1995

Food habits of some estuarine fishes in a small, seasonal central California lagoon

John A. Martin
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

Recommended Citation

Martin, John A., "Food habits of some estuarine fishes in a small, seasonal central California lagoon" (1995). *Master's Theses*. 1012.
DOI: <https://doi.org/10.31979/etd.4fka-yr75>
https://scholarworks.sjsu.edu/etd_theses/1012

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

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**

**FOOD HABITS OF SOME ESTUARINE FISHES IN
A SMALL, SEASONAL CENTRAL CALIFORNIA LAGOON**

A Thesis

Presented to

**The Faculty of the Department of Biology
San Jose State University**

In Partial Fulfillment

**of the Requirements for the Degree
Master of Science**

By

John A. Martin

May, 1995

UMI Number: 1374603

UMI Microform 1374603

Copyright 1995, by UMI Company. All rights reserved.

**This microform edition is protected against unauthorized
copying under Title 17, United States Code.**

UMI

**300 North Zeeb Road
Ann Arbor, MI 48103**

Copyright 1995

John A. Martin

ALL RIGHTS RESERVED

APPROVED FOR THE DEPARTMENT OF BIOLOGY

A handwritten signature in cursive script, appearing to read "Jerry Smith", written over a horizontal line.

Dr. Jerry Smith

A handwritten signature in cursive script, appearing to read "Vida Kenk", written over a horizontal line.

Dr. Vida Kenk

A handwritten signature in cursive script, appearing to read "Howard Shellhammer", written over a horizontal line.

Dr. Howard Shellhammer

APPROVED FOR THE UNIVERSITY

A handwritten signature in cursive script, appearing to read "Serena D. Stanford", written over a horizontal line.

ABSTRACT

FOOD HABITS OF SOME ESTUARINE FISHES IN A SMALL, SEASONAL CENTRAL CALIFORNIA LAGOON

by John A. Martin

I investigated the food habits of fish using the Pescadero Estuary/Lagoon over several seasons and habitat conditions from 1985-1988. The stomach contents of 1079 seine-captured fish were analyzed for frequency of occurrence and estimated volumes of prey items. Steelhead (Oncorhynchus mykiss) and other fish species fed most heavily upon the gammarid amphipods Corophium and Eogammarus, the shrimp Neomysis, and the isopod Gnorimosphaeroma when the lagoon mouth was open to tidal inflows. Fish shifted much of their diet to freshwater-dependent dragonfly nymphs (Odonata), mayfly nymphs (Ephemeroptera), and the midge Chironomus after sandbar formation. Differences between the feeding habits of upper and lower lagoon fish increased after stream mouth closure in 1986. Upper lagoon fish fed on more abundant freshwater prey and pockets of euryhaline populations, especially those of Gnorimosphaeroma. Several fish species showed feeding specialization, eating foods or prey sizes not significantly used by other fish.

Acknowledgements

I offer a heartfelt thank you to my advisor, Dr. Jerry J. Smith, for all of the help, support, and encouragement he provided, especially toward the end of this project. This thesis was kept afloat by his "staying rational" and would not have been completed without him.

I also give special thanks to Mark Robinson for his monumental work on invertebrates, his personal communications on unpublished information, his inspiration, and especially his friendship.

Gratitude is given to Dr. Vida Kenk for her warmth, patience, and review of the manuscript.

A sincere thank you goes to Dr. Howard Shellhammer for his caring, prodding, understanding, encouragement, and review of the manuscript.

To my colleagues, especially Kerry Twohig, Dave Ptak, and Ernie Kuwahara, who "picked up the slack," and provided constant support and motivation, I thank you.

Finally, to my son Michael and especially my wife Marina who patiently endured countless hours of my absence, and who brought peace of mind and the inspiration to finish, I offer my deepest love and gratitude.

Table of Contents

	Page
Abstract.....	iv
Acknowledgements.....	v
List of Figures.....	vii
Introduction.....	1
Study Area.....	2
Methods.....	4
Results.....	5
Steelhead rainbow trout (<u>Oncorhynchus mykiss</u>)	5
Staghorn sculpin (<u>Leptocottus armatus</u>).....	8
Starry flounder (<u>Platichthys stellatus</u>)	10
Threespine stickleback (<u>Gasterosteus aculeatus</u>)	12
Shiner surfperch (<u>Cymatogaster aggregata</u>).....	14
Topsmelt (<u>Atherinops affinis</u>).....	14
Speckled sanddab (<u>Citharichthys stigmaeus</u>).....	14
Discussion.....	15
Literature Cited	48

