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The Life History and Fishery of Pacific Whiting, *Merluccius productus*

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by

Kevin M. Bailey[1,2], Robert C. Francis[1], and Payson R. Stevens[3]

1. Northwest and Alaska Fisheries Center
   National Marine Fisheries Service
   Seattle, Washington 98112

2. College of Fisheries
   University of Washington
   Seattle, Washington 93195

3. Scripps Institution of Oceanography
   La Jolla, California 92093

Abstract

A synthesis of the life history of Pacific whiting, *Merluccius productus*, is presented, which includes the processes of reproduction, mortality, feeding, growth, and migration. The information on the size of whiting stocks, fishery, and management is reviewed.

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I. Introduction

Commercially and ecologically the Pacific whiting (also called Pacific hake), *Merluccius productus*, is one of the most important fish species on the west coast of North America. It supports a large commercial fishery that has been dominated by foreign nations. In recent years, however, a U.S. fishery has developed through ventures with foreign nations. Besides being an important resource to man, whiting is an important trophic link in the California Current ecosystem. As a large predator, whiting interacts with other fish and shellfish populations, notably the commercially important stocks of Pacific herring, *Clupea harengus pallasi*; northern anchovy, *Engraulis mordax*; and shrimp. Whiting is also important as prey in the diets of marine mammals and large fishes.

The objective of this synopsis is to synthesize available information on the biology and fishery of the coastal stock of Pacific whiting. Since the publication of a similar synopsis in 1970 (U.S. Fish and Wildlife Service 1970), a great deal of new information has become available. Most of this material is unpublished and thus is generally unavailable to scientists, managers, and fishermen. Further goals of this synopsis are to present new information, particularly concerning the migration of whiting, and to suggest areas of needed research.

II. The California Current System-The Habitat of Pacific Whiting

Pacific whiting ranges from the Gulf of Alaska to the Gulf of California (Hart 1973); however, it is most abundant within the region of the California Current system. The California Current system is the equatorward eastern boundary current system of the North Pacific Ocean. It extends from the coastal divergence of the westwind drift at 45°N in winter (and 50° in summer) southward to about 23°N where California current water mixes with equatorial water and bends westward to form the North Equatorial Current. As an eastern boundary current, it is associated with a coastal upwelling system. Nutrients brought from depth into the upper photic layer support high levels of primary production.

The California Current system is composed of: 1) an equatorward surface flow, the California Current; 2) a seasonally occurring poleward surface current identified as the Davidson Current north of Pt. Conception, and as the California Countercurrent in southern California; and 3) a poleward subsurface flow, the California Undercurrent (Figure 1). Several gyres, including the Southern California Eddy in the Los Angeles Bight, are semipermanent features of the California Current system.

Flow of the California Current is slow, broad, and shallow. The average speed of the current is about 0.5 knots or less (Wooster and Reid 1963); it extends to 500 m depth and to less than 100 km offshore (Hickey 1979). The nearshore region of flow is associated with wind stress and is most developed in spring and summer off California and in late summer off Washington.

At high latitudes, water of the California Current is subarctic in physical and chemical properties, characterized by low salinity and temperature. As the water flows southward, California Current water becomes more intermediate in nature through mixing with the high salinity and temperature water of the North Pacific Current and the Central Pacific water mass. California Current water may become tropical in nature off southern Mexico after mixing with equatorial water.

The Davidson Current is the surface poleward flow north of Pt. Conception that develops in winter. The Davidson Current appears in October off Vancouver

