FOOD AND FEEDING OF BOCACCIO (*SEBASTES PAUCISPINIS*) AND COMPARISON WITH PACIFIC HAKE (*MERLUCCIUS PRODUCTUS*) LARVAE IN THE CALIFORNIA CURRENT

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ABSTRACT

The composition of the diet of larval bocaccio (*Sebastes paucispinis*) and Pacific hake (*Merluccius productus*) overlapped in copepod types and developmental stages, but important differences were evident from gut content analyses of specimens collected in 1975 CalCOFI cruises. Both bocaccio and Pacific hake larvae have large mouths, but first-feeding bocaccio preyed on smaller organisms than first-feeding hake (30-170 μm wide vs 40-350 μm in hake). Compared with small hake larvae, early stages of bocaccio ingested a greater diversity of food types including larval euphausiids, diatoms, dinoflagellates, tintinnids, and cladocerans. Although copepod nauplii constituted the dominant prey in bocaccio larvae less than 7.0 mm long, there was a total lack of adult copepods and very low incidence of copepodites in the diet. In contrast, adult copepods, primarily calanoids, made up a significant portion of the diet in all sizes of hake larvae examined, contributing about 74% of overall prey volume compared to about 33% in 7-13-mm bocaccio larvae.

Observations of feeding incidence in relation to time of capture suggested a faster rate of gut evacuation in bocaccio larvae.

RESUMEN

La composición del alimento ingerido por las larvas de *Sebastes paucispinis* y *Merluccius productus* abarca similares especies de copépodos adultos y sus fases de desarrollo, pero importantes diferencias fueron observadas en el análisis del contenido estomacal de los ejemplares recolectados durante los cruceros CalCOFI de 1975. Las larvas de *S. paucispinis* y de *M. productus* tienen boca grande. Las larvas de *S. paucispinis* al iniciar su alimentación, capturan organismos más pequeños que las larvas de *M. productus* (30-170 μm de ancho y 40-350 μm de ancho respectivamente). Las larvas más jovenes de *S. paucispinis* ingieren una mayor diversidad de organismos que las larvas de merluza, incluyendo las fases larvales de eufáusidos, diatomeas, dinoflagelados, tintínidos y cladóceros. Aun cuando en larvas de *S. paucispinis* menores de 7 mm de longitud, los nauplios de copépodos constituyeron la presa dominante, hubo una total ausencia de copépodos adultos y escasos copepoditos. En contraste, en las larvas de merluza examinadas los copépodos adultos, principalmente Calánidos constituyeron el 74% del volumen total, comparado con un 33% en las larvas de *S. paucispinis* de 7-13 mm. de longitud.

La incidencia de alimentación en relación con la hora de captura sugiere que las larvas de *S. paucispinis* efectuan una evacuación del tramo digestivo más rapida.

INTRODUCTION

Rockfish (*Sebastes* spp, family Scorpaenidae) larvae are among the most commonly occurring larvae in the California Current; they rank third or fourth in relative abundance in California Cooperative Oceanic Fisheries Investigations plankton surveys, with peak abundance during January and February (Ahlstrom 1961, 1965). Identification of the more than 60 species that occur off California and Baja California is a difficult task, but complete larval series of some important commercial species have been described, including that of bocaccio, *S. paucispinis* (Moser 1967a; Moser et al. 1977). Bocaccio is the most abundant rockfish species in commercial catches from central and northern California (Frey 1971). In southern California this species is important in recreational fisheries: bocaccio constitute 37% of all rockfishes taken on partyboats (Hartman 1980) and rank first or second among rockfish species taken on private boats (Wine 1982; Racine 1982; Ono 1982).

Considerable biological information is available on bocaccio, including age and growth (Phillips 1964), fecundity (Phillips 1964; MacGregor 1970), reproductive biology (Moser 1967a, b; MacGregor 1970), and development and distribution of early life-history stages (Moser 1967a; Moser et al. 1977; Ahlstrom et al. 1978). There are no data, however, on the feeding of bocaccio larvae. Feeding studies of larvae of other major species in the California Current region were reported by Arthur (1976) for northern anchovy (*Engraulis mordax*), sardine (*Sardinops sagax*), and jack mackerel (*Trachurus symmetricus*) and by Sumida

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and Moser (1980) and Bailey (1982) for hake (*Merluccius productus*). Bocaccio and other rockfishes differ from many marine fishes in their mode of reproduction. They are highly fecund live-bearers and give birth to larvae that are 4-5 mm long, with functional jaws, eyes, and pectoral fins. In *Sebastes*, the yolk-sac stage occurs within the ovaries, and newborn larvae are equivalent to the first-feeding larvae of oviparous species. As part of a continuing study of the feeding habits of larvae of California Current fishes, this paper summarizes data on stomach contents, mouth size, and feeding incidence of bocaccio larvae.