List of Figures

Figure	Page
1. Percent frequencies of food types in steelhead from lower Pescadero Lagoon in 1985-1988.....	23
2. Mean of food volume percentages for steelhead from lower Pescadero Lagoon for 11 sample days in 1985-1988.....	24
3. Percent volume of food types in steelhead from lower Pescadero Lagoon in 1985-1988.....	25
4. Percent frequencies of food types in steelhead from upper Pescadero Lagoon in 1985-1987.....	26
5. Mean of food volume percentages for steelhead from upper Pescadero Lagoon for 8 sample days in 1985-1987.....	27
6. Percent volume of food types in steelhead from upper Pescadero Lagoon in 1985-1987.....	28
7. Steelhead fullness factors from upper and lower Pescadero Lagoon in 1985-1987.....	29
8. Percent frequencies of food types in staghorn sculpin from lower Pescadero Lagoon in 1985-1988.....	30
9. Mean of food volume percentages for staghorn sculpin from lower Pescadero Lagoon for 6 sample days in 1985-1988.....	31
10. Percent volume of food types in staghorn sculpin from lower Pescadero Lagoon in 1985-1988.....	32
11. Percent frequencies of food types in staghorn sculpin from upper Pescadero Lagoon in 1985-1987.....	33
12. Mean of food volume percentages for staghorn sculpin from upper Pescadero Lagoon for 6 sample days in 1985-1988.....	34
13. Percent volume of food types in staghorn sculpin from upper Pescadero Lagoon in 1985-1988.....	35

14.	Percent frequencies of food types in starry flounder from lower Pescadero Lagoon in 1985-1988.....	36
15.	Mean of food volume percentages for starry flounder from lower Pescadero Lagoon for 8 sample days in 1985-1988.....	37
16.	Percent volume of food types in starry flounder from lower Pescadero Lagoon in 1985-1988.....	38
17.	Percent frequencies of food types in starry flounder from upper Pescadero Lagoon in 1985-1986.....	39
18.	Mean of food volume percentages for starry flounder from upper Pescadero Lagoon for 6 sample days in 1985-1986.....	40
19.	Percent volume of food types in starry flounder from upper Pescadero Lagoon in 1985-1986.....	41
20.	Percent frequencies of food types in threespine stickleback from lower Pescadero Lagoon in 1985-1988.....	42
21.	Mean of food volume percentages for threespine stickleback from lower Pescadero Lagoon for 10 sample days in 1985-1988.....	43
22.	Percent volume of food types in threespine stickleback from lower Pescadero Lagoon in 1985-1988.....	44
23.	Percent frequencies of food types in threespine stickleback from upper Pescadero Lagoon in 1985-1987.....	45
24.	Mean of food volume percentages for threespine stickleback from upper Pescadero Lagoon for 6 sample days in 1985-1987.....	46
25.	Percent volume of food types in threespine stickleback from upper Pescadero Lagoon in 1985-1987.....	47

INTRODUCTION

Pescadero Creek Estuary/Lagoon is typical of small, central California streams in which the stream mouth is open to tidal mixing in winter but is closed by a sandbar in summer. Salinity and sources of primary production vary seasonally, producing a series of salt and freshwater invertebrate assemblages (Robinson, 1993).

This seasonal, estuarine habitat provides an important rearing area for juvenile freshwater fish (steelhead rainbow trout, Oncorhynchus mykiss) and saltwater fish (staghorn sculpin, Leptocottus armatus, starry flounder, Platichthys stellatus, and shiner surfperch, Cymatogaster aggregata) (Smith, 1990). It also provides habitat for resident estuarine fish (threespine stickleback, Gasterosteus aculeatus and tidewater goby, Eucyclogobius newberryi).

Pescadero lagoon was the subject of recent studies on water quality, habitat conditions, fish abundances and growth rates (Smith, 1990), and invertebrate distributions and abundances (Robinson, 1993). This study investigates the food habits of the most abundant fish species within the Pescadero Creek Estuary/Lagoon over a series of years and lagoon/estuary conditions.

Study area

Pescadero Creek Estuary/Lagoon is located in the Pescadero Marsh Natural Preserve in central California, 70 km south of San Francisco. Fed by Pescadero and Butano creeks, this lagoon often spreads over 300 acres. The largest portion of the lagoon is the lower embayment (called the lower lagoon in this study) which extends from the confluence of the two creeks 400 m downstream to the Highway 1 bridge. The lower lagoon averages 200 m wide and is subject to intense tidal mixing when the lagoon mouth is open. Upstream from the confluence (upper lagoon) the narrow (10-20 m) channels experience reduced salt water invasion while the lagoon mouth is open and much of their volume can be drained and become fresh at low tide (Robinson, 1993).

The sandbar that closes the lagoon mouth undergoes dramatic seasonal changes. Powerful winter storm waves remove much of the sand from the beaches, undermining the sandbar until it breaches from storm runoff. Wave action and scouring by high winter streamflows usually prevent sandbar reformation until late spring or summer. The open stream mouth exposes the entire lagoon to tidal action, and converts the lagoon into a salt water system. Weaker spring and summer waves rebuild beach height, forming a new sandbar across the stream mouth each year. The impounded lagoon grows from stream inflows and occasional waves washing over the sandbar, such that the lower lagoon often reaches 2 m in depth and the upper lagoon 1-1.5 m in summer. Early sandbar formation, while streamflows are relatively strong, results in rapid conversion of the lagoon to freshwater. Low inflows and/or

artificial breaching of the sandbar can produce a salty, warm, and partially anoxic, summer lagoon that never converts to freshwater (Smith, 1990).

With adequate inflows, the shallower upstream portion of the lagoon converts to freshwater faster than the lower lagoon. The upper lagoon also supports the earliest and heaviest populations of the pondweed Potamogeton foliosus (Robinson, 1993).