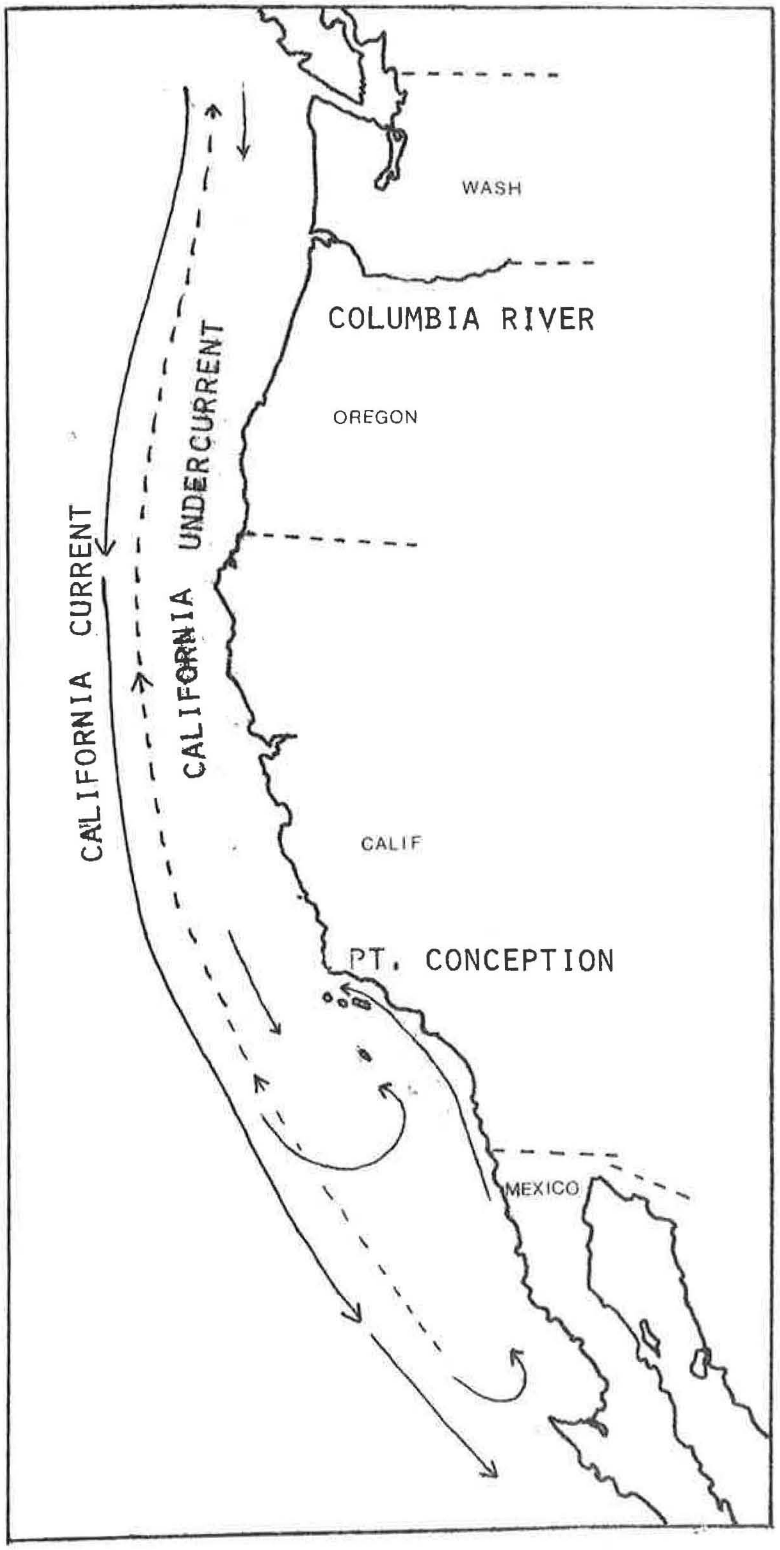

Figure 1.--The California current system.

Island and occurs southward later. It is present off the Oregon-Washington coast from October until February and extends seaward 300 km (Hickey 1979). Off California it occurs from November to January and extends 100 km offshore. Poleward surface flow off the coast is associated with the occurrence of northward or westward winds in the Pacific Northwest and the absence of southward winds off California.

The California Undercurrent is a northward flow of high salinity, high temperature water of equatorial nature. It occurs seaward of the continental shelf as far north as Vancouver Island below the main pycnocline. Off California the depth of the undercurrent varies seasonally (Pavlova 1966). Wooster and Jones (1970) reported that in August, 75 km offshore of Punta Colnet, Baja California, poleward subsurface flow was at 200-500 m depth and 20 km wide, reaching speeds up to 40 cm/s (0.8 knots). A poleward undercurrent develops over the continental shelf in late summer and early fall (Hickey 1979). The California Undercurrent is theoretically driven by positive wind stress curl (Pedlovsky 1974), and indeed the current, as shown from geostrophic calculations, underlies areas of positive wind stress curl (Bakun and Nelson 1977).

