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Aspects of the Life History of the Olive Rockfish, Sebastes serranoides

Author
Love, Milton S.

Publication Date
1978-08-01

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LOVE, MILTON STEVEN
ASPECTS OF THE LIFE HISTORY OF THE OLIVE
ROCKFISH, SEBASTES SERRANOIDES.

UNIVERSITY OF CALIFORNIA, SANTA BARBARA,
PH.D., 1978

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UNIVERSITY OF CALIFORNIA
Santa Barbara

Aspects of the Life History of the Olive Rockfish, *Sebastes serranoides*

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Biological Sciences

by

Milton Steven Love

Committee in charge:

Professor Alfred W. Ebeling, Chairman

Professor Alice Alldredge

Professor Elmer R. Noble

Doctor Bruce Robison, Research Associate

August 1978

The thesis of Milton Steven Love
is approved:

Elmer R. Noble

Alice Alldredge

Bruce H. Robison

Alfred W. Ebeling
Committee Chairman

Robert O. Collins
Dean, Graduate Division

August 1978

August 25, 1978

PUBLICATION OPTION

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Signed Milton Lee

DEDICATION

To Regina, who toiled on two labors of Love at the same time, this work is lovingly dedicated.

ACKNOWLEDGEMENTS

I thank Alfred W. Ebeling, Alice Alldredge, Bruce Robison and Elmer Noble for critically reading the manuscript and offering much needed suggestions.

Norm Lammer provided technical help with boating operations. Fred Benko of Sea Landing Sportfishing graciously allowed me space on partyboats for sampling. I particularly thank partyboat operators Chet Phelps, Irv Grisbeck, Frank Hampton, George Kelly and Dick Clift. All assisted in making sampling possible and pleasurable. Numerous individuals assisted in collecting specimens. Those people most helpful included Richard Bray, Craig Fusaro, Bob Henderson, Lew Haldorson, Ralph Larson, Dave Laur, Gerry Robinson, Jerry Wellington.

Last, but assuredly not least, I thank my wife, Regina Paull-Love, for typing the manuscript and for supporting and assisting me, even though she thinks anyone interested in fish is hare-brained.

This work is a result of research sponsored by NOAA, Office of Sea Grant, Department of Commerce, under grant no. 04-7-158-44121 (Project r/f-39) and NSF Grant OCE 76-23301. The U.S. Government is authorized to produce and distribute reprints for governmental purposes, notwithstanding any copyright notation that may appear hereon.

VITA

March 10, 1947--Born--Los Angeles, California.

1970--B.A., University of California, Santa Barbara.

1970-1972--Teaching Assistant, Department of Biological Sciences, University of California at Santa Barbara.

1972-1975--Research Assistant, Department of Biological Sciences, University of California at Santa Barbara.

1974--M.A., University of California, Santa Barbara.

1976--Associate, Environmental Studies Department, University of California at Santa Barbara.

1976-1978--Sea Grant Trainee, Department of Biological Sciences, University of California at Santa Barbara.

PUBLICATIONS

Books

1971 Everyman's guide to ecological living (co-authors G. M. Cailliet and P. Y. Setzer). New York: Macmillan, 119 pp.

1978 Readings in ichthyology (co-author G. M. Cailliet). Santa Monica: Goodyear Publishing Company. In press.

Laboratory exercises in ichthyology (co-authors G. M. Cailliet and A. W. Ebeling). Santa Monica: Goodyear Publishing Company. In preparation.

ARTICLES

In preparation

Aspects of the life history of the olive rockfish, *Sehastes serranoides*. In preparation.

Aspects of the life history of the squarespot rockfish, *Sebastes hopkinsi*. In preparation.

Analysis of the Santa Barbara inshore partyboat sportfishery. In preparation.

Movements of the olive rockfish, *Sebastes serranoides*, with reference to other eastern Pacific rockfish. In preparation.

VITA (Cont.)

ARTICLES

In preparation

Seasonality, geographic variation and size selectivity in the parasite-mix of the olive rockfish, *Sebastes serranoides*. In preparation.

Spawning seasons of some northeastern Pacific rockfish (Scorpaenidae:*Sebastes*). In preparation.

Synonymy of three species of *Deretrema* (Digenea). In preparation.

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VITA (Cont.)

ARTICLES

1973	Partial ambicoloration in three California flatfishes (co-author J. Vucci). Calif. Fish Game 59(2): 146-148.
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ABSTRACT

Aspects of the Life History of the Olive Rockfish, *Sebastes serranoides*

by

Milton Steven Love

I investigated the movements of the olive rockfish, *Sebastes serranoides*, off Santa Barbara, California, using both mechanical and parasite tags. Movements were very restricted over shallow reefs though somewhat less so around deeper oil platforms. Limited movements may contribute to over fishing, as comparisons of olive rockfish size frequencies between two reefs indicates that fishing pressure has reduced olive rockfish populations to almost all prereproductive individuals on the more heavily fished site. I discuss movements of other rockfish and suggest potential management problems and solutions.

Age and growth relations, reproduction and food habits of the olive rockfish were also studied. Olive rockfish grew at a faster rate off Avila than Santa Barbara. Evidence from laboratory studies indicate this differential may be due to ambient temperature. Females grew at a faster rate and attained a larger maximum size than males. Off Avila, spawning took place from December through March. Off Avila, fish mature between 4 and 8

years of age (total length 28-39 cm TL). Olive rockfish feed primarily on midwater nekton during both day and night, though nocturnal benthic feeding (on octopi) becomes increasingly important in larger individuals.

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INTRODUCTION

Rockfishes comprise the extremely speciose genus Sebastes in the family Scorpaenidae. More than 100 species have been described worldwide, with the vast majority of these living in the North Pacific. They are the dominant inshore fish genus in the neritic water of the continental shelf (Eschmeyer and Hureau 1971; Eschmeyer pers. commun.). In the Northern Hemisphere, the genus occurs in the Pacific in coastal waters from Taiwan to the Gulf of California; and in the Atlantic, from Massachusetts to Norway. A few species are found in the Southern hemisphere, off Chile, the Falkland Islands, and South Africa (Chen 1971; Chen 1975; Eschmeyer pers. commun.). Most species (currently about 60) occur off California (Miller and Lea 1972). Here, they occupy virtually every marine habitat from the intertidal to at least 800 m, and show a spectrum of shapes ranging from spiny, heavy bodied, depressed bottom dwellers to sleek, fusiform pelagic forms.

The genus is ovoviviparous: the young develop into larvae within the female, but receive no nutrition from her. Most species reproduce once per year, generally during the late winter or early spring. Larvae are pelagic and are found in the mixed layer and in the upper part of the thermocline (from the surface to a maximum of about 120 m; Ahlstrom 1959).

Rockfish are an important part of the sportfishing catch (Miller and Gotshall 1965; Wine and Hoban 1976; Maxwell and Schultze 1976abc; Maxwell and Schultze 1977ab; Black and Schultze 1977; Crooke and Schultze 1977; Crooke 1978), forming about 70% of the partyboat total statewide (McAllister 1976; Schultze pers. commun.) and about 30% of the private-vessel total in southern California (Wine and Hoban 1976).

The olive rockfish, *Sebastes serranoides*, is a major constituent of the partyboat and private-vessel catch throughout southern and central California (Miller and Gotshall 1965; Wine and Hoban 1976; Maxwell and Schultze 1976abc; Crooke and Schultze 1977; Crooke 1978; Love, in prep.). Despite its importance, little was known about the biology of the species. The objectives of this dissertation are to: (i) describe its movements in and about kelp beds off Santa Barbara (Chapter 1); (ii) analyze its life history, including age and growth, maturity, and spawning (Chapter 2); and (iii) analyze its feeding habits (Chapter 3) for areas and for size classes not previously investigated. Also, the Appendix gives a redescription of the species, based on a large number of individuals.

CHAPTER 1

Movements of the olive rockfish, *Sebastes serranoides*, with observations on the movements of other eastern Pacific rockfish

INTRODUCTION

Rockfishes, genus Sebastes (Family Scorpaenidae), form the most diverse fish group along the California coast. Some 60 species are found in these waters (Miller and Lea 1972 and Lea pers. commun.), inhabiting virtually every marine (occasionally estuarine) habitat from intertidal waters to depths of more than 610 m (Miller and Lea 1972). The genus is very important to both sport and commercial fishing industries; in California waters in 1974, rockfish ranked third in the commercial fishery (poundage landed) and first in the sport fishery (numbers landed) (McAllister 1976).

California species can be roughly divided into two bathymetric groups: (1) shallow species that inhabit subtidal areas of reef and kelp, and (2) those that live in relatively deep water (deeper than about 70 m). All species are ovoviviparous, producing pelagic larvae. There is some evidence that the shallow water species may remain within a relatively small area of reef or kelp (Miller and Geibel 1973), while evidence presented in this paper suggests that individuals of some deeper-living species may wander from one area to the next, perhaps following an otherwise limited food supply.

A species that consists of relatively sedentary, reef-oriented aggregations would present potential problems in management, because proper management of a fishery depends, among other things, on movements of the fish (Harden Jones 1968; Cushing 1968). If the exploited species inhabits reefs for example, it might soon be decimated at a heavily-fished reef if individuals were parochial and did not move from an unexploited site to repopulate the depleted one. Obviously, a management strategy to protect this type of segregated reef species would differ from that for a species whose individuals move between sites. Many rockfish species grow very slowly (Miller and Geibel 1973; Chen 1971; Westrheim and Harling 1975). Thus, even if a depleted reef were densely settled by a successful year class, it would not harbor adults for a number of years. Before then, the subadults would probably be caught before the age of first maturity, so the reef would effectively be lost as a site of propagation for the species. If this process continued through all available reef sites, the species would be endangered.

On the other hand, a rockfish species whose individuals move from reef to reef may be less vulnerable to such perturbations. Even a locally depleted reef could be sufficiently repopulated by adults during breeding season because of the high fecundity of females and great dispersability of pelagic larvae. Thus the fishery might be effectively managed by conventional procedures of establishing catch limits etc.

The olive rockfish, *Sebastes serranoides*, inhabits reefs and kelp beds from San Benito Island, Baja California, north to Redding Rock, Del Norte Co., in northern California, from intertidal waters (juveniles) to 146 m (Miller and Lea 1972). The species is most common in southern and central California from surface waters to depths of about 75 m. It is a major constituent of the sportfishing industry throughout much of the state (Wine and Hoban 1976; Miller and Gotshall 1965; Maxwell and Schultze 1976; Love, in prep.) particularly in southern and central California. I have studied the movements of olive rockfish to see if individuals move from reef to reef and if individuals are generally smaller at heavily fished reefs.

METHODS AND MATERIALS

Artificial Tagging

Between 26 October 1973 and 17 October 1976, 1847 olive rockfish (19 to 43 cm total length), were tagged at 18 sites off southern California (Figure 1, Table 1). Generally, sites were selected on the basis of two criteria. First, sites were reefs regularly fished by partyboats and/or private vessels. This maximized the opportunity to recapture tagged animals. Second, sites had to be within 2 km of another regularly fished reef harboring olive rockfish. This maximized opportunity to recover fish that move short distances. The exception was Naples Reef, which had no other suitable site within 2 km. Naples Reef was included because its fish fauna is being studied intensively by other researchers. Only a few fish were tagged at some sites, such as Anacapa Island, Platform Holly and Avila, either because few olive rockfish were found there or because they are relatively remote.

The tags used were yellow Floy anchor type FD-67c, consisting of a plastic tube 42 mm long with a 15 mm nylon stem and a 10 mm cross bar attached to the stem. Tags were inserted with a Floy tagging gun, FDM 68, using a heavy-duty needle 2 cm long. My name, Department of Biology, UCSB and a number were printed on each tag.

The anchor was injected into the dorsal musculature, between the second and third dorsal spines, leaving the brightly colored end free. Even though bryozoan growth completely obscured the legend within a few months, this growth was easily rubbed off.

Fish were caught by hook and line aboard University vessels and sportfishing partyboats, then measured (total length), tagged and returned to the water. Because of expanded gas in their swimbladders, fish taken at depths greater than about 20 m had to be deflated before they could return to depth. Perhaps 10% of all fish tagged required deflation, using a technique modified slightly from Gotshall (1964). A 3.8 cm, 18 gauge hypodermic needle was inserted through the body wall into the swimbladder. However, instead of placing both fish and needle underwater, then waiting for the gas bubbles to stop emanating from the needle, I sucked gas from the bladders to speed the process. Then, if needed, the fish's everted stomach was pushed back into place. About 20% of the inflated fishes either died either before or immediately after being returned to the water. Undoubtedly some others that swam downward died soon after; of six fish placed in a tank after deflation, 2 died within one day, the rest survived for two weeks, to the end of the test. Eliminated were all fish whose eyes were everted by gas expansion in the choroid plexa. Experience with several rockfish species (*S. caurinus*, *S. miniatus*, *S. paucispinis* and *S. serranoides*) indicates that this condition frequently leads to blindness and/or death, whether or not pressure is released.

Tagging mortality in fish that did not have to be deflated was probably low. Ten of 12 tagged olive rockfish lived for 2 months in an aquarium, 2 dying after about one month, apparently of a fungal infection. I saw none of the extensive hemorrhaging previously observed in Floy-tagged Pacific mackerel, *Scomber japonicus* (Gregory, 1977).

Biological Tagging

I analyzed the parasite-mix of olive rockfish to determine the feasibility of using parasites as "biological tags". Differences in parasite infection rates between host groups within a species may indicate either a lack of, or at least reduced movement of fish between populations. Twenty olive rockfish from each of 6 sites (Naples Reef, Ellwood Pier, Horseshoe Reef, 4 Mile Reef, oil platforms Houchin and Hillhouse, see Figure 1) were sampled quarterly between June 1976 and March 1977. Fish were captured by hook and line or spear, placed on ice and frozen for later dissection.

After thawing, fish were measured (standard and total length) and the following parts of each fish were examined for parasites: external surfaces, gills, gill cavities, mouth, mesentery, heart, gall bladder, stomach, intestine and muscle. Initially, copepods, monogenetic and digenetic trematodes were fixed in AFA, and the monogenes and digenes were stained with Harris' hemotoxylin, cleared with xylene and mounted. Protozoans were studied unpreserved after thawing. Because most of the parasites recurred frequently, only those not readily identifiable were preserved in the latter parts of the study.

After a year of sampling, it was apparent that the Ellwood Pier population was the only one not infected with the gill monogenean, _Microcotyle sebastis_. To test whether environmental conditions precluded _M. sebastis_ from the site, 21 tagged, infected fish from the Horseshoe Reef were introduced into the Ellwood site. Specimens were collected after 1 and 6 months.

Size Variation

To test whether heavy fishing pressure altered the size composition of olive rockfish on reefs, I compared size frequencies of fish taken by a sportfishing partyboat at Naples Reef and at a portion of the mainland bed called Haskels, which lies inshore and east of Naples

Reef. Naples Reef is heavily fished by partyboats while Haskels has been fished by partyboats no more than four times in five years. On board the vessel, all olive rockfish taken were measured (total length). The measurements represent 13 trips to Naples Reef and 4 trips to Haskels.

RESULTS

Artificial Tagging

Table 2 shows the number of fish tagged at each location and the return rates. Of the 1847 fish tagged, 216 were recovered, an 11.6% return. Nine individuals were recaptured twice. Recaptured fish were at large between 1 and 514 days. The highest return rates were from Horseshoe Reef (34.6%), Naples Reef (23.7%) and the 3 oil platforms off Summerland (15.2%). All are heavily fished by partyboats (Love, in prep.). Eighty-one percent of all returns were made by partyboat fishermen.

Only fish tagged around the Summerland oil platforms showed any movements. Nine individuals had moved from one platform to another (about .8 km).

Biological Tagging

Only the incidence of infection of the gill monogenean, *Microcotyle sebastis*, differed significantly among study sites (Table 3). Naples Reef and Ellwood Pier differed significantly from the other four sites: a G test of independence was significant when all 6 sites were included ($G = 186.45$, $p<0.005$), but not significant when only the oil platforms, 4 Mile Reef and Horseshoe Reef were included ($G = 1.14$, $0.9>p>0.5$). Naples Reef also differed significantly from Ellwood Pier

($G = 16.8$, $p<.005$).

Rates of infection by seasons are shown in Table 3. There was no seasonality in rate of infection: G tests of independence among four seasons were not significant for any site (Naples Reef, $G = .348$, $0.9>p>0.5$; Platform Hillhouse, $G = .92$, $0.9>p>0.5$; Platform Houchin, $G = 2.9$, $0.5>p>0.1$; Horseshoe Reef, $G = 2.4$, $0.9>p>0.5$; 4 Mile Reef, $G = 1.63$, $0.9>p>0.5$).

To test whether environmental conditions at Ellwood Pier were suitable for the monogene, tagged fish from Horseshoe Reef infected with *M. sebastis*, were introduced into the site. Untagged fish were collected one and 6 months later. After one month 2 of 20 fish (10%) and after 6 months 7 of 20 (35%) were found to be infected. As none of the tagged Horseshoe Reef fish was collected again, the presence of *M. sebastis* in the population seems to indicate that the monogenean had spread to the local population.

Size Variation

Fish lengths differed significantly between sites (Figure 2) (t-test, $t = 9.3$, p .001). A-posteriori comparisons show that fish from the heavily-fished site, Naples Reef, were significantly shorter than fish from the lightly-fished Haskels site. In addition, most fish taken from Naples Reef were prereproductive, while mature individuals made up a sizeable percentage of the Haskels catch.

DISCUSSION

Biological Tagging

Kabata (1963) lists five criteria which should ideally be met if a parasite is to be useful as a tag: (1) the parasite is common in one population and rare or absent in another; (2) the parasite should have a direct life cycle, infecting only one host species during its life; (3) the parasitic infection should be of fairly long duration; (4) the incidence of infection must stay relatively stable; (5) environmental conditions throughout the study site(s) must be within the physiological tolerance of the parasite.

Compared to artificial tags, biological tags have both advantages and disadvantages. Artificial tags may alter the normal behavior of the tagged animal, whereas, in most cases, parasites do not (but see Kennedy 1975). Moreover, the parasite-mix of a population is usually the result of long-term processes, and may be a more accurate indicator of movements than short-term tagging studies. On the other hand, parasite tags will not indicate individual movements. Over the past 20 years, studies using parasites as tags have delineated nursery grounds (Olson and Pratt 1973), spawning grounds (Hare and Burt 1976; Margolis 1963) and discrete or semidiscrete populations (Sindermann 1961; Kabata 1963).

Movements of Shallow-living Rockfish

Tagging, both artificial and biological, indicate that olive rockfish rarely move between shallow-water reefs. A good example of this is the apparent lack of movement between Naples Reef and Ellwood Pier. Though only about 2 km apart, no tagged Naples Reef fish were taken at Ellwood Pier or anyplace else, nor were any of the parasitic *M. sebastis* found infecting Ellwood Pier fish before I introduced it, though they infect Naples Reef fish.

Like other monogeneans, *M. sebastis* has a direct (one host) life cycle. The maximum distance the infective oncomiricidium larval stage can travel before finding a host is not known, though it is probably limited to a few meters (Llewellyn 1972). Apparently, Ellwood fish were not parasitized because they were sufficiently isolated from others to escape exposure to infected fish, even pelagic larvae.

Yet neither tagging nor parasite data indicates whether fish move from the Ellwood area to Naples Reef. However, size frequency data of fish taken on Naples Reef and at Haskels (adjacent to the Ellwood Pier) (Figure 2), imply that there is probably little movement from Ellwood to Naples. Naples Reef harbors primarily juvenile and preadult olive rockfish (Love and Ebeling 1978; Love, in prep.) and adults are rarely observed (Ebeling, pers. comm.). Apparently, fishing pressure removes fish before they can mature. However, adults are abundant at the lightly-fished Ellwood Pier and limited sampling along a 16 km stretch of kelp inshore of Naples Reef indicated that mature fish are common throughout the bed. Apparently, few of these fish move across the sandy stretch between Naples Reef and the inshore bed.

The relatively low rate of parasitic infection at Naples Reef is probably due to the low density of host fish there (Love and Ebeling, 1978). Observations on mammals (Pester and Laurence 1974) and fish (Kennedy 1975) indicate that the degree of parasite transmission is often influenced by the abundance of hosts. Increased density may lead to greater opportunities for infection. Olive rockfish populations at the other study sites are probably denser, hence infection is widespread. Bascom, Mearns and Moore (1976) estimated that about 4,000 olive rockfish occurred around an inshore oil platform off Summerland. It seems likely based on large catches from the sport fishery, that populations are also very dense around the oil platform study sites, Horseshoe

Reef, and 4 Mile Reef. However, the absence of infection at Ellwood cannot be entirely attributed to low fish density there. Underwater observations indicate that at least 250 individuals live in the relatively small area around the pier.

Because Naples Reef has only a small population of olive rockfish, relatively few fish are available to immigrate inshore; and the infection rate is relatively low among these fish. Hence, the chance of an infected Naples fish reaching Ellwood Pier is probably quite small. However, parasite-mixes form over relatively long periods of time and so it is likely that any long-term movement of rockfish from Naples would be reflected by infection of the Ellwood population. If the Naples population is not a recent one, therefore, it is likely that the lack of infection at Ellwood reflects non-immigration from Naples.

Though inshore movements seem to be inhibited by stretches of sandy bottom, movement from one oil platform to another obviously is not: tagged fish must have swum a minimum of 0.8 km over sandy bottom with a depth of about 50 m to reach the adjacent site. Miller and Geibel (1973) observed a similar greater mobility in deep waters for blue rockfish, *S. mystinus*.

Some rockfish in deep waters (greater than about

90 m) must forage over greater distances because prey is less abundant at these depths. Olive rockfish off Santa Barbara feed primarily on midwater organisms (nekton and plankton) rather than substrate-oriented prey (Love and Ebeling 1978). It is not known whether these prey are less abundant at the platforms compared to inshore waters. If they are less abundant, olive rockfish might be more likely to leave the platform to follow prey. I have noted fish feeding on anchovies as much as 300 m away from the platforms. Perhaps in some of these cases, the fish do not return to the original platform.

This study emphasized movements of fish that inhabit isolated reefs. Little work was done on fish from the extensive area of continuous kelp forest which parallels most of the Santa Barbara coast, because sampling is more time consuming in such areas of low rockfish densities. Moreover, much of the tagging was done aboard partyboats which rarely fish these extensive beds growing over sand bottom. It is quite possible that olive rockfish in kelp beds move about considerably more than those on isolated reefs. I suspect that the limited movement I observed is due to the relatively barren bottom surrounding the reef-like study sites. Fish are rarely taken over sand, either in otter trawls (Ebeling, Werner, DeWitt and Cailliet 1971; Cailliet, pers. commun.; Mearns, pers. commun.) or in the sportfish catch (Love, in prep.), and seem to be strongly attracted to high-relief substrate, such as that of platforms and rocky reefs. Also, kelp beds may provide "bridges" from one reef to another.

The few previous studies of rockfish movements (Table 4) corroborate the present results. The two most extensively investigated benthic species, *S. carnatus* and *S. chrysomelas*, defend small feeding territories and shelter holes (Larson 1977; Hallecher 1977). Also, agonistic displays by *S. serriceps* (Feder, Turner and Limbaugh 1974; Haaker, in press) and longterm residence in particular crevices by *S. nebulosus* (McElderry, in prep.) indicate that these benthic species may also be territorial. Thus, it seems likely that most or all benthic reef rockfish may move around relatively little.

Similarly, most midwater rockfishes that live over these shallow reefs, seem to stay within a fairly small area. In particular, tagging of *S. mystinus* (Miller and Geibel 1973) showed that it has very restricted movements, and tagging of *S. flavidus* (Carlson and Haight 1972) showed that it has a strong homing tendency. However, seasonal movements (Washington, pers. commun.) and pelagic capture (Dunn and Hitz 1969) of *S. melanops*, indicated that it probably moves about extensively, perhaps from reef to reef.

