San Jose State University
SJSU ScholarWorks

Master's Theses

Master's Theses and Graduate Research

1997

Aspects of the life history of Orthonopias tricis in Monterey Bay, California

Linda Browne Snook
San Jose State University

Recommended Citation

Snook, Linda Browne, "Aspects of the life history of Orthonopias tricis in Monterey Bay, California" (1997). *Master's Theses*. 1602.
DOI: https://doi.org/10.31979/etd.js7a-9by3
https://scholarworks.sjsu.edu/etd_theses/1602

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

ASPECTS OF THE LIFE HISTORY OF
ORTHONOPIAS TRIACIS
IN MONTEREY BAY, CALIFORNIA

A Thesis Presented to
The Faculty of Moss Landing Marine Laboratories
San Jose Sate University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Linda Browne Snook
December, 1997

UMI Number: 1388220

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

APPROVED FOR MOSS LANDING MARINE LABORATORIES

Gregor M. Cailliet

Dr. Gregor Cailliet

Robert N. Lea

Dr. Robert Lea

Dr. Michael Foster

APPROVED FOR THE UNIVERSITY

Serena W. Stanford

ABSTRACT

ASPECTS OF THE LIFE HISTORY OF
<u>ORTHONOPIAS TRIACIS</u>
IN MONTEREY BAY, CALIFORNIA

by Linda Browne Snook

Reproductive condition and diet were examined in 514 specimens of the subtidal marine cottid, Orthonopias triacis. Fish were collected monthly from the U.S. Coast Guard breakwater jetty in Monterey, California from June 1991 through November 1992. Egg size frequency diagrams suggest O. triacis is a multiple spawner and that spawning is not synchronous within a population. Spawning peaked in late winter and early spring. Gonosomatic indices (GSI) were highest from October 1991 through March 1991. Hydrated eggs were present from February through April, and in July in one individual. Larvae of O. triacis were laboratory reared with limited success. Meristics are reported for six larvae ranging from 3.3 mm to 5.1 mm notochord length. Population size frequency diagrams did not indicate seasonal recruitment pulses. The diet was dominated by gammarid amphipods, juvenile decapod crabs, and polychaete worms. Minor prey items were snails, shrimp, copepods, ostracods, algae, fish eggs, pycnogonids, isopods, and pelecypods.

DEDICATION

In Memory of

Mark Timothy MacMillan

April 19, 1965 - November 14, 1987

ACKNOWLEDGMENTS

Many thanks to all those who assisted me with field work: Karen Beattle, Susan Craig, Karen Crow, James Downing, Korie Johnson, James Kanihan, Lisa Kerr, Jeanne King, Deborah Nebenzahl, Deidre Sullivan, and Dr. Gregor Cailliet's advanced ichthyology class of 1993.

I would like to thank my committee members, Dr. Gregor Cailliet, Dr. Robert Lea, and Dr. Michael Foster for their guidance and review comments.

For their enthusiastic support and assistance, I thank the faculty, staff, and students of Moss Landing Marine Laboratories.

Finally, I thank my husband, Jim Snook, whose continual support and encouragement were invaluable.

TABLE OF CONTENTS

Abstract iv

List of Tables viii

List of Figures ix

Introduction 1

Methods

Study Site and Collection 4

Size frequency Analysis 4

Gonad Analysis 4

Larval Descriptions 7

Dietary Analysis 7

Results

Study Site 9

Population Size Frequency Analysis 9

Gonad Analysis 10

Larval Descriptions 12

Dietary Analysis 13

Discussion 14

Literature Cited 21

Tables 24

Figures 30

LIST OF TABLES

1. T-test comparisons of fresh eggs and eggs preserved in formalin and ethanol.
2. Comparison of egg size distributions in the anterior, center, and posterior sections of the ovary of O. triacis.
3. Meristics and morphology of larval O. triacis.
4. Percent Similarity Index comparison of O. triacis diets among seasons.
5. Percent Similarity Index comparison of O. triacis diets among size classes.
6. Percent Similarity Index comparison of O. triacis diets between sexes.

LIST OF FIGURES

1. Map of study site in Monterey, CA

2. Frequency histograms of standard lengths of O. triacis captured from August 1991 through November 1992.

3. Frequency histograms of egg diameters from individual O. triacis captured in February, March, May, and August.

4. Number of large eggs vs. standard length of female.

5. Monthly percentage of O. triacis containing hydrated eggs.

6. Frequency histograms of egg diameters from monthly collections of O. triacis.

7. Gonosomatic index for male and female O. triacis

8. Photographs of larval O. triacis.

9. Cumulative species curves for O. triacis gut contents.

10a. Index of Relative Importance diagram for prey of O. triacis, late Upwelling 1991.

10b. Index of Relative Importance diagram for prey of O. triacis, Oceanic 1991.

10c. Index of Relative Importance diagram for prey of O. triacis,Davidson 1991-1992.

10d. Index of Relative Importance diagram for prey of O. triacis, Upwelling 1992.

10e. Index of Relative Importance diagram for prey of O. triacis, Oceanic 1992.

INTRODUCTION

The family Cottidae is highly speciose and widely distributed in a variety of habitats. It is represented worldwide by approximately 300 species in 70 genera. Cottids occur in all oceans except the Indian Ocean and are most speciose along the west coast of North America, where there are 40 genera and 115 species (Nelson 1994). They occur mostly in intertidal marine waters, but some are subtidal, and some occupy freshwater or estuarine environments. Because it is a large and diverse family, many taxonomic relationships are still unclear.

Most research on cottid life history has focused on intertidal and freshwater species because of their greater accessibility and greater abundance, subtidal species are much less well known. O'Connell (1953) made an extensive study of the life history of the cabezon, Scorpaenichthys marmoratus, which is the largest North American cottid and is a popular sport fish on the California coast. Tokranov (1988) and Zolotov and Tokranov (1989) studied subtidal cottids off Kamchatka. Breder and Rosen (1966) discussed reproduction in some subtidal cottids.

The most comprehensive work on cottid taxonomy for both subtidal and intertidal species was published by Bolin (1944) More recently Washington et al. (1983a) re-examined cottid taxonomy based on larval characteristics. A comprehensive collection of cottid larval descriptions was published in the same volume (Washington et al. 1983b).

Seasonality of the spawning cycle has been described for numerous intertidal and subtidal cottids. Peak spawning on the Pacific Coast of North

America generally occurs in the winter, during the low-productivity Oceanic and Davidson current periods (Freeman et al. 1985, Grossman and DeVlaming 1984). The incubation period for the eggs is generally three to four weeks (Breder and Rosen 1966), so the larvae hatch in the spring, during the high-productivity Upwelling period. Timing of spawning may vary with latitude (Tasto 1975), or environmental factors (Grossman and DeVlaming 1984). A number of sculpins have peak spawning in the winter, but can have ripe gonads during any month of the year indicating year-round spawning capability. (Wells 1986, Goldberg 1980).

Larvae have been described for only 30 of the 70 genera of Cottidae. This paucity of information may be largely due to low dispersal distances of intertidal cottids. In a British Columbia study, almost all cottid larvae were captured within 20 meters of shore (Marliave 1986), an area too close to shore to be sampled by most ichthyoplankton surveys. Laboratory rearing has been the most productive means of describing cottid larvae.

A few studies have been done describing cottid dietary habits, and comparing diets among seasons, among different sized individuals, and between sexes. Most of this work has been done on intertidal fishes, but O'Connell (1953) found that adult *Scorpaenichthys marmoratus* ate mainly crabs, while juveniles ate a variety of other crustaceans. Molluscs and fishes also became a significant portion of the adult diets during winter and spring. Freeman et al. (1985) describe ontogenetic shifts in the diet of the the intertidal cottid, *Oligocottus snyderi* (fluffy sculpin), an which ate mainly gammarid amphipods and polychaete worms. Prey diversity increased with fish size.

They also found that females consumed more food than males during the low productivity Oceanic and Davidson current periods of fall and winter. They suggest this may be due to increased dietary needs of females during egg production. Seasonal changes in the diet of O. snyderi were minimal.

Orthonopias triacis, the snubnose sculpin, is a small fish (up to 10 cm total length) that ranges from northern Pacific Baja California to Monterey Bay, California. It is a cryptic bottom dweller, commonly found in nearshore rocky subtidal habitats from 0 to 30 meters depth (Eschmeyer et al. 1983). It is abundant in Monterey Bay.

Studies of O. triacis life history are few. Its reproduction mode has been suggested to be external fertilization with internal gametic association (Munehara et al. 1989). Munehara et al. (1989) discovered this reproductive mode in the elkhorn sculpin, Alcichthys alcicornis and surmised that O. triacis may behave similarly based on a report by Bolin (1941) that viable O. triacis eggs were obtained from an isolated female, but that egg development did not begin until after extrusion into seawater. This fertilization mechanism has not been verified for O. triacis. Bolin (1941) found a female O. triacis containing ripe eggs during April, but a complete study of its reproductive seasonality has not been made, and its eggs have not been found in the wild.

Larvae of O. triacis have been described at early yolksac stages from laboratory-reared specimens by Bolin (1941), and at post-yolksac stages from wild-caught specimens by Feeney (1992). Wild-caught descriptions have not been verified. O. triacis larvae were not found in the ichthyoplankton surveys conducted annually from 1954 through 1984 (Moser et al, 1993). No report of the diet of O. triacis has been published.

This study describes aspects of the life history of O. triacis including synchrony and timing of reproductive events, total or batch spawning, fecundity estimates, and egg and larval description. It also examines temporal changes in the diet of O. triacis, as well as differences in diet between males and females during breeding and non-breeding seasons.

METHODS

Study site and collection methods

The study was conducted from June 1991 through November 1992 in the nearshore subtidal zone in Monterey, California near the U.S. Coast Guard Jetty (Figure 1). Approximately 30 O. triacis specimens were collected per month when weather permitted. The exact location of collection was determined by choosing a random position along the length of beach. Two SCUBA divers swam in a direction perpendicular to shore, and submerged at a depth of approximately 2.5 meters. They continued to swim offshore until either fish were encountered or the depth exceeded 10 meters. At 10 m depth, divers randomly turned left or right, swam for 10 m parallel to shore and then turned inshore until either a fish was encountered or a depth of 2.5 m was reached. At 2.5 m depth, divers randomly turned left or right, swam for 10 meters and turned offshore again. This pattern was repeated for the duration of the dive with divers capturing every fish encountered on the paths perpendicular to shore.

Fish were caught using a small aquarium dipnet, and placed in Ziplock bags. Immediately upon surfacing from the dive, fish were placed in 4%

formalin. They were then transported to the lab, weighed to the nearest milligram, and measured (standard length) to the nearest 0.1 mm with calipers. Fish were dissected, and gender was determined when possible. Gonads were extracted, weighed, and placed in 70% ethanol for further study. The stomach and intestine were also removed and placed in 70% ethanol.