Methods

Fish were captured by seines (32.3 m x 1.8 m x .95 cm or 9.1 m x 1.2 m x .48 cm) during fish sampling for a California Department of Parks and Recreation Study by Smith (1990). Because determining fish food habits was not the primary goal of Smith's study, sampling was not conducted on a regular basis. Of over 2200 fish collected from 1985-1988, 1079 were used for this study.

Immediately after capture, fish were preserved in 4% formaldehyde and later transferred to 40% isopropanol. Fish stomachs (the anterior 1/3 of the digestive tracts) were removed and cleared of their contents. Food items were separated for identification under a dissecting scope. Food items were identified to genus (or lowest possible taxonomic level) and volumes of each food type were estimated by assigning points based on the relative size of the food items compared to size of reference specimens of common species.

Stomach fullness factors for steelhead trout and staghorn sculpin were calculated by dividing food volume points by the cube of the fish's standard length-- $[\text{food pts.}/(\text{std. length})^3]$ in order to index stomach contents to fish size. Fullness factors were calculated for similar-size fish.

Results

Steelhead

Steelhead trout were sampled on 11 days from August 1985 to November 1988 in the lower lagoon, and showed wide variation in the relative abundance of foods among sample days. The gammarid amphipods Corophium and Eogammarus appeared in samples on 10 of 11 days. Other commonly-occurring food types found in the lower lagoon trout (in descending order of sample day appearances) were: the isopod Gnorimosphaeroma (9), the fly larva Chironomus (7), and the shrimp Neomysis (6) (Figure 1).

Corophium had the highest frequency of occurrence in trout stomachs within the lower lagoon samples. This food had a frequency of occurrence equal to or higher than all other food types on 7 of 11 sample days. Gnorimosphaeroma had the highest frequency on 3 of 11 sample days, while Chironomus, Neomysis and Eogammarus each were most frequent on 2 of 11 sample days (Figure1).

Over the entire August 1985 to November 1988 study period (with all dates weighted equally regardless of sample size), Corophium constituted the highest average diet volume at 27.9 % (Figure 2). Eogammarus and Chironomus had diet volumes of 17.9% and 16.3% respectively for the same period.

Corophium also had the greatest percent volume in the lower lagoon steelhead diet on 3 of 11 days (Figure 3). Chironomus had the highest percent volume on 2 of 11 days. Each of the following prey species occupied the largest percent of the diet volume on 1 of the 11 sample days: Eogammarus on 20 February, 1987 (58.5%), Gnorimosphaeroma on 7 August, 1988 (55.9%),

Neomysis on 28 July, 1986 (48.1%), fish on 26 September, 1986 (37.5%) and odonata nymphs on 2 November, 1985 (36.4%) (Figure 3).

During two successive winters (1985-1986 and 1986-1987), while the lagoon was open to tidal action, steelhead fed primarily on Corophium. This gammarid amphipod made up 85.5% of the steelhead diet volume on 27 December 1985, and 74.5% of the diet volume on 28 November, 1986 (Figure 3). Corophium also filled the largest diet volume (55.2%) during a spring sample (19 April, 1986), again while the lagoon mouth was open (Figure 3). During two summer samples, made while the lagoon mouth was closed, steelhead were feeding primarily on the adult form of the midge Chironomus. These insects filled the greatest diet volumes on 14 August, 1985 (57.6%) and 24 June, 1987 (100%) (Figure 3).

Steelhead were sampled in the upper lagoon on 8 days from May 1985 to June 1987. Gnorimosphaeroma appeared in samples on all 8 of the sample days. Other common foods found in the upper lagoon trout were Corophium and Eogammarus (7 of 8 days), and Neomysis and the water bug Trichocorixa (6 of 8 days) (Figure 4). Gnorimosphaeroma was found in the greatest number of trout stomachs (highest frequency) from the upper lagoon. This isopod equaled or bettered all other food types in frequency of occurrence on 4 of 8 sample days (Figure 4). Corophium had the highest frequency on 2 of 8 sample days, while the midge Chironomus, Trichocorixa, and terrestrial insects each held the highest percentage frequency on 1 sample day each (Figure 4).

Gnorimosphaeroma contributed the greatest overall volume (24.1%) to the upper lagoon trout diet during the entire study period from May 1985 to

June 1987 (Figure 5). Corophium had the second highest overall volume at 22%. Gnorimosphaeroma were either the primary or secondary prey item (by percent volume) on 5 of 8 sample days (Figure 6). Gnorimosphaeroma lead all prey types with diet volumes of 41.4% on 2 November, 1985 and 62.9% on 27 September, 1986 (Figure 6). Other food types that occupied the largest diet volumes for a sample day were: Corophium at 75.8% on 27 December, 1985, Trichocorixa at 73.2% on 13 August 1985, terrestrial insects at 60.3% on 24 June, 1987, Neomysis at 50.1% on 28 July, 1986, and Eogammarus at 43.6% on 2 July 1986 (Figure 6).

As with lower lagoon trout, upper lagoon trout fed primarily on Corophium while the estuary was open to tidal action. Corophium was the primary trout food, filling 75.8% of the diet volume, on 27 December 1985, and the secondary food item, filling volumes of 31.9% and 32.4%, on 2 November, 1985 and 2 July, 1986, respectively (Figure 6). After lagoon mouth closure, upper lagoon trout consumed a variety of primary prey items, including Gnorimosphaeroma, Chironomus, Trichocorixa, Neomysis, and terrestrial insects (Figure 6).