Relatively parochial midwater rockfish, such as S. mystinus, S. serranoides and S. flavidus, do not appear to be territorial, in the sense that a territory is a "defended" (Noble 1939) or "exclusive" (Schoener 1968) area. Indeed, thse species often form single or multi-species aggregations of thousands of individuals, which show little or no agonistic behavior toward one another. The sizes of rockfish home ranges have not been estimated, though Miller and Houk (pers. commun.) believe that S. mystinus aggregations are quite patchy within a kelp bed and some fish may remain within a very limited area for extended periods. In kelp beds, individuals of S. serranoides may move about somewhat more than those of S. mystinus. Miller (pers. commun.) noted that S. serranoides individuals were not seen as consistently as those of S. mystinus in kelp-bed transects in Monterey Bay. As S. mystinus preys primarily on plankton and animals on plant surfaces (Gotshall, Smith and Holbert 1965; Hallacher, 1977; Love and Ebeling 1978), it seems likely that this species spends much of its time waiting for prey to drift by. S. serranoides feeds somewhat more on moving prey (Love and Ebeling 1978) and so may forage more widely.

Some seasonal movement of rockfish may also occur, at least north of Pt. Conception. A number of studies report that rockfish numbers on shallow-water reefs seem to decrease during winter (Burge and Schultz 1973; Miller and Geibel 1973; Moulton 1977; McElderry, pers. commun.). Increased turbulence may drive the fish into deeper water or into reef shelters where they are less visible. Ebeling (pers. commun.) observed no winter decrease in rockfish abundance at Naples Reef. The waters of the Santa Barbara Channel are considerably less turbulent than those above Pt. Conception; perhaps here fish can remain on the reefs despite winter storms. Miller and Geibel (1973) noted a sharp winter decrease in S. mystinus numbers on a reef in Monterey Bay. Yet despite extensive tagging at this site and intensive sampling and underwater observation of surrounding reefs during winter, no tagged individuals were found at other reefs (Miller, pers. commun.). Factors other than turbulence may account for a winter exodus. Some rockfish species may leave inshore reefs to spawn. In Puget Sound, populations of S. melanops, which breed during the winter, may leave the shallow reefs to spawn (Washington, pers. commun.). If fish do leave the reef, the extent of their movement is, in general, not known. Moulton (1977) found that rockfish on Puget Sound reefs retreated only short distances, into slightly deeper water.

Movements of Deep-living Rockfish

Species composition of the rockfish assemblage changes gradually with depth between about 35-40 m and 70-90 m (Miller and Geibel 1973; Love in prep.). At the greater depths, the generally brown, black and blue-hued rockfish species of inshore waters give way (with some exceptions) to species colored predominantly red, orange and yellow. Even drab deeper water species, such as *S. flavidus* and *S. entomelas*, are tinged with yellow and pink. Also, rockfish tend to be more bottom oriented in deeper water. Whereas rockfish, such as individuals of *S. mystinus* or *S. serranoides*, may occur from bottom to surface over inshore reefs, rockfish tend to occur near the bottom over deeper, offshore reefs.

Relative to their position in the water column, rockfish in deeper water may be generally categorized as to whether they usually occur on the bottom (benthic) or near the bottom. Benthic species such as *S. constellatus*, *S. chlorostictus*, *S. helvomaculatus* and *S. rubrivinctus* usually have deep bodies with large headspines and rounded caudal fins. They eat mostly bottom-living prey, such as crabs and octopi. On the other hand, near-bottom species may be found as much as 60 m above the bottom (*S. jordani*, at the extreme, is often pelagic); they are usually more elongate and streamlined than benthic rockfishes, with reduced or absent headspines and more deeply forked caudal fins. The more active species, such as pelagic S. jordani, resemble scombrids. Near-bottom species eat a wide range of prey, ranging from microplankton (S. jordani) and macroplankton (S. entomelas) to nekton such as fish and squid (S. paucispinis and S. goodei - Phillips 1964).

Benthic and near-bottom species overlap somewhat in distribution and behavior. Near-bottom species are often found very close to or on the bottom, while a few benthic species, such as S. miniatus, are occasionally found well off the bottom (S. miniatus, as much as 27 m).

Because they are difficult to observe, movements of the deeper water species are not well known. Thus, evidence of movements has been indirect; changes in species distributions and abundances, based on catch data from commercial, sport or research fisheries. Some near-bottom species seem to move substantial distances. Based on catch data, S. alutus, the only species observed extensively, makes annual bathymetric migrations, spending winters in deeper water and summers over somewhat more shallow bottoms (Alverson and Westrheim 1961; Major and Shippen 1970; Gunderson 1977). There is some evidence that S. melanops (Dunn and Hitz 1969) and S. jordani (unpubl. data) occur pelagically.

There is accumulated evidence, moreover, that deeper-living species move about more extensively than most inshore species. Fathometer tracings and sportfishing catch data from isolated reefs in 75-200 m off Santa Barbara indicate that near-bottom rockfish tend to move on and off the reefs. Catches and tracings will remain spotty or nil for months, only to suddenly increase dramatically. Because the nearest adjacent reefs to those fished are often 1-2 km away, fish would have to move at least this distance to appear in catches and tracings. For example, on one isolated reef in 92 m, no widow rockfish (*S. entomelas*) were taken by partyboats during March and April of 1976. Catches increased in May, then peaked and ended in June. No widow rockfish were taken from the reef during the rest of the year.

I made two direct observations of rockfish moving about on the 12 Mile Reef in the Santa Barbara Channel. An extensive area of rocky ridges and pinnacles, this reef is at 110-220 m depth and extends for perhaps 16 km along the center of the channel. In January, 1970, I located with strip-chart fathometer an aggregation of rockfish over the bottom, which were at about 135 m depth. Fish were detected and angled as much as 27 m above the bottom. Then a buoy was set to mark the fish aggregation's location and a string of baited hooks was lowered. Apparently the aggregation was moving, because successive drifts with hooks over the original location yielded no fish. But a search of the area revealed the aggregation some 100 m from the original location. By relocating the aggregation and immediately lowering the hooks, I could catch fish for brief periods before they again moved on. When I stopped fishing after 7 hours, the fish had moved over 2.4 km from the original site to a new location where the bottom depth was 157 m. Species caught from the aggregation were predominantly S. paucispinis, S. goodei and S. entomelas along with fewer individuals of S. miniatus and S. levis. The fish were apparently following a school of squid, which were regurgitated by angled fish and which were caught on lures in the same area. Similarly, in July, 1971, I tracked a moving aggregation of S. paucispinis, S. goodei and S. entomelas, but observed no readily apparent reason for the movement.

Perhaps deeper-living rockfish must move relatively more to find sparsely distributed prey. There is some evidence that food for near-bottom species is less abundant and more patchy in offshore waters than over shallow reefs (Marlow and Miller 1975) (Longhurst 1967) (Ahlstrom 1959, 1961) (Hartmann pers. commun.).

Little is known about how prey patchiness affects the movements of reef fish, although in general, it has been shown that patchy food resources may lead to greater searching time (MacArthur and Pianka 1966) and larger territory size (Slaney and Northcote 1974; Simon 1975; Larson 1977). Perhaps as the prey of rockfish are depleted or move out from a reef, near-bottom predators also leave either to find new prey sources or to follow the old. Certainly, some near-bottom species move upward to feed. Lyubimova (1965) noted that *S. alutus* rises 20-50 m during feeding periods. Off the Columbia River, *S. flavidus* ate myctophids at depths as much as 27 m above the bottom in 137 m of water (Pereyra, Pearcy and Carvey 1969). I detected individuals of *S. paucispinis*, *S. entomelas*, *S. goodei* that were as much as 45 m off the bottom and were apparently feeding, as they regurgitated fresh prey.

Thus these and other near-bottom species may leave an area to follow or search out prey. They appear to be less substrate oriented than are shallow-water species. Several near-bottom species, notably *S. paucispinis* and *S. goodei*, which seem common over high relief, rocky bottoms, are often taken by trawlers over smooth bottoms.

Fishing Pressure and Size Variation

The between site difference in mean fish length probably reflects a difference in fishing pressure. The more heavily fished site averaged smaller fish and fewer mature ones because larger fish are selectively angled.

If this is generally true, then heavily fished sites may contain only prereproductive individuals (as, in general, does Naples Reef). Thus reproduction of mature fish at lightly fished sites must supply recruits for all areas.

Management of Rockfish Stocks

Limited movement of inshore rockfishes among shallow reefs poses problems in regulating the fishery. Throughout California, sportfishermen take most of the rockfish caught in shallow waters. On partyboats, particularly in central and northern California, anglers are primarily interested in catching the maximum poundage possible within the permitted bag limits. Therefore, partyboat operators are pressured to find rockfish of the largest size. So as all large fish are caught from nearby reefs, and are not replenished by immigrants (Miller and Geibel 1973; Love, in prep.) the operators seek fish on less exploited reefs farther from port. This, of course, increases time and cost, and leads to inevitable declines in fish size and density on ever more remote reefs, until the boats reach their economic cruise limit. On the heavily fished Naples Reef near Santa Barbara, for example, mature fish are so rare (Ebeling, pers. commun.) that only two were noted in two years' weekly scuba-diving surveys.

Hence, somehow the number of large fish caught from accessible inshore reefs must be regulated to preserve populations of growing mature adults. Yet this is difficult - because olive rockfish grow slowly, some 5-7 years to age of first maturity, and are unlikely to move from virgin to exploited areas.

Shallow reefs harbor several species, all of which mature and reach fishable lengths at different sizes. Thus setting minimum fish-size limits will probably not work. First, anglers usually do not distinguish the various rockfish species they catch. Second, even if size limits could be followed, many of the returned undersized fish would die, due to gas bladder expansion.

Closed seasons, either for all or selected species of rockfish, would probably not be feasible. The sportfisheries at several ports depend on rockfish - usually a very limited number of species - throughout much or all the year. Therefore, a closed season on all rockfishes would effectively eliminate sport fishing at these ports. Closed seasons for some species but not others would be inappropriate, because anglers could not avoid catching out-of-season species from multi-species aggregations.

Creating preserve areas may be a viable alternative. Specific areas of reef and kelp could be completely closed to all fishing for several years or more to exceed the relatively long generation time of rockfishes. Because most replenishment of an area comes from juvenile recruitment, not adult immigration, several years are required for the slowly growing fish to reach suitable size. Perhaps a few areas, close to port, should remain open to accommodate skiff fishermen.

Enforcement might not be too difficult. Except where very large numbers of small boats ply the reefs, partyboats create the greatest problem. A single partyboat catches far more fish than several small boats. However, partyboat operators and some anglers are beginning to express support for creating fishing preserves (Hardwick pers. commun.; Love, in prep.). A widespread educational campaign, explaining the where and why of preserves may convince the public of such a program's desirability.

Yet even proper management of deeper-living rockfish stocks requires more information on the biology of the various species. Several factors still must be explored in detail: stock sizes, larval movements and the aforementioned adult movements. The time remaining for implementation of viable management programs, particularly in heavily fished areas, may be limited. For instance, some of the only reefs in southern California not heavily exploited are those farthest out on the continental shelf, including reefs around Cortez and Tanner Banks, and San

Nicholas and San Miguel Islands. Perhaps these reefs supply much of the recruits to more heavily exploited reefs. It is also possible that potential recruits originate north of the area and are carried southward by the California Current, although it is more likely that most recruitment originates within the southern California Bight (Love and Larson 1978). In any event, the few remaining reefs not yet extensively fished should be evaluated as to their importance in supplying recruits to inshore populations.

Such studies require a combination of techniques. For example, in spite of its well known bathymetric movements, there is evidence that _S_. _alutus_ is composed of a number of isolated or semi-isolated populations (Fadeev 1968; Westrheim 1973; Gunderson 1977), perhaps co-occurring within a single bank (Westrheim 1973; Sekerak 1975). If artificial tagging remains unfeasible, biological tagging utilizing electrophoresis, parasites or other natural markers may be needed to distinguish the different stocks.

SUMMARY

The movements of the olive rockfish, *Sebastes serranoides* were investigated off Santa Barbara, California.

1847 olive rockfish were tagged with anchor tags on inshore reefs and about offshore oil platforms. 216 tags were recovered. No movement was noted on inshore reefs, while limited movements were seen between oil platforms.

The absence of a gill monogenean, *Microcotyle sebastis*, from a population of olive rockfish around Ellwood Pier provided further evidence of very restricted movements, as the monogenean is found in olive rockfish on nearby Naples Reef.

Size frequencies of fishes from a heavily-fished reef are significantly smaller than those from an adjacent lightly fished one, apparently because of little recruitment from nearby reefs.

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Table 1.--Descriptions and locations of tagging sites.

Table 1

Name	Description
Diablo Canyon, Avila	11 km west of Avila Harbor, 9 m reef in 33 m, .3 km offshore.
Naples Reef	24 km west of Santa Barbara, 1.6 km offshore, in 8-10 m, surrounded by 16-20 m deep sand flats.
Oil Platform Holly	18 km south-west of Santa Barbara, in 60 m, about 3.2 km offshore.
1 Mile Reef	2 km south-east of Santa Barbara, 2-6 m reef in 30-35 m.
Horseshoe Reef	10 km east of Santa Barbara. Average depth 8-10 m, surrounded by 12-13 m.
Oil Platform Hilda	8.7 km east of Santa Barbara, 3.1 km offshore in 34 m.
4 Mile Reef	6.4 km south-east of Santa Barbara, 6-8 m pinnacle in 40 m.
Oil Platform Hillhouse	10.4 km south-east of Santa Barbara, 8.9 km offshore in 58 m.
Oil Platforms Houchin, Hogan and Hope	About 14.0 km south-east of Santa Barbara, about 7 km offshore in 50 m.
Talcott Shoals, Santa Rosa Island	64.0 km south-west of Santa Barbara, 2-15 m pinnacles in 4-45 m.
Fraser Pt., Santa Cruz Island	46 km south of Santa Barbara, 2-6 m reefs in 12-15 m.
Smugglers Cove, Santa Cruz Island	40 km south-east of Santa Barbara.

Table 1--Continued

Name	Description
Anacapa Island	43 km south-east of Santa Barbara.
Rincon Oil Island	19 km east of Santa Barbara (not figured).
Deephole Reef	68 km east of Santa Barbara, 2-6 m reefs in 24-28 m, about 1.8 km offshore (not figured).

Table 2.--Percent recapture of tagged olive rockfish at the different study sites.

Table 2

	Number Tagged	% Recovered
Horseshoe Reef	75	34.6
Naples Reef	177	23.7
Platforms Houchin, Hogan, Hope	513	15.2
Talcott Shoals (Santa Rosa Island)	159	9.4
Fraser Pt. (Santa Cruz Island)	81	7.4
Deephole Reef	369	6.5
Rincon Oil Island	17	5.8
1 Mile Reef	240	5.0
4 Mile Reef	99	3.0
Other Sites*	117	0.0
TOTAL	1847	11.2

*Platform Hilda, Platform Holly, Anacapa Island, Smuggler's Cove

Table 3.--Percent infection by parasite (*Microcotyle sebastis*) of 80 olive rockfish from 6 sites over 4 quarters.

Table 3

	June-Aug.	Sept.-Nov.	Dec.-Feb.	Mar.-May	Total	
	# infected	# infected	# infected	# infected	# infected	% infected
Ellwood Pier	0	0	0	0	0	0.0
Naples Reef	4	3	3	4	14	17.5
Platform Houchin	12	12	14	15	51	63.8
Platform Hillhouse	10	14	13	15	52	65.0
Horseshoe Reef	14	11	15	15	55	68.8
4 Mile Reef	17	13	15	12	57	71.3

Table 4.--A summary of observations of rockfish movements in the northeastern Pacific.

Table 4

Species	Location	Method	Results	Source
S. alutus	N.E. Pacific	Analysis of fish catch data	Seasonal bathymetric; movements of many km's and 100 m & in depth.	Review in Gunderson (1977) and Major and Shippen (1970)
S. atrovirens	Monterey	Tagging	No movement	Miller and Geibel (1973)
S. auriculatus	Monterey	Tagging	No movement	Miller and Geibel (1973)
	Humboldt Bay	Tagging	No movement	DeWees and Gotshall (1974)
	Puget Sound	Underwater observation	No movement	Washington (pers. commun.)
S. carnatus	Santa Barbara Channel	Underwater observation, tagging	Has home range; no evidence of extensive movement	Larson (1977)
	Monterey Region	Underwater observation, tagging	No movement	Hallacher (1977)
S. caurinus	Monterey Bay	Tagging, underwater observation	Limited movement, furthest 2.4 km	Miller and Geibel (1973)
	Monterey Region	Tagging	No movement	Hallacher (1977)
	Humboldt Bay	Tagging	No movement	DeWees and Gotshall (1974)

Table 4--Continued (p. 2)

Species	Location	Method	Results	Source
	Puget Sound	Underwater observation	Fewer individuals seen on shallow water during summer	Dewees and Gotshall (1974), Patten (1973)
	Puget Sound	Underwater observation	Limited movement to ∿.8 km	Percy Washington (pers. commun.)
	Puget Sound	Underwater observation	Very limited bathymetric and onshore-offshore movement, a few meters vertical movement between summer & winter	Moulton (1977)
S. *chrysomelas*	Santa Barbara Channel	Underwater observation, tagging	Species has home range, no evidence of extensive movement	Larson (1977)
	Monterey Region	Underwater observation, tagging	No movement	Hallacher (1977)
	Monterey Bay	Tagging	No movement	Miller and Geibel (1973)
S. *flavidus* (Juv.)	Puget Sound	Underwater observation	Very limited bathymetric and onshore-offshore movement. A few meter vertical movement between summer & winter	Moulton (1977)

Table 4--Continued (p. 3)

Species	Location	Method	Results	Source
	Alaska	Tagging	Homing study, species homed up to 22.5 km	Carlson and Haight (1972)
S. maliger	Puget Sound	Underwater observation	No movement	Percy Washington (pers. commun.)
S. melanops	Monterey	Tagging	No movement	Miller and Geibel (1973)
	Humboldt Bay	Tagging	No movement	DeWees and Gotshall (1974)
	Puget Sound	Underwater observation	May make extensive seasonal bathymetric movements, absent from inshore waters Dec.-Mar.	Percy Washington (pers. commun.)
	Puget Sound	Underwater observation	Very limited bathymetric and onshore-offshore movement. A few meter vertical movement between summer & winter	Moulton (1977)
	Vancouver Isl.	Tagging	Little movement during summer, some dispersion during winter	McElderry (in prep.)
	Gulf of Alaska	Capture	Review of pelagic captures	Dunn and Hitz (1969)

Table 4--Continued (p. 4)

Species	Location	Method	Results	Source
S. miniatus (Juv.)	Redondo, Cal.	Tagging	Movement of 8-9.6 km	Turner, Ebert and Given (1969)
(Juv.?)	Monterey	Tagging	No movement	Miller and Geibel (1973)
S. mystinus	Southern to Northern Cal.	Tagging	Generally little or no movement; slight (to 1.6 km) movement in deeper water	Miller and Geibel (1973)
	Monterey Bay	Tagging	Restricted movement	
S. nebulosus	Vancouver Isl.	Underwater observation, tagging	Limited movement	McElderry (in prep.)
S. pinniger	Monterey Bay	Tagging	No movement	Miller and Geibel (1973)
S. rosaceus	Monterey Region	Underwater observation	No movement	Hallacher (1977)
S. ruberrimus	Oregon	Tagging	No movement	Coombs (in prep.)
S. serranoides	Santa Monica Bay	Tagging	No movement	Turner, Ebert, Given (1969)

Table 4--Continued (p. 5)

Species	Location	Method	Results	Source
	Santa Barbara Channel	Tagging	No movement in shallow water, limited movement in deeper water	Present paper
S. serriceps	Santa Barbara Channel	Underwater observation	No movement	Larson (pers. commun.)

Figure 1.--Location of tagging and sampling sites. Specific sites are marked with an "x". Descriptions of each site are given in Table 1. Deep Hole Reef (68.6 km east of Santa Barbara) and Rincon Oil Island (19 km east of Santa Barbara) are not included.

Figure 1

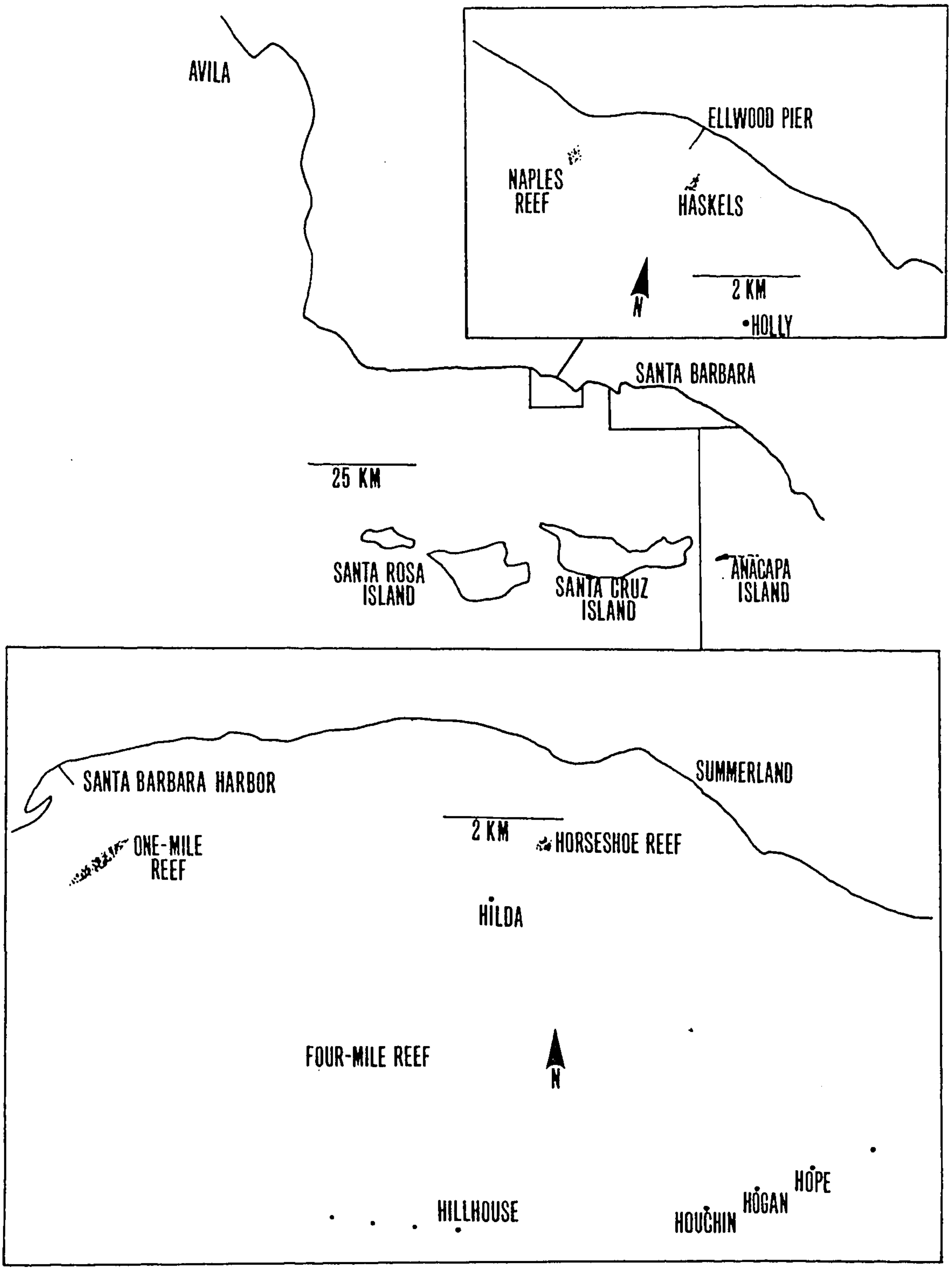
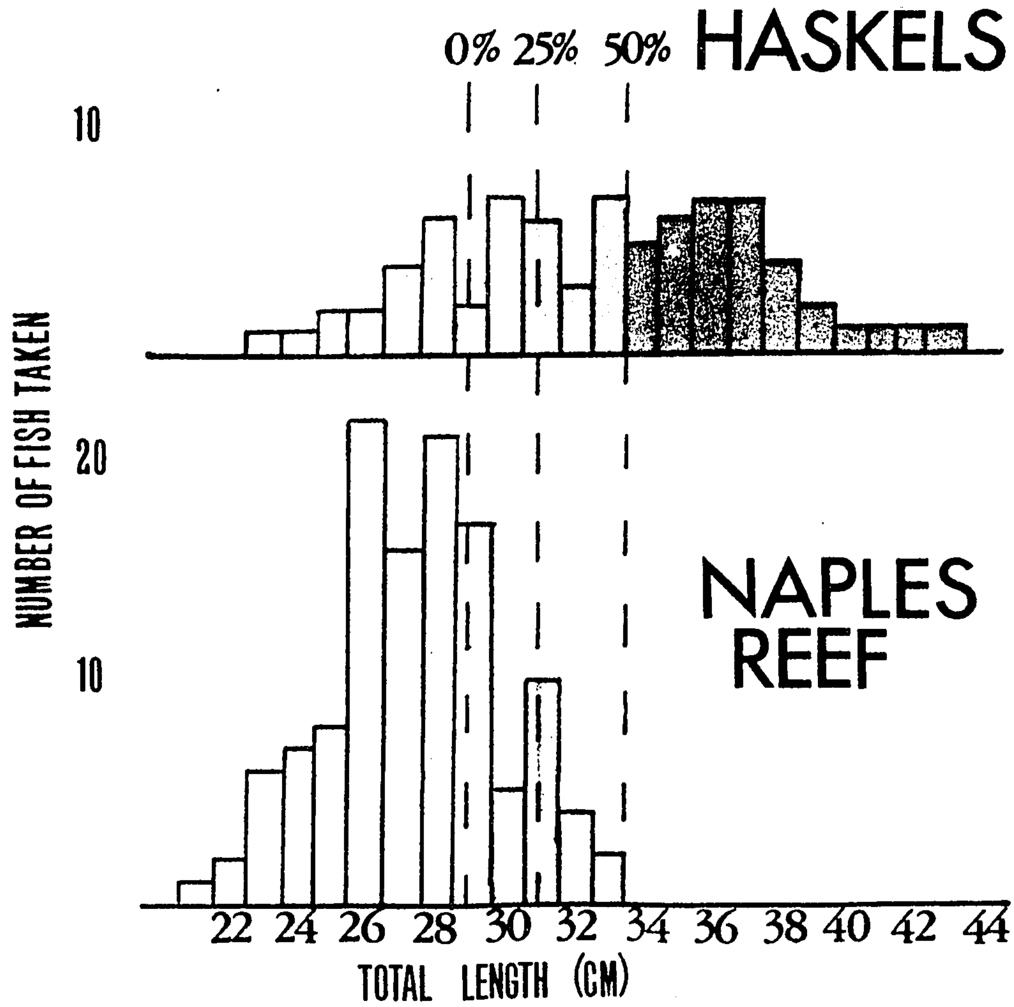

AVILA
ELLWOOD PIER
NAPLES REEF
HASKELS
2 KM
N
•HOLLY
SANTA BARBARA
25 KM
SANTA ROSA ISLAND
SANTA CRUZ ISLAND
ANACAPA ISLAND
SANTA BARBARA HARBOR
SUMMERLAND
ONE-MILE REEF
2 KM
HORSESHOE REEF
HILDA
FOUR-MILE REEF
N
HOPE
HOGAN
HOUCHIN
HILLHOUSE

Figure 2.--Size frequencies (total length) of *S. serranoides* taken aboard a partyboat at a heavily fished (Naples Reef) and lightly fished (Haskels) site. The size at which 0%, 25%, and 50% of the fish are mature is shown by dashed lines.