Surface horizontal currents and vertical circulation are driven by winds. Upwelling occurs when surface water driven equatorwards by wind stress is deflected offshore by Coriolis force and underlying water from a few hundred m depth rises near the coast to replace it. The offshore extent of the upwelling zone is about 50 km. In theory poleward winds would similarly cause downwelling. Favorable wind conditions for upwelling occur off Baja California all year long, but offshore transport peaks in spring. Off California the most intense upwelling is confined to the summer period (Bakun 1973, 1975).

III. Life History

A. Stocks and Distribution

1. Stocks

Four distinct reproductively isolated stocks of Pacific whiting may exist. These include stocks of: 1) coastal region of the California Current system; 2) Puget Sound; 3) Strait of Georgia; and 4) Baja California, which is a dwarf type. Only two of the stocks, Puget Sound and the coastal stock, have been identified as genetically distinct spawning stocks (Utter and Hodgins 1971). However, separate spawning areas in Puget Sound and Strait of Georgia have been identified.

The separate identities of the dwarf and coastal stocks is controversial. MacGregor (1971) and Vrooman and Paloma (1977) discussed several differences in the dwarf whiting found off Baja California compared to the coastal whiting found farther north. Dwarf whiting grow slower from age 1 onwards (Figure 2), mature earlier, and have several different morphometric and meristic characteristics compared to the coastal whiting. Vrooman and Paloma (1977) believed that these differences indicate separate stocks. These differences may not be genetic, and are not inconsistent with changes caused by environmental effects in the different habitats. Dwarf whiting could be individuals of the coastal stock that are resident off Baja California. Their small size results from maturing at age 1. Ahlstrom and Counts (1955) examined larvae found off Baja California and were not able to distinguish two separate stocks, thus supporting the hypothesis of one spawning stock. Certainly this is a subject requiring further study.

The remainder of this synopsis will discuss only the coastal stock of the Pacific whiting.