Size Frequency Analysis

Size frequency diagrams of fish standard lengths were plotted to elucidate peaks due to recruitment pulses or strong age classes. Fish captured within 3 month intervals (winter, spring, summer, fall) were combined to increase sample size, and 2 mm size classes were used. These histograms were examined visually for age class modes, and recruitment pulses. A Kolmogorov-Smirnov test (Zar 1974) was used to test for statistical differences in size distributions among seasons.

Gonad Analysis

Size frequency distributions of eggs were plotted against time to elucidate timing of spawning events. Eggs collected from all females captured within a one month period were pooled. An initial test was done to determine whether different egg sizes were distributed evenly throughout the ovary. Egg size distributions from the anterior, center, and posterior portions of the ovary were compared using a Kolmogorov-Smirnov test. Because this test showed that eggs increase in size toward the posterior end of the ovary in some females ($p<0.05$) , equal numbers of eggs from the anterior, center, and posterior parts of the ovary were used to construct egg size frequency curves in further analysis.

Another preliminary test was done to determine the influence of the preservatives formalin and ethanol on egg size. Egg diameters were obtained for 50 eggs. These eggs were placed in a 4% formalin solution for 4 hours, measured, placed in 70% ethanol for 24 hours, and then measured again. The mean sizes were then compared using a Student's t-test.

Because the number of eggs in an ovary can be large, ovaries were subsampled in a stratified manner for size frequency analysis. The right ovary was divided into three equal portions. The eggs in each of these portions (anterior, center, and posterior) were teased apart using forceps and a probe, placed in a gridded dish, and stirred with a probe. The diameters of 200 eggs from each subsample were measured to the nearest micron using a dissecting microscope and an image analyzer. Egg sizes from all females collected within each one month sampling period were used to construct a size frequency histogram. These monthly histograms were then examined for the presence of large eggs to determine when spawning occurred.

To determine whether <u>O. triacis</u> was a total spawner (lays one batch of eggs per spawning season) or a batch spawner (lays multiple groups or "batches" of eggs within a spawning season), size frequency histograms of eggs from individual fish were examined for multiple size class modes. When multiple modes were apparent, modes were counted to obtain an estimate of the number of batches laid. When modes were apparent and there was a size class with diameter greater than 600 microns, all eggs of the largest size class from both halves of the ovary were counted to obtain a batch fecundity estimate.

Two other related methods were also used to elucidate timing of spawning. First, the gonosomatic index (GSI) was calculated as gonad weight divided by body weight and plotted against time to illustrate seasonality of gonadal development. Second, the percentage of adult females (> 44 mm standard length) containing hydrated eggs was plotted against time.

Larval Descriptions

Eggs were obtained from one ripe female following Bolin (1941) by gently pressing the abdomen. They were placed in a 50 gallon container of filtered seawater with gentle aeration. After hatching, larvae were fed rotifers twice per day. Larvae were sacrificed at 4, 6, 7, 9, 10, and 12 days from hatch date. The meristic characters were recorded, body measurements were taken, and melanophores were counted for each individual using a dissecting microscope and image analyzer. Larvae were then photographed through a 10X dissecting microscope lens with 35 mm color slide film.

Dietary Analysis

To evaluate seasonal changes in feeding, samples were divided into the three oceanographic periods described by Bolin and Abbott (1962). which are generally believed to describe the major changes in temperature and productivity on the California coastline. These periods are the low productivity Oceanic period from about August through October, the Davidson current period from November to January is also characterized by low-productivity, and the Upwelling period beginning in Feb. with a dramatic increase in productivity which lasts until July or August.

After the stomach and intestine were removed from each fish, the percent fullness of the stomach was visually estimated. This procedure was minimally subjective because the stomach of O. triacis is a well-defined sack which is hollow when empty and does not stretch with increasing fullness. Next, the prey items were identified and sorted into the lowest possible taxa and counted.

A cumulative species curve was constructed by plotting the cumulative number of prey types encountered against the number of guts sampled (Cailliet et al. 1986). The order in which guts were analyzed was randomized, and the cumulative number of prey types encountered was plotted against the number of guts sampled. This was done separately for each time period to determine whether sample sizes were sufficient to represent dietary content in each season.

After individuals in each prey group were counted (N), the percent contribution to the total volume of prey in that stomach (v) was estimated visually. This volume was multiplied by the percent fullness to obtain percent volume (%V). Index of Relative Importance (IRI; Caillliet et al. 1986) was calculated for each of the three Oceanic periods described above: IRI= (%F)(%V+%N) where %N=percent by number, %V=percent by volume, and %F=frequency of occurrence.

Percent Similarity Indices (PSI) of the mean IRI were calculated to compare the diet of O. triacis among time periods (Oceanic, Davidson current, and Upwelling). The same technique was used to compare diets among size classes. Diets were also compared between males and females for each time period using PSI of the mean IRI.

Gut fullness was compared between sexes, and among seasons by analysis of variance (ANOVA). These data were tested for and met the assumptions of ANOVA: homogeneity of variance (Bartlett's test) and normality (Chi squared goodness of fit test).

RESULTS

Study site

The study area ranged in depth from 3-10 meters, and encompassed an area of approximately 300 square meters (Figure 1). The bottom was mainly granite boulders interspersed with patches and channels of coarse sand and shell debris. Giant kelp, Macrocystis pyrifera dominated the surface canopy while fleshy red and coralline algae generally covered the bottom. Beyond a depth of 10 m, the bottom type changed to a very fine grain sand with no rock. No O. triacis were seen on this type of habitat during reconnaissance surveys.

Population size frequency analysis

A total of 475 fish was caught between June 10, 1991 and November 16, 1992. The fish ranged in size from 15.5 to 74.3 mm standard length. The smallest fish identified as a female was 22.2 mm SL, and the largest female captured was 66.2 mm SL. The smallest identified male was 23.6 mm SL, and the largest male was 74.3 mm SL. The smallest fish containing hydrated eggs was 44.2 mm SL.

Size frequency diagrams have several peaks potentially indicating age classes (Figure 2). However, these peaks were not clearly enough defined to assume they represent cohorts and calculate growth curves. Males and females were not analyzed separately because the gender of small fishes was not determinable, and sample sizes were low . Small fish (<20 mm SL) were captured during the months of February, May through August, and November, suggesting a long season of recruitment of juveniles to the area.

Gonad analysis

Egg preservation technique did not affect egg diameter. There was no significant change in egg diameter after preservation in formalin, or formalin followed by ethanol for hydrated or non-hydrated eggs (Table 1).

In half of the eight females tested, there was a significant difference in egg size distribution among the anterior, center, and posterior sections of the ovary (Kolmogorov-Smirnov test; Table 2). This was due to large mature eggs being concentrated in the posterior portion of the ovary.

The ovaries had features characteristic of batch spawners. The first such feature was the presence of multiple size classes of eggs at different developmental stages within individual females (Figure 3). The smallest eggs (<100 microns diameter) were translucent white, tightly bound up in the stroma, and distributed throughout the ovary. A second, larger size class (>500 microns) was opaque yellow and only loosely bound in the stroma. These eggs were also distributed throughout the ovary. Hydrated eggs were approximately 1000 microns in diameter, translucent yellow, and held loosely in the ovarian lumen. The uneven distribution of egg sizes throughout the ovary is also indicative of the presence of multiple developmental stages. Typically, as eggs mature, they become less tightly bound in the stroma. Shortly before hydration, they migrate toward the ovarian lumen from which they are released upon maturity, thus yielding a non-uniform distribution of egg sizes.

Another factor suggesting batch spawning is low fecundity. Fecundity estimates obtained by counting the number of large eggs (>500 microns) in pre-spawned females ranged from 124 to 194, with an average of 128 eggs. If O. triacis lays three such batches per year (the maximum number of size classes observed in a female), its annual fecundity would average 384 eggs. It is not possible to tell from this study how many batches are actually laid, as small eggs could either be resorbed, or produce more batches. Fecundity was not significantly correlated with female standard length for fish collected during March 1992 (Figure 4; r=0.56, n=14).

The seasonal presence of mature, hydrated eggs in adult females indicated peak spawning in spring (Figures 5 & 6). Although large, vitellogenic eggs were found throughout most of the year (all months of the study except May 1992 and August 1992), hydrated eggs were present only from February through April 1992, and in one individual during July 1992. Individuals containing multiple size classes of eggs were found during fall, winter and spring. In summer, most females contained a single size class of small eggs. There were exceptions in August 1991 and July 1992.

Gonosomatic indices indicated spawning activity from winter to early spring. The mean gonosomatic index for females (Figure 7) was high (3.0) from October 91 through March 1992, and dropped to near zero by June 1992. There was a moderate rise in early fall 1992 but the GSI was again near zero in October and November 1992. Males showed a similar pattern with a high GSI in fall 1991 and early spring 1992. The GSI for males was near zero from April through November 1992.

Larval descriptions

At the age of two weeks, there was a large die off of the cultured O. triacis larvae, but six larvae were sacrificed before that time. Larvae sacrificed at 9 days and 12 days after hatching were unusually small and showed signs of starvation, therefore only the remaining four larvae were described. Larval meristics are presented for all six larvae. Sample size was too small for statistical analysis (Table 3).

The four day old larva, at 3.3 mm length, had a spindle-shaped body typical of Cottidae (Norvillo and Zhuravleva 1989; Figure 8a). Its head was bluntly rounded with a large eye, the diameter of which was about half the head length. The mouth was small, with the posterior end of the jaw beneath the front third of the eye. Head and nape pigments were small, faint round brown dots with slightly ragged edges. Ventral melanophores were darker and had more distinct edges. The top of the gut was densely covered with dark, star-shaped melanophores, but there were no ventral gut pigments.

The six and seven day old larvae at 3.5 mm length (Figure 8b) had similar morphology, but the head and nape melanophores were darker and star-shaped.

The 10 day larva at 5.1 mm length (Figures 8c and 8d) had a slightly longer jaw relative to the head size, but the jaw still did not extend behind the front third of the eye. Caudal fin rays were beginning to develop. The ventral melanophores were darker, larger and more star-shaped than in smaller larvae.

The number of head melanophores increased to 11. Gut diverticulae which are seen in some cottids (Washington 1983b) were absent. There was no sign of flexion in this largest specimen.

Dietary analysis

The cumulative number of prey types encountered increased with increasing sample size for all periods of the study (Figure 9). This was due mainly to the continual addition of rare species, as the diet was largely dominated by three prey types throughout the year, gammarid amphipods, decapod crabs, and polychaete worms.

The diet of O. triacis showed little seasonal variation. Throughout the study, the most common prey was gammarid amphipods, followed by decapod crabs in the zoea and megalops stages, and then polychaete worms. Snails were fourth in abundance throughout the study but showed considerably lower IRI values than did polychaete worms. Shrimp ranked fifth in abundance during all periods of the study, except the Oceanic period of 1992 when they were absent.

Relative abundance of other rare prey items varied among seasons (Figure 10). For example, ostracods were found in the diet only during the Upwelling periods of 1991 and 1992. Copepods were part of the diet during the Oceanic period 1991 and the Upwelling period 1992. Pelecypods and isopods appeared in the diet from the Upwelling period 1992 through the Oceanic period 1992. Pycnogonids were found only in a single collection during the Davidson current period 1991-1992.

