1953).

Because of the importance of the Pacific mackerel fishery, many studies have been made, mostly related to its fisheries biology. These studies include age and size evaluations, reproductive and growth ratios, and migratory pathways (Kramer 1969; Schaefer 1980). But quantitative studies on its feeding ecology are scarce (Molina-Ocampo 1993).

The main objective of this study is to assess and describe the functional morphology of the filtering apparatus and its implications in food retention, as well as the composition and variability of the diet of the Pacific mackerel during four interannual periods.

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METHODS

We collected 350 specimens of Pacific mackerel from four experimental cruises in the Gulf of California carried out in August 1993 (13 stations, 110 fish); November 1993 (5 stations, 80 fish); January 1994 (2 stations, 80 fish); and September 1994 (4 stations, 80 fish). All samples were taken at night in the central and northern gulf (figure 1), with a midwater trawl with an 8-mm-opening mesh net. The size of fish caught was fairly homogeneous within three intervals of standard length (SL): 0–170 mm, 171–200 mm, and >200 mm. Each fish was

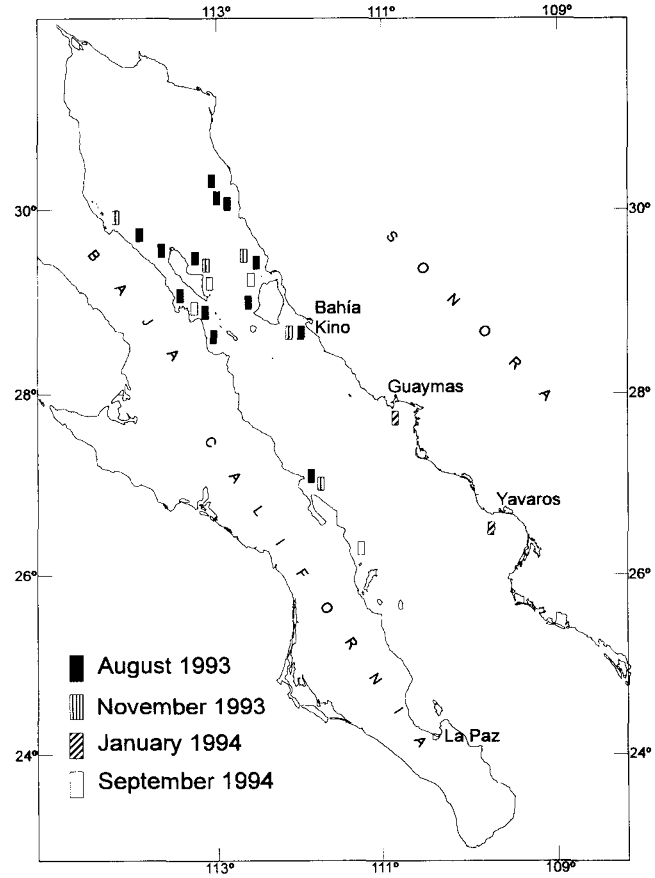

Figure 1. Study area showing locations and dates of collections of Pacific mackerel (*Scomber japonicus*) in the Gulf of California.

injected with 4% buffered formalin in the gastric cavity to avoid degradation of the stomach contents and loss of food material.

At the laboratory, the fishes were measured and dissected. The head was separated from the body, and the first branchial arch was removed from the main branchial basket in order to make counts and metric measures (Magnuson and Heitz 1971; Hammann 1985). The digestive tract was removed from the gastric cavity to make counts and gravimetric measures (Hyslop 1980; Molina-Ocampo 1993).

The stomach contents were recovered, placed in a 50-ml glass dish, and stained for 24 h in Bouin solution to facilitate the isolation and identification of food items (López-Martínez 1991). All examinations of the stomach contents were made with a stereoscopic microscope; the recognizable food items were identified to the lowest possible taxonomic level. Pielou's sample size method was used to determine the minimum sample size (Hoffman 1978).