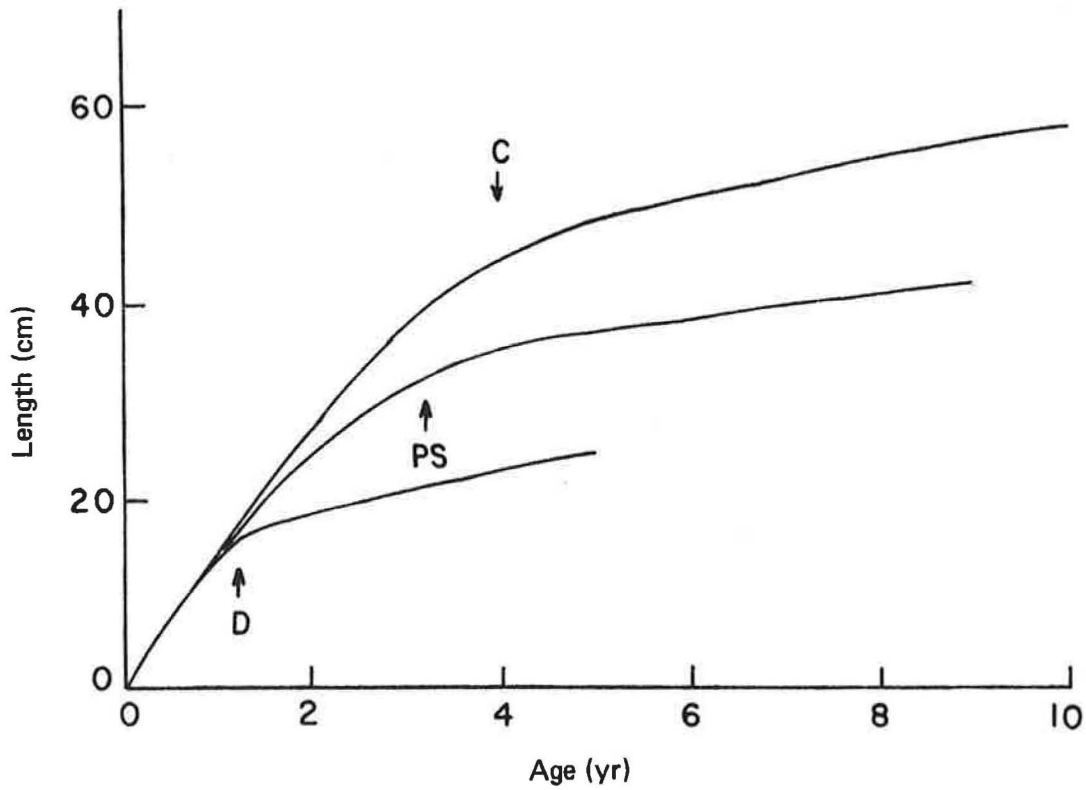

Figure 2.--Growth curves for coastal (C), Puget Sound (PS) and Dwarf (D) Pacific whiting stocks. Arrows mark age when most individuals mature.

2. Distribution

Pacific whiting are most abundant within the coastal region of the California Current system. This area extends from the coastal divergence of the westwind drift at 45°-50°N, southward to the southern tip of Baja California at about 23°N. Whiting are not found normally seaward of the continental slope, although there are occasional reports of whiting eggs and larvae (as well as of juveniles and adults) far seaward of the slope (Frey 1971). In autumn adult whiting make an annual migration from the summertime feeding grounds off the Pacific Northwest coast to spawn in winter off the coasts of southern California and Baja California. In spring and summer, large fish migrate northwards as far as central Vancouver Island and juveniles remain off the Californias. The horizontal and vertical migrations of whiting are shown in Figure 3 and are described in detail below.

B. Spawning

Spawning schools of Pacific whiting have been difficult to locate. Nelson and Larkins (1970), Tillman (1968), Bureau of Commercial Fisheries 1964[1/], Erich et al. (1980), and Stepanenko[2/] report spawning schools in southern California in midwater at depths of 130-500 m and over bottom depths corresponding to those of the continental slope. Ermakov (1974) also reports spawning over the continental slope. However, Erich, et al. (1980) report a spawning school some 400 km seaward in the southern part of the Los Angeles Bight and Stepanenko[3/] reports a spawning school about 300 km offshore in central California.

The distribution of eggs and small larvae (2-3 mm) indicates that whiting spawn from Cape Mendocino to southern Baja California. Almost all eggs and larvae are located over water depths corresponding to depths of the continental slope (Table 1), except in the Los Angeles Bight, where eggs and larvae are