Percent Similarity Indices comparing diets among periods ranged from 0.79 to 0.95, indicating a high degree of similarity in the diet among the four periods of the study (Table 4). The lowest similarity (0.79) was between the Oceanic periods of 1991 and 1992, and the highest was between the Oceanic period of 1992 and the Upwelling period of 1992, indicating that there was no seasonal pattern in the diet.

There was a high degree of similarity in the diet among all the size classes of fish sampled, indicating that diet does not change significantly as fish mature (Table 5).

Males and females had similar diets throughout the year. Percent Similarity Indices of IRI values ranged from 87.8% to 99.1% (Table 6) indicating a high degree of similarity between sexes for all time periods.

Gender had no significant effect on gut fullness (ANOVA, F=1.19, p=0.308), and there was no significant difference in gut fullness among seasons (ANOVA, F=0.750, p=0.474).

DISCUSSION

O. triacis appears to be a batch spawner, which is not uncommon in the Cottidae. The intertidal Clinocottus analis (woolly sculpin), spawns multiple batches per year (Wells 1986), and two subtidal cottids, Chitonotus pugetensis (roughback sculpin) and Icelinus quadriceriatus (yellowchin sculpin) show evidence of batch spawning (Goldberg 1980).

Batch spawning is a possible adaptation to variable environmental conditions. It ensures that the entire year's reproductive output is not subject to a single catastrophic event such as a storm which might knock eggs loose from a substrate, or a large predator which might eat a whole clutch of eggs. It is also a means by which a small fish can increase the number of eggs produced without decreasing egg size. The subtidal cottid, Scorpaenichthys marmoratus co-occurs geographically with O. triacis, but is a total spawner (O'Connnell 1953). However, this fish is much larger than O. triacis (up to 99 cm standard length; Eschmeyer et al. 1983). It lays a large batch of eggs which it firmly attaches to a stable substrate, and the male of the species vigorously guards the eggs from predators.

Fecundity has been estimated for only a few cottids on this coast. For total spawners these estimates have been obtained by counting eggs in spawned egg masses (Zolotov and Tokranov 1989), or counting ripe eggs in sacrificed females (Tasto 1975). Fecundity is more difficult to determine for batch spawners. Usually, batch fecundity is estimated in a similar manner to that of annual fecundity for total spawners. Then, an estimate is made of the number of batches spawned per year base on size frequency analysis of eggs Wells (1986). Problems arise if the spawning period is long in that small eggs may be resorbed, or retained for the next year (Lisovenko and Andrianov 1992). Fecundity can also vary with size and age of female, sequential batch number, and various environmental factors (Ludwig and Lange 1975).

The mean batch fecundity of 128 eggs is somewhat lower than similar sized marine cottids. The intertidal sculpin, Clinocottus analis, was found to have a mean batch fecundity of 242 eggs with at least three egg size classes present (Wells 1986). Batch fecundity of Leptocottus armatus (staghorn sculpin) in captivity was 200 to 300 eggs (Tasto 1975). Tasto (1975) suggested that low fecundities might be indicative of egg protection or guarding behavior. Such behavior is common in members of the cottid family, including the marine subtidal species Scorpaenichthys marmoratus (O'Connell 1953), Hemilepidotus hemilepidotus (red Irish lord; DeMartini and Patten 1979), and Artedius harringtoni (scalyhead sculpin; Ragland and Fischer 1987). It is not likely that the eggs of O. triacis are guarded for two reasons. First, no defensive behavior was ever observed in O. triacis despite many hours of observation and hundreds of encounters with fish. Second, since a female can lay eggs as much as two weeks after copulation (Bolin 1941, pers. observation), the male is probably not present during spawning, and in most fish species the male guards the eggs (Breder and Rosen 1966).

If O. triacis is a batch spawner, we must know the actual number of batches released by a female in a year to estimate annual fecundity. This is often determined by counting the size class modes of eggs, but this method is complicated by the fact that the smallest eggs may either be resorbed or not develop until the next year (Hunter et al. 1985). Since there was a maximum of two larger size classes of vitellogenic eggs present in a female, it is possible that they release at least two batches of eggs per year. Low batch fecundity would lead one to suspect that they lay more than two batches. Estimation of annual fecundity is further complicated by the fact that the reproductive season for O. triacis appears to be somewhat variable among fish and among years.

Evidence from this study suggests that spawning is asynchronous within the population, that is individual females lay eggs at different times within the spawning season. Synchronous spawning is typically characterized by a low variability in gonadal condition among individuals within a time period, and by a modal progression in egg sizes throughout time. Such a progression is frequently correlated with environmental conditions such as day length or moon phase. More frequent sampling with larger sample sizes would be required to detect such a pattern, but high variability in egg development stages and gonosomatic indices among fish captured at the same time, within close proximity to each other, suggest that synchronous spawning does not occur in O. triacis.

Asynchronicity may indicate that spawning is triggered more by very small-scale factors applicable to the individual fish rather than large-scale ones. For instance, a female's spawning condition may be more dependent on food abundance, mate availability, or availability of suitable spawning substrate than on day length or temperature.

Synchronous spawning can be advantageous in populations with external fertilization when low population density or other factors make finding a mate difficult. It increases the probability that an appropriate mate will be found which is in the proper gonadal condition to spawn. This advantage is probably not important for O. triacis because they occur in such high density that finding a mate is probably not difficult. Because female O. triacis are capable of retaining viable sperm for at least two weeks (Bolin 1941), the timing of mating relative to egg maturity is not as critical. Therefore, there may be no great advantage to synchronous spawning in O. triacis.

O. triacis is mainly a spring spawner, but this timing is variable. There was a general peak in the gonosomatic index in the winter of 1991 and spring of 1992 followed by rapid declines which follows the pattern typical of cottids along the west coast of North America(Goldberg 1980, O'Connell 1953). This winter and spring spawning allows recruitment of young to occur during spring and summer when productivity is highest. Unexpected variations in the pattern are the low mean GSI for males and females in fall of 1992, and a peak in the female GSI during July of 1992. A longer study would be required to adequately describe the seasonal patterns in spawning of *O. triacis*, and to determine causes for variation in the timing of spawning.

The presence of hydrated eggs in a few individuals during all months of the year except May suggests the possibility of year-round spawning capabilities in *O. triacis*. A protracted spawning period is common in sculpins along the west coast of North America. The intertidal sculpin, *Oligocottus snyderi*, was found to have an eight month spawning period (Grossman and DeVlaming 1984). *Chitonotus pugetensis* (roughback sculpin)and *Icelinus quadriceriatus* in Southern California also have extended spawning periods (Goldberg 1980). All of these fishes show their peak spawning in late winter and spring, as does *O. triacis*.

Most of the cottids which have been found to spawn primarily in late winter and spring have also been found to have a corresponding recruitment pulse in late spring and summer during the high productivity Upwelling season. There is some possibility that such a pulse exists for *O. triacis* too, but was not found for one of several reasons. It may be that too few fish were collected to represent the actual size frequency of the population. Juveniles may also have been missed because of their small size, or because they tend to occupy a different habitat than that of the adults.

The larval descriptions in this report are very preliminary due to catastrophic events in the rearing facility. With more resources however, *O. triacis* larvae could probably be raised successfully, and described more thoroughly. Such an effort would be warranted, as published literature in this area is lacking. The meristics and morphology found in this study were in agreement with those reported by Bolin (1941) who described embryonic and newly hatched larval stages of *O. triacis* from captive specimens. They were also consistent with those presented by Feeney (1992) in an account of wild caught *O. triacis* larvae from 3.3 mm to 5.5 mm notochord length. The larvae reared in this study had more pigment in the head and nape areas than did those described by Feeney (1992) or Bolin (1941), but pigments of lab-reared larvae are known to vary with environmental conditions. Further larval rearing would be useful to describe intermediate sizes, and to further verify identification of the wild caught specimens.

The general diet of *O. triacis* did not reflect general seasonal changes in oceanic productivity in that the same organisms dominated the diet all year. It appears that gammarid amphipods, decapod crabs, and polychaete worms are sufficiently abundant to remain the major constituents in the diet of *O. triacis* throughout the year.

O. triacis appear to be very opportunistic and flexible in their diet. While they rely mainly on the dominant prey, they are capable of taking advantage of the occasional availability of other prey such as snails, shrimp, copepods, ostracods, fish eggs (probably Coryphopterus nicholsii, the blackeye goby) and isopods, and have great diversity in their diet because of these rarely eaten items.

Most prey appeared to have been swallowed whole. The algae and sand found in the guts of a few fish were probably incidental to feeding on other items. The algae did not appear to be digested. When O. triacis were observed feeding on several occasions, they waited for prey to come close, and then with a very small forward motion, sucked in the whole prey item. This observed diet and feeding behavior are consistent with those predicted by Norton (1991) for small-mouthed cottids based on morphology and attack kinematics. Elusive prey such as fish and shrimp are rarely eaten, while small grasping prey are favored, and a suction type feeding mechanism is used.

There was no significant difference in prey composition among different sized individuals, as has been found in other nearshore cottids (Wells 1986; Freeman et al. 1985). This might be indicative that competition for food between adults and juveniles is not strong enough to stimulate resource partitioning. Also, unlike other cottids which have been found to change their diet as they grow (e.g. Clinocottus analis, Wells 1986), O. triacis has a small mouth. This should result in a smaller overall change in mouth size with growth, which might prohibit great expansion of the diet. Further morphological research would be required to confirm this.

LITERATURE CITED

Bolin, R.L. 1941. Embryonic and early larval stages of the cottid fish Orthonopias triacis Starks and Mann. Stanford Ichthyol. Bull. 2(3):73-83.

Bolin, R.L. 1944. A Review of the marine cottid fishes of Califorrnia. Stanford Ichthyol. Bull. 3(1):1-135.

Bolin, R.L., and D.P. Abbott. 1962. Studies on the marine climate and phytoplankton of the central coastal area of California, 1954-1960. CALCOFI Repts. 9(1):23-45.

Breder, C.M., and D.E. Rosen. 1966. Modes of Reproduction in Fishes. Natural History Press. Garden City, New York, 941 pp.

Cailliet, G.M., M.S. Love, and A.W. Ebeling. 1986. Fishes: A Field and Laboratory Manual on Their Structure, Identification, and Natural History. Wadsworth Publishing Co. Belmont, California, 194 pp.

DeMartini, E., and B. Patten. 1979. Egg guarding and reproductive biology of the red Irish lord, Hemilepidotus hemilepidotus (Tilesius). Syeses 12:41-55.

Eschmeyer, W.N., E.S. Herald and H. Hammann. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin Co. Boston, Mass. 336 pp.

Feeney, R.F. 1992. Post-yolksac Larval Development of Two Southern California sculpins, Clinocottus analis and Orthonopias triacis (Pisces: Cottidae). Fishery Bull., U. S. 90:454-468.