MATERIALS AND METHODS

Specimens examined in this study consisted of 96 larvae, 4.2-12.8 mm in body length, from 34 formaldehyde-preserved samples collected during the CalCOFI cruises of 1975 (7412, 7501, 7503, and 7505) aboard R/V *David Starr Jordan* and R/V *Alexander Agassiz*, Stations occupied represent an area bounded by 37°16.8'N, 124°19.9'W and 32°40.8'N, 117°52.4'W, approximately off San Francisco Bay south to San Diego, California. Samples were collected with a 505-m-mesh, 1-m aperture plankton net towed obliquely from an approximate depth of 210 meters to the surface.

Procedures for measuring larval body length, mouth width, and for dissecting the gut and identifying stomach contents are discussed in Sumida and Moser (1980). Food volume index was calculated for each food particle by treating copepod eggs as spheres, and nauplii, copepodites, and adults as ellipsoids. Details of the mathematical computations are explained in Sumida and Moser (1980).

RESULTS AND COMPARISONS

Composition of Food

Copepod nauplii were the dominant food items (75%-81%) consumed by bocaccio less than 7 mm long, with calanoid nauplii far outnumbering those of other groups (Table 1). Copepod eggs and eggs of other invertebrates, copepodites, tintinnids, coccoliths, cladocerans, and phytoplankton constituted a minor portion of the diet. Adult copepods were entirely lacking in the guts of larvae less than 7 mm long. Copepodites and adult copepods were found in increasingly greater numbers in larvae longer than 7 mm; however, copepod adults did not become significant prey until the larvae reached 10 mm. Copepod nauplii remained the dominant prey category until the larvae reached 9 mm, and declined thereafter. Of the other diverse categories found in larvae shorter than 7 mm, only invertebrate eggs were found consistently in larger larvae.

Food in bocaccio larvae contrasts with that found in hake larvae, where calanoid adults and copepodites made up the major portion of the diet in all sizes of larvae examined (Sumida and Moser 1980).

Size of Food, Mouth Width

The bulk of food particles ingested by bocaccio larvae less than 8.5 mm long was concentrated in a size range of 50-200 μm, and prey of this size range continued to be a major part of the diet in larvae larger than 8.5 mm (Figure 1). Beginning at about 7 mm, prey sizes up to 400-500 μm appeared in the guts; however, prey items less than 300 μm dominated in the diet even in the largest larvae (Figure 1).

Mouth width was about 0.3 mm at birth, doubled before the larvae reached 6 mm, and doubled again just before the larvae reached 9 mm (Figure 2). Maximum size of prey items ingested by first-feeding bocaccio larvae was about 50% of maximum mouth width, and reached a maximum of 60% in 5-mm larvae (Figure 1). In comparison, maximum prey size was about 90% of maximum mouth width for first-feeding hake larvae, 80% for 4-mm larvae, and about 70% for 5-mm larvae (Sumida and Moser 1980). This reflects dietary differences in first-feeding larvae of the two species; copepod nauplii were the primary constituent in the bocaccio, whereas adult copepods and copepodites composed much of the diet in hake. This is clearly seen in comparisons of the two species' total volumes of major prey items (Table 2). The total volume (in percent) of nauplii consumed by bocaccio larvae in this study was five times that found in hake larvae, whereas the volume (in percent) of adult copepods eaten by bocaccio was less than half that found in hake. Although first-feeding bocaccio larvae have smaller mouths than hake, the rate of increase in mouth width is greater in bocaccio, and mouth size in bocaccio exceeds that of hake at about 7 mm length (Figure 2). Coincidentally, this is also when notochord flexion occurs.