Figure 2


0% 25% 50%
HASKELS
NAPLES REEF
NUMBER OF FISH TAKEN
10
20
10
22 24 26 28 30 32 34 36 38 40 42 44
TOTAL LENGTH (CM)

CHAPTER 2

Life history of the olive rockfish, *Sebastes serranoides*

INTRODUCTION

The olive rockfish, Sebastes serranoides, comprises a major portion of the sportfish catch, both from partyboats and private vessels, along southern and central California (Miller and Gotshall 1965; Wine and Hoban 1976; Maxwell and Schultze 1976abc; Crooke and Schultze 1977; Crooke 1978; Love, in prep.). It lives in relatively shallow neritic water, mostly in areas of reef and kelp, from Del Norte County, California to San Benito Island, Baja California, Mexico. Unlike most of the 100 or so species in the scorpaenid genus, which is typified by spiny, sluggish benthic forms, olive rockfish are active, fast-swimming, streamlined predators of the neritic water column (Hobson and Chess 1976; Love and Ebeling 1978).

Off Santa Barbara, the diminishing sport catch of olive rockfish is now mostly of juvenile and subadult fish, younger than the age of first maturity (Chap. 1). Individuals apparently grow to adulthood in a relatively small, circumscribed area, once they settle out of the plankton. Since these fish grow very slowly, a reef can be depleted of large individuals by overfishing. No immigrants replace the lost adults and recruitment is slow. Yet, despite the importance and vulnerability of the olive rockfish, little was known about its life history. The objective of the present study, therefore, was to investigate the life listory of _S_. _serranoides_, including age and growth, maturity, fecundity, and spawning season. Specimens sampled from off central California are included in the study, because large, mature adults are available there.

For references in Chapter 2, please see the literature cited section in Chapter 3.

METHODS

Unless otherwise noted, specimens were collected between 1972 and 1977, at a group of shallow-water pinnacles, about 11 km west of Avila, California (Figure 1). These pinnacles, at depths of 20-30 m, are situated 100-300 m offshore of Diablo Cove and North Cove, and rise to within 5-10 m of the surface. Brown algae (predominantly *Nereocystis* sp.) grow on the shallower reefs during summer and fall. Sampling was sporadic until 1975, when, with a few exceptions, monthly collections were made.

Specimens were collected by hook and line and by pole spear (in about equal proportions), immediately placed on ice aboard the diving vessel and then frozen for later examination ashore.

All specimens were measured (total and standard lengths - TL, SL) to the nearest mm and weighed to the nearest .1 gr. The fish were sexed (individuals larger than about 15 cm TL) and their gonads weighed to the nearest .1 gr.

Age and Growth

Attempts to age rockfish have utilized various calcified structures (scales: Phillips 1964; Miller and Geibel 1975; otoliths: Chen 1971; Patten 1973; Westrheim and Harling 1975; vertebrae, opercles, otoliths, scales, anal pterygiophores etc.: Six and Horton 1977), each with varying success. Otoliths and scales have been most useful and in this study fish were aged with sacular otoliths. Sagittae were removed from 655 specimens, collected by hook and line or spear from the Avila sites and 583 from shallow (5-35 m) reefs off Santa Barbara. Otoliths were then cleaned and stored in water. Often thick and difficult to read, otoliths from S. serranoides older than about 7 years were immersed in clove oil for several months to increase their transparency. A chalky coating covering an occasional otolith was cleared away with a weak hydrochloric acid solution. Care was taken to prevent dissolving annuli at the otolith margins.

Otoliths were placed in a black-bottomed watch glass filled with water (or clove oil) and read under a dissecting microscope at a magnification of 10X. All otoliths were read twice, approximately two months apart. Agreement between readings was highest (100%) in 0 year fish, declining to 25% in 14 year olds (Table 1). Sample sizes of fish older than about 12 were too small for meaningful comparisons. If the readings did not agree, the otoliths were read again. The value of two coincident readings was accepted as the best estimate of age. If all three readings were different, the mid-reading was accepted.

A few otoliths were rejected as unreadable due to wide fluctuations in readings.

The otoliths of many temperate and arctic fishes are characterized by alternating opaque and transparent bands or zones (Williams and Bedford 1974). Opaque zones are those which appear white when examined on a black background with reflected light. Transparent zones are clear. The opaque zones are generally thought to be associated with periods of maximum growth (Nikolskii 1963; Williams and Bedford 1974), though the factors governing zone formation are not thoroughly known (Casselman 1974). Many temperate and arctic fishes lay down one opaque and one transparent zone per year (Pannella 1974; Nikolskii 1963) and these fishes may be aged by counting zones. However, because some species may lay down more than two zones per year (Nikolskii 1963), it is necessary to verify that zone formation is annular before otoliths are used in ageing.

There is no published work in ageing olive rockfish (with the exception of a few fish examined by Burge and Schultz 1973), and the use of their otoliths in age studies had not been validated. To determine if the opaque and translucent zones were annular, I observed the development of the opaque zone on the edge of otoliths of fishes from Avila, taken during a five-year period. The occurrence of a particular zone among most or all individuals during one part of the year would indicate that the zones were suitable for age determination (see discussion in Dark 1975; Williams and Bedford 1974). Because the opaque zones become narrow and difficult to distinguish in older fish and the timing of zone deposition may be influenced by the species' age or state of maturity (Williams and Bedford 1974; Dark 1975), I limited this sampling to 1-3 year old (immature) olive rockfish.

Figure 2 indicates that opaque-zone deposition was seasonal. The percentage of otoliths with opaque edges was low during fall and winter, but rose abruptly during late spring and peaked in summer months. Hence, the production of opaque zones coincides with the upwelling period along central California (Bakun 1973) and probably reflects increased feeding and growth. The percentage of opaque zones during the early spring may be underestimated, as the newly deposited opaque material is quite thin and somewhat transparent. On the other hand, the beginnings of the transparent zone during the fall are readily apparent.

The age-length relationship was fit to the von Bertalanffy growth-in-length equation,

$$L_t = L_\infty(1-\ell^{k(t-t_o)})$$

where L_t = length at time t

L_∞ = theoretical asymptotic length

K = constant expressing the rate of approach to L_∞

t_0 = theoretical age at which $L_t = 0$

The least squares method of Tomlinson and Abramson (1961), weighted according to sample size, was employed. Relationships were computed for fish from Avila and Santa Barbara, and for each sex from Avila.

To compare the growth curves generated at the two sites and between sexes at Avila, I computed mean lengths for each year class and their 95% confidence intervals.

Early in the study, it became apparent that there might be differences in growth rate between olive rockfish from Santa Barbara and Avila. As water temperatures off Santa Barbara are higher than off Avila (Schwartzlose 1957), I conducted an experiment to test whether temperature was involved in the observed growth rate differences. I captured 22 fish from a shallow (20 m) reef off Santa Barbara and placed 11 in each of two tanks. The fish were measured (TL) and tagged by clipping a dorsal spine. The Santa Barbara tank contained water pumped directly from Goleta Bay, while water was run through a cooler to a second tank and adjusted monthly to Avila surface temperatures (as reported by the Avila Harbor Department). The fish were fed chopped anchovies (twice per week) to satiation. Two fish in the Santa Barbara tank died within 3 days. The remainder were measured every 4 months. The study began in December 1973 and ended in August 1974.

Length and Weight

A total of 670 specimens were weighed and measured (312 males, 304 females and 54 of undetermined sex). The relationship between total length and weight was determined for each sex separately and combined, using log transformation and fitting the values to a straight line by least squares.

Maturation and Reproduction

Insemination and Spawning Season.

The gonads of mature olive rockfish undergo marked, yearly cyclical changes. Immediately after spawning, spent ovaries are flaccid and reddish, purple or gray. A resting period follows as the ovaries firm up, turning pink-red. Ovaries turn bright orange (very rarely cream-colored), and contain opaque eggs, during the mature phase, before fertilization. During the fertilized stage, the eggs clear and turn gray as larvae develop in the ripe ovaries.

Mature males undergo a simpler cycle. Resting stage testes are small and brown, becoming larger and whitish-brown as they develop. Fully developed testes are large, white and delicate.

With information, it was possible to determine when fish reproduced and when insemination occurred. Stages of gonad maturation (condition) in 1056 adult olive rockfish, taken during 1972-77 were determined using the criteria of Westrheim (1975) (Table 2). A gonad index:

$$\frac{\text{gonad weight}}{\text{body weight}} \times 10^2$$

was computed to quantify changes in gonad size and condition with season.

Size and Age at Maturity. It was often difficult to distinguish prereproductive female olive rockfish from mature late resting stage females (as noted by Westrheim 1975 and Gunderson 1977 in *S. alutus*). Females develop small orange ovaries 1 or 2 years before they are able to reproduce. During much of the year these "maturing" fish were easily distinguished from reproductive individuals, by their ovary size and color. However, during late spring and early summer, the ovaries of both reproductive and maturing fish are small and orange. That the maturing fish are indeed non-reproductive is seen in Figure 3, which compares gonad weight to body length for both reproductive and maturing females during summer and winter. Because of this difficulty, females captured during late spring and early summer were not included in this analysis.

Fecundity. The ovaries of 83 mature fish captured in October and November were placed in modified Gilson's solution (100 ml 60% isopropanol, 880 ml fresh water, 15 ml 80% nitric acid, 18 ml glacial acetic acid and 20 gr. mercuric chloride - Bagenal and Braum 1971) to harden the eggs, and were periodically shaken to loosen them from ovarian tissue. Eggs were kept in the solution for about 2 months, after which the fluid was poured off and replaced by water. Before eggs were counted, the ovaries were further broken up and repeatedly washed with water to remove remaining connective tissue. The eggs were placed in a large beaker and water was then added until 2,000 ml of eggs and water had been obtained. The mixture was stirred magnetically until the eggs were homogeneously distributed throughout the water column, and a 5 ml subsample was drawn with a pipette. Three subsamples were taken.

Eggs in each subsample were counted, using a dissecting microscope, and the mean number per ml was calculated for the three subsamples. Fecundity was estimated by $F = 2{,}000n$, where F = fecundity and n = mean number of eggs per ml in the mean subsample.

Juveniles

Rockfish larvae are pelagic for a number of months, after which they settle into waters of various depths. The settling time and habitat of olive rockfish from Santa Barbara was determined from information based on underwater observations by a number of personnel during a seven year period (1971-77) at Naples Reef, north-west of Santa Barbara. Data from Avila is based on diver observations from 1974-77 and on data supplied by David Behrens from a one year study at Diablo Cove during 1977.

RESULTS

Age and Growth

Plots of mean fish lengths by year class indicate that fish grow significantly faster off Avila, north of Point Conception, than off Santa Barbara, to the south (Figure 4). And, since larger fish occur at Avila, samples were large enough for computing confidence intervals of means to age 14 for Avila fish, but only to age 10 for Santa Barbara individuals. In fact, fish as old as 25 years (females - 51.4 cm TL; male - 42.4 cm TL) were caught off Avila.

At least two data points per age were necessary for computing the von Bertalanffy relationship. Because not every year class was represented by more than one individual after ages 14 (Avila) and 12 (Santa Barbara), curves ended at these points (Figure 5). Therefore, the computed theoretical maximum lengths (L_∞) are smaller than some observed lengths (>50.2 cm, with maximum length 61.2 cm off Avila; >41.0 cm, with 52.0 cm maximum off Santa Barbara).

Results of the laboratory experiment suggest that this difference in growth rates is related to differences in ambient water temperature. Fish in the colder tank (adjusted to Avila surface temperatures) grew significantly faster during the 8-month test period than those in the warmer (Santa Barbara) tank (mean length increase of fish in the cold tank = 6.09 cm; in the warm tank = 2.54 cm; t-test, $p<.001$).

Off Avila, female olive rockfish grew to a larger size at a significantly faster rate (at about 6 years of age) than males (Figures 6, 7). The growth rates in both sexes decline at about age 6, perhaps due to the onset of reproductive maturity.

Length and Weight

Although females grow faster than males, they do not do so disproportionately as indicated by length-weight relations (Figures 8, 9). Data were pooled for length-weight relations of all fish (Figure 9). The pooled relation estimates weights per length slightly below those of either females or males separately. This is due to the inclusion of a large number of unsexed small (less than 15 cm) individuals in the pooled sample.

Maturation and Reproduction

Insemination and Spawning Season.

For females off Avila, spawning occurs from December through March, peaking during January (Figure 10). Spent females are most prevalent during early spring, followed by a June peak in resting fish and a September-October peak in mature individuals. Fertilized fish were found from November through

January. Ovary weights remain essentially constant during the spring and summer (Figure 11), averaging perhaps 0.3% of body weight, occasionally as little as 0.1%. Then, during the winter spawning season, ripe ovaries averaged 13.8% of body weight (maximum 20.7%, minimum 2.3%).

For males, testes sizes (based on the gonad index) are relatively constant during spring and early summer, though they begin to increase in size a month or two earlier than females (Figure 11). During the constant period, they remain at minimum size, about 0.1% of body weight. They increase to .9-1.0% (maximum 2.2%) of body weight in late fall. It appears that insemination occurs from October to December, perhaps peaking in November.

Size and Age and Maturity. There was considerable variation in size and age at first maturity (Figures 12, 13). A few fish were mature at 3 years old (males 28.1-32.5 cm TL, females 31.1-33.6 cm TL). Yet not all males were mature before 7 years and 39.0 cm TL, females before 8 years and 37.0 cm TL. Over 50% of the females had spawned by 4 years and 34.0 cm TL, while males were age 5 and 32.0 cm TL before reaching the 50% mark. In general, males spawned at a somewhat smaller size and somewhat later age than females.

I compared age and length at first maturity relations for olive rockfish between the samples from Avila and Santa Barbara. Though Santa Barbara fish matured at a considerably later age than Avila fish (about 4 years later at the 50% level; Figure 14), the two groups nearly coincided in size at first maturity (Figure 15).

Fecundity. The non-linear relation between fecundity and total length (Figure 16) was best described by the function $F = aL^b$, where F = number of eggs in thousands, L = total length in centimeters and a and b = constants. Values of a and b were computed by fitting the linear function $\log F = \log a + b \log L$ by least squares. Estimated fecundity ranged from 30,000 eggs for a 32.6 cm TL individual to about 490,000 from one 46.8 cm long.

Juveniles

Based on spawning season and young-of-the-year sightings, olive rockfish probably spend 3-6 months as pelagic larvae before settling out. Young of the year first appeared inshore off Avila during March and April and off Santa Barbara in April and May. At this stage, they were particularly common under the kelp canopy and over very shallow, protected rocky reefs (occasionally in the lower intertidal). Although they were not observed there, young-of-the-year probably also occur at reefs somewhat more offshore (depth 20-50 m), as they were often found in the stomachs of resident rockfish in these habitats.

DISCUSSION

Age and Growth

The growth rates of a number of northeastern Pacific rockfish have been investigated. Previous comparisons between populations (Alaska-British Columbia; British Columbia-California) have indicated an inverse relationship between growth rate and latitude (the further south the population, the faster the growth rate) (Westrheim 1973; Westrheim and Harling 1975). However, Boehlert (in prep.) has found that S. diploproa grows faster in the northern part of its range (Washington) than in the south (off southern California). My work with the olive rockfish indicates that it, too, grows more quickly off Avila where the water is cooler than at the more southerly and warmer Santa Barbara.

The reasons for variability in growth rates among rockfish populations are not completely known, though ambient temperature is almost certainly involved. While a number of factors influence fish growth (including salinity - Gibson and Hirst 1955, Kinne 1960; oxygen levels - Ebeling and Alpert 1966; food availability - Brown 1957), temperature has been shown to be one of the most influential factors (Brown 1957; Paloheimo and Dickie 1966; Liu and Walford 1966; Brett et al. 1969). In general, growth is temperature-dependent in fishes (Bourliere 1957; Liu et al. 1975), and fish often have an optimal growth temperature, above and below which growth is retarded (Kinne 1960; Liu and Walford 1966; Brett et al. 1969; Andrews and Stickney 1972).

A number of laboratory studies, besides my own, indicate that relatively low temperatures may result in increased growth rates in some fishes (Brown 1957; Gibson and Hirst 1966; Liu and Walford 1966). In fact, Liu and Walford (1966), comparing growth rates of an annual cyprinodont, found both increased growth rates and life span in the lower temperature regime.

Reasons for optimal growth rates at a particular temperature are little known. It is likely that an optimal growth temperature represents a balance between several factors leading to optimal food conversion (Andrews and Stickney 1972). For example, it has been hypothesized that as temperatures are lowered, activity levels and maintenance metabolism decreases, hence more energy is available for growth (Brett et al. 1969). Below some point, however, feeding decreases and so growth rates decrease. Changes in enzymatic activity may affect growth rates. The activity of digestive enzymes may, at least in some cases, be temperature-dependent (Hoar 1966), with peak activity levels occurring at a particular temperature.

Highest growth rates may occur at temperatures where enzyme activity is high, yet maintenance metabolism is relatively low.

If rockfish growth rates are temperature dependent, rates may reach a peak in some part of a species range, declining in populations on either side. Though a number of studies have examined populations on the northern edge or central part of a species range, no study has yet covered an entire range.

Not all rockfish species show the observed tendency for females to grow faster than males. Though females grow faster and attain a larger size in a number of species (S. goodei, S. paucispinis, S. saxicola - Phillips 1964; S. mystinus - Miller and Geibel 1973), many rockfish show little or no differentiation (S. umbrosus - Chen 1971; S. crameri, S. diploproa, S. entomelas, S. flavidus, S. jordani, S. miniatus, S. pinniger - Phillips 1964).

Maturation and Reproduction

Insemination and Spawning Season. Moser (1967) found "a brood of advanced embryos or larvae and a series of ova undergoing vitellogenesis" in the rockfishes Sebastes chlorostictus, S. constellatus, S. eos, S. goodei, S. levis, S. ovalis, S. paucispinis and S. rosaceus, and stated that this offered direct evidence of multiple brood production during a spawning season. Similar findings for some of the above species were reported by MacGregor (1970). Miller and Geibel (1973) noted that one of 648 *S. mystinus* examined showed multiple spawning. I found no evidence of multiple spawning in olive rockfish. Females usually retained a few unexpelled eyed larvae, which appear to be resorbed within a few months.

Based on very limited sampling, MacGregor (1970) noted that multiple spawning rockfish species generally had fewer eggs (116-211) per gram body weight than single-spawners (192-374) as compared with 223 determined for olive rockfish in the present study. Although there may be a relationship between egg number per body weight and single or multiple spawning, MacGregor's values are based on only a few fish per species and his values would probably have decreased had he examined a more representative sample (Figure 17).

Spawning seasons vary widely among California rockfish (Moser 1967; Chen 1971; Westrheim 1975; Love in prep.). Most species have peak spawning during either winter (December, January or February) or spring (March, April and May) and a few species spawn during summer and early fall. Olive rockfish are probably winter spawners; spawning seasons are probably of three or four months' duration.

The evolution of reproductive isolating mechanisms in the genus Sebastes may not have included the restriction of random mating by seasonal isolation. It seems likely that the time from insemination to spawning is similar among closely related species. Rockfish species which mate over the same period, probably spawn at the same time during a later season. Olive rockfish and their presumed subgeneric congeners, S. flavidus, S. mystinus and S. melanops spawn and probably mate during the same seasons (see also Phillips 1964; Miller and Geibel 1973; Love in prep.), as do other closely related rockfish species groups (e.g. S. paucispinis-S. goodei - Moser 1967; S. chrysomelas-S. carnatus - Love in prep.); and other subgenera (Sebastomus - Chen 1971; Love in prep.).

Instead, habitat isolation among some species (such as S. chrysomelas-S. carnatus - Larson 1977) may restrict interspecific mating. However, a number of species pairs (notably S. paucispinis-S. goodei and S. miniatus-S. pinniger) may aggregate together throughout the year. Even though closely related species mate in the same habitat, during the same season, hybrids are very rare in California waters (the "hybrids" in Phillips 1964 are now recognized as distinct species), indicating that other anti-hybridization mechanisms are involved.

Though it is possible that extensive cross-specific mating occurs, and gametic or zygotic mortality prevents hybridization, it seems more likely that internal fertilization, necessitating close coordinated contact, has lent itself as a mechanism of mechanical and/or behavioral isolation. The copulatory organs of male *S. serranoides* are relatively small, thus a degree of closely coordinated movements is probably necessary to effect mating. Auditory, visual and chemical cues may all play a part. It is known, for instance, that some rockfish species produce sounds (Hallacher 1974) and these may be used in species recognition. Deeper-water species, living in relative darkness, may depend primarily on non-visual recognition during mating season.

Size and Age at Maturity. Age of first maturity varies widely among rockfish species. At one extreme, *S. emphaeus* matures at 2-4 years (Moulton 1975), *S. umbrosus*, *S. ensifer* (Chen 1971) and *S. jordani* (Phillips 1964) at 3 years; while at the other, *S. chlorostictus*, *S. rosenblatti* and *S. constellatus* mature at about 10 years (Chen 1971) and some stocks of *S. alutus* do not mature until 11 years or later (Gunderson 1977). Modal period for first reproduction seems to be about 4-7 years of age for most species (Phillips 1964; Patten 1973; Miller and Geibel 1973).

Olive rockfish from the different study sites matured at about the same lengths, although Santa Barbara fish were about 4 years older. Gunderson (1977) also noted differences in age and length at first maturity between stocks of *S. alutus*, and suggested that body length may be more important than age in mediating maturation in *S. alutus*.