Freeman,M.C., N. Neally and G. D. Grossman. 1985. Aspects of the life history of the fluffy sculpin, Oligocottus snyderi. Fish. Bull. 83(4): 645-655.

Goldberg, S.R.1980. Seasonal spawning cycles of two marine cottid fishes, Chitonotus pugetensis and Icelinus quadriceriatus from Southern California. Bull. Mar. Sci. 30(1):131-135.

Grossman, G.D. and V. DeVlaming. 1984. Reproductive ecology of female Oligocottus snyderi Greeley: a North American intertidal sculpin. J. Fish. Biol. 25:231-240.

Hunter, J.R., N.C.H. Lo, and R.J.H. Leong. 1985. Batch fecundity in multiple spawning fishes. NOAA Tech. Rep. NMFS 36. pp 67-77.

Hurtubia, J. 1973. Trophic diversity measurement in sympatric predatory species. Ecology 54(4):885-890.

Lisovenko, L.A., and D.P. Andrianov. 1992. Determination of absolute fecundity of intermittently spawning fishes. J. Ichthyol. 31(9):143-155.

Ludwig, G.M., and E.L. Lange. 1975. The relationship of length, age, and age-length interaction to the fecundity of the northern mottled sculpin, Cottus b. bairdi. Trans. Amer. Fish. Soc. 1975(1):64-67.

Marliave, J.B. 1986. Lack of planktonic dispersal of rocky intertidal fish larvae. Trans. Am. Fish. Soc. 115:149-154.

Moser, H.G., R.L. Charter, P.E. Smith, D.A. Ambrose, S.R. Charter, C.A. Myer, E.M. Sandknop, and W. Watson. 1993. Distributional atlas of fish larvae in the California Current region: Taxa with less than 1,000 total larvae, 1951 through 1984. CALCOFI Repts 32:181 pp.

Munehara, H., K. Takano and Y. Koya. 1989. Internal gametic association and external fertilization in the elkhorn sculpin, Alcicthys alcicornis. Copeia (3): 673-678.

Nelson, J.S. 1994. Fishes of the World, 3rd ed. John Wiley and Sons. New York. pp322-324.

Norton, S.F. 1991. Capture success and diet of cottid fishes: The role of predator morphology and attack kinematics. Ecology 72(5):1807-1819.

Norvillo, G.V., and N.G. Zhuravleva. 1989. Early post embryonic development of the Arctic staghorn sculpin Gymnacanthus tricuspis. J. Ichthyol. 29(5):148-150.

O'Connell, C.P. 1953. The life history of the Cabezon, Scorpaenichthys marmoratus (Ayres). Fish. Bull. 93. 76 pp.

Parrish, R.H., C.S. Nelson, and A. Bakun. 1981. Transport mechanisms and reproductive success of fishes in the California Current. Biol. Oceanog. 1(2):175-203.

Ragland, H.C. and E.A. Fischer. 1987. Internal fertilization and male parental care in the scalyhead sculpin, Artedius harringtoni. Copeia 1987(4):1059-1062.

Smith, P.E. and S.L. Richardson 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Fish Tech. Pap.175. 100p.

Tasto, R. 1975. Aspects of the biology of Pacific staghorn sculpin Leptocottus armatus Girard, in Anaheim Bay. Cal. Dept. Fish and Game Fish. Bull. 165:123-135.

Tokranov, A.M. 1988. Reproduction of sculpins of the genus Gymnocanthus (Cottidae) in the coastal waters of Kamchatka. J. Ichthyol.28(3):124-128

Washington, B.B., W.N. Eschmeyer, and K.M.Howe. 1983. Scorpeniformes: Relationships. in H.G. Moser, W.J. Richards, D.M. Coher, M.P. Fahay, A.W. Kendall Jr. and S.L. Richardson (eds.) Ontogeny and Systematics of Fishes. Am. Soc. Ichthyol. Herpetol. Spec. Publ. no. 1. pp438-447

Washington, B.B., H.G. Moser, W.A. Larouche, and W.J. Richards. 1983. Scorpaeniformes: Development. In H.G. Moser, W.J. Richards, D.M. Coher, M.{. Fahay, A.W. Kendall Jr., and S.L. Richardson (eds.) Ontogeny and Systematics of Fishes. Am. Soc. Ichthyol. Herpetol. Spec. Publ. no. 1. pp405-428

Wells, A.J. 1986. Aspects of ecology and life history of the woolly sculpin, Clinocottus analis, from Southern California. Calif. Fish and Game 72(4): 213-226.

Yoshiyama, R.M., C. Sassaman, and R.N. Lea. 1986. Rocky intertidal fish communities of California: temporal and spatial variation. Env. Biol. Fish. 17:23-40.

Zar, J.H. 1974. Biostatistical Analysis. Prentice-Hall Inc. Englewood Cliffs, New Jersey 620 pp.

Zolotov, O.G., and A.M. Tokranov. 1989. Reproductive ecology of Hexagrammidae and Cottidae in the Pacific waters of Kamchatka. J.Ichthyol. 25(5):54-61.

	Non-Hydrated **t (d.f.)**	**Hydrated** **t (d.f.)**
Fresh vs. Formalin	0.99 (42)	0.74 (42)
Fresh vs. Formalin+ EtOH	0.92 (50)	0.39 (50)

TABLE 1: T-Test comparisons of Orthonopias triacis eggs when fresh, fixed in formalin for four hours, and fixed in formalin for for hours and then ethanol for 24 hours

D_{max}	$D_{.05}$	n	significant
.197	.113	142	yes
.150	.121	127	yes
.130	.150	84	no
.096	.096	199	no
.104	.106	163	no
.170	.096	200	yes
.230	.096	200	yes
.005	.096	200	no

Table 2: Kolmogorov-Smirnov test comparison of egg size distributions from the anterior, center, and porterior sections of ovaries of eight individual Orthonopias triacis.

AGE (days)	4	6	7	9	10	12
notochord length	3353	3522	3489	3888	5130	3005
snout to anus	1217	1177	1025	1274	1821	1122
head length	737	660	582	749	953	600
snout length	234	137	106	160	356	160
upper jaw length	219	467	—	493	676	488
eye diameter	346	381	267	392	467	374
body depth at pectoral fin base	632	709	489	729	927	641
body depth at anus	519	568	343	614	832	473
pectoral fin length	—	426	—	455	581	—
# of myomeres	34	37	34	36	35	35
ventral melanophores	34	48	34	34	42	42
1st myomere with ventral melanophores	11	13	11	13	12	12
head melanophores	5	5	5		11	
nape melanophores	4	2	4		4	

TABLE 3: Meristics, morphology, and melanophore counts of laboratory-reared Orthonopias triacis. (Measurements are in microns)

	Oceanic '91	Davidson '91-'92	Upwelling '92	Oceanic '92
late Upwelling '91	0.89	0.94	0.93	0.89
Oceanic '91		0.94	0.83	0.79
Davidson '91-'92			0.89	0.85
Upwelling '92				0.95

TABLE 4: Percent Similarity Index comparison of Orthonopias triacis gut contents among five oceanic periods from June1991 through November 1992. Variable compared is percent Index of Relative Importance (IRI).

Standard length (mm)	n	20-30mm	30-40mm	40-50mm	50-60mm	60-70mm
0-20	5	88	90	84	92	94
20-30	67		96	87	91	93
30-40	116			90	95	95
40-50	93				91	88
50-60	63					96
60-70	11					

TABLE 5: Percent Similarity Index comparison of gut contents among Orthonopias triacis of different size clases (standard length in mm). Variable compared is percent Index of Relative Importance (IRI).

OCEANIC 1991	99.1
DAVIDSON 1991-1992	90.1
UPWELLING 1992	91.9
OCEANIC 1992	87.8

TABLE 6: Percent Similarity Index comparison of diets between male and female O. triacis collected during four time periods from August 1991 through November 1992. Variable compared is percent Index of Relative Importance (IRI).

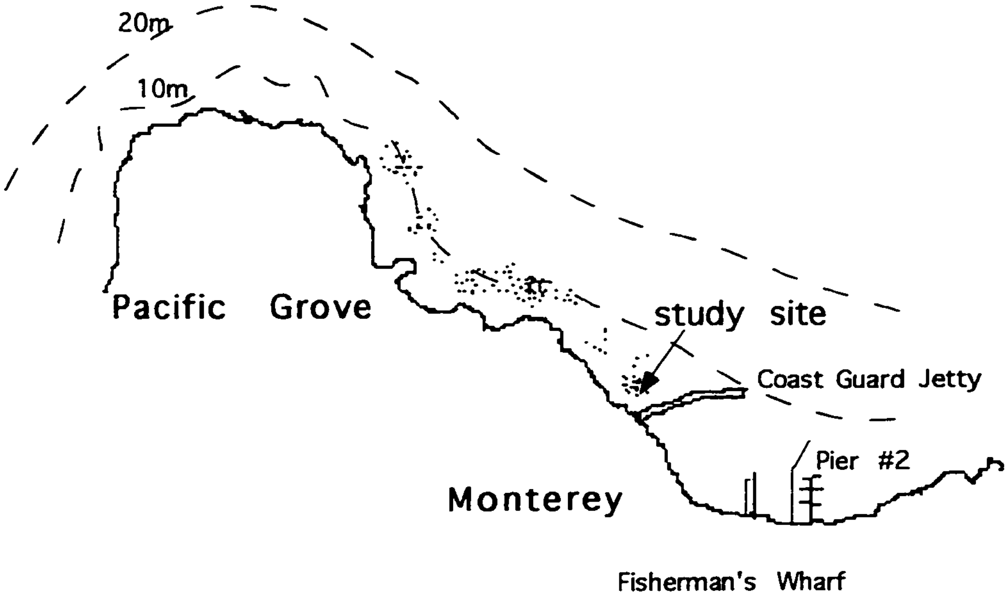

FIGURE 1: Location of <u>Orthonopias</u> <u>triacis</u> collection in Monterey, CA