Steelhead stomach fullness factors

Stomach fullness factors were calculated for steelhead sampled between August 1985 and June 1987, and showed that steelhead fed more heavily while the lagoon was open to tidal action or immediately after closure. Steelhead from the lower lagoon had their highest fullness factor (4.9×10^{-5}) on 28 July 1986 (Figure 7). The lagoon had only recently closed.

The lowest fullness values were recorded for fish living in closed lagoons on 14 August 1985 (5.0×10^{-6}) and on 24 June, 1987 (2.8×10^{-6}) (Figure 7).

Steelhead from the upper lagoon showed the same trend of greatest fullness values during open lagoon conditions and lowest values during lagoon closure.

Staghorn sculpin

Foods of staghorn sculpin were sampled on 6 days in the lower lagoon from August 1985 to August 1988. The gammarid amphipod Corophium appeared in samples on each of the 6 sample days, while the gammarid amphipod Eogammarus, the isopod Gnorimosphaeroma, and the mysid Neomysis each appeared in stomachs on 4 of 6 sample days (Figure 8). The midge Chironomus was present on 3 of 6 sample days. Corophium were found in the greatest number of lower lagoon staghorn sculpins (highest frequency percentage). This amphipod led all other food types in frequency of occurrence on 5 of 6 sample days (Figure 8). Corophium was the most important food by volume (59.8%) in the lower lagoon sculpin over the entire study, followed by Eogammarus (7.9%), fish (7.7%), and Neomysis (7.6%) (Figure 9). Corophium also made up the greatest volume of the staghorn sculpin diet on 4 of 6 sample days, with volume percentages of 94.4, 35.8, 98.6, and 84.5 on 28 July, 1986, 26 September 1986, 24 June, 1987, and 7 August, 1988 respectively (Figure 10). Other foods that led volume percentages for a day were Neomysis at 39.3% on 19 April, 1986 (the only sample date when the lagoon was open), and Eogammarus at 34.4% on 14 August, 1985 (Figure 10).

Fish were also an important part in the lower lagoon sculpin diet, accounting for the second largest diet volume percentages on the August,

1985 (20.3%) and September, 1986 (26.1%) samples (Figure 10). The consumed fish were small (under 30 mm) and heavily digested.

Staghorn sculpin were sampled in the upper lagoon on 4 days from May 1985 to June 1987. Corophium, Gnorimosphaeroma, and fish appeared in upper lagoon staghorn sculpin on each of the 4 sample days (Figure 11). Eogammarus was found in sculpins on 3 of 4 sample days (Figure 11). Corophium appeared in the greatest number of staghorn sculpin stomachs (highest frequency percentage) from the upper lagoon. This amphipod had the highest frequency percentages of all foods on 3 of 4 sample days (Figure 11). Gnorimosphaeroma had the highest frequency percentage on the remaining sample day.

Corophium was the most important food by volume in upper lagoon staghorn sculpins, making up 38.3% of the overall volume for the study period (Figure 12). Gnorimosphaeroma (21.1%), Eogammarus (13.2%) and fish (12.9%) also contributed substantially to the overall diet volume. Corophium was the primary food on 2 of 4 sample days, accounting for diet volumes of 47.1% (27 May, 1985) and 64.2% (24 June, 1987) (Figure 13). Corophium also ranked second in diet volume, filling 34.2% of the sculpin diet on 2 July, 1986 (Figure 13). Other important prey species for upper lagoon staghorn sculpins were: Eogammarus with 37% diet volume on 2 July, 1986, Gnorimosphaeroma with 39.4% on 27 May, 1985 and 21.9% on 24 June, 1987, and fish with 28.3% on 13 August 1985 (Figure 13).

Staghorn sculpin stomach fullness factors

Stomach fullness factors were calculated for sculpin on six dates between May 1985 and September 1986, and showed sculpin feeding more heavily both before and shortly after sandbar formation.

In 1986, stomach fullness factors for lower lagoon sculpin rose from 2.3×10^{-5} on 19 April (open lagoon) to 5.1×10^{-5} on 28 July, just two weeks after lagoon mouth closure. The staghorn fullness factor then declined to 7.6×10^{-7} by September 26, 1986. The stomach fullness factors for both lower lagoon sculpin and steelhead reached their highest values in July of 1986.

Sculpin from the upper lagoon had their highest fullness factor (1.2×10^{-4}) on 2 July, 1986 while the lagoon mouth was open. In 1985 the lagoon mouth closed in late April, and stomach fullness factors for upper lagoon sculpin dropped from 7.1×10^{-5} on 27 May, 1985 down to 2.0×10^{-5} , four months after lagoon mouth closure, on 27 August, 1985.

Starry flounder

Foods of starry flounder were sampled on 8 days in lower Pescadero lagoon from August 1985 to November 1988, and showed wide variation in relative abundances. The gammarid amphipods Corophium and Eogammarus appeared in samples on 6 of 8 days, while the isopod Gnorimosphaeroma and annelids appeared on 4 of 8 sample days (Figure 14). Less common foods were the shrimp Neomysis (3 of 8 days), the midge larva Chironomus (2 of 8 days), and larval odonata (1 of 8 days) (Figure 14). Eogammarus had the highest frequency of occurrence in lower lagoon starry flounder overall and

bettered or equaled all other food types in frequency on 4 of 8 sample days (Figure 14).