We used the index of relative importance (IRI) described by Pinkas et al. (1971) to assess the importance of food items in the fish diet. The IRI equation can be expressed as

$$\mathrm{IRI}_j = (\%N_j + \%V_j) \times \%FO_j$$

where j is a taxon or prey category present in the stomach contents; $\%N$ is the percent number; $\%V$ is the percent volume; and $\%FO$ is the percent frequency of occurrence of j. These values were calculated from the following equations:

$$\%N_j = \frac{n_j}{\sum_{j=1}^{n} \mathrm{N}} \times 100$$

$$\%V_j = \frac{v_j}{\sum_{j=1}^{v} \mathrm{V}} \times 100$$

$$\%FO_j = \frac{e_j}{E} \times 100$$

where n_j and v_j are the numeric and volumetric ratio of j; e_j is the number of stomachs containing j; and E is the total number of examined stomachs. We calculated the unit volume for each prey category by using stereometric equations (Molina-Ocampo 1993).

We performed a chi-square (χ^2) statistical test of the stomach contents to determine if the Pacific mackerel were consuming items at random within the study period. A two-way, $R \times C$, contingency table was used, where R is the number of prey categories and C is the study period (Bernard et al. 1985).

The IRI makes it possible to rank the prey category by this combination index, and is represented in a three-way graph. Here, a rectangle with a vertical axis comprised of $\%N$ and $\%V$, and the horizontal axis, re-zeroed for each prey, representing $\%FO$, indicates the importance of the prey as a food item (Cailliet et al. 1990).

The first branchial arch belonging to each of 53 Pacific mackerel ranging from 80 to 280 mm SL was measured completely and by segments. We measured the length and width of each segment and counted the gill rakers. We also measured the gill-raker gap of 73 specimens ranging from 95 to 260 mm SL, and used the SL for regressions. We used a stereoscopic microscope equipped with an ocular micrometer with sensitivity of 0.01 mm for these examinations.

RESULTS AND DISCUSSION

Filtering Apparatus

The Pacific mackerel's branchial basket is formed by five pairs of branchial arches; the most external and largest has gill rakers on its external margin (figure 2). A feeding function specifically related to food retention is attributed to the gill rakers: they present a series of marginal teeth that, when interlocked with those of the adjacent gill rakers, form an extremely fine sieve. No gill rakers can be seen in arches 2 through 4; instead, there are protuberances that tend to disappear as the arches appear. The fifth branchial arch is completely modified as an epibranchial organ possessing a feeding function.

No significant bilateral differences were found in the development of the first branchial arch; the ceratobranchial segments on both sides of six specimens ranged in size as follows: 149, 157, 166, 187, 196, and 230 mm. Gill-raker length, as well as width ($t = 0.68$; $p = 0.05$), and the dimension of the gill-raker gap ($t = 0.29$; $p = 0.05$) had no significant morphometric variation.

The development of the filtering apparatus, indicated by the growth of the first branchial arch, is faster in the ceratobranchial segment than in the epibranchial and hypobranchial segments, which have very similar growth rates (figure 3). The length and width of the gill rakers measured in the first branchial arch showed a growth rate that increases with increasing development of the arch (figures 4 and 5). Furthermore, since both measures are greater than the growth rate of the branchial arch, the gill-raker gap in the whole filtering apparatus becomes reduced as the fish reaches its maximum length (figure 6). This morphological change is important, since the alimentary quality of smaller particles is greater.