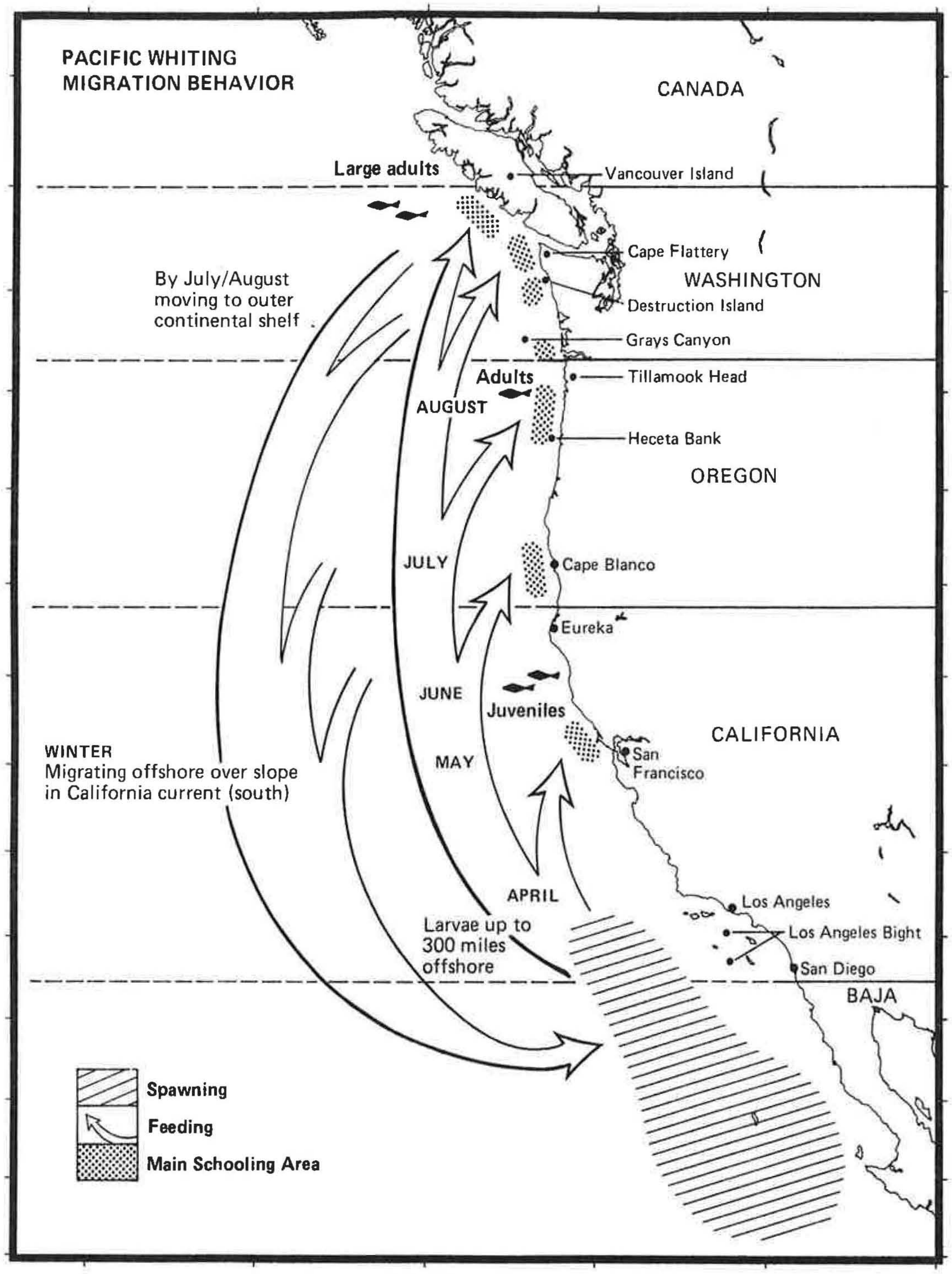

Figure 3.--Migratory patterns of Pacific whiting.

Table 1.--The distribution of Pacific whiting eggs and larvae in relation to the continental slope. Analysis of eggs is from surveys in 1955, 1972, and 1975; analysis of larvae, 2.0-2.7 mm length, is from 1963-69 surveys.

Stage of development	Over slope		Not over slope (inshore or offshore)	
	Number	%	Number	%
Larvae	37937	90.6	3922	9.4
Eggs	49088	84.6	8979	15.4

often found over very deep water and far out to sea (400 km). Bailey (1981) postulated that whiting spawn in the California Undercurrent, which usually occurs over the continental slope at depths of 200-400 m, but spreads seaward some 200-400 km in the Los Angeles Bight and some other places where eddies occur. Large concentrations of eggs and larvae are found in areas of northward geostrophic flow at 200 m depth (Figure 4). Based on the northward distribution of larvae, spawning appears to commence when the southward migrating adults arrive in the warm and saline waters of the southern transitional water mass (Figure 5). Variability in the northern front of spawning is correlated to the temperature (Table 2), indicating that in warm years the southern transitional water mass is farther north and spawning is northward also.

Larvae of all size classes occur in significant numbers in the water from December to May (Stauffer and Smith[4/]), but some 80% of eggs and small larvae are found in 2 mo, January and February, (Figure 6) which indicates a very sharp peak in spawning. Most Soviet reports indicated that January and February are the primary spawning months, but sometimes heavy spawning is reported in March. Ermakov (1974) observed schools of post-spawning whiting off northern California by early March in several years.

Pacific whiting females mature and spawn in winter at 3 to 4 yr of age and at lengths of 34-40 cm (Best 1963; MacGregor 1966, 1971; Ermakov 1974). MacGregor (1971) found some males maturing at 28 cm.