Fecundity. Olive rockfish fecundity levels reflected the ranges determined for a number of other rockfish species, notably *S. mystinus* (Miller and Geibel 1973) and *S. alutus* (Alverson and Westrheim 1961). In all species studied, smaller individuals tend to carry fewer eggs. There is some evidence (MacGregor 1970) that smaller species also carry fewer eggs. Thus far, the maximum number of eggs counted was well over one million (in a 53.0 cm SL *S. ruberrimus* - MacGregor 1970), more than twice the maximum number computed for *S. serranoides*.

Rockfish fecundity measurements, however, are tenuous at best and should only be looked upon as first approximations. Computations made before and after fertilization (Lisovenko 1956) or by differences in subsampling techniques (Gunderson 1977) may cause discrepancies between studies. Moreover, the relationship between the number of maturing eggs in an ovary and viable larvae produced is unknown. Unfortunately, it is not practical to count larvae in the ovaries, as some may be lost during capture. Fecundity may also vary due to environmental factors (temperature - Rounsefell 1957 and food availability - Bagenel 1966) or genetic differences (Bagenel 1966).

Juveniles

In some areas off southern California, olive rockfish apparently migrate into deeper waters as they mature. Although immature fish are abundant in kelp beds, mature individuals are not seen in inshore waters (Santa Catalina Island - T. Chess pers. commun.; Redondo Beach - J. Stephens pers. commun.; San Onofre - E. De Martini pers. commun.). Juveniles of many rockfish species settle in water more shallow than the adult depth (Table 3) and later move into deeper water. Off central and northern California, young-of-the-year of a sibling species, *S. flavidus*, aggregate with *S. serranoides* in inshore waters for a number of months before the former moves into deeper waters. Bathymetric movements of olive rockfish and other species may be related to a wider temperature tolerance in juveniles than adults. Surface water temperatures off Catalina, Redondo Beach and San Onofre are significantly higher (Schwartzlose 1957) than off Santa Barbara and other more northerly sites, where little or no olive rockfish bathymetric movement occurs. The planktivorous juvenile rockfish may have evolved a wider temperature tolerance than adults, allowing them to take advantage of the food-rich inshore waters.

Table 1.--Consistency (percent agreement) of otolith readings from olive rockfish.

Table 1

No. of Zones	N	%
0	45	100
1	12	100
2	55	98
3	72	94
4	66	83
5	72	83
6	74	80
7	73	77
8	60	72
9	45	69
10	37	63
11	15	58
12	10	40
13	8	38
14	12	25

Table 2.--Stages in gonad maturation as applied to olive rockfish.

Table 2

1.	Immature	Ovary small and translucent
2.	Maturing	Ovary small and orange
3.	Mature	Ovary firm, oocytes orange (occasionally white) and opaque
4.	Fertilized (uneyed)	Ovary not firm, eggs orange and translucent
5.	Ripe (eyed)	Ovary not firm, eggs translucent with black dots or visible larvae
6.	Spent	Ovary large and flaccid with a red, purple or dark gray color, a few larvae may be present
7.	Resting	Ovary firm, moderate size, pink-gray

Table 3.--Juvenile rockfish known to commonly inhabit water shallower than, or in the most shallow part of, the adult range. Rockfish, which live in inshore waters as adults are not listed. Although common in inshore waters throughout much of southern California, *S. caurinus* and *S. serranoides* are listed below, because juveniles differentially occur inshore where the species occurs.

Table 3

S. alutus - Westrheim (1970)

S. caurinus (southern California) - Larson (1972)

S. crameri - Phillips (1964)

S. elongatus - McElderry (pers. commun.)

S. entomelas - Miller and Geibel (1973)

S. flavidus - Miller and Geibel (1973)

S. goodei - Phillips (1964); Miller and Geibel (1973)

S. jordani - Miller and Geibel (1973)

S. levis - Allen, Pecorelli and Word (1976)

S. macdonaldi - Moser (1972)

S. miniatus - Carlisle, Turner and Given (1964); D. Miller (pers. commun.)

S. ovalis - Miller and Geibel (1973)

S. paucispinis - Moser (1967)

S. proriger - Westrheim, Davenport and Harling (1977)

S. ruberrimus - Hart (1973)

S. saxicola - Phillips (1964)

S. serranoides (southern California) - T. Chess (pers. commun.); J. Stephens (pers. commun.)

S. zacentrus - Westrheim, Davenport and Harling (1977)

Figure 1.--Location of sampling sites (marked with an "x").

Figure 1

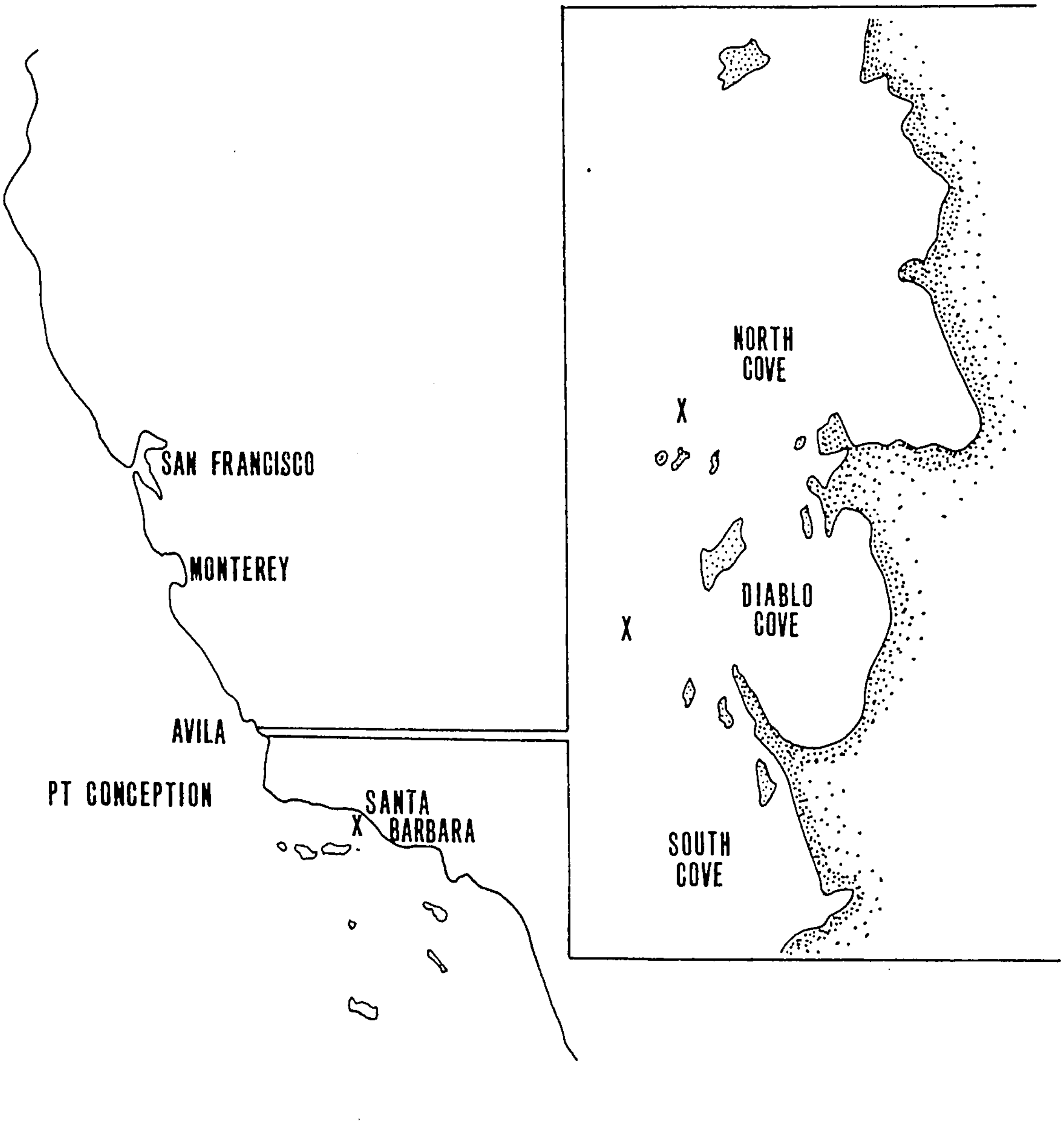

SAN FRANCISCO
MONTEREY
AVILA
PT CONCEPTION
SANTA BARBARA
X
NORTH COVE
X
DIABLO COVE
X
SOUTH COVE

Figure 2.--Monthly percentages of olive rockfish otoliths with opaque margins. Sample size is in parentheses.

Figure 2

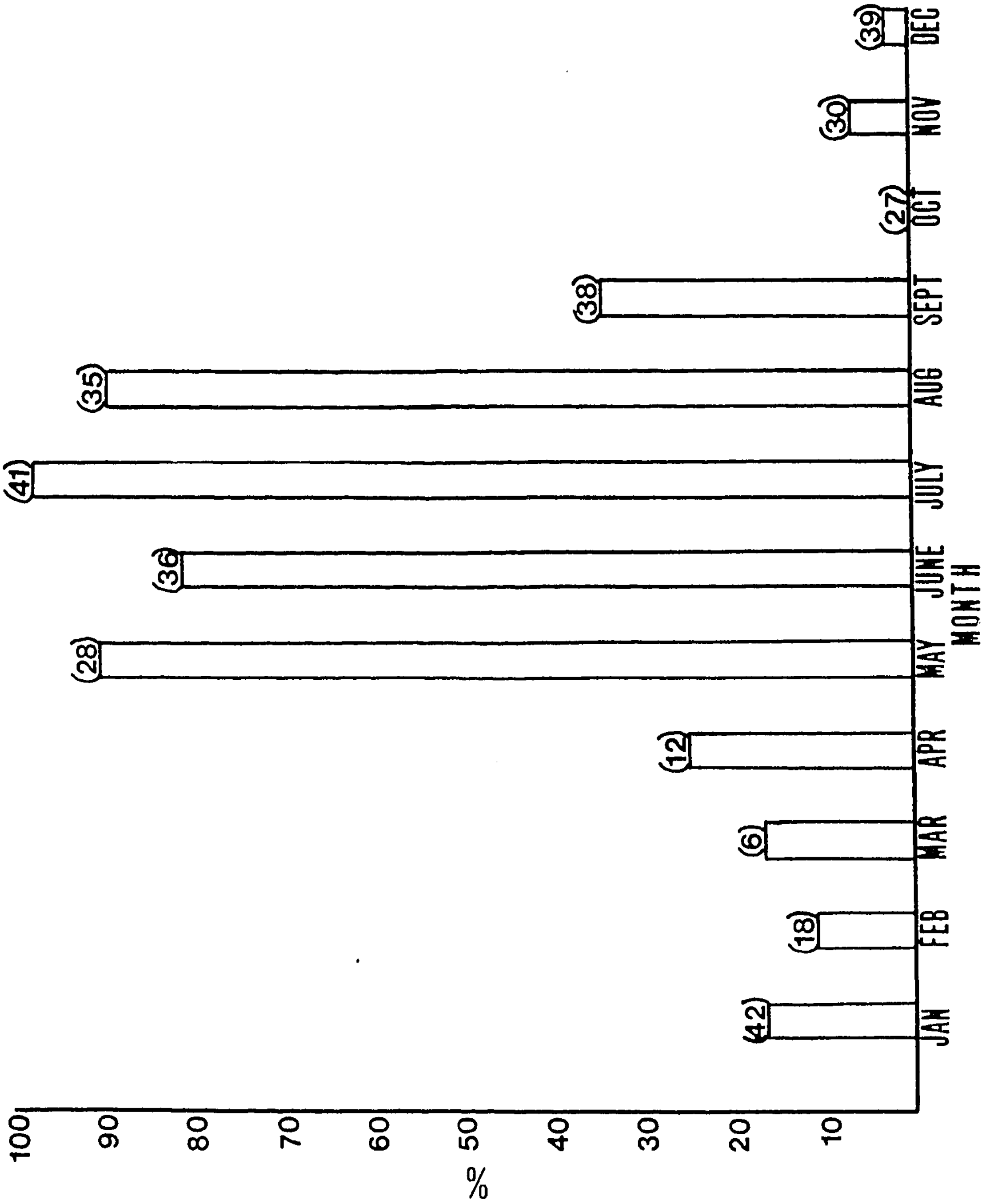

%
100
90
80
70
60
50
40
30
20
10
MONTH
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
(42)
(18)
(6)
(12)
(28)
(36)
(41)
(35)
(38)
(27)
(30)
(39)

Figure 3.--Seasonal difference in relative gonad weight of mature and "maturing" female olive rockfish, by length of fish.

Figure 3

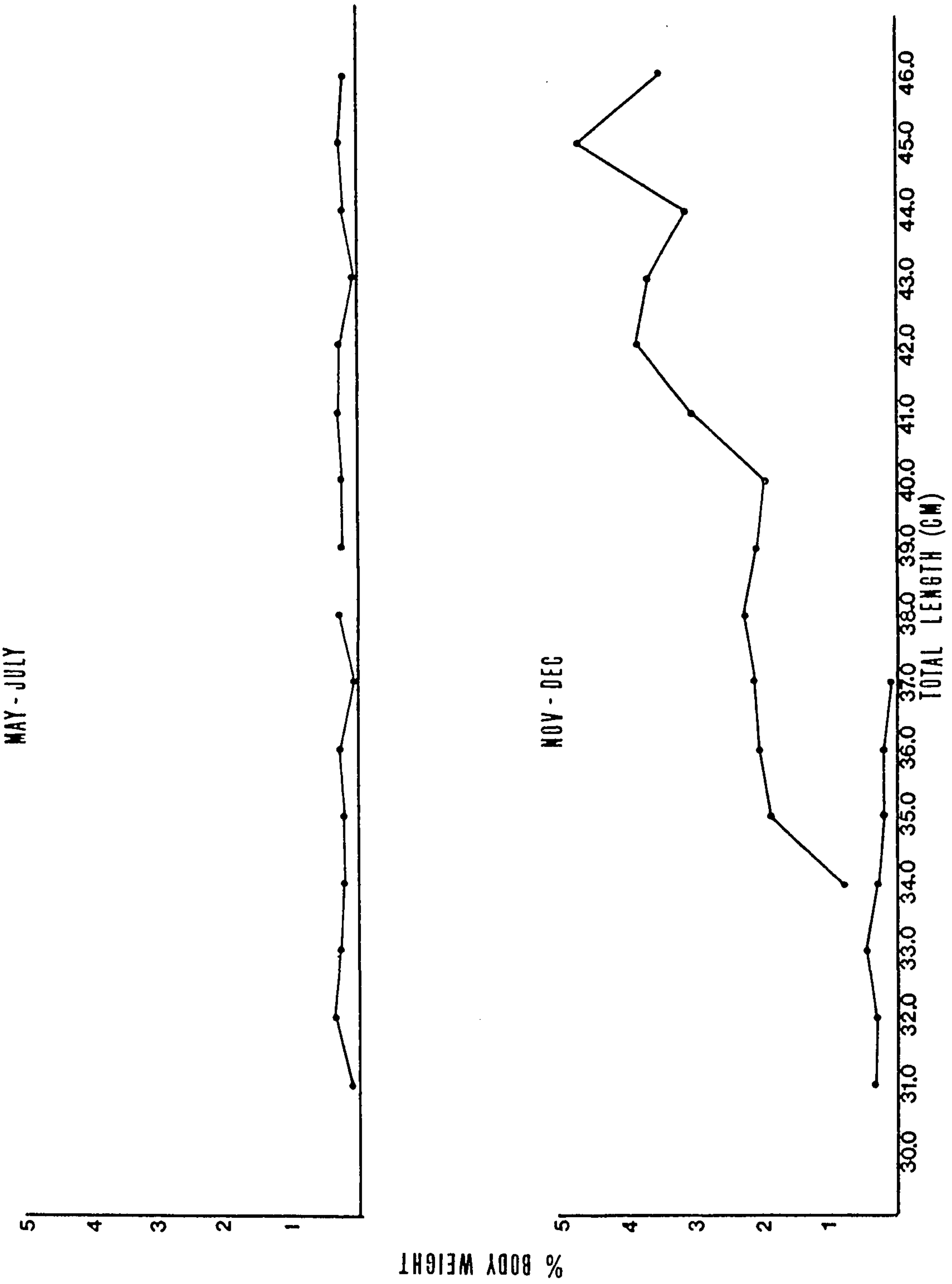

MAY - JULY
NOV - DEC
% BODY WEIGHT
1
2
3
4
5
TOTAL LENGTH (CM)
30.0
31.0
32.0
33.0
34.0
35.0
36.0
37.0
38.0
39.0
40.0
41.0
42.0
43.0
44.0
45.0
46.0

Figure 4.--Mean lengths and 95% confidence intervals for year classes of olive rockfish sampled off Avila and Santa Barbara.

Figure 4

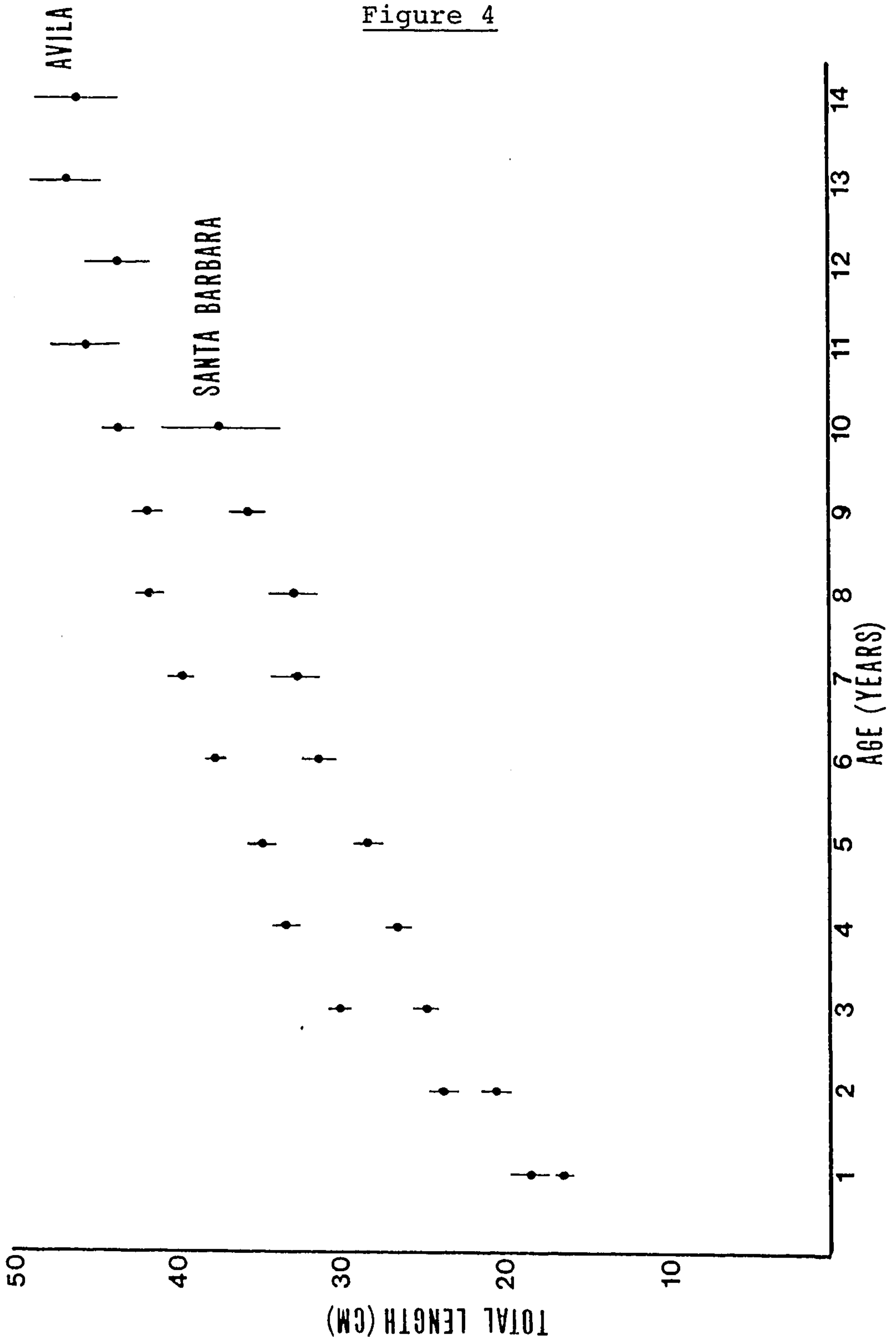

AVILA
SANTA BARBARA
1
2
3
4
5
6
7
8
9
10
11
12
13
14
AGE (YEARS)
50
40
30
20
10
TOTAL LENGTH (CM)

Figure 5.--Von Bertalanffy growth curves for olive rockfish taken off Avila and Santa Barbara.

Figure 5

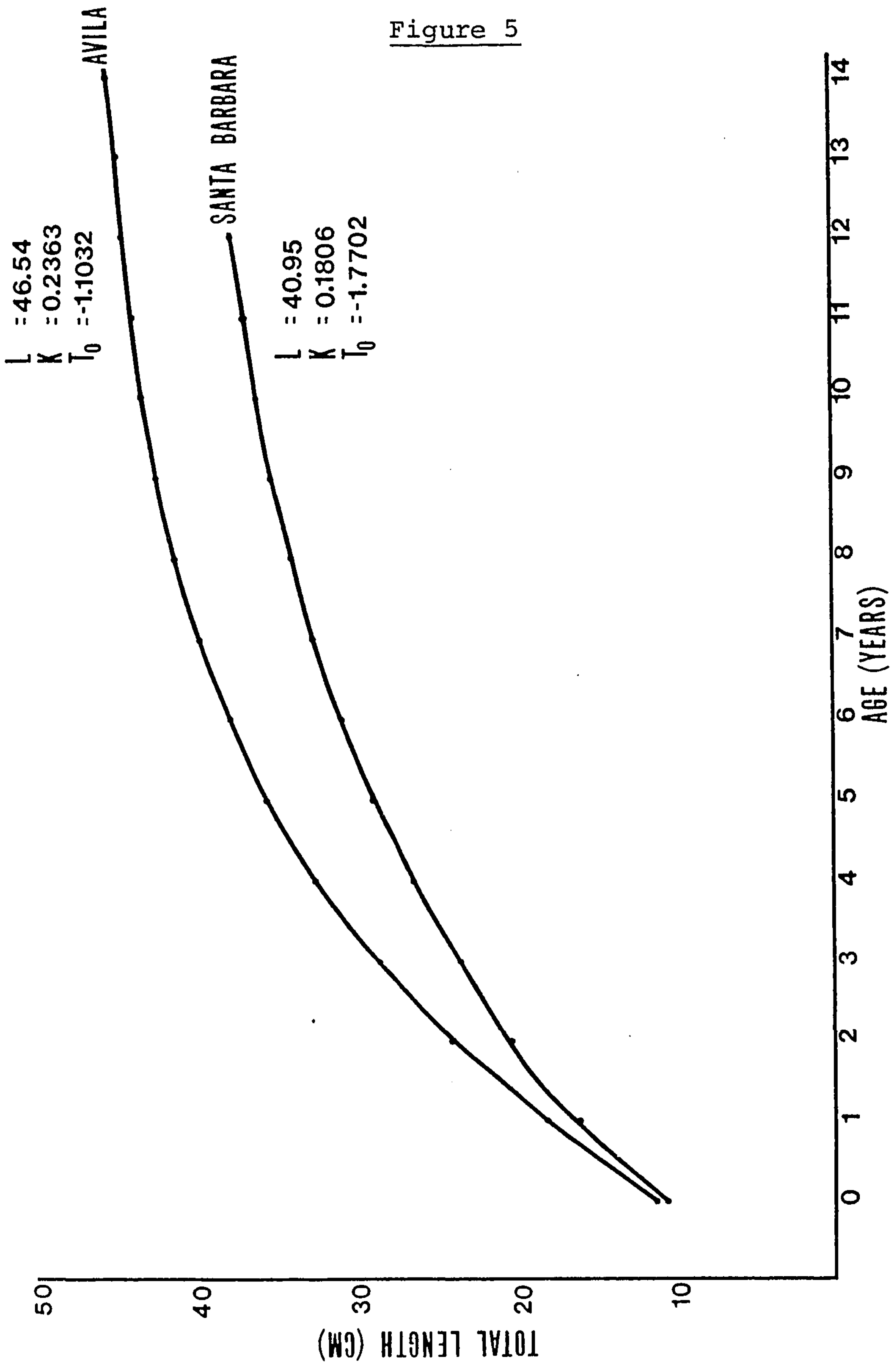

AVILA
SANTA BARBARA
L =46.54
K =0.2363
T_0 =-1.1032
L =40.95
K =0.1806
T_0 =-1.7702
TOTAL LENGTH (CM)
50
40
30
20
10
AGE (YEARS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 6.--Mean lengths and 95% confidence intervals for year classes of female and of male olive rockfish sampled off Avila.