Three foods contributed most to the overall volume percentages in the lower lagoon for the entire study period from August 1985 to November 1988: Eogammarus (32.3%), Corophium (28.4%), and oligochaetes/polychaetes (20.9%) (Figure 15). Flounders were the only species checked in this study which made significant use of oligochaetes and polychaetes as food. Eogammarus made up the greatest volume percentage in the starry flounder diets on 3 of 8 sample days, with volume percentages of 69.4 on 14 August, 1985, 40.8 on 19 April, 1986 and 100 on 20 February, 1987 (Figure 16). Corophium had the greatest diet volume percentage on 2 of 8 days, with volumes of 98.2% on 28 July, 1986 and 92.6% on 26 September, 1986 (Figure 16). Annelids filled most of the lower lagoon starry flounder diet on 2 of 8 days, with volumes of 47.1% on 28 November, 1986, and 93.9% on 6 November, 1988 (Figure 16).

Starry flounder were sampled in the upper Pescadero lagoon on 6 days from August 1985 to September 1987, and showed wide differences in food use among dates. Corophium appeared in upper lagoon starry flounder on 6 of 6 days (Figure 17). Eogammarus and Gnorimosphaeroma were each found in starry flounder on 5 of 6 sample days (Figure 17). Neomysis appeared in starry flounder on 4 of 6 sample days (Figure 17). Gnorimosphaeroma had the highest frequency of occurrence overall within the upper lagoon. This isopod had higher or equal frequency of occurrence than all other food types on 4 of 6 sample days with frequencies ranging from 60%-85.7% (Figure 17). Eogammarus had the highest frequency on 2 of 6 sample days. (Figure 17).

Over the entire August 1985 to September 1987 study period, three foods made up the greatest volume of the upper lagoon starry flounder diet: Gnorimosphaeroma with 32.6%, Eogammarus with 27%, and Corophium with 19.1% (Figure 18).

Despite its high frequency of occurrence in the upper lagoon and its high total volume contribution, Gnorimosphaeroma had the highest percent volume on only 1 of 6 samples (27 September, 1986--92.4%) (Figure 19), two months after sandbar closure. Corophium had the highest percent volume on 2 of 6 sample days, with volumes of 52.6% on 27 December, 1985 and 41.2% on 2 July, 1986 (Figure 19). The lagoon mouth was open on both of these sample days. Other leaders in diet volume on individual sample days were Eogammarus with 61.4% on 2 November, 1985, and Neomysis with 49.5% on 28 July 1986 (Figure 19).

Flounders occurred as both young of the year (55-135 mm standard length) and yearling fish (140-215 mm standard length). Foods generally were the same between the two age/size groups; however, odonates and annelids were consumed primarily by larger flounders.

Threespine stickleback

Threespine stickleback were sampled on 10 days in the lower lagoon from August 1985 to November 1988 and heavily fed upon the gammarid amphipod Corophium which appeared in samples on 9 of 10 days. Other commonly-occurring food types used by lower lagoon stickleback were (in descending order of sample day appearances): the shrimp Neomysis(8), the midge Chironomus(7), and the amphipod Eogammarus(6) (Figure 20). Prey

used by stickleback were smaller (usually less than 1/3) than foods consumed by other fish.

Corophium made up the largest overall diet volume in the stomachs of lower Pescadero lagoon stickleback, accounting for 38.6% of the volume for the study period August 1985 to November 1988 (Figure 21). On 6 of 10 sample days, Corophium led all other food types with diet volumes ranging from 46.4%-65.1% (Figure 22). Neomysis had the highest percent volumes on 2 of 10 sample days with 36.5% on 26 September, 1986 and 70.5% on 28 November, 1986 (Figure 22). Chironomus also occupied the largest percent of the diet volume on 2 of 10 days with volumes of 35.5% on 19 April, 1986 and 43.7% on 6 November, 1988 (Figure 22).

In the upper Pescadero lagoon, threespine stickleback were sampled on 6 days from May 1985 to June 1987. Corophium and Gnorimosphaeroma appeared in stickleback on 6 of 6 sample days (Figure 23). Other frequently consumed foods were Eogammarus, Neomysis, and Chironomus, each found on 5 of 6 sample days (Figure 23). Corophium had the highest frequency percentage on 4 of 6 days. These frequencies of occurrence ranged from 65%-90% (Figure 23). Chironomus and mayfly nymphs (Ephemeroptera) each had the highest frequency of occurrence for 1 day (Figure 23).

In the upper Pescadero lagoon stickleback, Corophium made up, by far, the largest overall volume (48.9%) for the study period from May 1985 to June 1987 (Figure 24). Corophium ranked first in diet volumes on 3 of 6 sample days, filling volumes of 84.4% on 2 November, 1985, 59.6% on 27 December, 1985, and 59% on 24 June, 1987 (Figure 25). Neomysis, mayfly nymphs, and Chironomus each had the largest diet volume percentage for 1 of 6 sample days (Figure 25).

Interestingly, fish eggs, equal in size to those of gravid female stickleback, filled 21.3% of the stickleback diet volume for the 24 June, 1987 sample (Figure 25).