Spawning whiting do not appear to migrate vertically. Two layers are sometimes observed on echo traces, the top layer seeming to be males and the bottom one females (R. McNeely, Northwest and Alaska Fisheries Center, Seattle, WA 98112, pers. commun.). Bilayered spawning schools have also been reported in the Strait of Georgia (J. Mason, Pacific Biological Station, Nanaimo, B.C.,

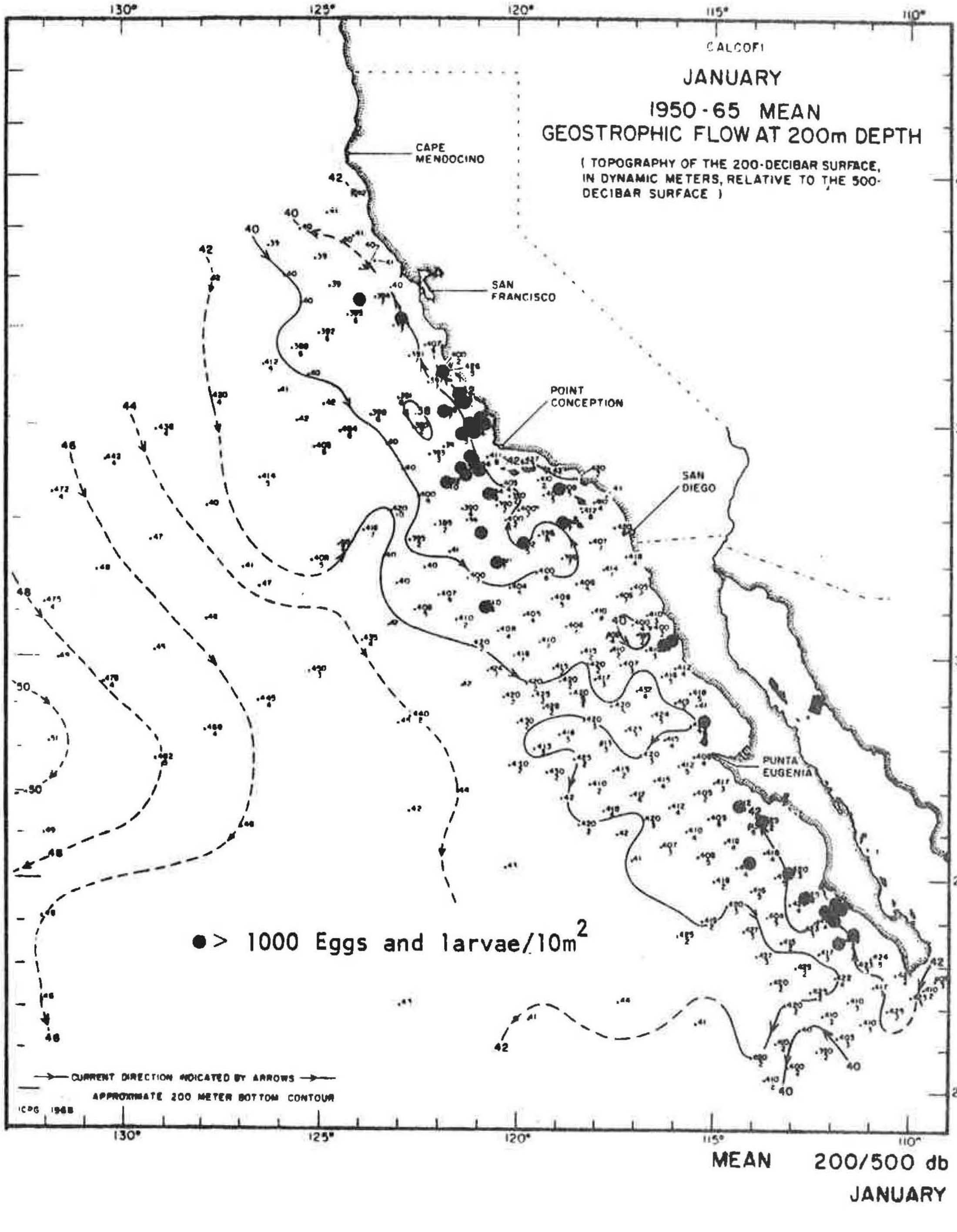

Figure 4.--Large catches of Pacific whiting eggs and larvae (all size classes) in January surveys, 1950-79, plotted on a chart showing geostropic flow at 200 m depth (from Wyllie 1967).