Figure 6

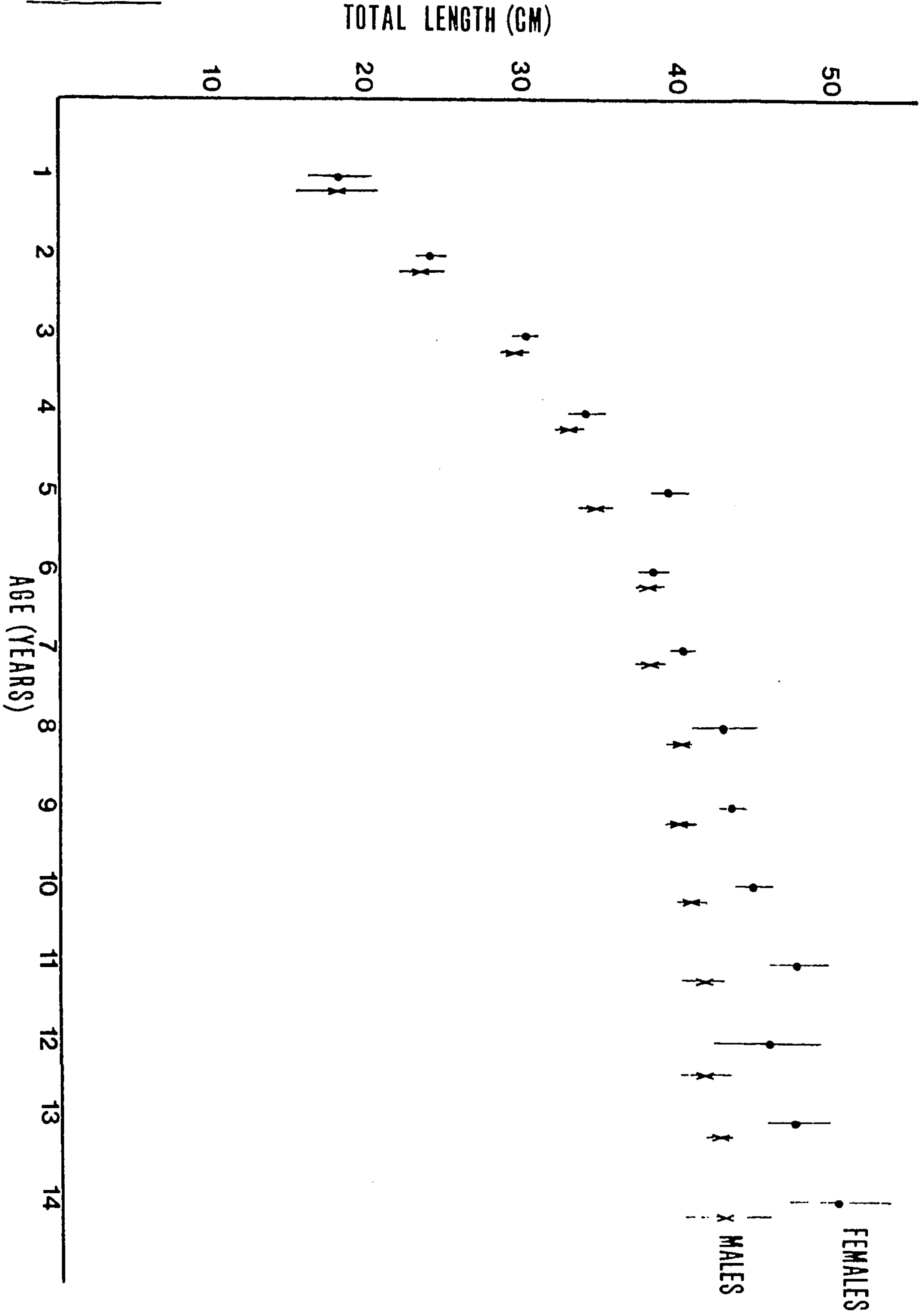

TOTAL LENGTH (CM)
10
20
30
40
50
1
2
3
4
5
6
7
8
9
10
11
12
13
14
AGE (YEARS)
FEMALES
x MALES

Figure 7.--Von Bertalanffy growth curves for female and male olive rockfish taken off Avila.

Figure 7

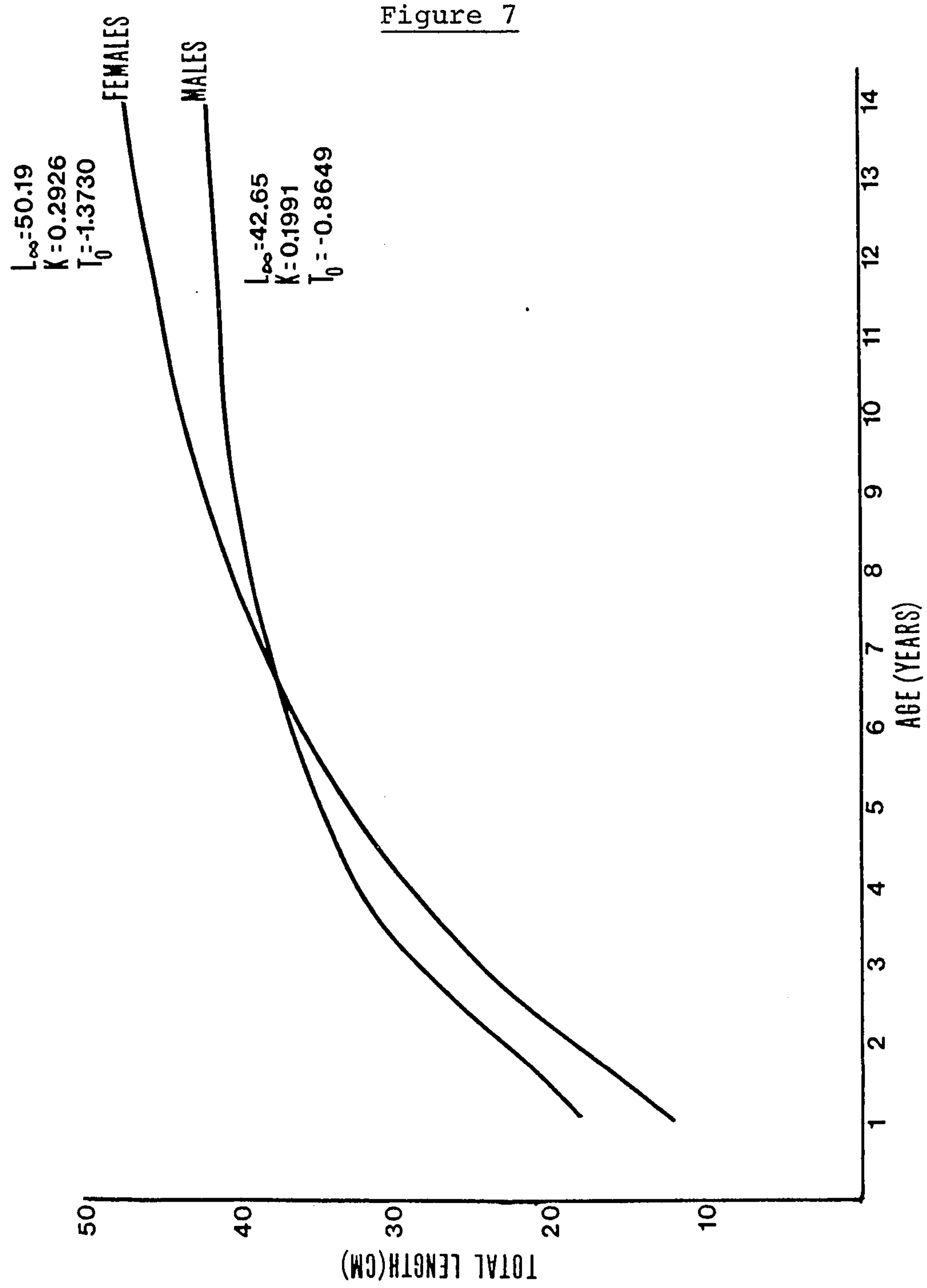

L∞=50.19
K=0.2926
T0=-1.3730
FEMALES
MALES
L∞=42.65
K=0.1991
T0=-0.8649
TOTAL LENGTH(CM)
10
20
30
40
50
AGE (YEARS)
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 8.--Length-weight relations based on 304 female and 312 male olive rockfish sampled off Avila.

Figure 8

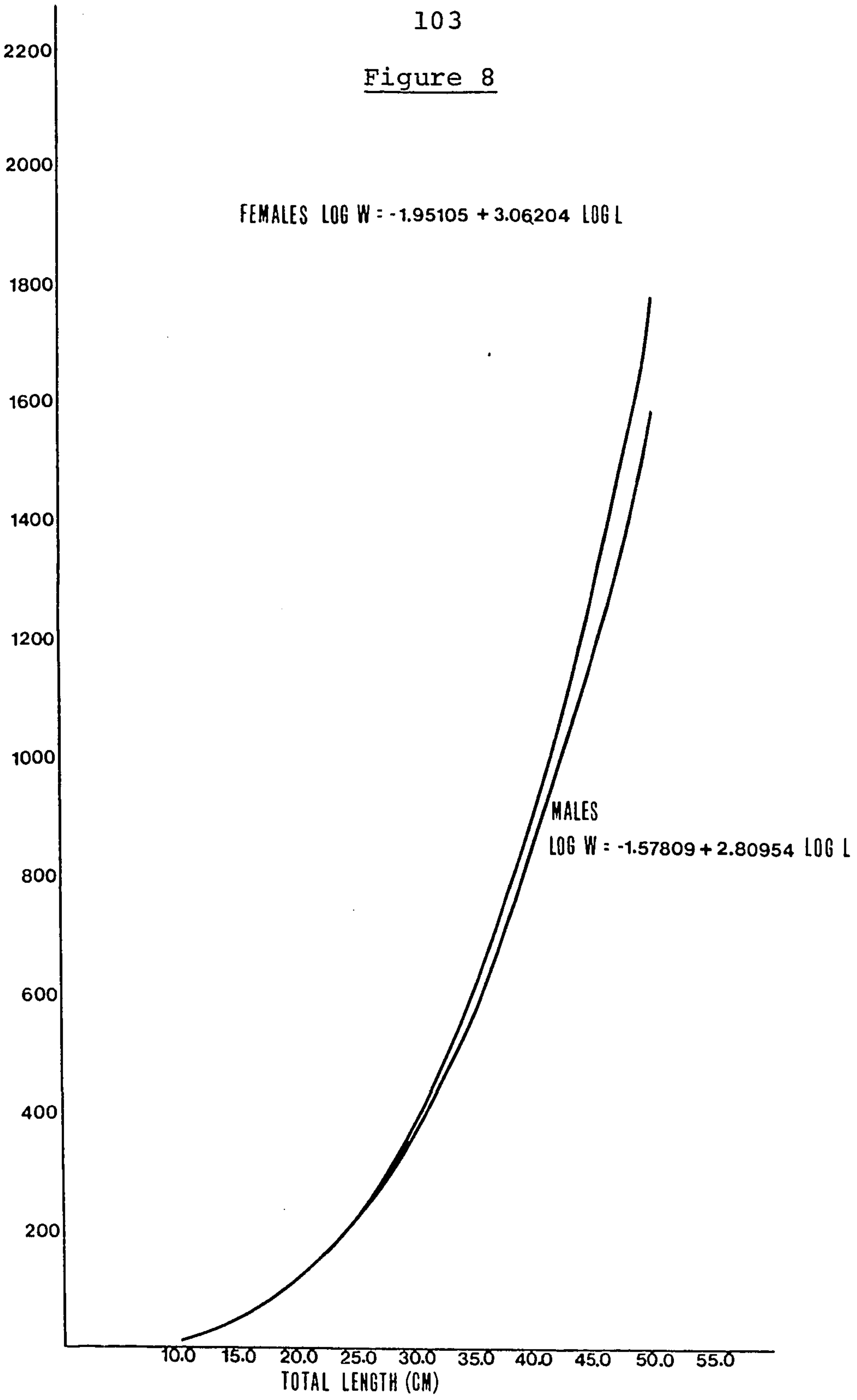

2200
2000
1800
1600
1400
1200
1000
800
600
400
200
FEMALES LOG W = -1.95105 + 3.06204 LOG L
MALES
LOG W = -1.57809 + 2.80954 LOG L
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
TOTAL LENGTH (CM)

Figure 9.--Length-weight relation based on a pooled sample of 669 olive rockfish, including males, females and immature fish, sampled off Avila.

Figure 9

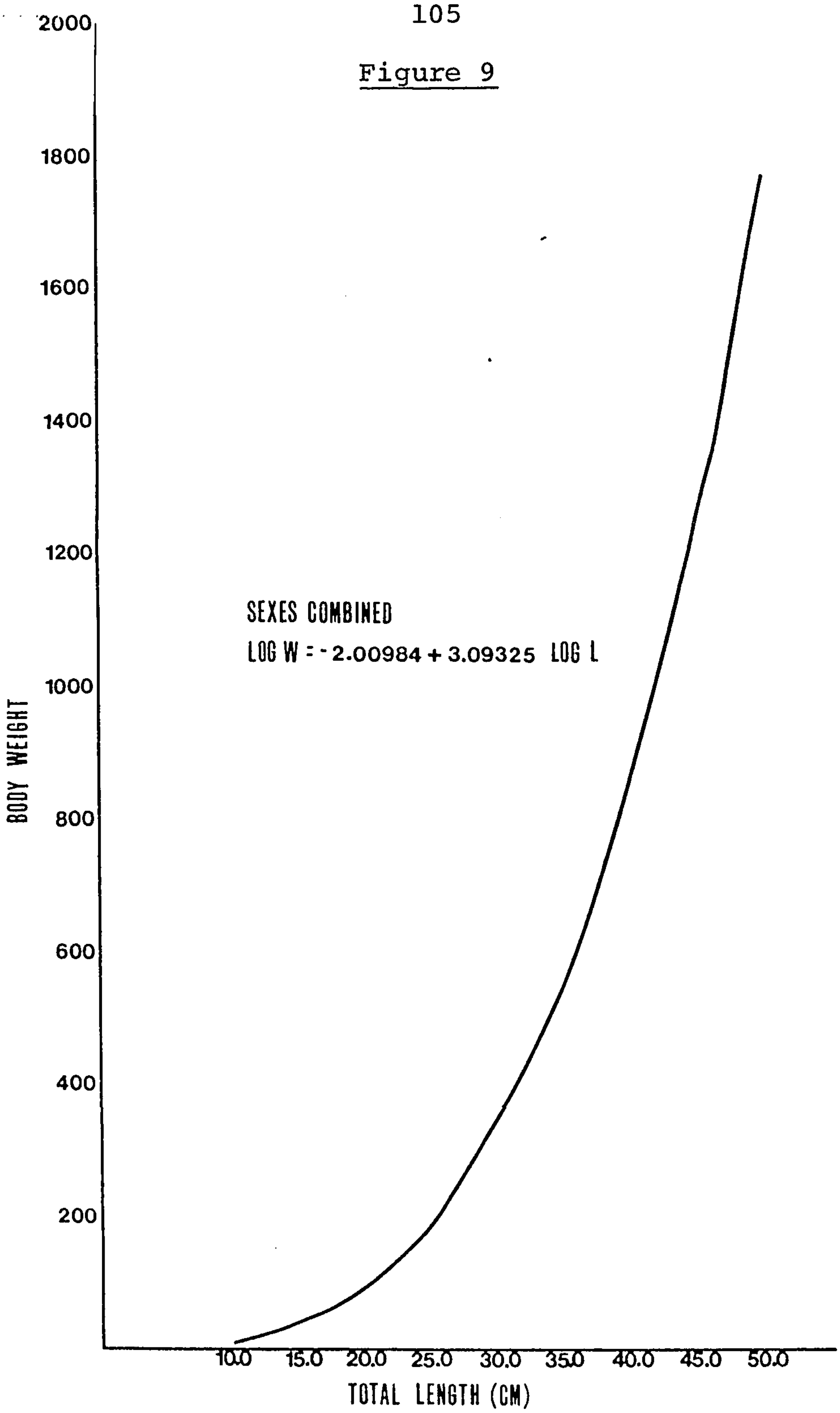

2000
1800
1600
1400
1200
1000
800
600
400
200
BODY WEIGHT
SEXES COMBINED
LOG W = -2.00984 + 3.09325 LOG L
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
TOTAL LENGTH (CM)

Figure 10.--Percent composition by month of 5 gonad condition stages for olive rockfish taken off Avila, 1972-77. See text and Table 2 for gonad condition criteria.

Figure 10

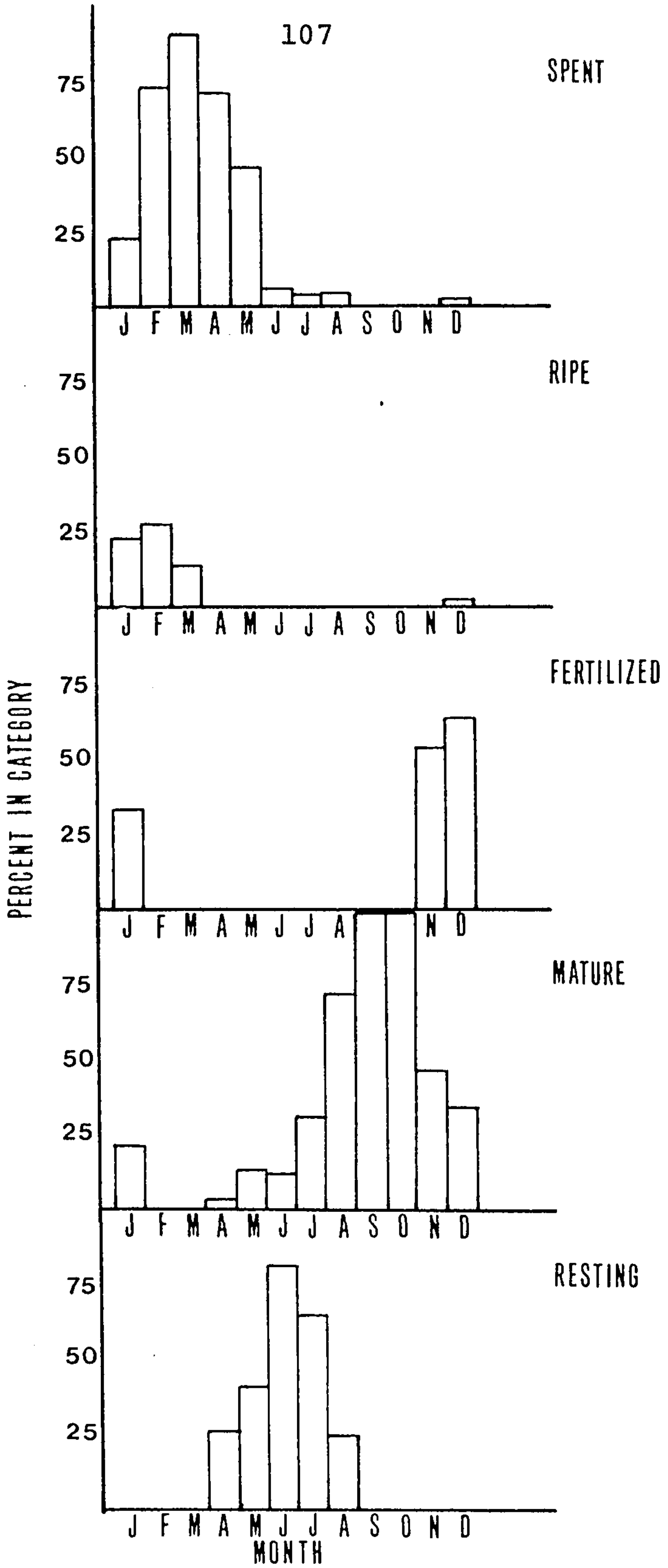

SPENT
RIPE
FERTILIZED
MATURE
RESTING
75
50
25
J F M A M J J A S O N D
PERCENT IN CATEGORY
MONTH

Figure 11.--Seasonal changes in the gonosomatic indices of male (closed circles) and female (open circles) olive rockfish. Vertical lines indicate 95% confidence intervals of the mean. See text for explanation of indices.

Figure 11

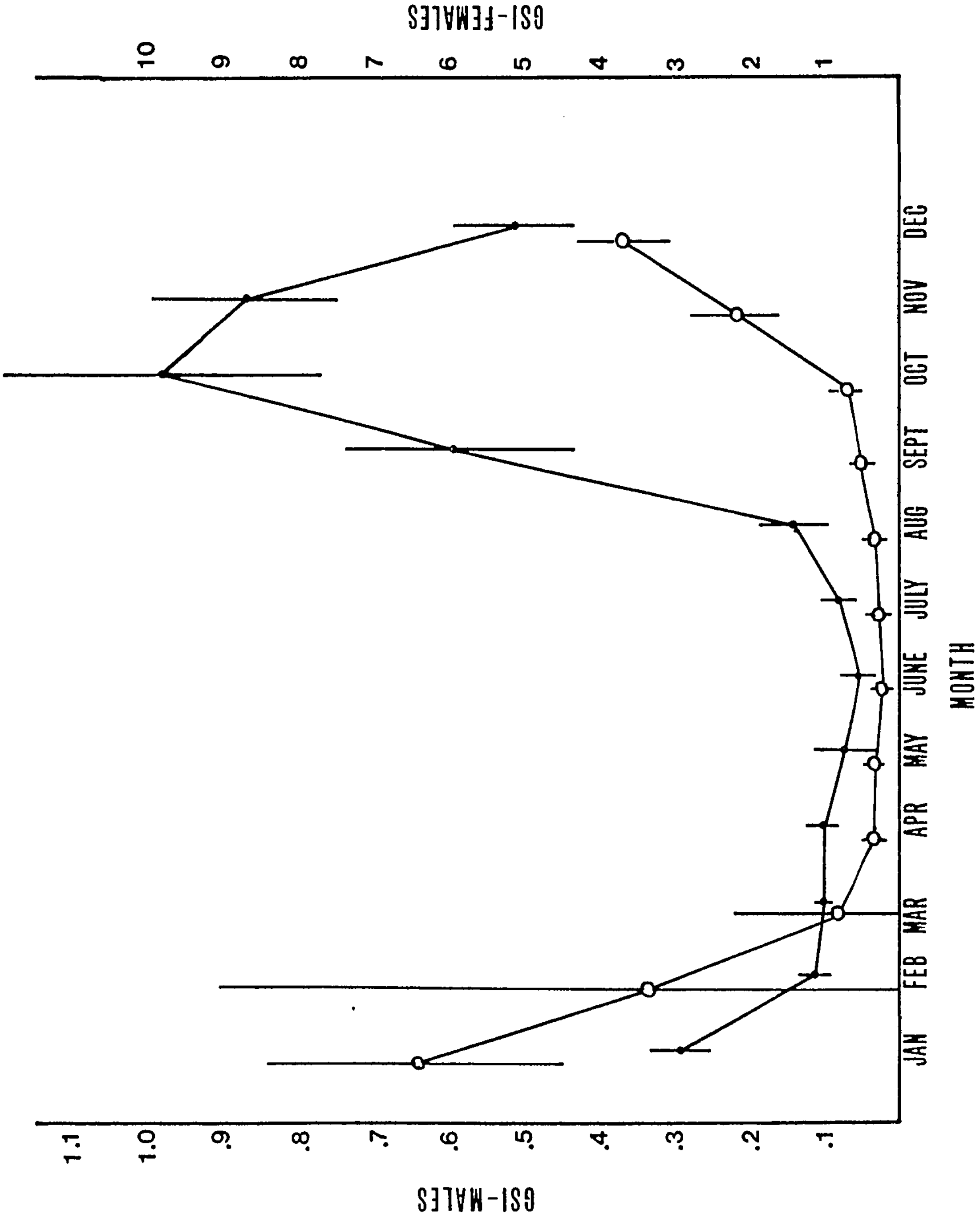

GSI-FEMALES
10
9
8
7
6
5
4
3
2
1
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
MONTH
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
GSI-MALES

Figure 12.--Length-maturity relations for 331 females (open circles), 318 males (closed circles), and both sexes pooled (dotted line) of olive rockfish collected off Avila 1972-1977.