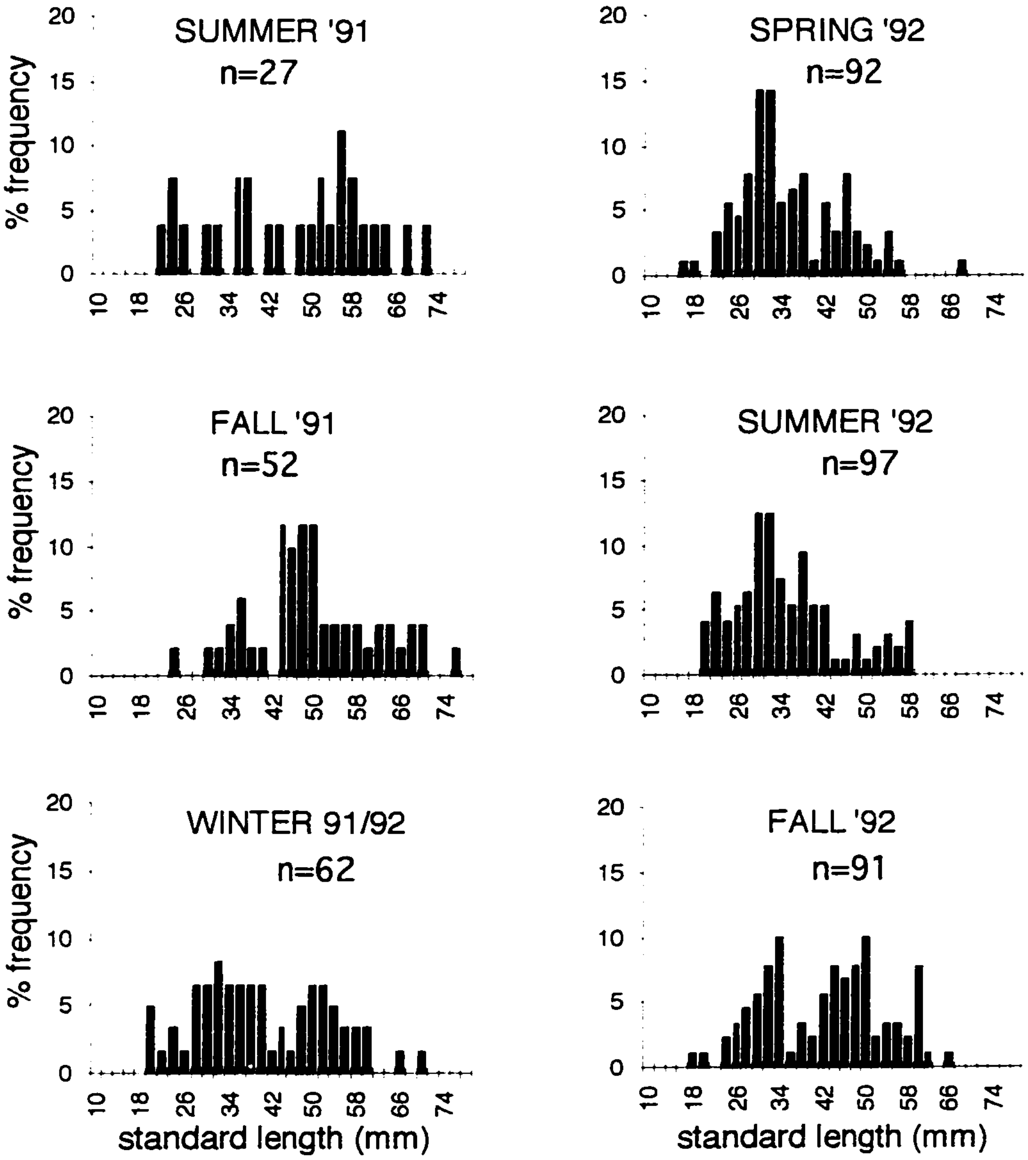

FIGURE 2: Size frequency distributions of <u>Orthonopias</u> <u>triacis</u>. Sizes are fish standard length in millimeters

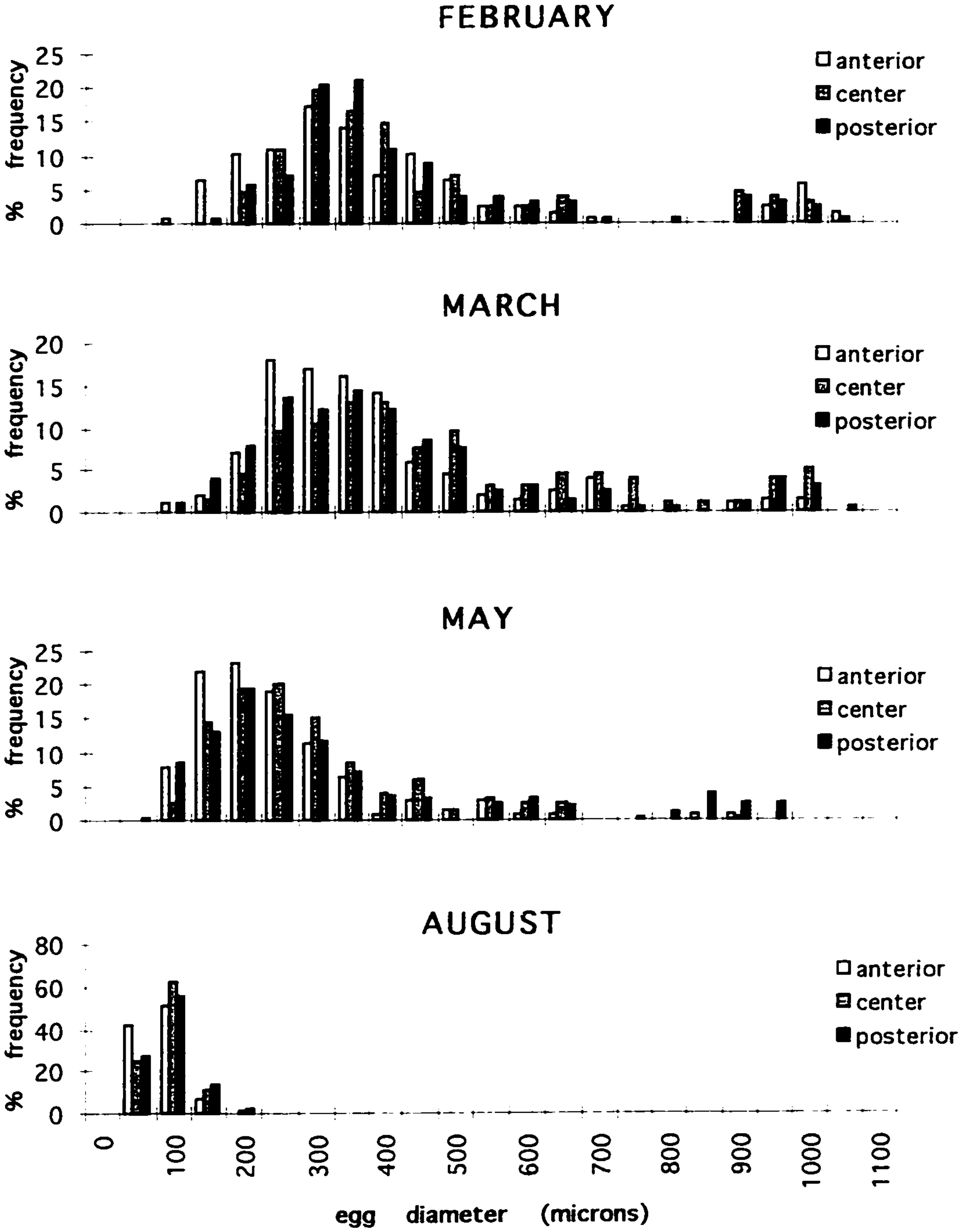

FIGURE 3: Egg size distributions from individual Orthonopias triacis collected in February, March, May, and August. Egg diameters from the anterior, center, and posterior parts of the ovary are plotted separately.

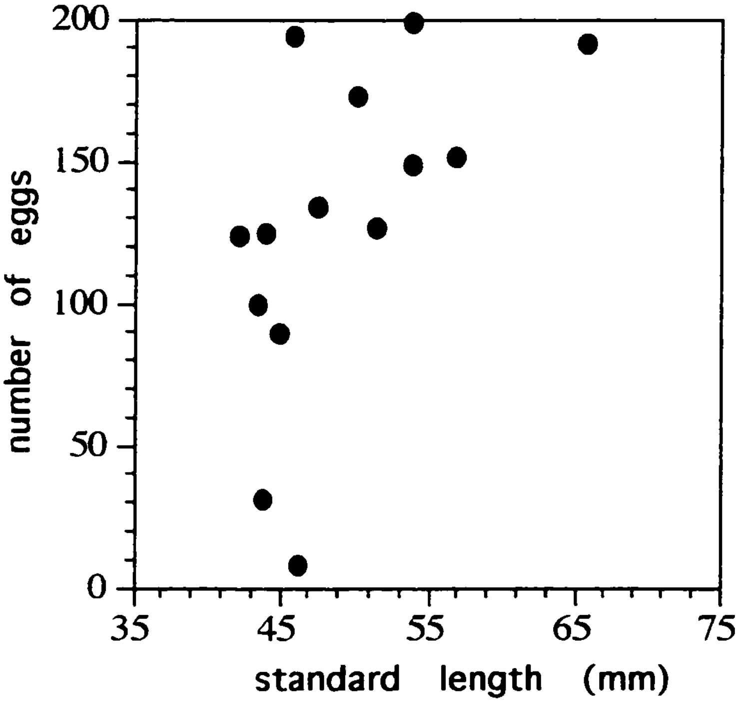

FIGURE 4: Relation of number of eggs larger than 500 microns in diameter with standard length of female.

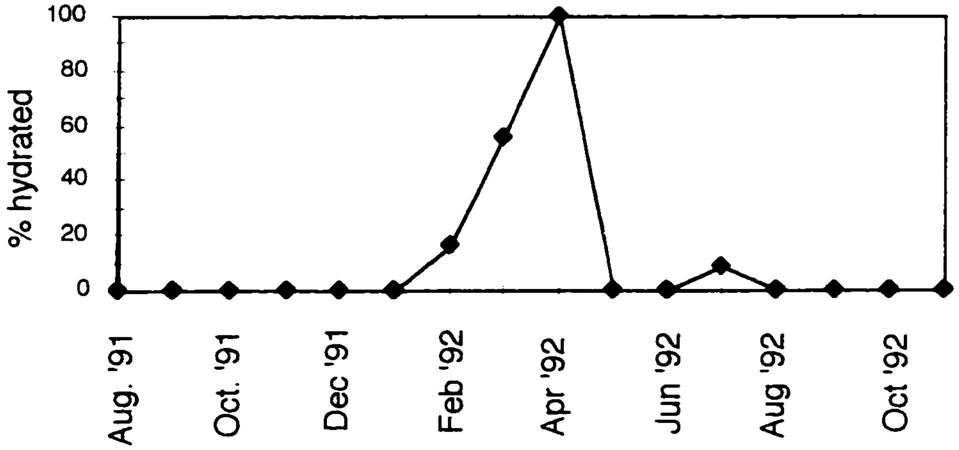

FIGURE 5: Percentage of adult female <u>Orthonopias</u> <u>triacis</u> containing hydrated eggs from August 1991 to October 1992