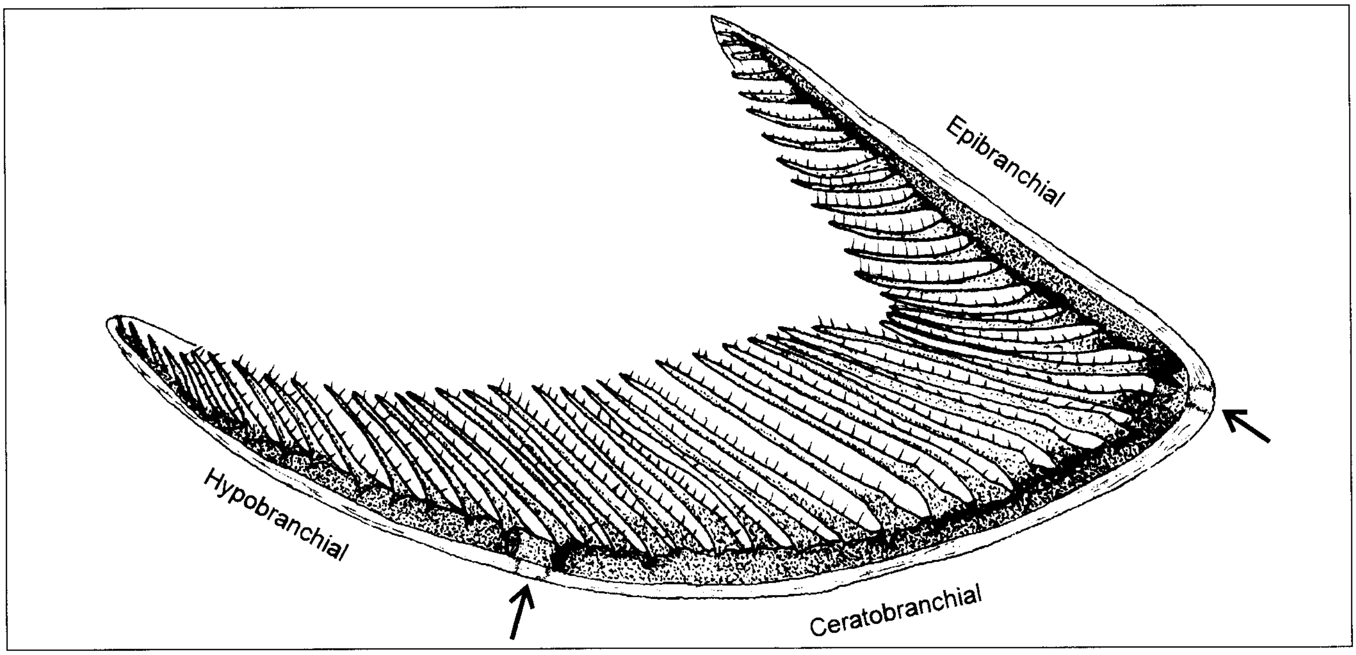

Figure 2. First branchial arch (*left side*) of a 196-mm SL specimen of Pacific mackerel. *Arrows* indicate the cartilaginous junctions of the three segments composing the arch.

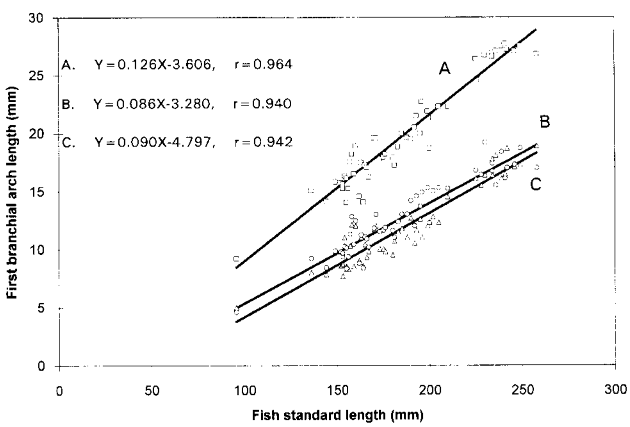

Figure 3. First branchial arch's segment dimensions versus standard length in the Pacific mackerel: *A*, ceratobranchial; *B*, hypobranchial; and *C*, epibranchial segments (n = 53).

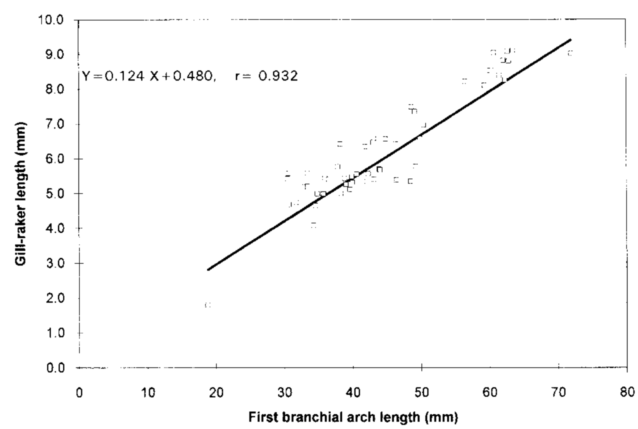

Figure 4. First branchial arch's gill-raker length versus arch length in the Pacific mackerel (n = 53).