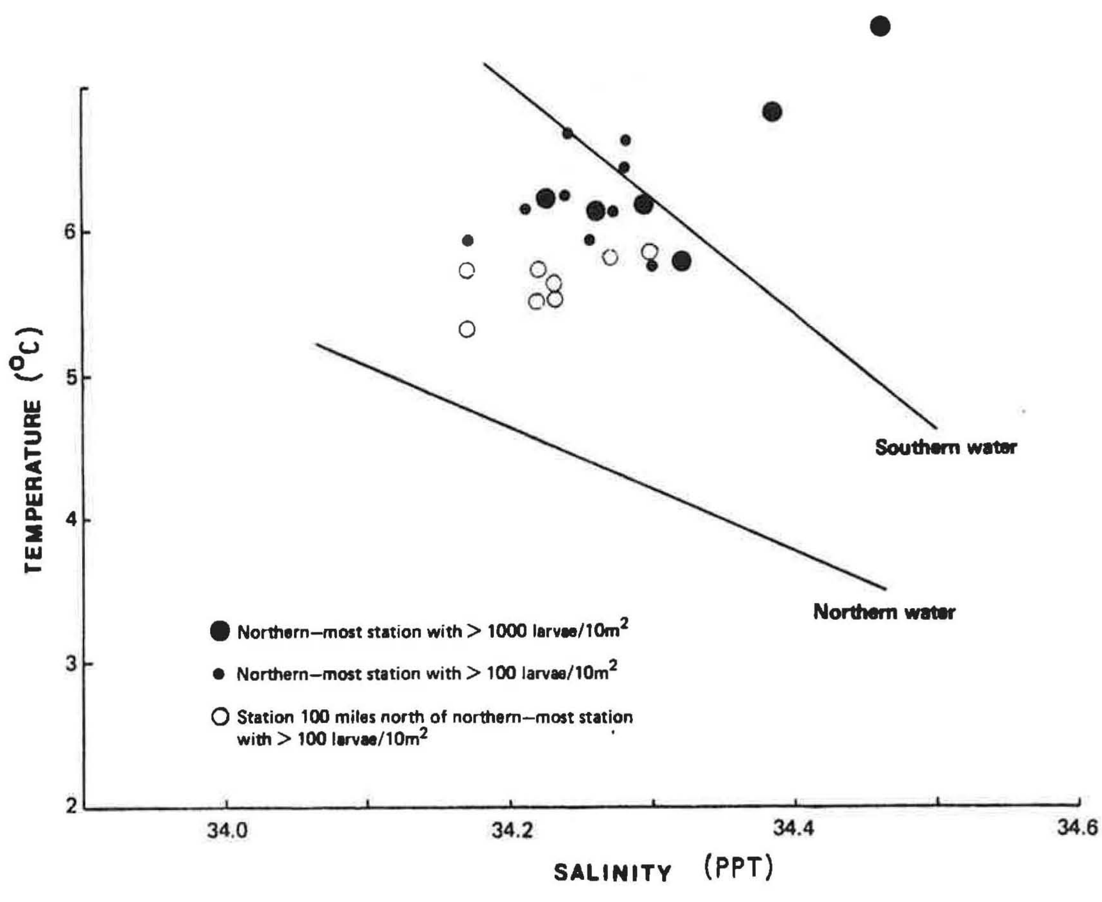

Figure 5.--The temperature-salinity relationship at 500 m depth of stations over the inner slope on lines where large catches of whiting larvae occurred and did not occur. Data used was from January cruises, 1963-78. Also shown is the temperature-salinity relationship of northern and southern transitional water from Blanton and Pattulo (1970).

Table 2.--The northward extent of 2-3 mm-standard length whiting larvae (in numbers greater than 100 larvae/10 m^2) during January surveys, compared to the average January 50 meter temperature in the Los Angeles Bight. Smaller line numbers are farther north.