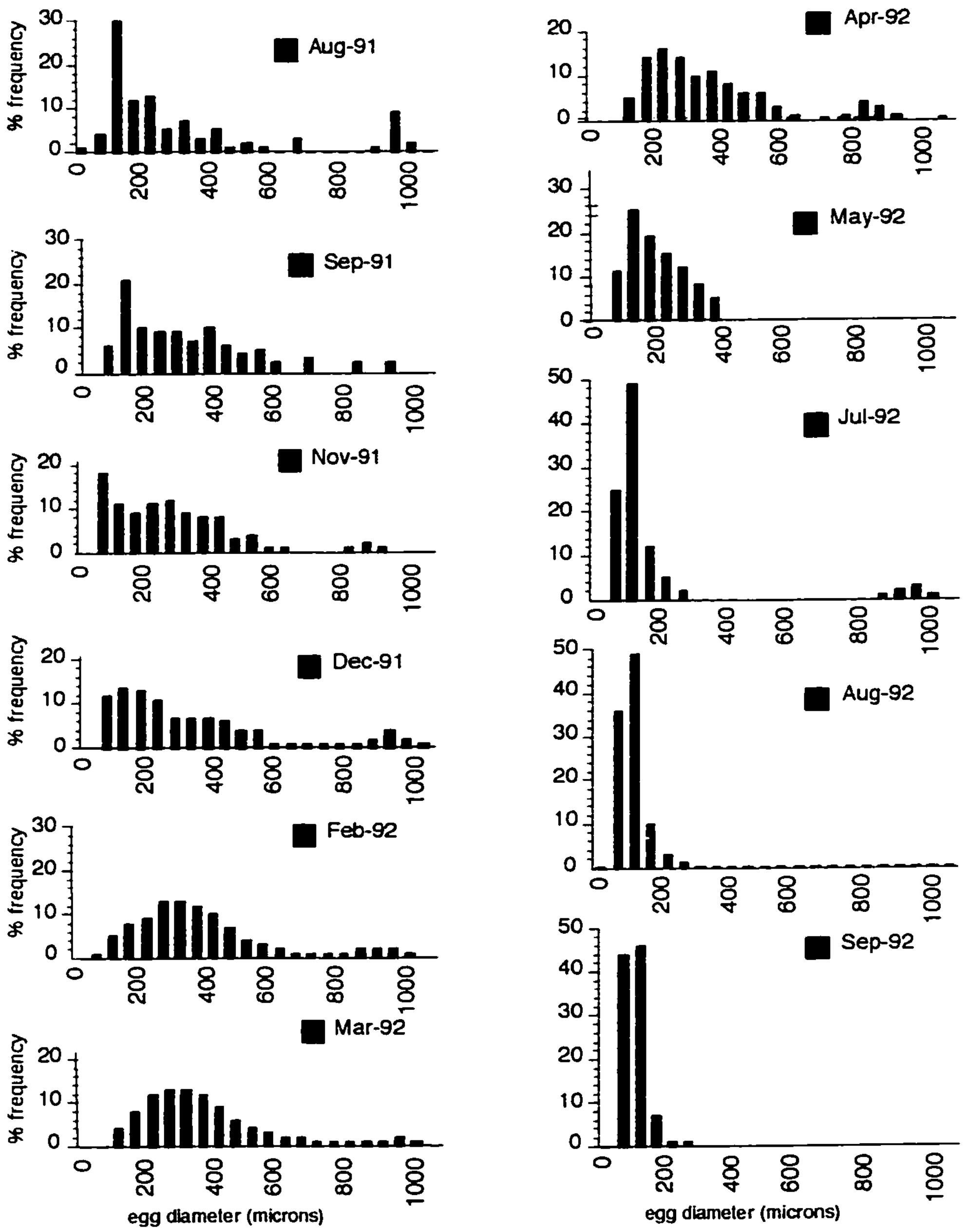

FIGURE 6: Egg size frequency distributions (50 micron size classes) for adult female Orthonopias triacis from August 1991 through September 1992

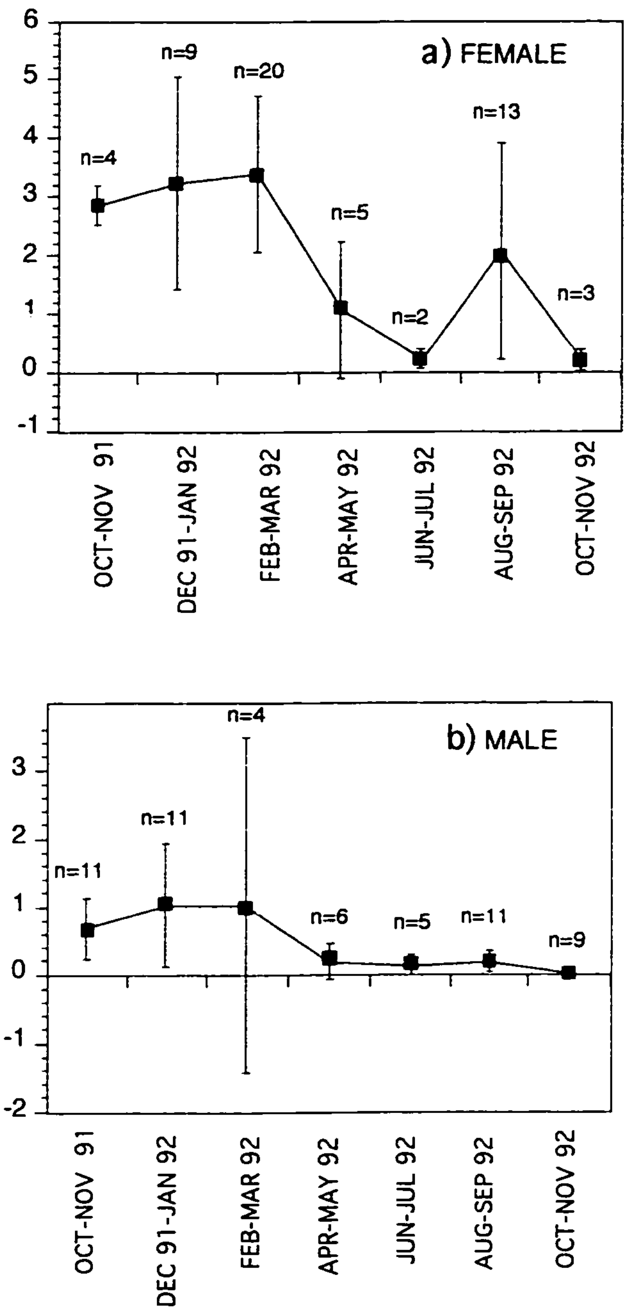

FIGURE 7 Gonosomatic indices with standard deviations for adult a) female and b) male Orthonopias triacis in Monterey, CA between Oct. 1991 and Nov. 1992

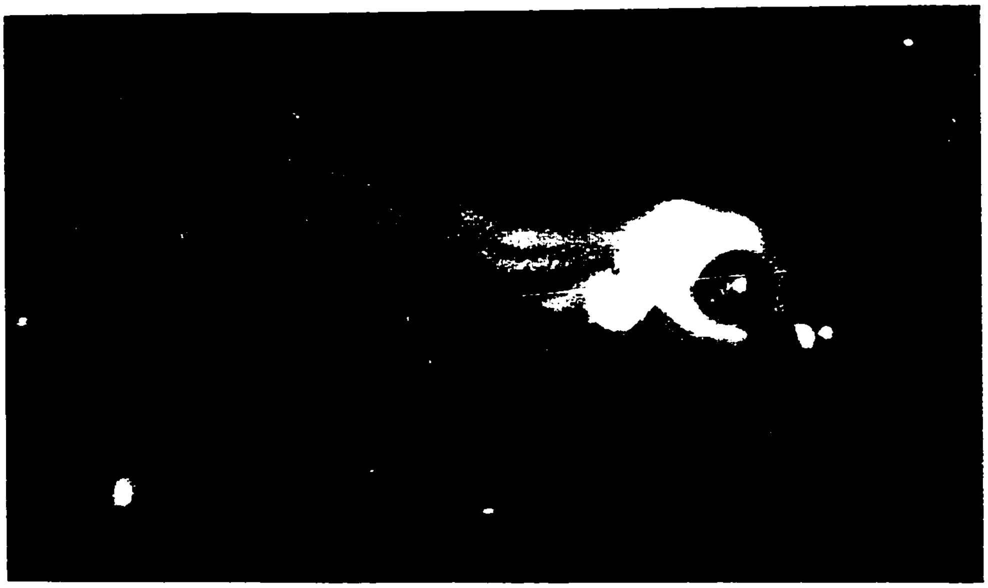

FIGURE 8a: Early larval stage of Orthonopias triacis. Notochord length =3.2 mm

FIGURE 8b: Early larval stage of Orthonopias triacis. Notochord length =3.5 mm

FIGURE 8c: Early larval stage of Orthonopias triacis. Notochord length =5.1 mm

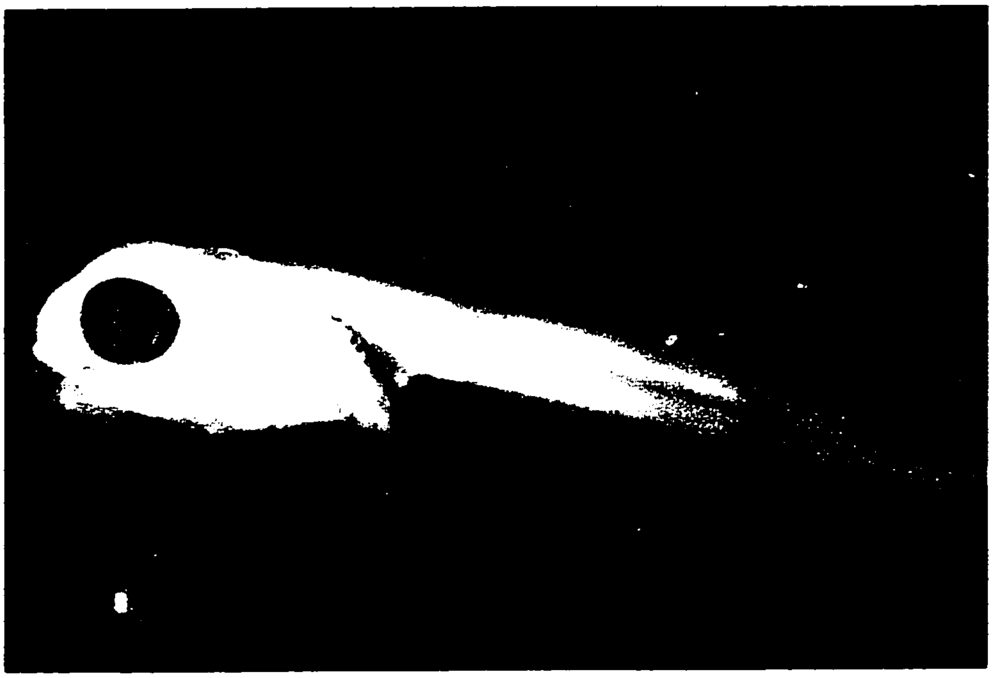

FIGURE 8d: Early larval stage of Orthonopias triacis (dorsal view). Notochord length =5.1 mm