Shinersurfperch (*Cymatogaster aggregata*)

Eleven surfperch sampled on July 28, 1986, just two weeks after sandbar formation, ate primarily Corophium. The surfperch diet volume was 94% Corophium and 9.1% Gnorimosphaeroma. Twenty-five surfperch sampled from a closed, brackish lower lagoon on November 6, 1988 fed overwhelmingly on snails. The snails had an 84% frequency of occurrence in the sample and made up 100% of the surfperch diet volume.

Speckled sanddab (*Citharichthys stigmaeus*)

Twenty speckled sanddab were sampled in the upper lagoon on July 2, 1986, while the sandbar was open. The sanddab fed on a mixed diet of Eogammarus and Corophium. Eogammarus accounted for 46% of the total volume and had a 95% frequency of occurrence. Corophium made up 44% of the sanddab diet volume and appeared in 85% of the fish sampled.

Topsmelt (*Atherinops affinis*)

Ten topsmelt were sampled from the recently opened lower lagoon on November 2, 1985. The topsmelt fed primarily on Corophium, which accounted for 98% of the diet volume and was found in 100% of the fish sampled.

DISCUSSION

Most fish in Pescadero lagoon showed broad, opportunistic feeding behavior, taking advantage of the changing assemblages of prey. There were also major differences in prey used by individual fish of the same species from the same habitat. For example on November 2, 1985 some of the steelhead stomachs held only the isopod Gnorimosphaeroma, while others in the sample had fed primarily on Corophium.

Most fish fed heavily on the gammarid amphipods Corophium and Eogammarus, the shrimp Neomysis, and Gnorimosphaeroma when tidal inflows boosted the populations of these euryhaline prey species (Robinson, 1993). Overall, Corophium was the most commonly used food, reflecting their high abundances, especially while the stream mouth was open (Robinson, 1993). However, the tube-dwelling Corophium was rarer in fish stomachs than its overwhelming relative abundance in the lagoon (Robinson, 1993). It appears that Eogammarus, Neomysis, and especially Gnorimosphaeroma are more available or vulnerable to feeding fish. The erratic swimming pattern used by Gnorimosphaeroma may make them especially vulnerable to predation by fish. The isopod twirls upside-down as it leaves the substrate to swim, and must roll back over after hitting the bottom in order to crawl (unpublished personal observation).

After sandbar formation, the populations of marine and euryhaline invertebrate species declined (Robinson, 1993), and fish often shifted much of their diet to the rising populations of freshwater dependent dragonfly nymphs (Odonata), mayfly nymphs (Ephemeroptera), and the midge Chironomus.

Differences between the feeding habits of upper and lower lagoon fish increased after lagoon mouth closure in 1986, as upstream habitats quickly became freshwater and became abundant with pondweed (Smith, 1990; Robinson, 1993). The deeper portions of the lower lagoon suffered prolonged salinity stratification with warm hypoxic bottom waters, which depressed abundance of invertebrates for several months after sandbar closure (Robinson, 1993). Fish in the upper lagoon took advantage of the more abundant freshwater prey items and pockets of euryhaline populations, especially those of the isopod, Gnorimosphaeroma (Robinson, 1993).

Several fish species showed feeding specializations, eating foods not significantly used by other fish. Staghorn sculpin preyed most heavily upon fish, especially in late summer when invertebrates were scarcer. Starry flounder were the only fish to make use of polychaetes and oligochaetes as food, and they were the most important food item on several sample dates. Sticklebacks apparently cannibalized stickleback eggs. Surfperch were the only species to prey significantly on snails. Steelhead and flounder both ate significant numbers of dragonfly nymphs.

A discussion of food habits by individual fish species follows.

Steelhead

Steelhead diet reflected the transitory nature of food assemblages and abundances in Pescadero lagoon. Steelhead also were apparently able to feed heaviest when the lagoon was open to tidal mixing. Measurements of stomach fullness indicated that late summer months were particularly lean times for steelhead (Figure 7). The lowest fullness values for lower lagoon

steelhead were in August, 1985 (5.0×10^{-6}) and June, 1987 (2.8×10^{-6}). These corresponded to low late summer growth in the freshwater lagoon in 1985 and poor growth throughout summer in the warm, brackish lagoon in 1987 (Smith, 1990). In 1986, stomach fullness factors declined sharply from July (immediately after lagoon closure) to September, a period when the stratified lagoon suffered reduced water quality and invertebrate abundance (Robinson, 1993) and reduced fish growth (Smith, 1990). Invertebrate numbers recovered after freshwater conversion in October (Robinson, 1993); November fish showed heavy feeding.

Fullness values for the November and December of 1985 and November 1986 increased from the summer lows, and correspondingly, Smith (1990) found higher fall fish growth. When winter storms converted the lagoon into a saltwater system in 1985 and 1986, steelhead fed heaviest on Corophium, followed by Eogammarus (and Neomysis in 1986) resulting in high ($> 3 \times 10^{-5}$) fullness values for the winter months. This feeding pattern coincides with food species abundances found by Robinson (1993).

After lagoon closure in 1986, summer conditions caused euryhaline species abundance to drop (Robinson, 1993), and fresh water species (esp. midge adults) became abundant in the trout diet. Lower lagoon trout feeding exclusively on midge adults showed the lowest stomach fullness values of all the trout sampled. Summer hardship was reduced for those trout feeding in the upper lagoon.