Feeding Incidence

Arthur (1976) defines feeding incidence as the percentage of larvae containing at least one food item in the gut for a given sample. This term refers to presence of food in the gut and does not necessarily reflect recent feeding activity. The plot of feeding incidence of bocaccio larvae at time of sampling shows a diurnal pattern, reaching a maximum from about 0800 to 1600 PST and declining rapidly thereafter (Figure 3). Although the sample size and temporal coverage are limited, the data suggest that bocaccio have a rapid rate of digestion and evacuation after cessation of feeding, compared with hake. This is also evident in plots of the mean food volume index and mean num-

TABLE 1
Food Composition of Bocaccio Larvae

	Size range (mm)																	
	4.0-4.9		5.0-5.9		6.0-6.9		7.0-7.9		8.0-8.9		9.0-9.9		10.0-10.9		11.0-11.9		12.0-12.9	
Food item	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Copepod adults																		
Clausoclanaus sp	—		—		—		—		—		2		—		4		7	
Paracalanus sp	—		—		—		—		2		—		—		3		—	
Oithona sp	—		—		—		2		3		2		31		26		73	
Calanoid	—		—		—		—		—		4		—		—		20	
Total adults	—		—		—		2	1.2	5	3.9	8	2.9	31	43.7	33	31.1	100	45.2
Copepodites																		
Oithona sp	2		11		—		10		2		2		11		5		18	
Calanoid	7		2		1		8		21		3		2		37		23	
Cyclopoid	2		2		—		2		—		—		—		—		—	
Disintegrated/ unidentifiable	4		6		3		—		12		—		4		—		12	
Total copepodites	15	2.4	21	3.9	4	14.8	20	12.0	35	27.1	5	1.8	17	23.9	42	39.6	53	24.0
Copepod nauplii																		
Calanoid	388		334		22		103		70		34		17		11		14	
Cyclopoid	82		78		—		22		6		13		1		3		1	
Harpacticoid	1		1		—		—		—		—		2		—		—	
Disintegrated/ unidentifiable	5		3		—		—		2		3		—		—		—	
Total copepod nauplii	476	75.3	416	77.6	22	81.5	125	75.3	78	60.5	50	18.0	20	28.2	14	13.2	15	6.8
Copepod eggs	21	3.3	6	1.1	—	—	—	—	—	—	212	76.5	1	1.4	—	—	47	21.3
Copepod egg clusters	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1.9	—	—
Euphausiid																		
Eggs	—	—	—	—	—	—	3	1.8	2	1.6	—	—	—	—	—	—	—	—
Nauplii	—	—	2	0.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Calyptopis	2	0.3	—	—	—	—	—	—	—	—	—	—	—	—	1	0.9	1	0.4
Metanauplii	—	—	1	0.2	—	—	—	—	—	—	—	—	—	—	—	—	3	1.4
Diatom	1	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dinoflagellate	1	0.2	3	0.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tintinnid	7	1.1	1	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Invertebrate eggs (.14-.26 most .14-.17mm)	79	12.5	66	12.3	1	3.7	14	8.4	8	6.2	2	0.7	2	2.8	14	13.2	—	—
Cladoceran	3	0.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Salp	—	—	—	—	—	—	1	0.6	—	—	—	—	—	—	—	—	—	—
Coccolith	5	0.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Unid. crustacean	3	0.5	1	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Unid. particle w/brown chloroplasts	12	1.9	12	2.2	—	—	1	0.6	—	—	—	—	—	—	—	—	2	0.9
Unid. particles	7	1.1	7	1.3	—	—	1	0.8	—	—	—	—	—	—	—	—	—	—
Total no. food particles	632		536		27		166		129		277		71		106		221	
No. larvae examined* ($\Sigma=96$)	55		19		6		6		3		2		1		1		3	
No. larvae with food ($\Sigma=66$)	33		17		2		4		3		2		1		1		3	

*None with yolk

TABLE 2
Cumulative Frequency Distribution of Numbers and Volume for Major Prey Types in Bocaccio and Hake Larvae