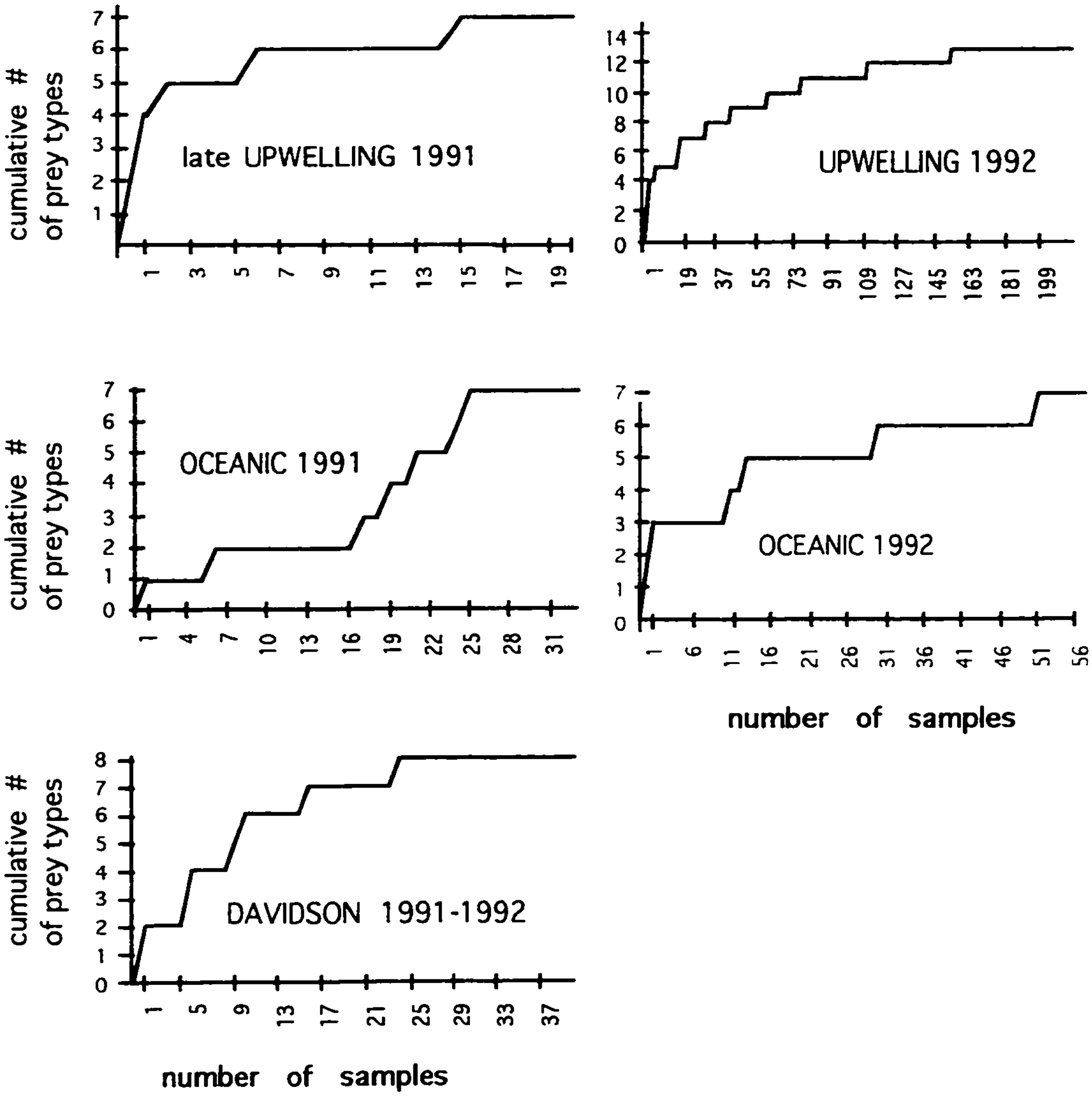

FIGURE 9: Number of prey types encountered vs. number of <u>Orthonopias</u> <u>triacis</u> gut samples examined for five oceanic periods between June 1991 and November 1992.

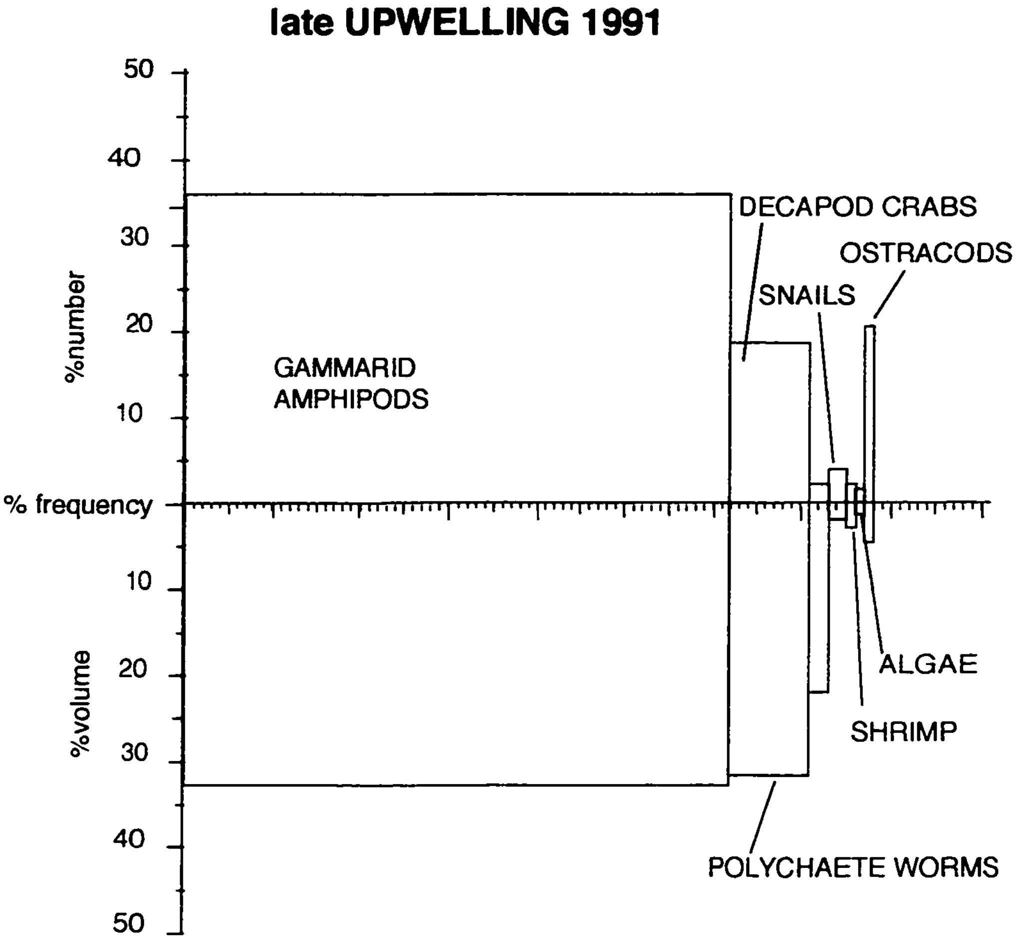

FIGURE 10a: Index of Relative Importance diagram for prey of Orthonopias triacis during the late Upwelling period of 1991 (June-Aug.)

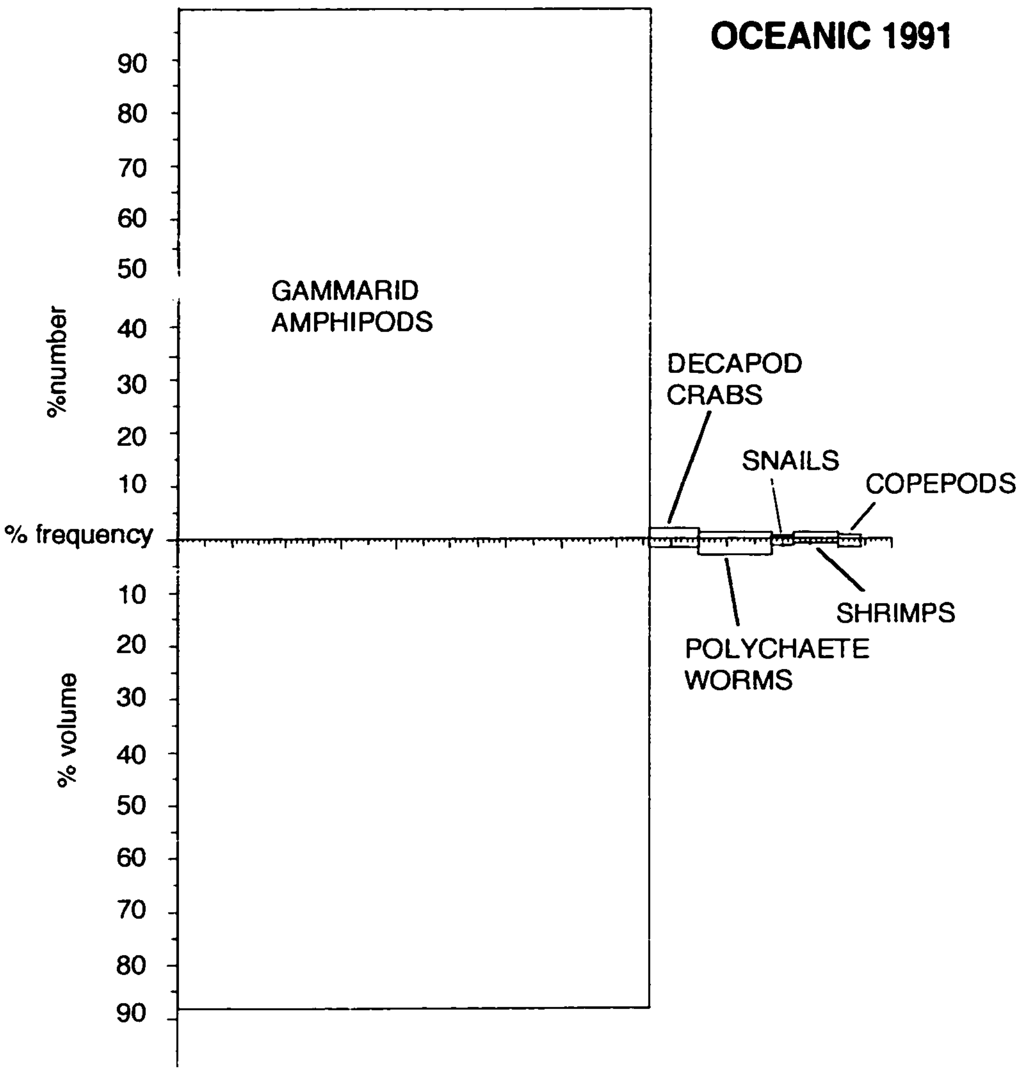

FIGURE 10b: Index of Relative Importance diagram for prey of Orthonopias triacis during the Oceanic period of 1991