Trout feeding in the upper reaches of the lagoon often showed higher fullness values than their lower lagoon counterparts. In July 1986, immediately after sandbar closure, fullness was similar at the two locations,

but lower lagoon trout were much larger (Smith, 1990). In September the fullness of lower lagoon fish had substantially declined compared to July and to September values for the upper lagoon. More rapid conversion of shallow upstream sites to freshwater, better water quality, and higher pondweed and freshwater invertebrate abundance (Robinson, 1993) may have been responsible for the better feeding conditions upstream.

Upper lagoon trout captured in August, 1985 fed primarily (73.2% of diet volume) on Trichocorixa reticulata, a brackish water hemipteran (Smith and Carlton, 1975). Robinson included this water boatman among his "euryhaline assemblage" and found their populations more abundant at upper lagoon sites in 1986.

In the September, 1986 samples, Gnorimosphaeroma made up 63% of the upper lagoon trout diet volume, yet only provided 0.8% of the diet volume in the lower lagoon fish. Corophium, too, played a larger part in the upper lagoon fish diet, occupying 12% of diet volume there, compared to 6.3% at the lower site. These diets coincided with the greater populations of both Gnorimosphaeroma and Corophium at the upper sites after lagoon mouth closure (Robinson, 1993).

In June, 1987 upper lagoon trout also showed greater fullness values than their lower lagoon counterparts. A portion of this greater fullness may be attributed to greater abundances of freshwater species at the site. One hundred percent of the upper lagoon trout sampled were feeding on freshwater dipterans (primarily Chironomus), but complimented their diet volumes with euryhaline Gnorimosphaeroma (17%). Downstream fish fed exclusively on flies, and only 71% of these fish contained any food.

It appears that when the lagoon is open to full tidal mixing steelhead find food abundant throughout the lagoon. After sandbar closure food appears to be most available at sites where there is freshwater, where pondweed is abundant, and where freshwater and euryhaline invertebrates are abundant.

Staghorn sculpin

Staghorn sculpins in both upper and lower Pescadero lagoon preyed heavily upon Corophium. These tube-dwelling amphipods were both abundant and benthic. The sculpin's benthic, lie-in-wait predator behavior (Moyle, 1976) may give them an advantage in detecting Corophium movement in and around their tubes. Because of this feeding strategy, staghorns may hold a competitive feeding advantage over trout for benthic Corophium prey.

Increased use of prey items other than Corophium reflected increased abundances of those species and/or declines in the Corophium populations. Heavy Neomysis consumption by sculpin in April, 1986 was presumably due to the Neomysis population bloom and Corophium population crash recorded by Robinson (1993) through May of 1986. The high relative abundance of Eogammarus in the sculpin diet for August, 1985 probably reflects similar changes in Corophium and Eogammarus relative abundance or vulnerability.

In the upper lagoon, Corophium made up the largest portion of the sculpin diet (38.3% of overall volume), reflecting high prey abundances (Robinson, 1993). As with the steelhead, staghorn sculpins in the upper lagoon ate more Gnorimosphaeroma than their lower lagoon counterparts. Robinson (1993) found greater abundances of Gnorimosphaeroma at shallow water stations after sandbar closure, and a positive correlation of their

populations with Potamogeton (pondweed) abundance. Both the pondweed and shallow water are characteristic features of the upper lagoon after sandbar closure.

Sculpins fed on fish in late summer 1986. The fish in the sculpin stomachs were heavily digested. However, all prey were apparently small (< 30 mm) and no stickleback spines were found. They may have been tidewater goby, a small, benthic and abundant fish in the lagoon (Smith, 1990).

Starry flounder

Starry flounder throughout Pescadero Creek Lagoon made significant use of Eogammarus, and Corophium as food. There were some food preference differences between the lower and upper lagoon flounders, and, as with other lagoon fish, flounders shifted their diets when lagoon conditions and prey abundances changed.

A major diet shift occurred after lagoon mouth closure in 1986, when lower lagoon flounders changed from eating a mixed diet to one almost exclusively of Corophium. Sculpins in the lower lagoon showed a similar switch to eating Corophium at this time. Hypoxic to anoxic bottom waters in the closed lagoon (Smith, 1990) may have induced behavioral changes in Corophium, such as altered feeding and aeration activity, or migration (Green, 1968). These changes may have made Corophium more susceptible to fish predation, especially to benthic species like sculpin and flounder. Upper lagoon flounder stopped eating significant numbers of Eogammarus and Corophium after the lagoon mouth closure in 1986, and ate mainly Neomysis and Gnорimosphaeroma, which Robinson (1993) found to be abundant.

Foods used by the lower lagoon flounders and not their upper lagoon conspecifics included odonata nymphs, which were also consumed by lower lagoon steelhead, in November 1985. Flounders from the lower lagoon fed on annelids in August 1985, and November 1986 and 1988. No other lagoon fish made significant use of annelids as food. An interesting question is how flounder are able to detect and capture such buried prey.

Threespine stickleback

Stickleback in Pescadero lagoon ate primarily smaller Corophium and Neomysis. Diet volumes of Corophium and Neomysis in the stickleback diet for 1986 usually coincided with invertebrate abundances recorded by Robinson (1993).