Figure 12

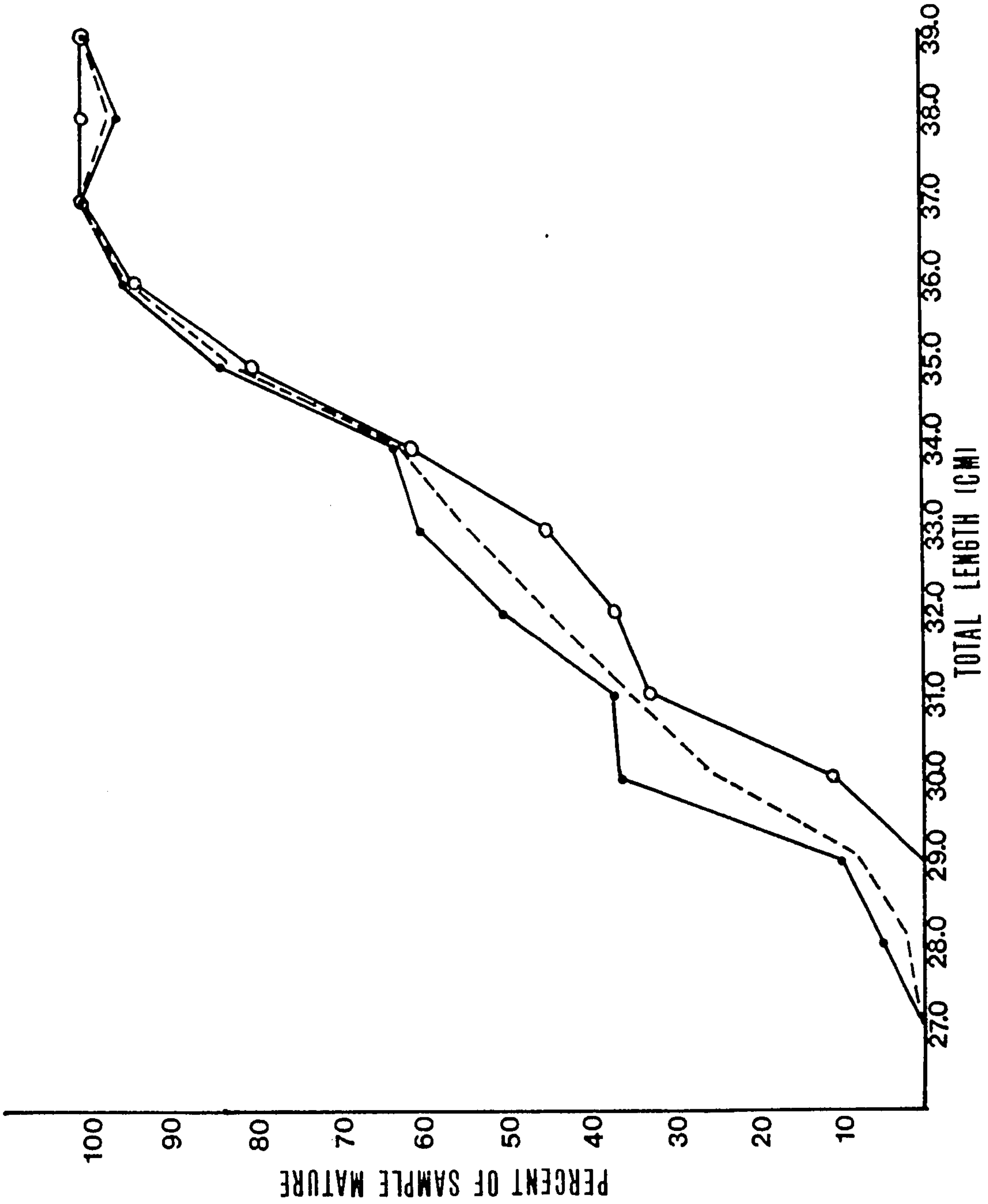

PERCENT OF SAMPLE MATURE
100
90
80
70
60
50
40
30
20
10
TOTAL LENGTH (CM)
27.0
28.0
29.0
30.0
31.0
32.0
33.0
34.0
35.0
36.0
37.0
38.0
39.0

Figure 13.--Age-maturity relations of 317 females (open circles) and 302 males (closed circles) olive rockfish collected off Avila 1972-77.

Figure 13

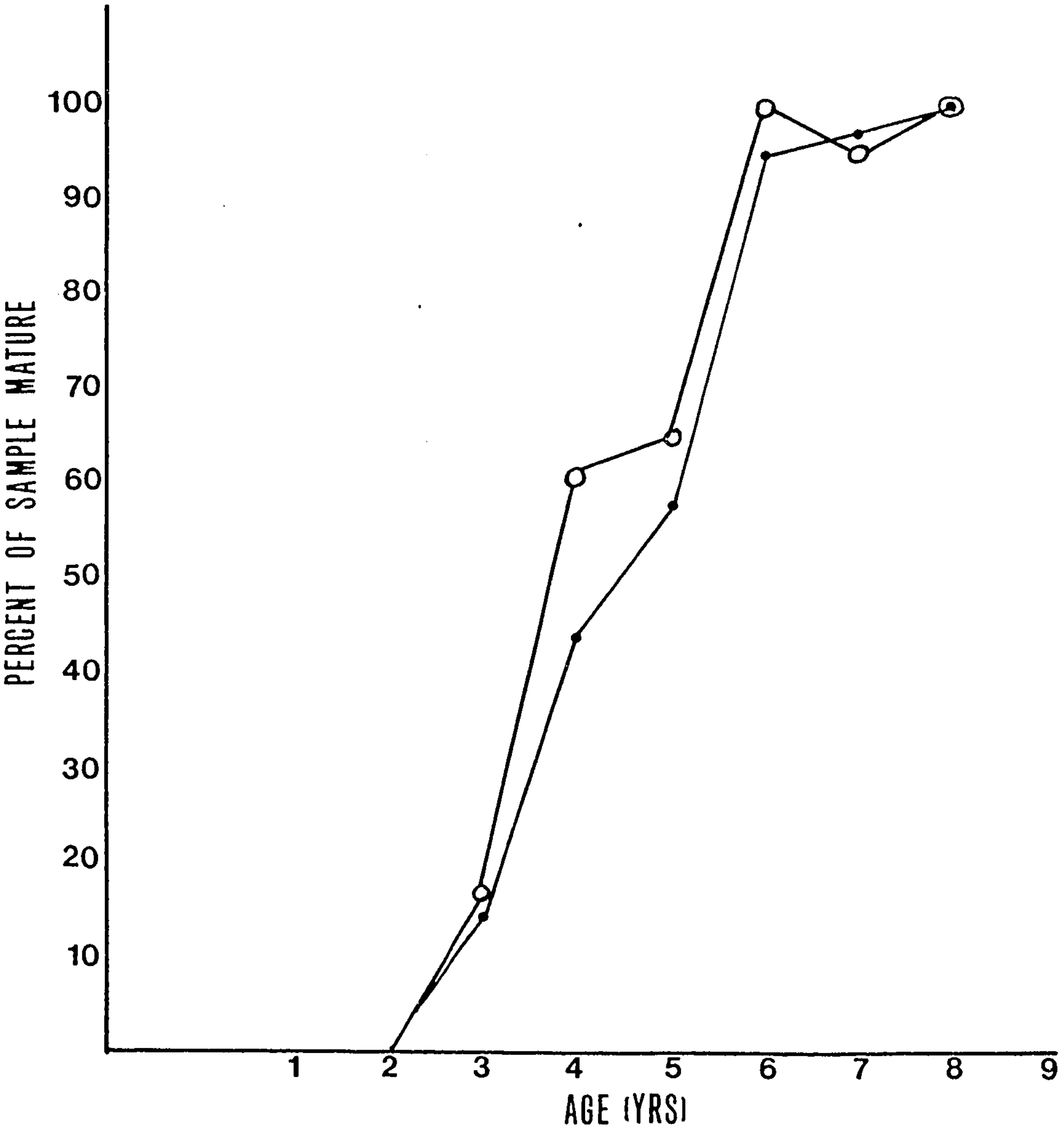

PERCENT OF SAMPLE MATURE
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
AGE (YRS)

Figure 14.--Comparison of age-maturity relations of 619 olive rockfish (sexes pooled) from Avila (open circles) and 365 olive rockfish from Santa Barbara (closed circles).

Figure 14

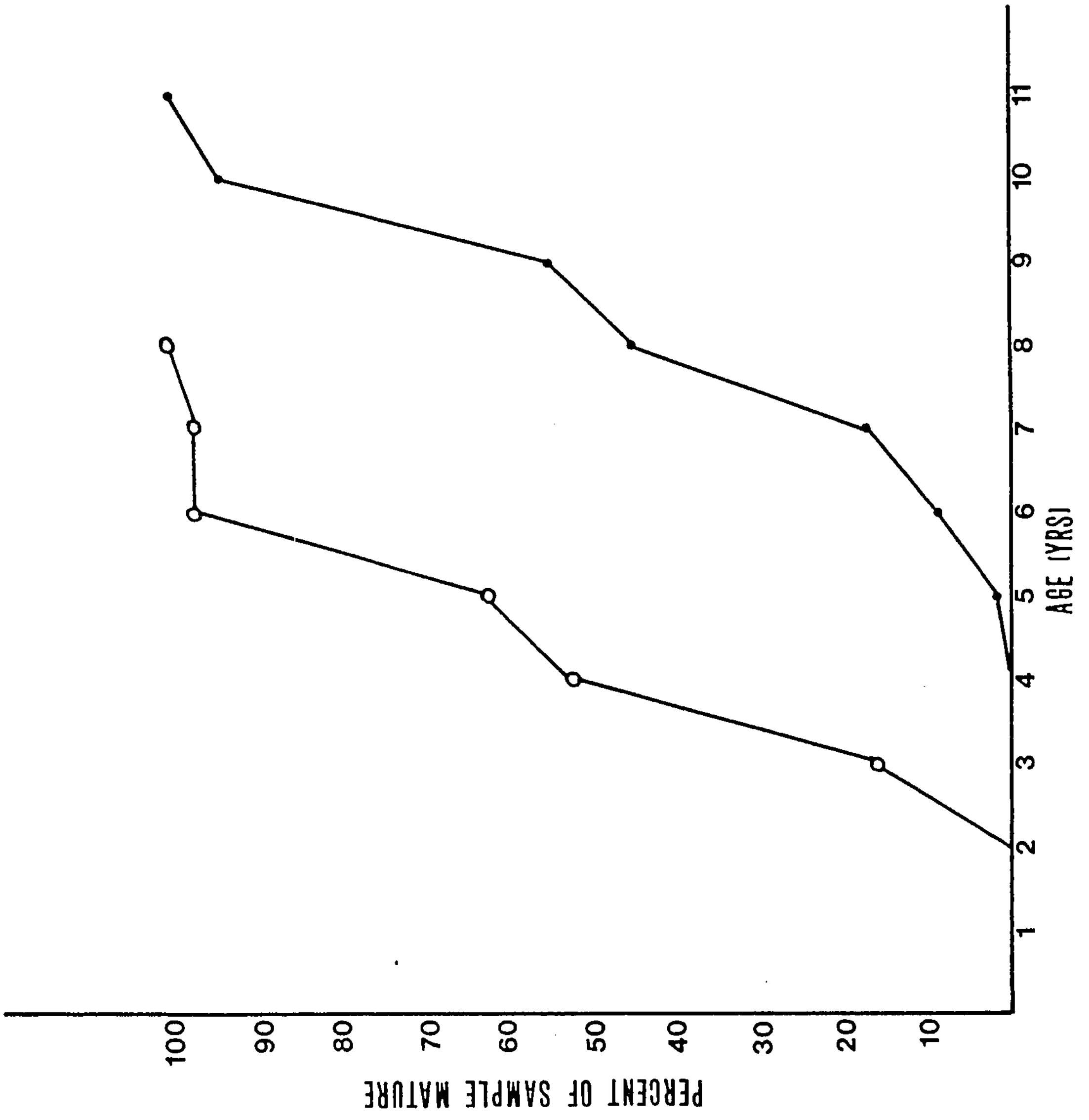

PERCENT OF SAMPLE MATURE
100
90
80
70
60
50
40
30
20
10
AGE (YRS)
1
2
3
4
5
6
7
8
9
10
11

Figure 15.--Comparison of length-maturity relations of 619 olive rockfish (sexes pooled) from Avila (open circles) and 365 olive rockfish from Santa Barbara (closed circles).

Figure 15

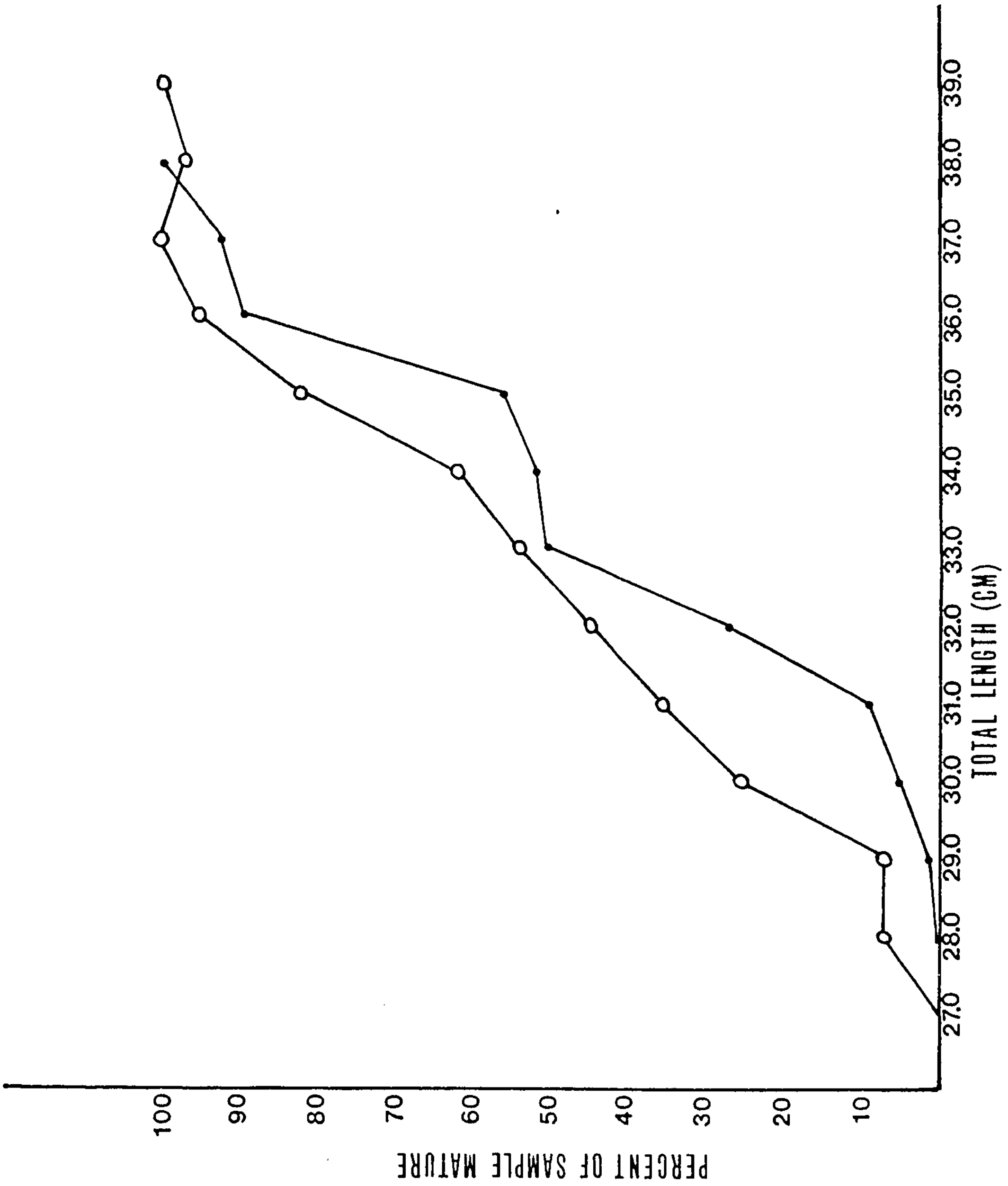

PERCENT OF SAMPLE MATURE
100
90
80
70
60
50
40
30
20
10
27.0
28.0
29.0
30.0
31.0
32.0
33.0
34.0
35.0
36.0
37.0
38.0
39.0
TOTAL LENGTH (CM)

Figure 16.--Fecundity-total length relation for 87 olive rockfish collected off Avila 1972-77.

Figure 16

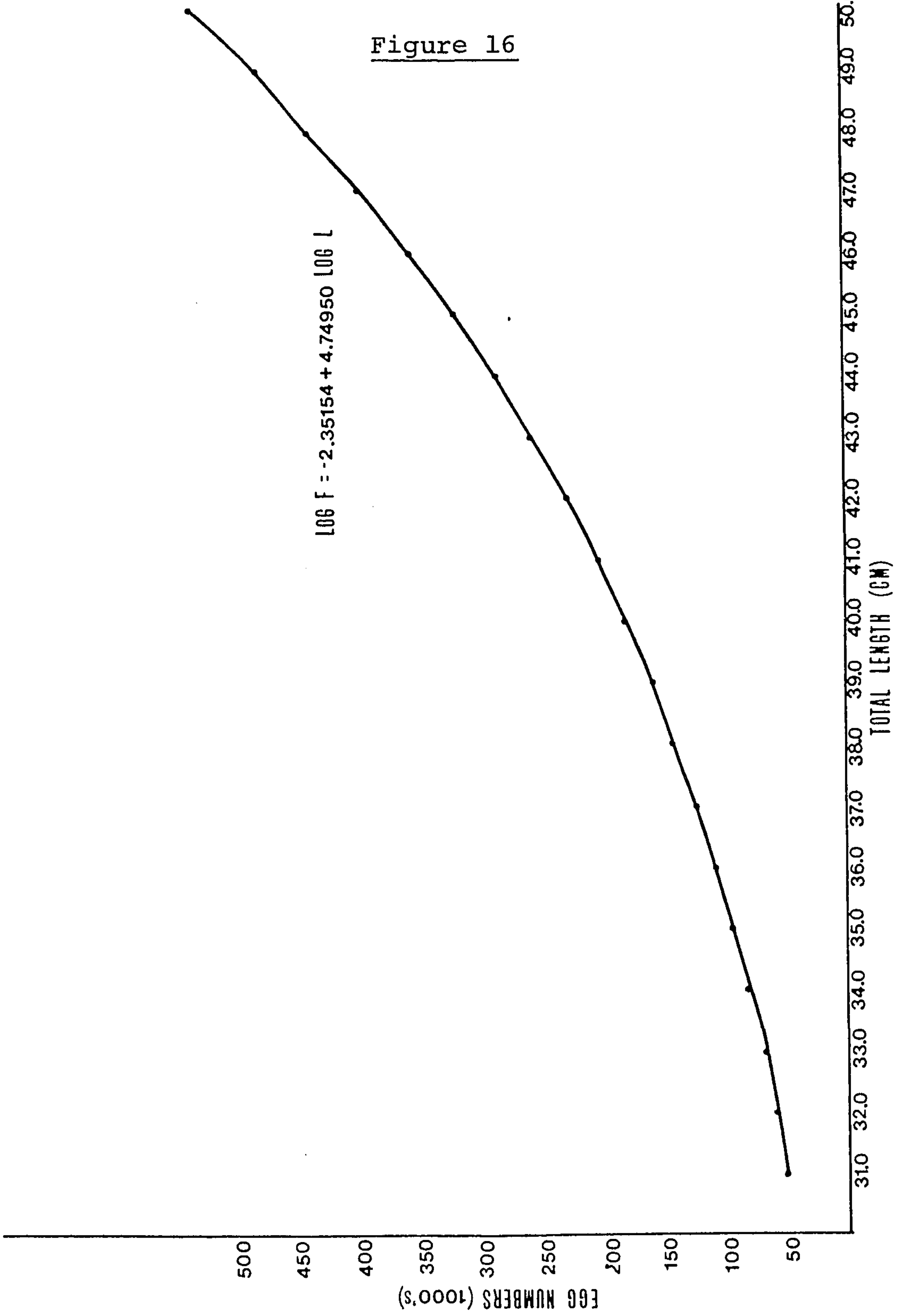
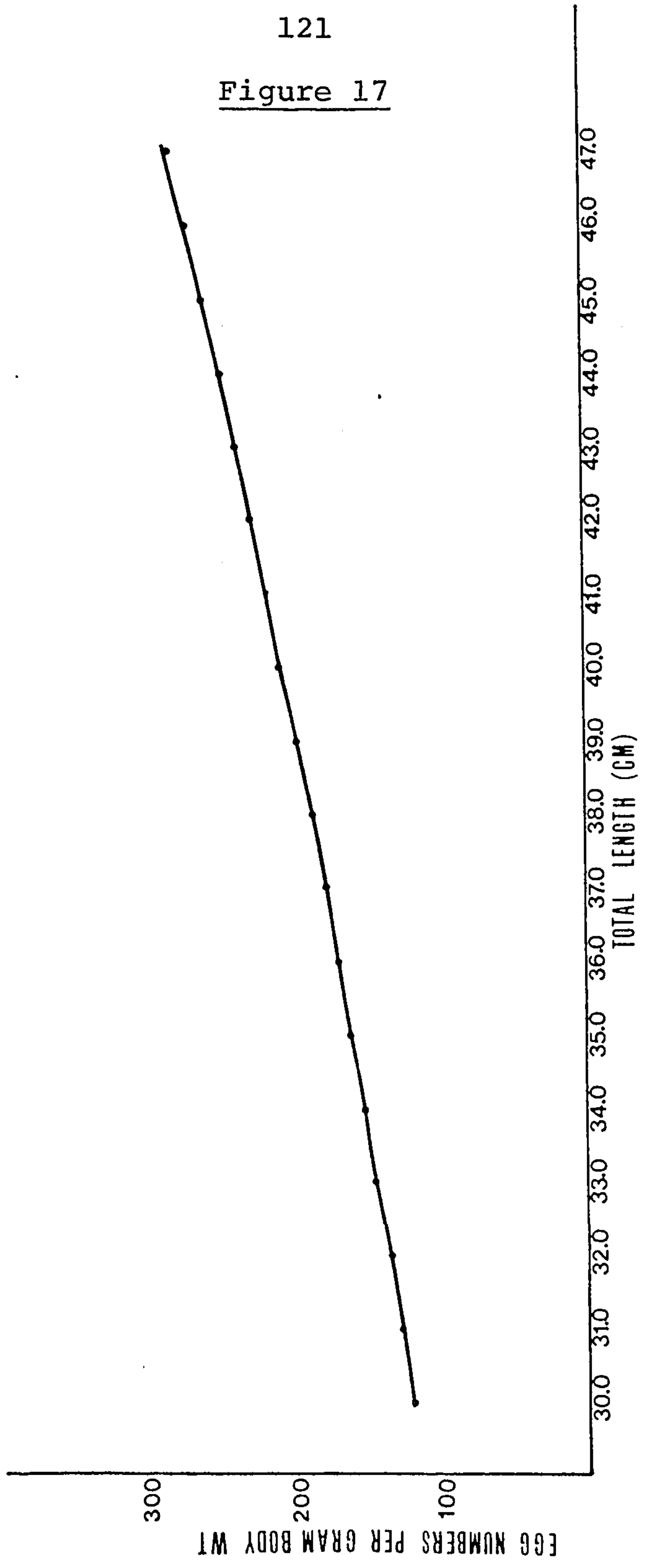

LOG F = -2.35154 + 4.74950 LOG L
EGG NUMBERS (1000's)
500
450
400
350
300
250
200
150
100
50
TOTAL LENGTH (CM)
31.0
32.0
33.0
34.0
35.0
36.0
37.0
38.0
39.0
40.0
41.0
42.0
43.0
44.0
45.0
46.0
47.0
48.0
49.0
50.0

Figure 17.--Relation of egg number per gram body weight and total length (based on 78 olive rockfish captured off Avila 1972-77): $F = aL^b$, where F = number of eggs per gram body weight, L = total length and a and b are constants.