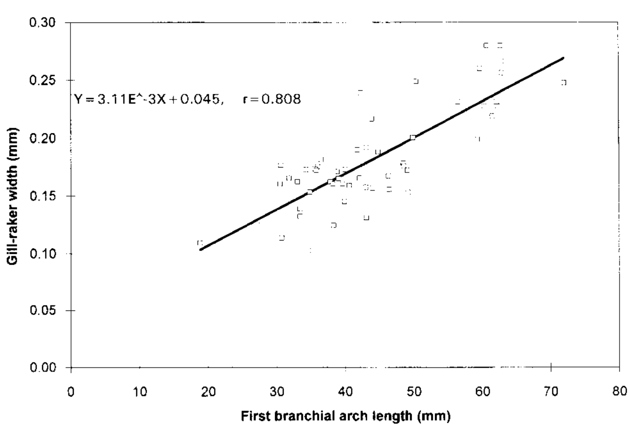

Figure 5. First branchial arch's gill-raker width versus arch length in the Pacific mackerel (n = 53).

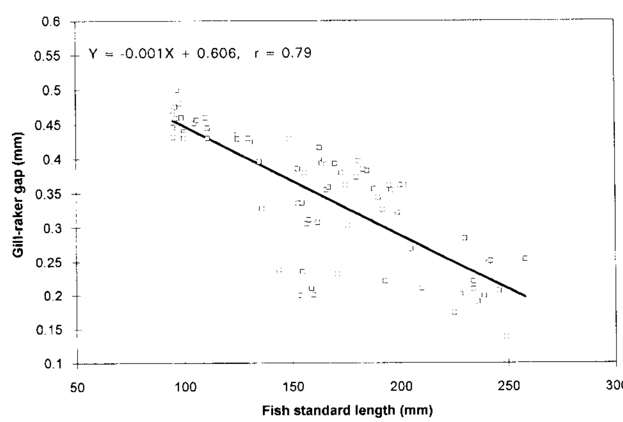

Figure 6. First branchial arch's gill-raker gap versus standard length in the Pacific mackerel (n = 73).

TABLE 1
Raw Data (%*N*, %*V*, and %*FO*) for Prey Categories and Index of Relative Importance (IRI) of the Pacific Mackerel (*Scomber japonicus*) Collected in the Gulf of California

	%*N*	%*V*	%*FO*	IRI	%IRI
August 1993					
Fish larvae	16	99.57	100	11,557	60.60
Crustacean larvae	30	0.21	100	3,021	15.84
Copepods	17	0.10	100	1,710	8.97
Euphausiids	6	0.04	75	453	2.38
Amphipods	6	0.03	75	452	2.37
ONI*	25	0.05	75	1,878	9.85
November 1993					
Fish larvae	6	98.45	100	10,445	54.21
Crustacean larvae	35	0.65	100	3,565	18.50
Copepods	7	0.11	100	711	3.69
Euphausiids	41	0.66	100	4,166	21.62
Chaetognaths	4	0.10	50	205	1.06
ONI*	7	0.03	25	175	0.91
January 1994					
Fish larvae	3	96.56	100	9,956	50.62
Crustacean larvae	41	1.63	100	4,263	21.68
Mollusc larvae	1	0.01	75	75	0.39
Copepods	27	0.89	100	2,789	14.18
Euphausiids	24	0.81	100	2,481	12.61
ONI*	4	0.10	25	102	0.52
September 1994					
Fish larvae	24	99.70	100	12,370	68.74
Crustacean larvae	41	0.19	100	4,119	22.89
Copepods	8	0.03	75	602	3.35
Euphausiids	4	0.02	50	201	1.12
Amphipods	5	0.02	50	251	1.39
ONI*	18	0.04	25	451	2.51