Prey type	Range max. width (μm)		Mean vol. ($10^6 \mu m^3$)		Frequency of occurrence		Freq. × vol. ($10^9 \mu m^3$)		% of total vol.	
	Bocaccio	Hake	Bocaccio	Hake	Bocaccio	Hake	Bocaccio	Hake	Bocaccio	Hake
Copepod and other invertebrate **eggs**	40-430	50-100	4.270	0.364	475	674	2.028	0.245	14.9	0.7
Copepod **nauplii**	50-370	40-300	3.088	4.013	1210	441	3.736	1.770	27.5	5.3
Copepodites	80-250	80-450	8.752	14.698	212	393	1.855	5.776	13.6	17.4
Copepod **adults**	120-390	110-600	25.202	57.418	179	426	4.511	24.460	33.2	73.8
Other	20-470	40-550	16.424	49.401	89	18	1.462	0.889	10.8	2.7

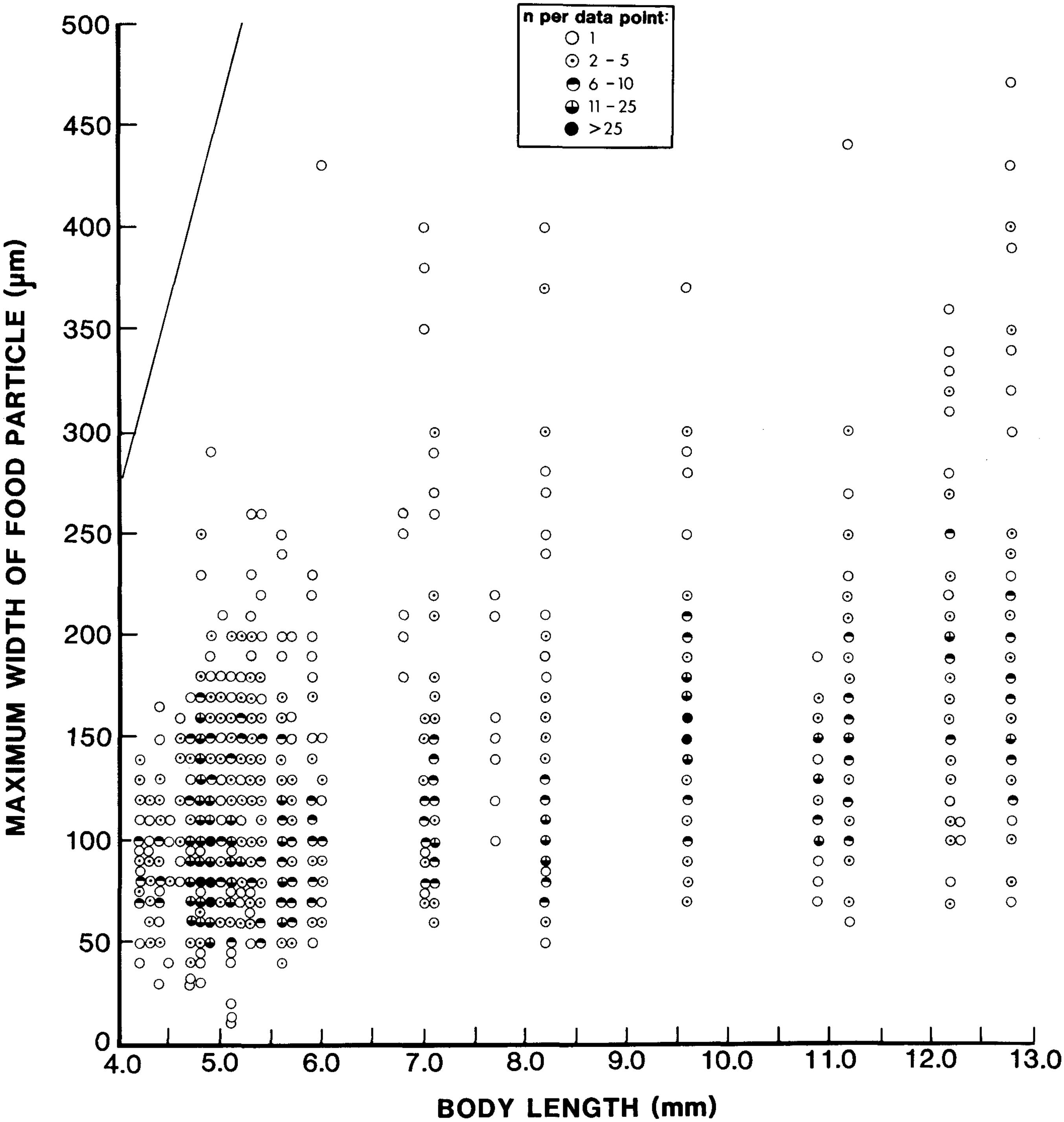

Figure 1. Size of food particles ingested by 66 bocaccio larvae. Oblique line represents maximum mouth width.

ber of food particles (Figure 4). The two plots agree closely except for the single large volume at time 0001-0300. This point represents a single 9.6-mm sample larva (others were empty), which consumed an unusually large number of adult copepods and copepodites.