Figure 17


300
200
100
EGG NUMBERS PER GRAM BODY WT
30.0
31.0
32.0
33.0
34.0
35.0
36.0
37.0
38.0
39.0
40.0
41.0
42.0
43.0
44.0
45.0
46.0
47.0
TOTAL LENGTH (CM)

CHAPTER 3

Ontogenetic and seasonal variation in food of olive rockfish (*Sebastes serranoides*) from kelp beds off central California

INTRODUCTION

Olive rockfish (Sebastes serranoides) are relatively active, fast-swimming predators of the midwater zone in reef and kelp areas off southern and central California (Limbaugh 1955; Quast 1968abc; Hobson and Chess 1976; Love and Ebeling 1978). Southern California fish may be classified in a feeding guild of "switch-feeding" carnivores, which eat mostly nekton, plankton, or substrate-oriented prey as the opportunity arises (Love and Ebeling 1978). Like other guild members (kelp bass - Paralabrax clathratus and blue rockfish - Sebastes mystinus), the olive rockfish is formed like a generalized predator, with a fusiform body, reduced head spines, a large mouth and large flexible fins.

Off central California, north of Point Conception, olive rockfish may replace kelp bass as the largest, most predatory member of the feeding guild (cf. Limbaugh 1955; Feder et al. 1974). The two species converge in general shape in coloration, having distinctive dorsal patches of white on a darker background. Olive rockfish off central California grow faster, suffer less intense exploitation, and are much larger as adults than those off Santa Barbara (Chapter 2). There have been few food studies of the central California fish. The objective of the present study, therefore, was to analyze ontogenetic and seasonal variation in diets of olive rockfish sampled from a cool-temperate, central Californian region north of Point Conception; and to compare this with Santa Barbara populations. The second objective was to then see how many readers remained awake at the end of the chapter.

METHODS

Specimens were collected nearly every month between May 1975 and April 1977, at a group of shallow-water pinnacles, about 11 km west of Avila, California (Figure 1) (Chapter 2). These pinnacles, at depths of 20-30 m, are situated 100-300 m offshore from Diablo Cove and North Cove, and rise to within 5-10 m of the surface. Brown algae (predominantly *Nereocystis* *sp*.) grow on the shallower reefs during summer and fall.

Specimens were collected by hook and line and by pole spear (in about equal proportions), immediately placed on ice aboard the diving vessel and frozen soon after for later examination ashore. I took precautions that only artificial lures were used and chumming or other disturbances were avoided, so that sampling method did not bias the stomach content composition. The study area is never fished by partyboats or commercial rockfish vessels and is visited only rarely by private pleasure boats. No other vessels were in the vicinity during the sampling.

As detailed in Love and Ebeling (1978), stomach contents were sorted taxonomically into 17 *food* *items* (Table 1). The volume of each category was measured by liquid displacement. Food items were also grouped into

3 *prey types* (substrate-oriented, nekton, plankton) based on the item's behavior and habitat. Nektonic prey included all nonlarval fish and squid. Substrate-oriented prey included all prey (except fish) that live on or about reef and plant surfaces; these may be motile, such as octopus or attached, like algae.

To examine the variation in diet relative to predator size, I divided olive rockfish into four size classes and computed prey volume and frequency of occurrence for each class (Table 1). The frequency of occurrence of each prey type was compared between size classes using a 2 x 2 G-test of independence (Sokal and Rohlf 1969). Food niche breadth and overlap between classes was computed from values of P_i, the proportion of item i used by each species. P_i is the proportionate volume of any of the food items included in the species total (S). *Resource breadth*,

$$B = \frac{1}{\sum_{i=1}^{s} P_i^2}$$

is described in Bray and Ebeling (1975) and Love and Ebeling (1978). *Overlap* between each size class is measured as:

$$I = 1.0 - [0.5(\sum_{i=1}^{s} |P_{ij} - P_{ik}{}^{1})],$$

where P_{ij} is the proportion of item i used by species j and S is the species total of food items eaten, and is scaled from zero (complete discordance) to 1.0 (all items used in equal proportions) e.g. Whittaker 1960; Cody 1974; Love and Ebeling 1978).

To examine seasonal variation in diet within each size class (except 10.1-20.0 cm which was too limited), food data was pooled by seasonal periods roughly corresponding to "upwelling" (March-August) and "oceanic" (September-February) oceanographic regimes off Avila. These periods were based on the 1975-77 coastal upwelling indices supplied by Andrew Bakun. The food items were ranked by volume and frequency of occurrence for each season and size class, and the seasonal rank orders were compared using Kendall's coefficient of rank correlation (Sokal and Rohlf 1969) (Tables 2, 3). I also tested for seasonal differences of frequency of occurrence of prey types, using a 2 x 2 G-test of independence (Figure 2). In this test, I compared prey frequency of occurrence between the March-August and September-February periods for each fish-size category.

RESULTS

Olive rockfish were found to be primarily midwater predators of nekton (Table 1). Very important among their prey were small fishes, including blue rockfish (*S. mystinus*), yellowtail rockfish (*S. flavidus*), young olive rockfish, pipefish (*Sygnathus* sp.), shiner perch (*Cymatogaster aggregata*), kelp gunnel (*Ulvicola sanctaerosae*), northern anchovy (*Engraulis mordax*), topsmelt (*Atherinops affinis*) and cottids. Other important nektonic prey were squid (*Loligo opalescens*). Among planktonic prey, small crustaceans (particularly crab megalops larvae), tunicates (*Oikopleura*, *Doliolium*), euphausids, fish larvae and polychaetes were commonly eaten. Among substrate-oriented prey, octopus was the most important food item, followed by gammarid amphipods, isopods (*Idothea*) and other small crustaceans.

As olive rockfish grow, their food habits change. Planktivory decreases, as larger fish eat relatively more nekton and substrate-oriented prey (Figure 3). Plankton consumed by smaller individuals included a wide variety of small and large crustaceans, fish larvae and polychaetes. For larger fish, planktivory is essentially limited to large items, such as euphausids, tunicates and polychaetes. Nekton feeding, though important in all size classes, increases to a peak for fish 30.1-40.0 cm long, then declines somewhat, as larger fish ate more substrate-oriented prey, primarily octopus. Predators in the 20.1-30.0 cm size class had the smallest food breadth (Table 4), eating mostly fish. Breadth increased for larger predators, as their diets were supplemented by squid and octopus. Dietary overlap was greatest between the two largest size classes of predators (Table 5).

Food habits showed some seasonal variation. Nekton feeding significantly increased (in the 30.1-40.0 and 40.1-50.0 cm size classes) during the upwelling period (Figure 2). Predation on both squid and young-of-the-year rockfish (which first appear, in large numbers, during April and May) increased during this period. Though juvenile rockfish were an important food item throughout the year, their importance decreased during fall and winter, probably because these growing juveniles become less vulnerable. Other food prey, such as the northern anchovy, were of greater importance during the fall and winter oceanic period. No significant seasonality was noted in food item frequency of occurrence, though some differences existed in the volume of food items consumed (Tables 2, 3). Tunicates and euphausids were eaten in far greater amounts during the upwelling season, particularly during April and

May.

Olive rockfish from Avila usually contained a dominant (i.e. over 95% by volume) prey type (Table 6), indicating that individuals concentrated their feeding efforts on one prey group at a time. This "switch feeding" was found in all size classes, which showed similar prey dominance frequencies. Fully 68% of the fish contained a single, dominant prey type.

DISCUSSION

Many fish species change their food habits with increasing size (Nikolskii 1963). Larger individuals of several rockfish species including olive rockfish, blue rockfish (Gotshall et al. 1965), copper rockfish (Patten 1973; Prince and Gotshall 1976) and redfish (Lambert 1960), eat relatively more fish prey.

Although most adult inshore reef fishes are either midwater or benthic feeders (Quast 1968c; Larson 1972; Hobson and Chess 1976), olive rockfish (along with kelp bass and blue rockfish) are both (Love and Ebeling 1978). Adults are streamlined pursuers, actively swimming after prey (primarily nekton) and spending most of their time in midwater. They have neither the sit-and-wait "ambusher" strategy, nor the morphological adaptations of the benthic rockfishes to eat benthic prey.

Even though they are not particularly adapted to benthic feeding, adults commonly eat substrate-oriented octopus. Octopus are very secretive during daylight hours, but are often exposed during the night (Bray pers. commun.), when they are more likely to be eaten by olive rockfish.

Thus, the nocturnal exposure of octopus may allow adult olive rockfish to feed successfully and continuously on the bottom during nocturnal feeding bouts. Of fish stomachs containing octopus, 67% had nothing else in them, while an additional 8% contained other substrate-oriented prey, primarily pipefish. Almost all the remaining 25% contained juvenile rockfish, which may have been ingested on or near the bottom.

Limbaugh (1955) speculated that olive rockfish may ecologically replace kelp bass in central and northern California, where kelp bass dwindle in numbers. The two species are similar in appearance; having elongate, fusiform bodies, reduced or (in kelp bass) absent head spines, large mouths and brownish bodies with light blotches along their back. In central and northern California, olive rockfish do, to a certain degree, assume the life style of kelp bass. They live over high relief bottom, and feed primarily on nekton, as do kelp bass. However, olive rockfish rarely prey on the substrate-oriented food items (with the exception of octopus), such as shrimp, algae and hydroids, favored by kelp bass (Quast 1968c; Love and Ebeling 1978). Thus, north of Pt. Conception, olive rockfish fill the "midwater nekton predator" part of the kelp bass role, while a number of benthic rockfish and other species (cabezon, kelp greenling etc.) fill the substrate-oriented part. Then, beginning in northern California, olive rockfish give way to midwater-feeding yellowtail and black rockfish (Moulton 1977).

Feeding seems to be more intense during the upwelling period. Significantly more stomachs contained prey during upwelling (182/246 = 74%) than during oceanic (178/380 = 46.8%) (G test, $p<.005$) periods, probably because more food was available then. Concentrations of both rockfish young-of-the-year and plankton are generally greatest during and after upwelling periods along central California (Bolin and Abbott 1963). Blue rockfish from central and northern California showed a similar pattern, consuming far more planktonic forms (particularly tunicates and crustaceans) and having fewer empty stomachs during upwelling periods (Gotshall et al. 1965; Miller and Geibel 1973).

Seasonal variation of prey availability may lead to switch feeding (Love and Ebeling 1978). Off Avila, both mature and immature olive rockfish appear to switch feed, as first reported (Love and Ebeling 1978) from juveniles off Santa Barbara. Murdoch et al. (1975) described switch feeding species as those which tend to specialize on whatever prey is most available at a particular time. As stated by Love and Ebeling, olive rockfish "are certainly equipped to switch from large to smahl prey" with "large mouths for engulfing big items, yet having protrusible laws and well-developed gill rakers for selecting and keeping small ones." If olive rockfish switch feed, it would be expected that most individuals would feed upon and therefore contain primarily one type of food item per feeding bout. In fact, the percentage of fish (68.4%) containing a single dominant prey item was also fairly high when compared to the estimated percentage (55%) for picker-type microcarnivores and that (13%) for demersal microcarnivores (Love and Ebeling 1968).

Switch feeding may decrease over more productive reefs, where prey is abundant. Predators over less productive reefs, which may show greater fluctuations in prey availability, would be expected to switch more often. Love and Ebeling (1978) noted that olive rockfish from the less productive One-Mile Reef switched (from fish to plankton) more often than did individuals from more productive Naples Reef. The extensive kelp forest at Naples Reef provides shelter and substrate for numerous potential prey items, particularly small fish. Reefs at the collection site off Avila were similar to One-Mile Reef in lacking Macrocystis cover. Food breadths, which measure switch feeding, were considerably higher for Avila and One-Mile fish than for Naples fish.

Most fishes living on or about tropical reefs show narrowly defined day-night activity patterns (Collette and Talbot 1972; Hobson 1974). In contrast to this stereotypic behavior, some temperate reef fishes seem to be much more plastic in their behavior (Ebeling and Bray 1976). This is particularly true of rockfishes (Table 7). Though some species are reportedly active during daylight hours (*S. flavidus*, *S. maliger* and *S. melanops*) or night (*S. atrovirens* and *S. serriceps*), others are active during both periods (*S. caurinus*, *S. carnatus*, *S. chrysomelas*, *S. mystinus* and *S. serranoides*).

Olive rockfish feed during both day and night. From observations of plankton and of the presence of nocturnal planktors such as euphausids and polychaetes in fish diets, Hobson and Chess (1976) concluded that small juvenile olive rockfish in the 55-157 mm size class feed predominantly at night off Santa Catalina Island. Love and Ebeling (1978), however, concluded that larger juveniles feed mostly during the day off Santa Barbara. Ebeling and Bray (1976) observed the species commonly in midwater during both night and day off Santa Barbara. Though olive rockfish off Avila fed extensively on nocturnal prey items (such as polychaetes, euphausids and octopi), I observed some crepuscular and even midday feeding bouts.

Some rockfish species appear to alter day-night behavior depending on locale (Table 7). *S. mystinus* are usually diurnal at Naples Reef, but both diurnal and nocturnal across the Santa Barbara Channel at Santa Cruz

Island (A. Ebeling, pers. commun.). Moulton (1977) reported diurnal behavior in juvenile S. flavidus at several Puget Sound sites and nocturnal behavior at others. Similarly, the strictly diurnal behavior of S. caurinus in Puget Sound (Moulton 1977) contrasts sharply with both day and night activity of fish from Humboldt Bay (Prince and Gotshall 1976). What environmental factors account for these differences are not known, though Ebeling (pers. commun.) suggests that the more turbid water at Naples Reef may limit nocturnal foraging there.

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Table 1.--Percent total volume and frequency of occurrence of 17 food items in stomachs of olive rockfish off Avila, California. Fish are divided into 10.0 cm (TL) size groups. Food items are listed by general characteristics. A tr indicates unmeasurable trace; a dash indicates none.

Table 1

Food Item	10.1-20.0 % Vol	10.1-20.0 % Freq	20.1-30.0 % Vol	20.1-30.0 % Freq	30.1-40.0 % Vol	30.1-40.0 % Freq	40.1-50.0 % Vol	40.1-50.0 % Freq	TOTAL % Vol	TOTAL % Freq
Primarily Planktonic (Sum =)	(54.2)		(20.9)		(8.8)		(7.9)		(9.3)	
Small Crustaceans (0.5-5mm)										
Zoea	-		.7	2.7	tr	1.9	-	-	tr	1.3
Copepods	.8	24.0	1.2	4.0	tr	3.2	tr	1.7	tr	4.2
Megalops	4.8	28.0	9.6	33.3	.2	7.0	tr	3.4	.6	12.2
Large Crustaceans (>10 mm)										
Euphausids	-	-	1.2	2.6	4.2	13.9	2.3	7.8	3.0	8.6
Small-Medium Sized, Transparent										
Tunicates (Salps, Larvaceans)	-	-	.3	1.3	2.6	6.3	5.3	.9	4.0	5.7
Fish Larvae	44.5	52.0	.9	6.6	.2	5.0	tr	1.7	.5	7.3
Polychaetes	4.1	16.0	7.0	28.0	1.6	22.8	.3	12.0	1.2	19.5
Primarily Nektonic (20-160mm) (Sum =)	(44.7)		(72.1)		(81.1)		(64.4)		(71.3)	
Fish	44.7	12.0	66.0	37.3	36.9	52.5	24.5	44.8	31.6	43.2
Squid	-	-	6.1	2.6	44.2	7.7	39.9	12.1	39.7	7.6
Primarily Substrate Oriented (Sum =)	(1.0)		(6.8)		(10.0)		(27.2)		(19.4)	
Free Moving Animals:										
Mysids	-	-	.9	4.0	tr	.6	tr	.9	tr	1.3
Isopods	-	-	.4	4.0	.3	6.0	-	-	.1	3.1
Gammaridean Amphipods	1.0	20.0	2.2	18.6	.1	3.8	tr	.9	.2	6.8
Caprellid Amphipods	-	-	-	-	tr	.6	-	-	tr	.2
Octopi	-	-	.7	2.6	9.3	12.0	27.2	37.9	18.6	16.7
Shrimp	-	-	.2	2.6	-	-	-	-	tr	.2
Algae	-	-	2.5	2.6	tr	1.9	tr	.9	.2	1.6
Pebbles	-	-	-	-	.3	1.3	tr	.9	.2	.8
TOTAL VOLUME OF FOOD CONSUMED (ML)	15.58		101.34		840.82		1162.65		2120.39	
TOTAL NUMBER OF SPECIMENS EXAMINED	25		75		158		116		374	

Table 2.--Seasonal variation in diets of three size classes of olive rockfish from Avila, California. The first five ranking food items with their percent volume are listed in order for each time period. Sample size is the number of fish pooled per period; τ is Kendall's coefficient of rank correlation (Sokal and Rohlf 1969).

Table 2

Size Class	March-August Item		September-February Item		τ
	Sample Size 38		Sample Size 37		
20.1-30.0	Fish	69.9	Fish	63.6	
14 Total Food	Megalops	11.6	Squid	14.6	.16
Items	Polychaetes	5.7	Polychaetes	9.2	
	Euphausids	3.0	Megalops	7.7	
	Gammarid Amph.	3.0	Algae	1.6	
	Sample Size 71		Sample Size 87		
30.1-40.0	Squid	51.4	Fish	71.6	
15 Total Food	Fish	25.1	Squid	16.0	
Items	Tunicates	8.6	Polychaetes	5.0	.19
	Octopus	8.5	Octopus	3.9	
	Euphausids	5.9	Isopods	1.2	
	Sample Size 63		Sample Size 53		
40.1-50.0	Squid	48.2	Octopus	127.7	
13 Total Food	Octopus	21.2	Fish	117.4	.5*
Items	Fish	20.7	Squid	58.0	
	Tunicates	6.1	Polychaetes	2.5	
	Euphausids	3.7	Tunicates	1.3	

* $.05 > P > .025$

Table 3.--Seasonal variation in percent frequency of occurrence of food items in diets of three size classes of olive rockfish from Avila, California. The first five ranking food items are listed in order for each time period. Sample size is the number of fish pooled per period; τ is Kendall's coefficient of rank correlation (Sokal and Rohlf 1969).

Table 3

Size Class	March-August Item		September-February Item		
	Sample Size 38		Sample Size 37		
20.1-30.0	Fish	14	Polychaetes	14	
14 Total Food Items	Megalops	11	Fish	13	
	Gammarid Amph.	9	Megalops	13	.43*
	Polychaetes	7	Gammarid Amph.	6	
	3 Tied	3	3 Tied	2	
	Sample Size 71		Sample Size 87		
30.1-40.0	Fish	45	Fish	39	
15 Total Food Items	Euphausids	21	Polychaetes	29	.4*
	Tunicates	15	Isopods	7	
	Octopus	10	Octopus	6	
	Squid	9	2 Tied		
	Sample Size 63		Sample Size 53		
40.1-50.0	Fish	34	Octopus	20	
13 Total Food Items	Octopus	25	Fish	15	
	Squid	10	Polychaetes	9	.48**
	Euphausids	10	Squid	4	
	Tunicates	8	2 Tied	2	

* .05>P>.025

** .025>P>.01

Table 4.--Food breadths for four size classes of olive rockfish from Avila, California. The text defines the breadth measure B, which is based on proportionate item volumes. Sample size is the number of fish examined that had food in their stomachs; S is the number of food items eaten; and maximum % volume is of the dominant item (Table 1).

Table 4

Size Class	Sample Size	S	B	% Maximum Volume	Dominant Item
10.1-20.0	25	6	2.49	44.7	Fish
20.1-30.0	75	15	2.20	43.6	Fish
30.1-40.0	158	16	2.92	44.2	Squid
40.1-50.1	116	13	3.40	39.9	Squid

Table 5.--Overlap in food, determined from dietary item volumes, among four size classes of olive rockfish from Avila, California. See text for definition of overlap.

Table 5

	SIZE CLASS (CM, TL)			
	10.1-20.0	20.1-30.0	30.1-40.0	40.1-50.0
10.1-20.0	-	.56	.39	.26
20.1-30.0	-	-	.47	.33
30.1-40.0	-	-	-	.79
40.1-50.0	-	-	-	-

Table 6.--Numbers and percent of fishes in each size category that contained more than 95% (by volume) of items of a single prey type (prey types listed in Table 1).

Table 6

Size Class	N	%
10.1-20.0	25	88.0
20.1-30.0	75	85.3
30.1-40.0	158	85.4
40.1-50.0	116	85.3
TOTAL	374	85.6

Table 7.--Activity periods of eastern Pacific rockfishes.

Table 7

Diurnal (including Crepuscular)	Diurnal and Nocturnal	Nocturnal
S. flavidus - Puget Sound Moulton (1977)		
S. maliger - Puget Sound Moulton (1977)		
S. melanops - Puget Sound Moulton (1977)		
S. mystinus - Juv. - Santa Barbara, Calif. Ebeling & Bray (1976)		
S. caurinus - Puget Sound Moulton (1977)	*S. caurinus* - Humboldt Bay, Calif. Prince & Gotshall (1976)	*S. caurinus* - Southern Calif. Allen (1977)
	S. mystinus - Santa Cruz Isl., Calif. (Ebeling, pers. commun.)	
	S. carnatus - Santa Barbara, Calif. Ebeling & Bray (1976)	
	S. chrysomelas - Santa Barbara, Calif. Ebeling & Bray (1976)	
	S. serranoides - Avila Present Paper	*S. serranoides* - Juv. - Santa Catalina Isl. Hobson & Chess (1976)
	S. serranoides - Juv. - Santa Barbara Love & Ebeling (1978); Ebeling & Bray (1976)	

Table 7--Continued

Diurnal (including Crepuscular)	Diurnal and Nocturnal	Nocturnal
S. *flavidus* - Juv. - Puget Sound Moulton (1977)		S. *flavidus* - Juv. - Puget Sound Moulton (1977) S. *atrovirens* - Santa Catalina Isl. Hobson & Chess (1976) S. *serriceps* - Southern Calif. (Ebeling, pers. commun.), Allen (1977)

Figure 1.--Location of sampling sites (marked with an "x").

Figure 1

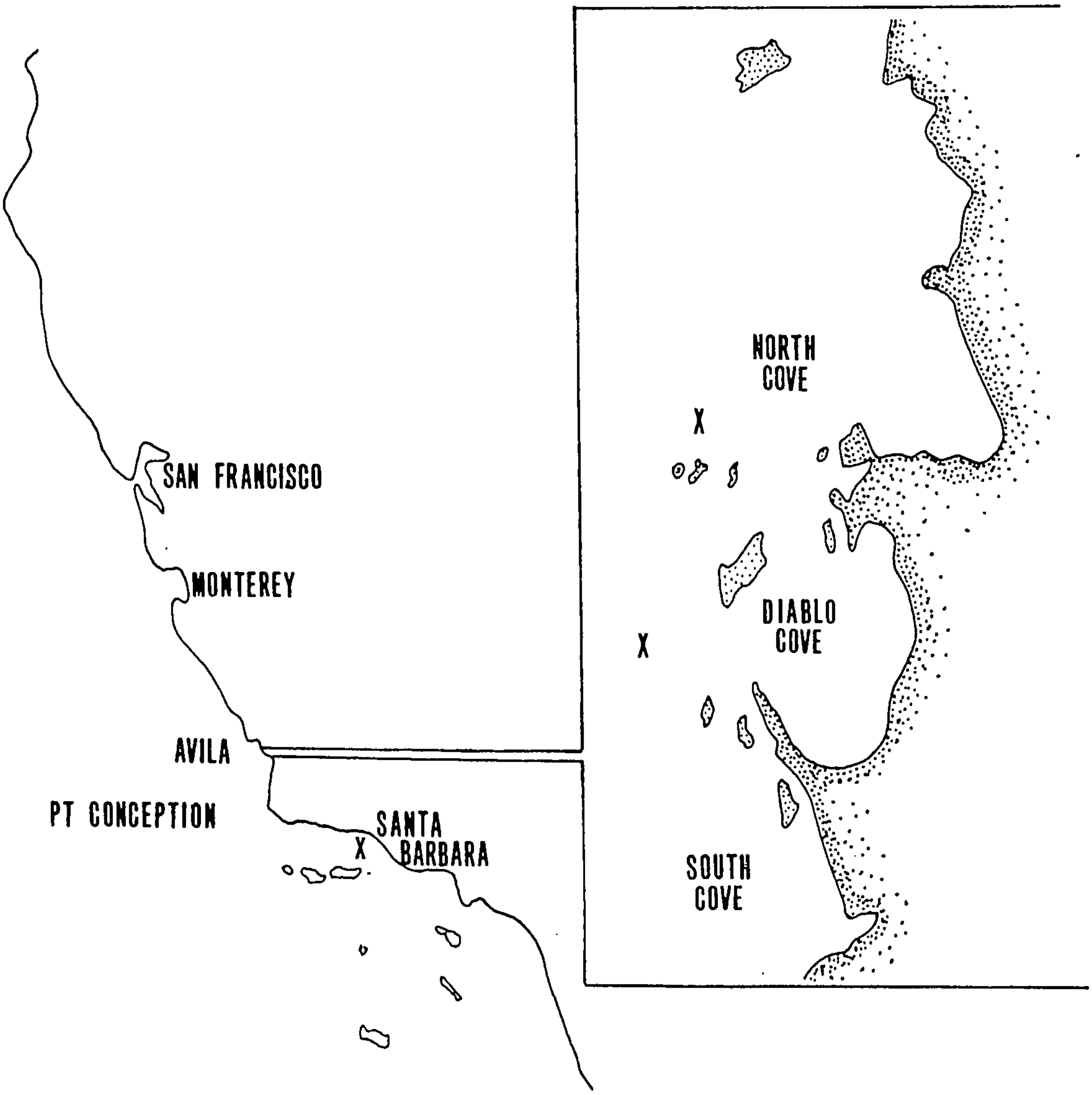

NORTH COVE
X
DIABLO COVE
X
SOUTH COVE
SAN FRANCISCO
MONTEREY
AVILA
PT CONCEPTION
SANTA BARBARA
X

Figure 2.--Seasonal variation in frequency of occurrence of prey types (bars and numbers) in stomachs of fishes in three size classes of olive rockfish from Avila, California. Prey types are designated: p, plankton; N, nekton; S, substrate-oriented prey, and are represented by any constituent food item under the appropriate prey-type heading in Table 1. Seasonal periods are explained in the text; and numbers in parentheses are number of stomachs with food material. Stars indicate significantly different frequencies at the indicated probabilities determined by 2x2 contingency G test.