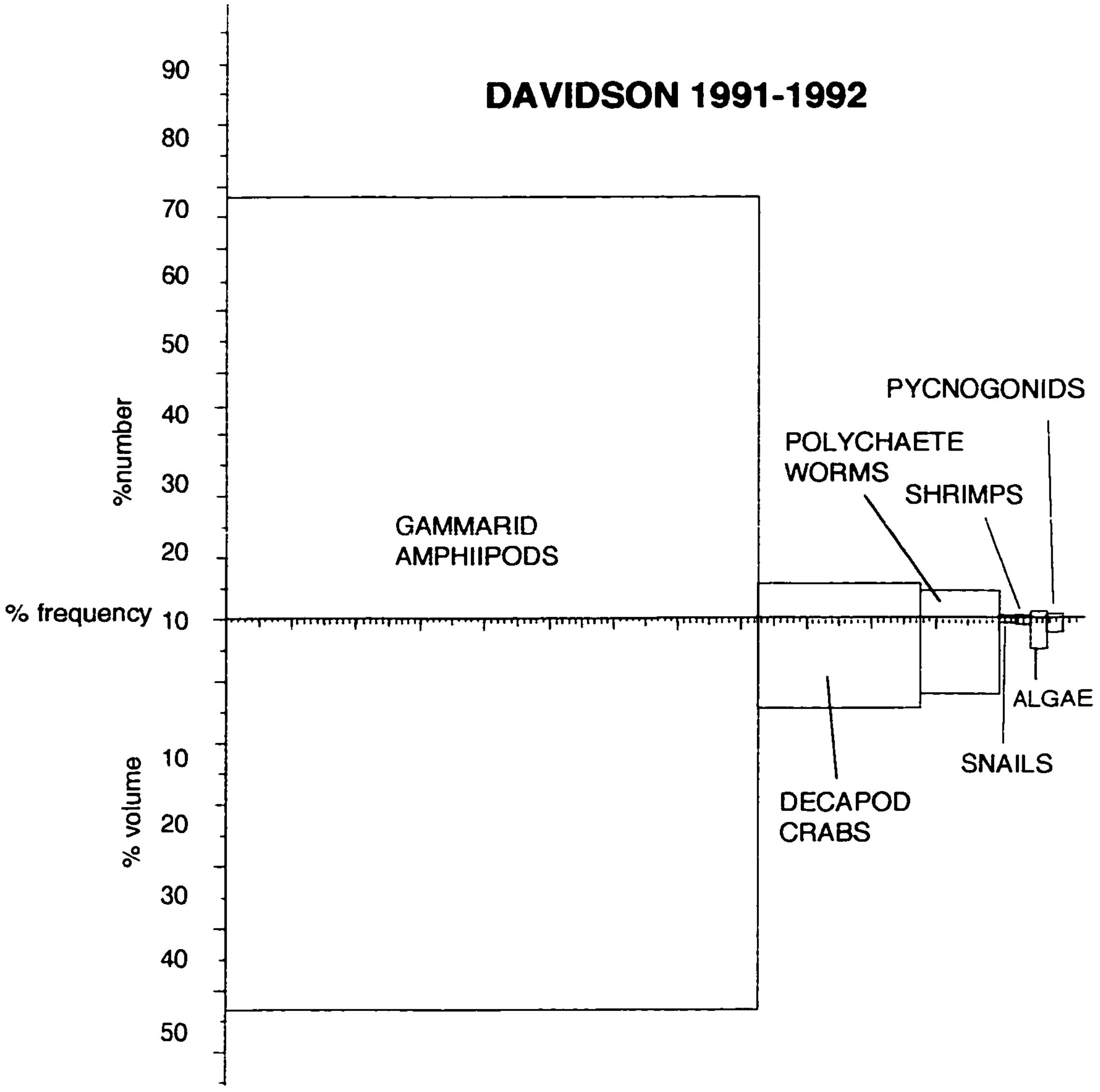

FIGURE 10c: Index of Relative Importance diagram for prey of <u>Orthonopias</u> <u>triacis</u> during the Davidson Current period of 1991-1992

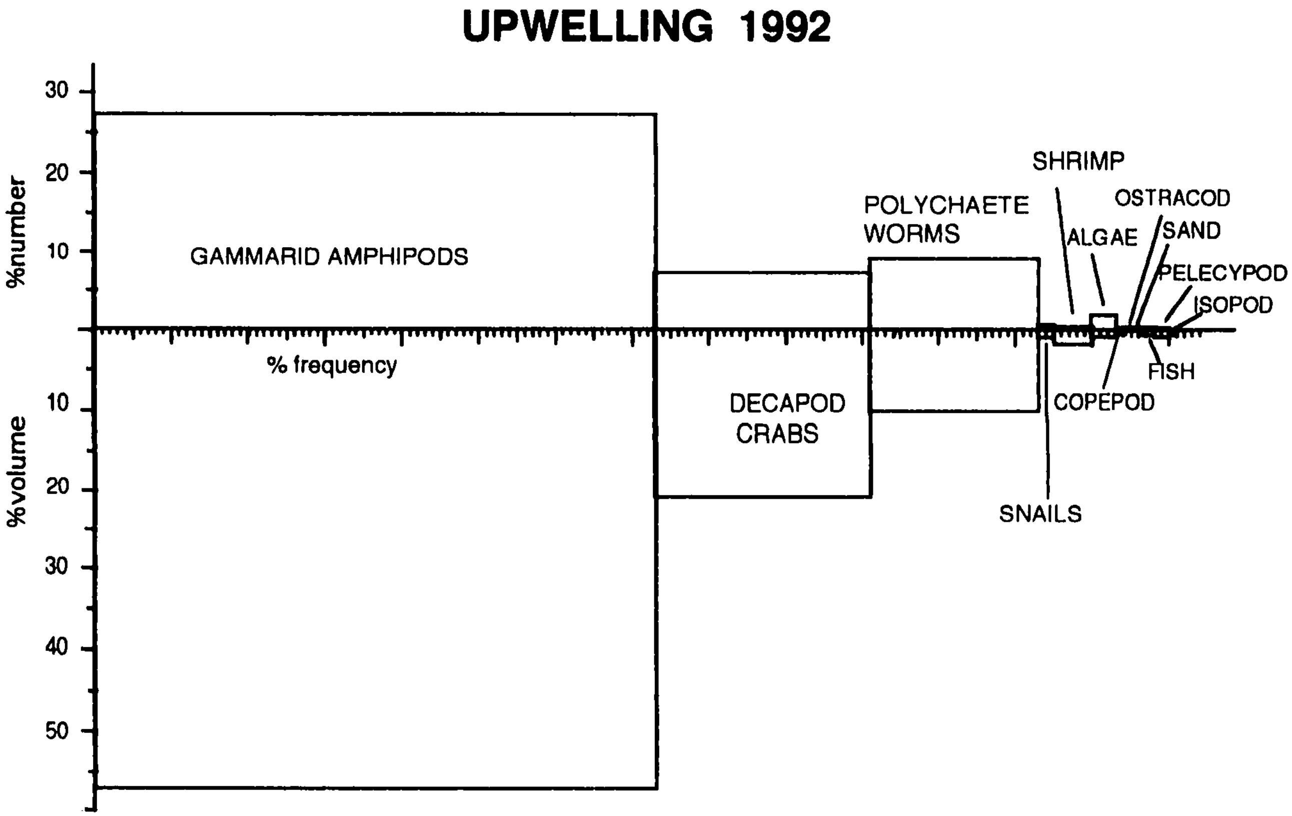
UPWELLING 1992

FIGURE 10d: Index of Relative Importance diagram for prey of <u>Orthonopias</u> <u>triacis</u> during the Upwelling period of 1992

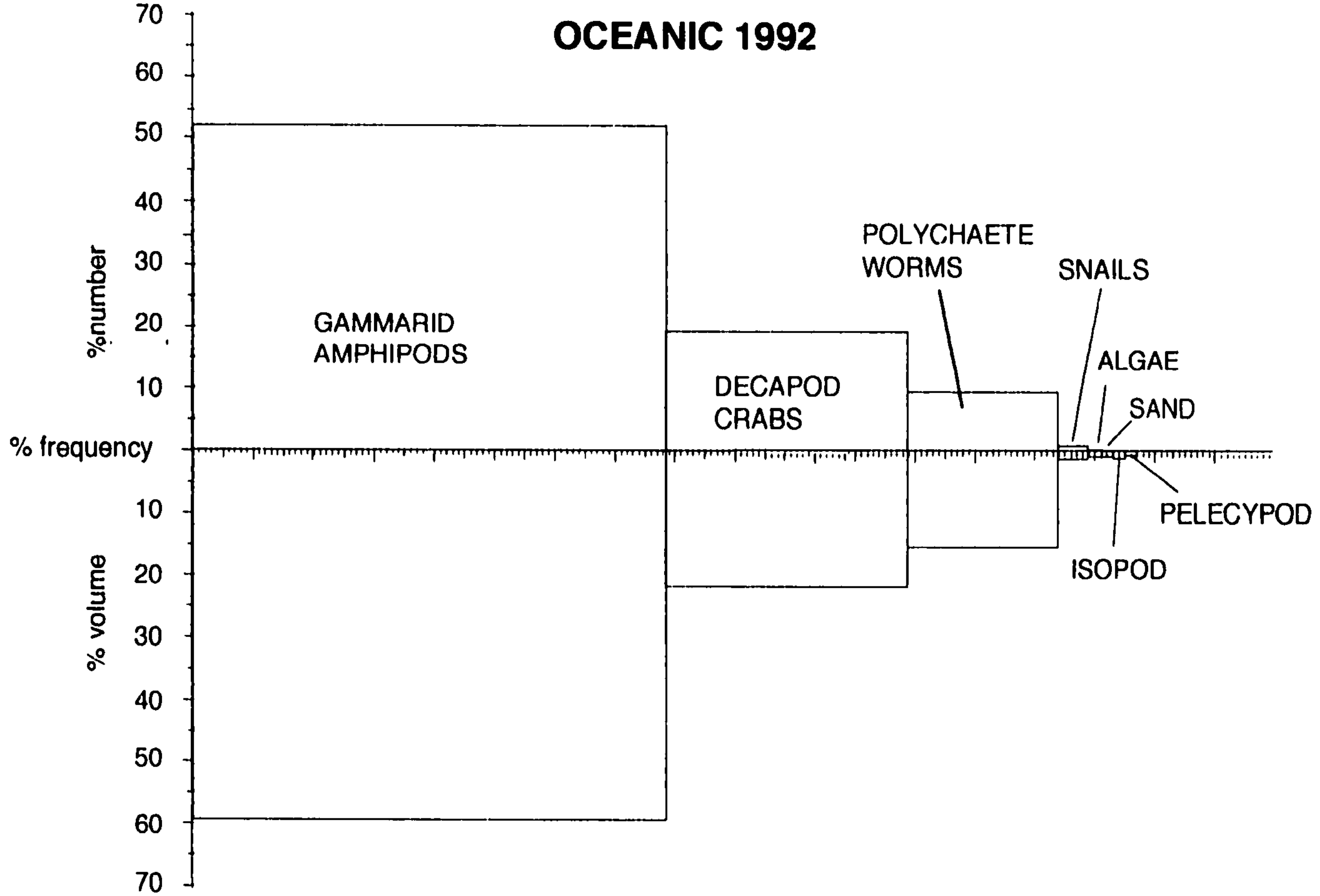

FIGURE 10e: Index of Relative Importance diagram for prey of Orthonopias triacis during the Oceanic period of 1992