DISCUSSION

Prey composition in the sample of bocaccio larvae studied is similar to that found in many marine teleosts—a diet dominated by copepod nauplii in the early larval stages, with copepodites and adult copepods becoming increasingly more important in later larval

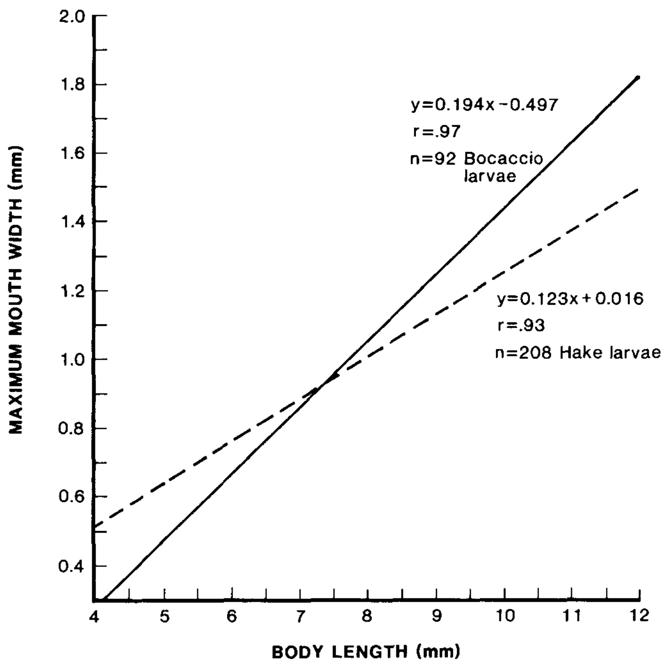

Figure 2. Mouth width of bocaccio (solid line) and Pacific hake (dashed line) larvae.

stages (Arthur 1976; Hunter 1981). The maximum size of prey increases with bocaccio larval growth, although small prey are consumed throughout the larval period, during which the minimum prey size changes little. This pattern contrasts with that seen in hake (*Merluccius productus*) larvae, where copepodites and adult copepods were eaten by the smallest larvae and were predominant prey in larvae larger than 4 mm.

Bainbridge and McKay (1968) observed similar contrasting patterns in two north Atlantic species: the redfish (*Sebastes* spp, a congener of bocaccio) and cod (*Gadus morhua*, a relative of *Merluccius*). Copepod eggs and nauplii dominated the diet of redfish, whereas postnaupliar stages predominated in cod. The contrast in feeding patterns may be partly explained by differences in mouth size: mouths are considerably wider in early hake larvae compared with bocaccio, although this relationship is reversed in larvae larger than 7.5 mm (see Figure 2). Another factor may be the depth distribution of larvae of the two species. Ahlstrom (1959) found *Sebastes* spp larvae in the upper mixed layer and thermocline, with an abundance maximum at about 40 m, whereas hake were within and