Figure 2

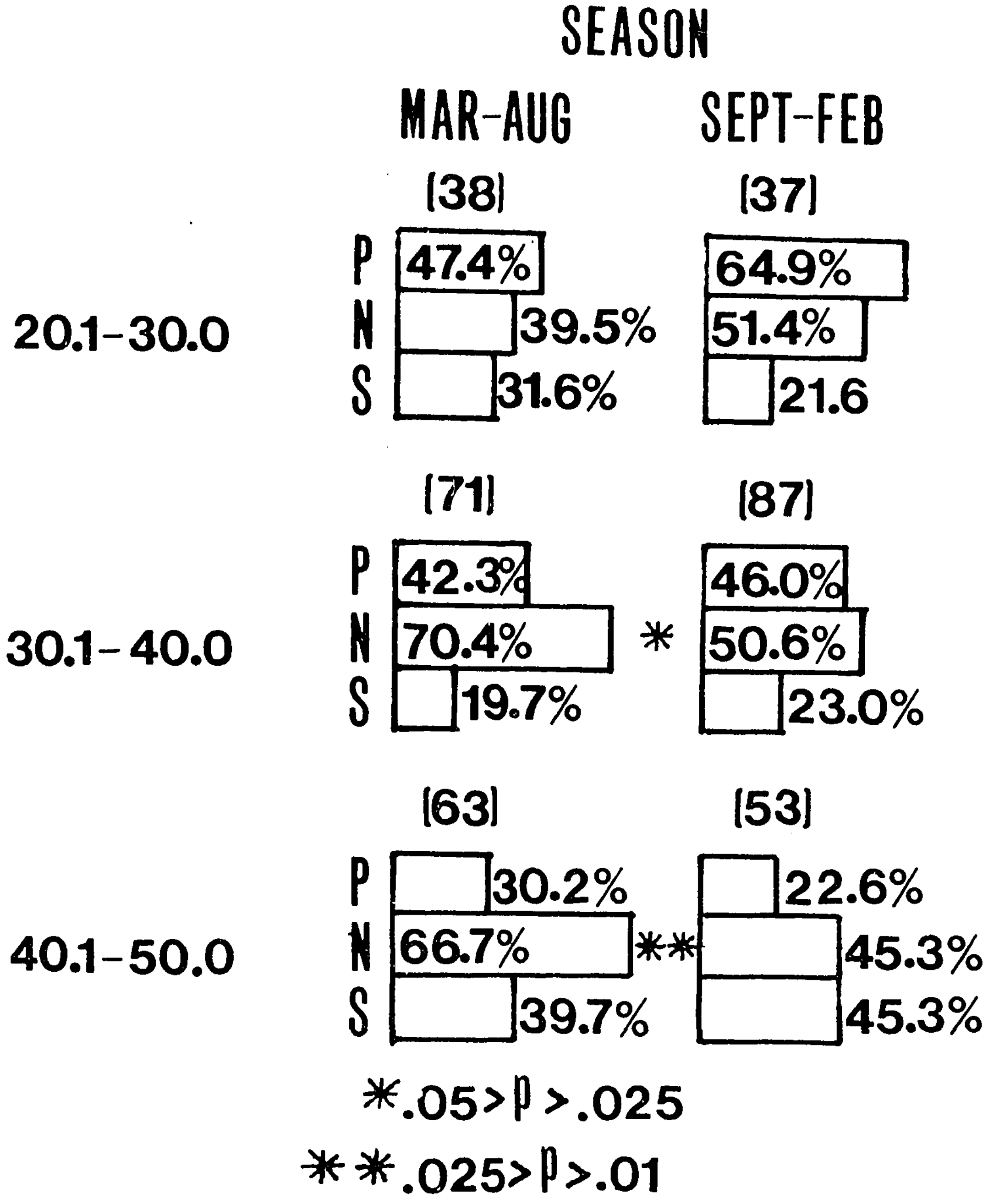
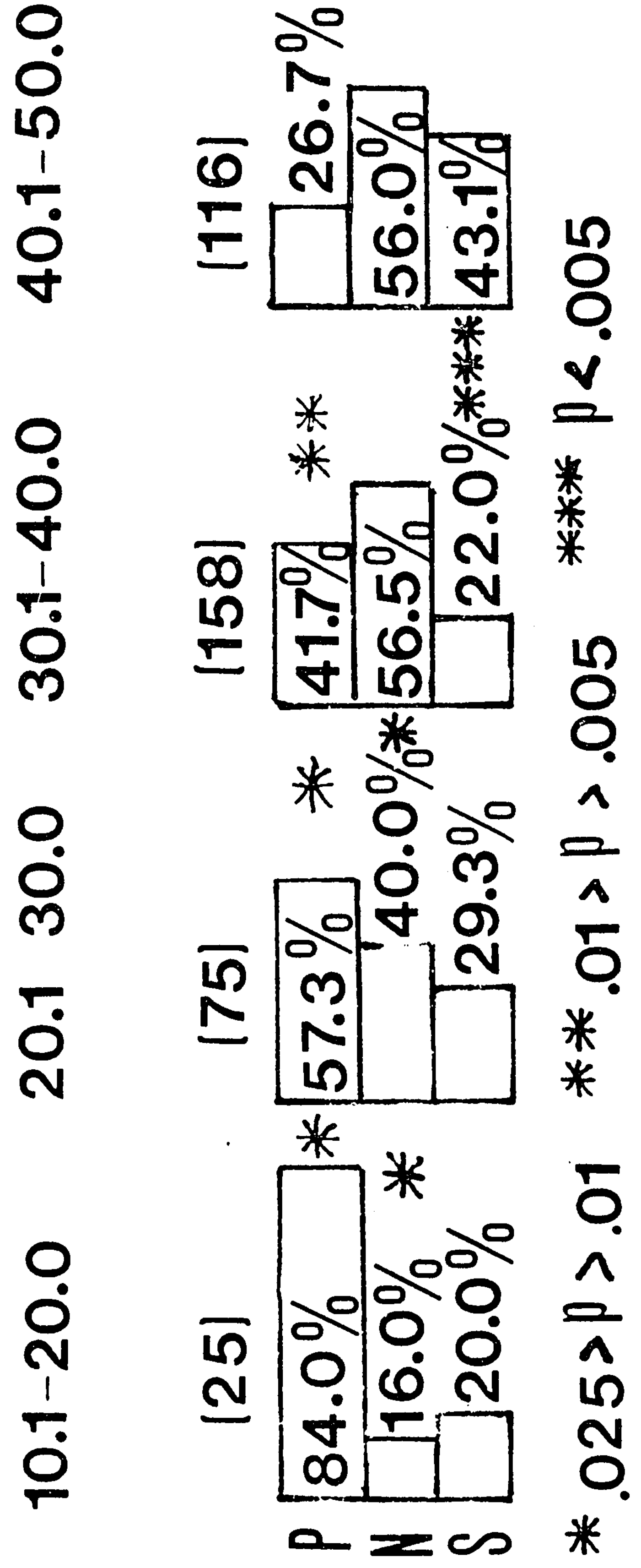

SEASON
MAR-AUG
SEPT-FEB
20.1-30.0
(38)
P 47.4%
N 39.5%
S 31.6%
(37)
P 64.9%
N 51.4%
S 21.6
30.1-40.0
(71)
P 42.3%
N 70.4%
S 19.7%
*
(87)
P 46.0%
N 50.6%
S 23.0%
40.1-50.0
(63)
P 30.2%
N 66.7%
S 39.7%
**
(53)
P 22.6%
N 45.3%
S 45.3%
*.05>p>.025
**.025>p>.01

Figure 3.--Comparison of relative volumes (bars and numbers) of prey types from stomachs of olive rockfish in four size classes. Prey types are designated in legend of Figure 2. Numbers in parentheses are numbers of fish stomachs examined. Stars indicate significantly different frequencies at the indicated probabilities determined by 2x2 contingency G-test.

Figure 3


P
N
S
10.1–20.0
[25]
84.0%
16.0%
20.0%
*
*
20.1 30.0
[75]
57.3%
40.0%
29.3%
*
*
30.1–40.0
[158]
41.7%
56.5%
22.0%
**
***
40.1–50.0
[116]
26.7%
56.0%
43.1%
* .025 > p > .01
** .01 > p > .005
*** p < .005

APPENDIX

Redescription of the olive rockfish, *Sebastes serranoides*

INTRODUCTION

A member of the speciose, mostly North Pacific scorpaenid genus *Sebastes*, the olive rockfish was originally described in a brief paragraph as *Sebastodes serranoides* Eigenmann and Eigenmann, 1890. Its type locality is the Cortez Bank 150 km off southern California. Phillips (1957) more completely described the species, but based on few specimens with no measure of variation.

Sebastes serranoides is apparently closely related to a group of midwater rockfish, including the yellowtail (*S. flavidus*), blue (*S. mystinus*) and black (*S. melanops*) rockfishes (L. Chen pers. commun.). No single meristic or morphometric character has been found that distinguishes it from its sibling, *S. flavidus*, even where the two co-occur abundantly off central California. Furthermore, the two species cannot be definitely distinguished by any character until juveniles reach about 7 cm TL, when *S. flavidus* has bright yellow streaks, which radiate downward and backward from the eyes, and a series of reddish brown spots, which stipple the flanks.

Considering the commercial importance of this common sportfish, the inadequacies of previous descriptions, and the difficulty of distinguishing it from its sibling, I thought it important to redescribe the species from a large sample and size range of individuals.

METHODS

Specimens for morphometric measurements were collected from Avila and Santa Barbara. However, for meristic counts, additional specimens were collected from the Farallon Islands, Monterey Bay, Santa Cruz Island, Redondo Beach, Tanner Bank and La Jolla.

Specimens were collected by both hook and line and pole spear (in about equal proportions), immediately placed on ice aboard the diving vessel and frozen soon after for later examination.

In general, I followed the format, measuring and counting methods and head-structure terminology of Phillips (1957). However, I omitted a few of the measurements and measured the length of the gill raker at the angle of the first gill arch rather than the "longest gill raker", as in Phillips.

For paired meristic structures, left counts are usually reported. However, as some bilateral asymmetry has been noted in these structures (Hubbs and Hubbs 1945; Chen 1971), I compared the left and right counts of pectoral fin rays and gill rakers (on first arches) using a χ^2 2x2 contingency table (Sokal and Rohlf 1969). Asymmetry was found in pectoral fins but not in gill rakers (Table 1). Right pectoral fins yielded significantly higher counts than left ones, when asymmetry existed. No such differences existed for gill raker counts. For this reason, both left and right pectoral ray counts were recorded in Table 2, while only left gill rakers were used.

DESCRIPTION

Range - San Benito Islands, Baja California to Redding Rock, Del Norte Co. (Miller and Lea 1972.)

Greatest Depth Taken and Maximum Size - Surface to 150 m; 60 cm (TL).

Body Color - Juveniles - Brown to red-brown or yellow-brown dorsally, becoming light brown to silver on ventral surface; flanks below lateral line flecked with brown; a number of irregular white to brown blotches above lateral line; dorsal fins brown with orange tint, occasionally orange; caudal and anal fins yellow, pectoral and pelvic fins orange or yellow in very small individuals, yellow in larger juveniles; anal fins occasionally flecked with a myriad of small black spots; dark black spot on posterior spinous dorsal, usually between spines 8 and 11, spot becoming progressively more diffuse as fish grows.

Adults - Dorsal area dark brown to greenish-brown, becoming silvery brown ventrally; sides flecked with gray or bladk; brown irregular blotches above lateral line; fins golden or olive, occasionally brown; black spot on spinous dorsal absent in most fish longer than 35 cm TL.

Mouth and Gill Cavities - Light gray or yellowish, occasionally silvery.

Peritoneum - Silvery; black speckling in juveniles to about 25 cm.

Top of Head, at Mid-orbits - Convex.

Spines on Top of Head - Head spine configuration changes as individuals grow (Figure 1). Some spines (preocular, supraocular, postocular, tympanic) are lost early, while others (parietal, nasal) are retained by a majority of individuals.

Juvenile rockfish of all species have a full or nearly-full complement of head spines (Moser 1967; W. Laroche pers. commun.). Bottom-dwelling species tend to retain the spines, while the more streamlined midwater species lose most or all of them.

Parietal Ridges - Weak, occasionally absent.

The Five Preopercular Spines - Strong and sharp; upper 4 directed backwards, the 5th directed backwards or angled downwards, often minute or occasionally absent; all may be bifid or trifid.

The Two Opercular Spines - Thin and sharp; upper spine larger than or equal to lower; upper-directed backwards, lower - backwards or angled downwards; both may be bifid or trifid.

Supracleithral and Cleithral Spines - Cleithral usually sharp, occasionally rounded or absent; supracleithral normally absent, occasionally present and weak; both may be bifid.

Lower Margin of Suborbital Bone - Occasionally one small spine.

Lower Posterior Edge of Gill Cover - Occasionally one small spine.

Symphyseal Knob - Usually absent, occasionally a small one is present.

End of Maxillary - From center of pupil to slightly beyond rear of orbit.

Maxillaries - Covered with scales.

Mandibles - Covered with scales.

Branchiostegals - Covered with scales.

Second Anal Fin Spine - Tip of second does not reach tip of third.

Meristic counts are listed in Table 2 and morphometric measurements in Table 3.

Table 1.--Bilateral asymmetry in the number of pectoral fin rays and rakers on the first gill arches of olive rockfish. L = number of higher counts on left side, R = number of higher counts on right side, P = level of significant differences between left and right. Only those differences significant at the .05 level or better are listed.

Table 1

	Pectoral Fins			
	N	L	R	P
Farallon Isls.	26	3	3	-
Monterey Bay	50	2	3	-
Avila	142	9	27	P<.025
Santa Barbara	231	14	44	P<.005
Santa Cruz. Isl.	50	0	12	P<.01
Redondo Beach	35	2	8	-
Tanner Bank	11	0	3	-
La Jolla	11	1	4	-

	Gill Rakers			
	N	L	R	P
Farallon Isls.	23	7	2	-
Monterey Bay	36	11	9	-
Avila	136	40	25	-
Santa Barbara	231	71	53	-
Santa Cruz Isl.	13	3	5	-
Tannker Bank	11	5	0	-
La Jolla	11	2	1	-

Table 2.--Meristic counts from olive rockfish captured from the Farallon Islands, Monterey Bay, Avila, Santa Barbara, Santa Cruz Island, Redondo Beach, Tanner Bank, La Jolla.

Table 2

	$\bar{X}$	Range	N
Number of spines in dorsal fin	13	(12-15)	643
Number of rays in dorsal fin	15-16	(12-17)	644
Number of spines in anal fin	3		593
Number of rays in anal fin	9	(8-10)	593
Number of rays in each pectoral fin	17-18	(16-19)	983
Number of unbranched rays in each pectoral fin (aduct)	8-9		527
Number of gill rakers on first arch	31-37	(8-10,20-26)	376
Number of pores in lateral line	49-56	(49-56)	53
Number of pyloric caeca	11-12	(9-13)	134

Distribution

Dorsal Spines	12	13	14	15			
	1	637	3	1			
Dorsal Rays	12	13	14	15	16	17	
	1	2	11	319	299	12	
Anal Rays	8	9	10				
	34	501	58				
Gill Rakers	31	32	33	34	35	36	37
	3	28	133	114	90	7	1
Pyloric Caeca	9	10	11	12	13		
	1	15	52	50	16		

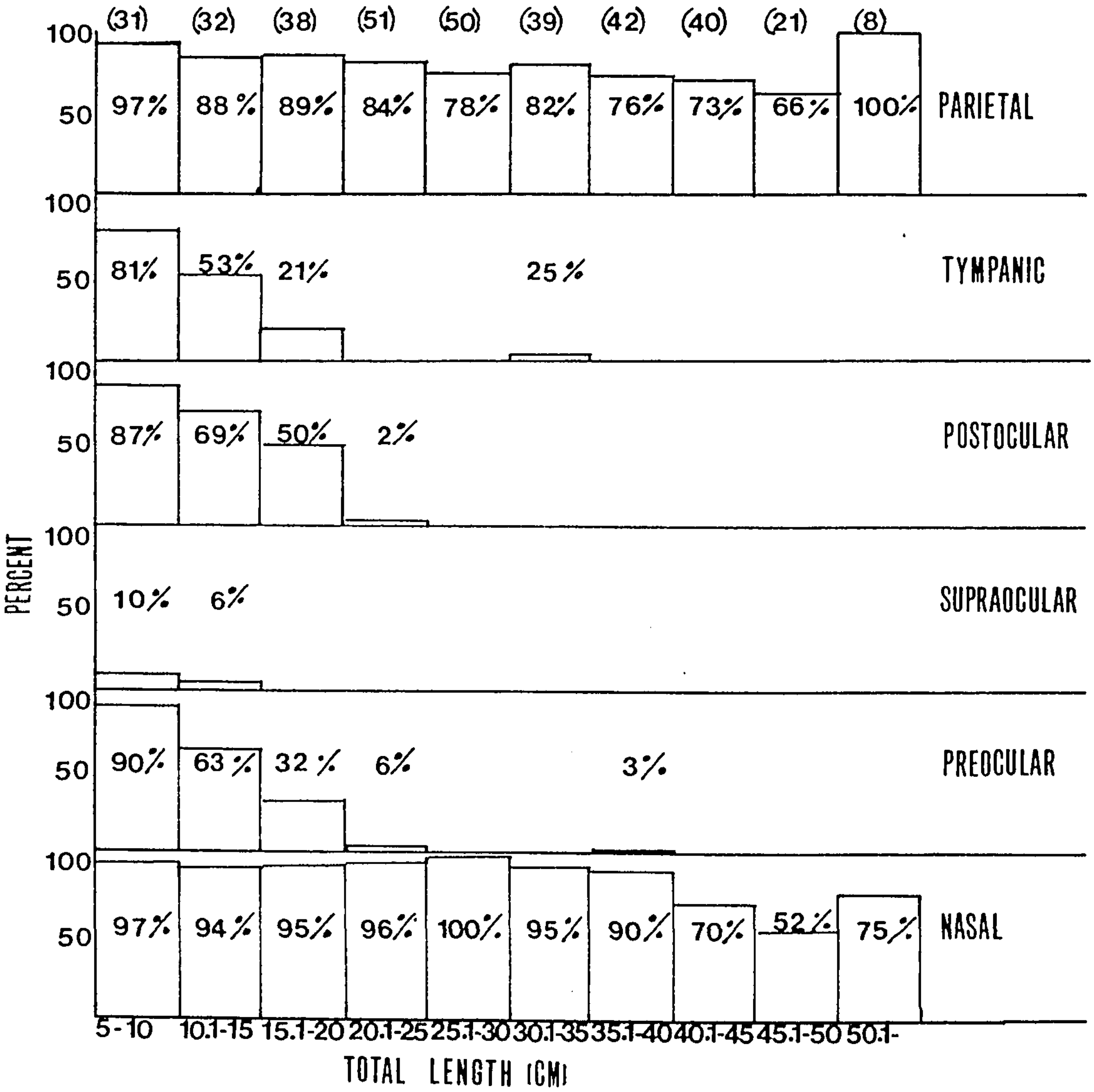
Table 3.--Morphometric measurements of 15-50 cm TL olive rockfish taken from the Farallon Islands, Monterey Bay, Avila, Santa Barbara, Santa Cruz Island, Redondo Beach, Tanner Bank, La Jolla.

Table 3

	Frequency of Measurement into:		Frequency of Orbit Width into:
Measurement	S.L.	H.L.	Orbit Width
Head Length	2.8- 3.2	-	3.9-4.7
Body Depth	2.8- 3.7	1.0-1.2	3.4-4.8
Length of Anal Fin Base	5.5- 6.8	1.8-2.3	1.9-2.5
Length of Snout	10.2-12.9	3.4-4.1	0.8-1.4
Width of Orbit	11.6-14.4	3.9-4.8	-
Width of Interorbital Space	11.3-13.5	3.8-4.6	0.9-1.2
Length of Upper Jaw	5.8- 6.7	1.7-2.8	1.6-2.7
Lower Jaw Projection	-	-	0.1-0.3
Pectoral Fin Length	3.7- 4.5	1.2-1.5	3.0-3.6
Pelvic Fin Length	4.4- 5.3	1.5-1.8	2.5-3.0
2nd Anal Spine Length	10.4-15.7	3.5-5.5	1.0-1.6
3rd Anal Spine Length	7.7-10.8	2.6-3.8	1.3-1.7
Length Longest Anal Ray	5.4- 7.9	1.7-2.3	1.9-2.3
Dorsal Base Length	1.6--2.0	0.5-0.7	6.7-8.6
Spinous Dorsal Length	2.5- 3.2	0.9-1.1	4.0-5.4
Soft Dorsal Length	3.6- 5.3	1.3-1.9	2.2-3.4
Longest Dorsal Spine Length	7.9- 9.9	2.6-3.3	1.4-1.7
Predorsal Length	2.6- 3.2	0.8-1.1	4.1-5.5
Prepelvic Length	2.2- 2.9	0.7-1.0	4.3-6.1
Caudal Peduncle Dorsal Length	4.4- 5.9	1.5-2.0	2.2-2.9
Caudal Peduncle Ventral Length	6.5- 8.9	2.0-2.9	1.6-2.1
Lower Jaw Length	4.6- 5.3	1.6-1.8	2.3-3.0
Maxillary Length	6.2- 7.5	2.1-2.4	1.7-2.2
Premaxillary Length	7.6- 9.7	2.3-3.3	1.3-1.9
Gill Raker at Angle Length	-	5.1-10.4	0.5-0.7

Figure 1.--The relationship of head spine occurrence with body length. Sample size in parentheses.

Figure 1



(31) (32) (38) (51) (50) (39) (42) (40) (21) (8)
100
50
97% 88 % 89% 84% 78% 82% 76% 73% 66% 100%
PARIETAL
100
50
81% 53% 21% 25 %
TYMPANIC
100
50
87% 69% 50% 2%
POSTOCULAR
PERCENT
100
50
10% 6%
SUPRAOCULAR
100
50
90% 63 % 32 % 6% 3%
PREOCULAR
100
50
97% 94% 95% 96% 100% 95% 90% 70% 52 % 75%
NASAL
5-10 10.1-15 15.1-20 20.1-25 25.1-30 30.1-35 35.1-40 40.1-45 45.1-50 50.1-
TOTAL LENGTH (CM)