Unexpectedly, Neomysis filled 70% of the lower lagoon stickleback diet volume on 28 November, 1986, when invertebrate sampling indicated very low abundance for this prey item (Robinson, 1993). This disparity may be indicative of heavy predation pressure on an already low prey population.

Some diet differences appeared between the lower and upper lagoon stickleback. Lower lagoon stickleback supplemented their diets with Chironomus and Eogammarus. However, the upper lagoon fish expanded their summer diets by feeding on the more abundant populations of mayfly nymphs and Gnorimosphaeroma (Robinson, 1993) and by eating stickleback eggs.

Shiner surfperch

Smith (1990) found severe declines for most fish species in the lagoon during late summer/fall of 1988. Only the shiner surfperch numbers

remained relatively high. This study found that the surfperch, while having fed heavily on Corophium in July 1986, fed exclusively on snails on 6 November, 1988. The use of snails as prey may have been key to the species' success in 1988, as snails, and relatively unavailable oligochaetes and polychaetes, were the only abundant invertebrates in the warm, brackish lagoon (Robinson, personal communication).

Management Implications

Most fish in Pescadero Lagoon fed heavily during winter months when the lagoon mouth was open to tidal inflows and after the closed lagoon had converted to freshwater. Robinson (1993) found rich invertebrate species diversity and abundance under these conditions. Extended summer periods of lagoon salinity stratification, with warm, hypoxic bottom waters strongly compromised fish feeding, growth, and survival (Smith, 1990). Interspecific and intraspecific competition probably intensified with reduced food abundances and heavy diet overlap. Creating and prolonging poor summer water conditions by artificial breaching of the sandbar and/or upstream diversion of freshwater leads to severe declines in both invertebrate and fish populations (Smith, 1990; Robinson, 1993).

Figure 1. Percent frequencies of food types in steelhead from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 2. Mean of food volume percentages for steelhead from lower Pescadero Lagoon for 11 sample days in 1985-1988.

Figure 3. Percent volume of food types in steelhead from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 4. Percent frequencies of food types in steelhead from upper Pescadero Lagoon in 1985-1987 (*Lagoon mouth open).

Figure 5. Mean of food volume percentages for steelhead from upper Pescadero Lagoon for 8 sample days in 1985-1987.

Figure 6. Percent volume of food types in steelhead from upper Pescadero Lagoon in 1985-1987 (*Lagoon mouth open).

Figure 7. Steelhead fullness factors from upper and lower Pescadero Lagoon in 1985-1987 (*Lagoon mouth open).

Figure 8. Percent frequencies of food types in staghorn sculpin from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 9. Mean of food volume percentages for staghorn sculpin from lower Pescadero Lagoon for 6 sample days in 1985-1988

Figure 10. Percent volume of food types in staghorn sculpin from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 11. Percent frequencies of food types in staghorn sculpin from upper Pescadero Lagoon in 1985-1987 (*Lagoon mouth open).

Figure 12. Mean of food volume percentages for staghorn sculpin from upper Pescadero Lagoon for 6 sample days in 1985-1988

Figure 13. Percent volume of food types in staghorn scuplin from upper Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 14. Percent frequencies of food types in starry flounder from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 15. Mean of food volume percentages for starry flounder from lower Pescadero Lagoon for 8 sample days in 1985-1988.

Figure 16. Percent volume of food types in starry flounder from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 17. Percent frequencies of food types in starry flounder from upper Pescadero Lagoon in 1985-1986 (*Lagoon mouth open).

Figure 18. Mean of food volume percentages for starry flounder from upper Pescadero Lagoon for 6 sample days in 1985-1986.

Figure 19. Percent volume of food types in starry flounder from upper Pescadero Lagoon in 1985-1986 (*Lagoon mouth open).

Figure 20. Percent frequencies of food types in threespine stickleback from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 21. Mean of food volume percentages for threespine stickleback from lower Pescadero Lagoon for 10 sample days in 1985-1988.

Figure 22. Percent volume of food types in threespine stickleback from lower Pescadero Lagoon in 1985-1988 (*Lagoon mouth open).

Figure 23. Percent frequencies of food types in threespine stickleback from upper Pescadero Lagoon in 1985-1987 (*Lagoon mouth open).

Figure 24. Mean of food volume percentages for threespine stickleback from upper Pescadero Lagoon for 6 sample days in 1985-1987.

Figure 25. Percent volume of food types in threespine stickleback from upper Pescadero Lagoon in 1985-1987 (*Lagoon mouth open).

Literature Cited

- Green, J. 1968. The biology of estuarine animals. University of Washington Press, Seattle, Washington.
- Moyle, P. B. 1976. Inland Fishes of California. University of California Press, Berkeley, California.
- Robinson, M. A. 1993. The distribution and abundance of benthic and epibenthic macroinvertebrates in a small, seasonal central California lagoon. Masters Thesis. San Jose State University, San Jose, California.
- Smith, J. J. 1990. The effects of sandbar formation and inflows on aquatic habitat and fish utilization of Pescadero, San Gregorio, Waddell and Pomponio Creek Estuary/Lagoon Systems. Interagency Agreement 84-04-324, Trustees California State University and California Dept. Parks and Rec.
- Smith, R. I., and J. T. Carlton. 1975. Light's manual: intertidal invertebrates of the central California coast. University of California Press, Berkeley, California.