*Others not identified

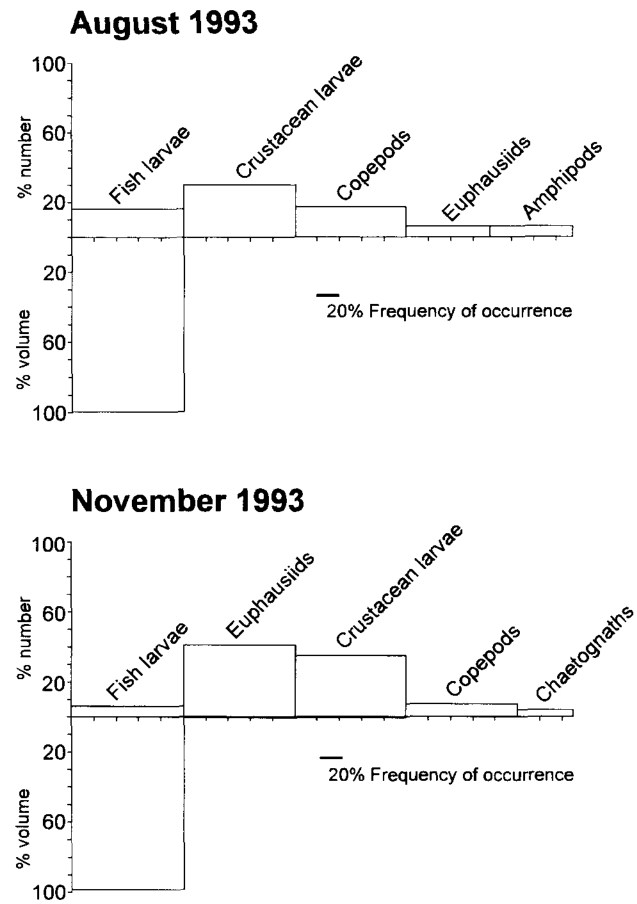

Figure 7. Graphic representation of the index of relative importance for the Pacific mackerel's diet during August and November 1993 ("others not identified" are not included).

Feeding Habits

The food items found in the stomachs of the Pacific mackerel show a facultative skew on the trophic spectrum, resulting in a high incidence of zooplanktonic and micronektonic prey as single food resources. The index of relative importance (IRI) associates seven prey categories—fish larvae, crustacean larvae, mollusk larvae, copepods, euphausiids, amphipods, and chaetognaths—as the main dietary components for the Pacific mackerel (table 1).

The diet composition based on the IRI during the study period (figures 7 and 8) shows that fish larvae were the largest component, contributing a minimum of 50.49% (for January 1994) and a maximum of 66.97% (for September 1994). The main prey category was the northern anchovy (*Engraulis mordax*), followed by clupeid larvae (probably belonging to the species *Sardinops caeruleus*), as well as myctophids, carangids, and sciaenids (figure 9).

The second group in relative importance was crustacean larvae, mainly composed of brachyuran zoeas and megalopas, as well as stomatopod alimas (figure 9), contributing average values of 19.71%.

The remaining groups were either present or absent at certain times and had a wider variation in IRI values. The copepods make up the transition group.

The taxonomic composition of the three trophic groups that are the major contributors to the diet of the Pacific mackerel is shown in figure 9.

The chi-square analysis for homogeneity showed a dietary variability during the study period (table 2) due to the fact that the abundance and availability of the food resources in the environment are a function of annual seasonal changes.

CONCLUSIONS

These studies on the filtering apparatus of the Pacific mackerel show that this species is a facultative-carnivorous feeder which employs particle feeding in preference to filter feeding. We found that a relation between the gill-raker gap and the ingested particle size could exist: the gill-raker gaps are smaller in the largest fish.

According to the IRI analysis, Pacific mackerel prefer certain prey categories, and consumption depends