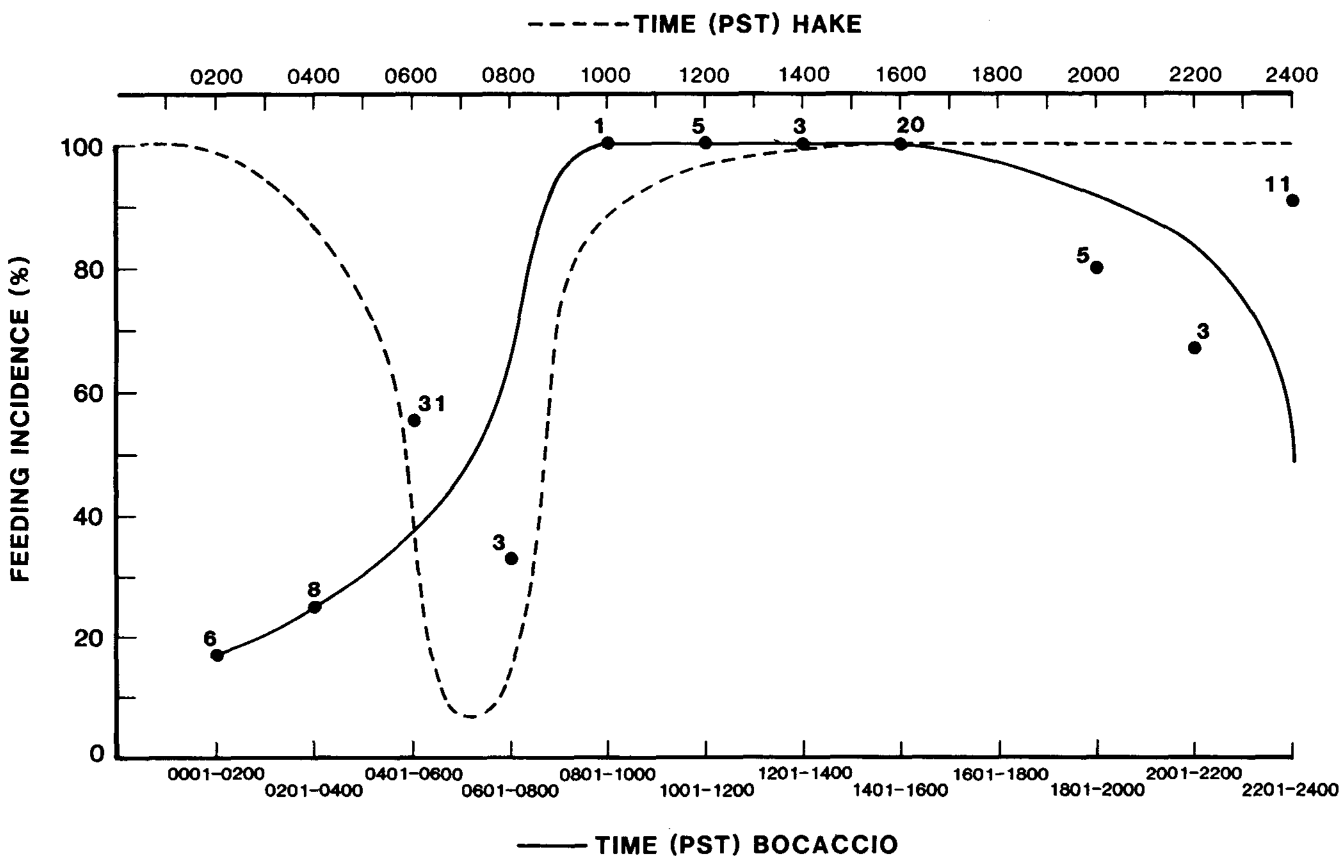

Figure 3. Feeding incidence of bocaccio and Pacific hake larvae at time of capture. Bocaccio data (solid line) grouped in 2-hour intervals, hake data (dashed line) in 1-hour intervals. Values of data points indicate sample size of bocaccio larvae. Curve for hake taken from Sumida and Moser, 1980.