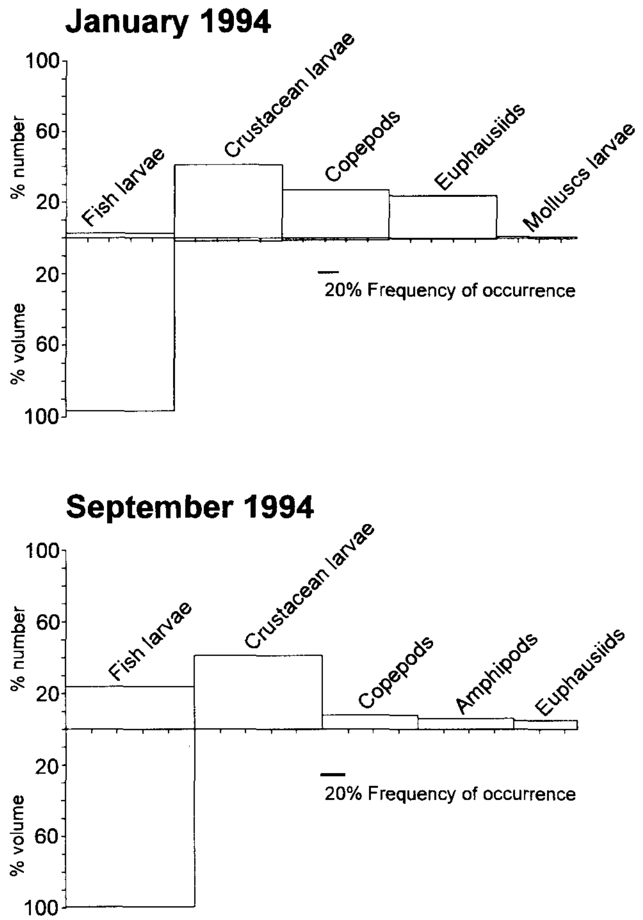

Figure 8. Graphic representation of the index of relative importance for the Pacific mackerel's diet during January and September 1994 ("others not identified" are not included).

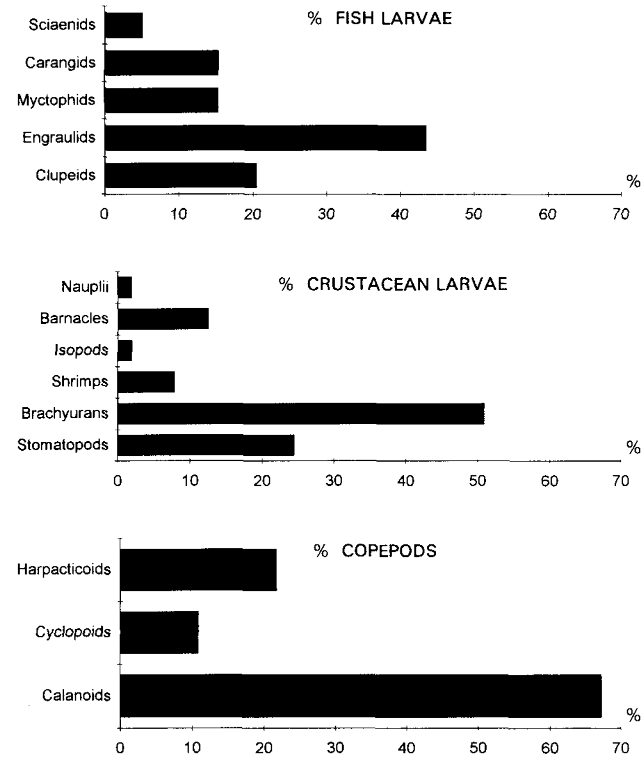

Figure 9. The three most meaningful prey categories (by taxonomic groups) in the Pacific mackerel's diet during the study period.

TABLE 2
Observed (Upper) and Expected (Lower) Values of the Percent Abundance for Seven Prey Categories of the Pacific Mackerel (*Scomber japonicus*) Collected in the Gulf of California

Prey category	Aug. 1993	Nov. 1993	Jan. 1994	Sep. 1994	Total
Fish larvae	16	6	3	24	49
	10.62	13.17	13.60	11.61	
Crustacean larvae	30	35	41	41	147
	31.86	39.51	40.79	34.84	
Mollusc larvae	0	0	1	0	1
	0.22	0.27	0.28	0.24	
Copepods	17	7	27	8	59
	12.79	15.86	16.37	13.98	
Euphausiids	6	41	24	4	75
	16.26	20.16	20.81	17.77	
Amphipods	6	0	0	5	11
	2.38	2.96	3.05	2.61	
Chaetognaths	0	4	0	0	4
	0.87	1.08	1.11	0.95	
Total	75	93	96	82	346

The prey abundance was shown to be time dependent through the statistical testing of the time independence (null) hypothesis, resulting in its rejection: chi-square (χ^2) = 111.97, degrees of freedom (df) = 18, confidence intervals (p) = 0.01, critical value (α) = 34.81.

mostly on prey distribution and availability. These latter factors are consequences of seasonal variations.

The Pacific mackerel, which preferentially uses zooplankton and fish larvae as food, is placed on the third and fourth trophic levels in the epipelagic ecosystem of the Gulf of California.

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