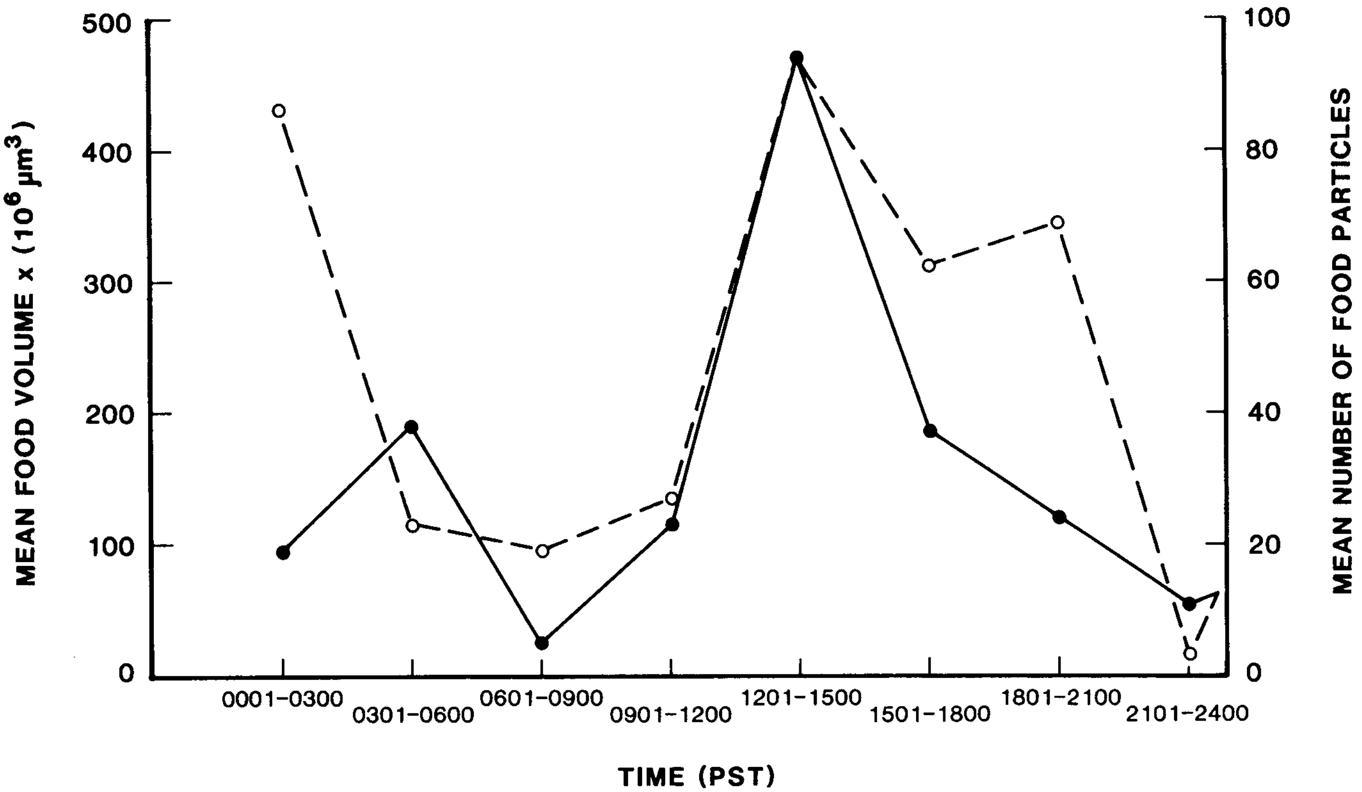

Figure 4. Mean food volume index (dashed line) and mean number of food particles (solid line) of bocaccio larvae. Samples grouped into 3-hour time intervals.

below the thermocline and had a peak abundance at about 70 m. Bailey (1982) examined Ahlstrom's samples of hake larvae for size-related vertical distribution, and found larvae < 8 mm at 50-100-m depth, but larger larvae at greater depths to 300 m. Beers and Stewart (1969) showed a sharp decline in total microzooplankton at about 50 m at several stations off southern California. Although this decline was most marked for tintinnids and other ciliates, it was also evident for naupliar and postnaupliar copepods in the 35-103-μm and > 103-μm size categories. The data suggest that bocaccio are consuming relatively abundant nauplii in their vertical range, while hake are either selecting the larger postnaupliar stages or are capturing them more effectively because their size makes them disproportionately more perceptible at low prey densities.

Arthur (1976) showed a diurnal maximum of feeding incidence in Pacific sardine and northern anchovy, as did Bainbridge and McKay (1968) for redfish and cod. Sumida and Moser (1980) showed that hake reach a peak incidence of 100% at sunset and maintain this until about 0100 hours. Then the incidence declines rapidly until sunrise, when it increases rapidly to 100%. In bocaccio, incidence peaks in midmorning, is maintained at 100% until sunset, then decreases steadily to a minimum at about 0100 hours. Incidence then begins to increase steadily to the midmorning maximum. The contrasting patterns could be explained by an intrinsically faster rate of digestion and evacuation in bocaccio compared with hake. Another possibility is that prolonged high incidence in hake is related to their larger prey size and the lower temperature of their habitat.

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