	Temperature		Distance	
Year	°C	Rank	Line	Rank
1963	12.0	9	87	8.5
1964	13.2	4	76	4
1965	12.4	7	80	6
1966	13.5	3	70	2.5
1968	12.8	5	70	2.5
1969	13.6	2	80	6
1972	12.2	8	87	8.5
1975	12.6	6	80	6
1978	13.9	1	63	1

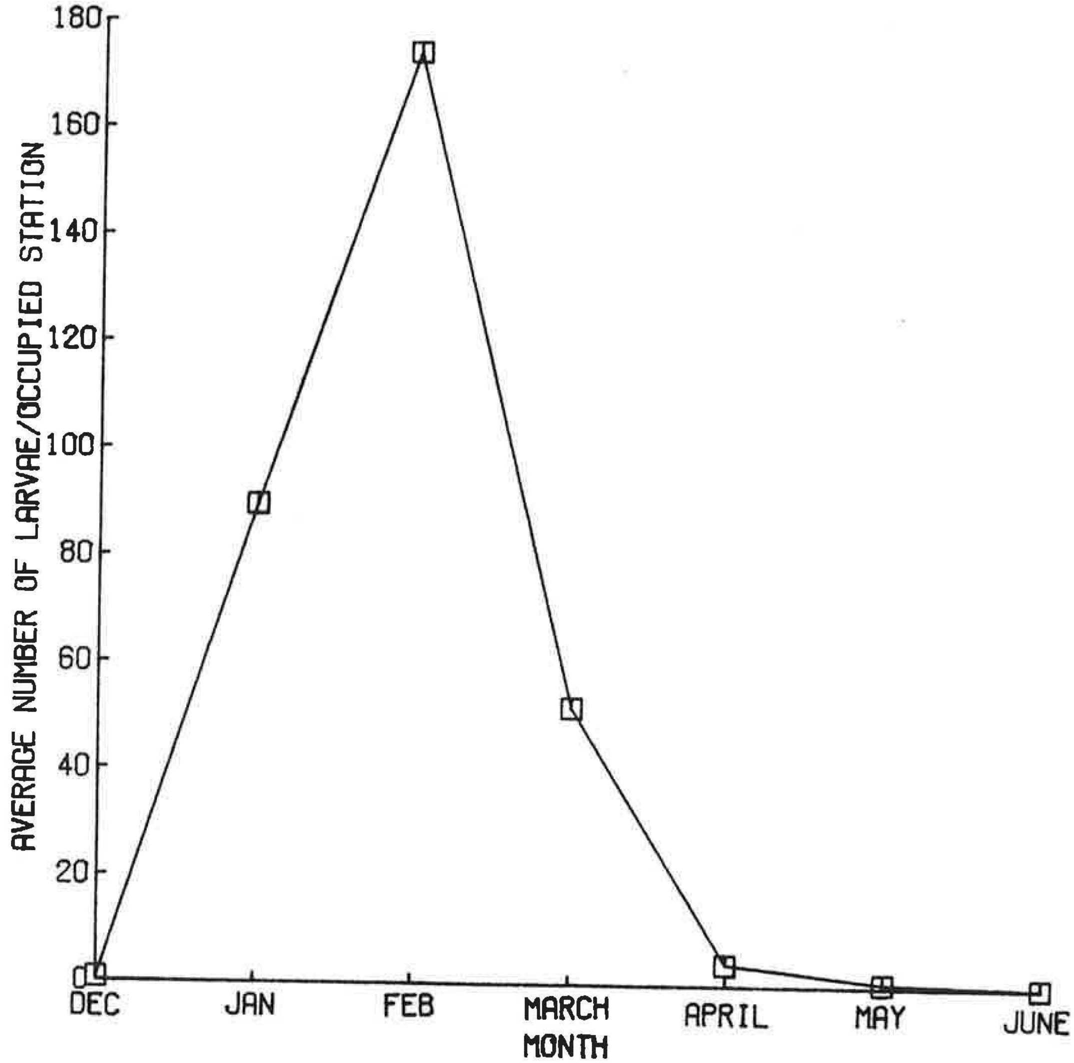

Figure 6.--The average monthly number of small whiting larvae/occupied station in the California Cooperative Oceanic Fisheries Investigations survey region, lines 60-120 over the years 1963-79. Small larvae are 2-3 mm-SL.

pers. commun.). Interestingly, in this area the top layer is composed of females.

Several modes of eggs appear in whiting ovaries (MacGregor 1966). MacGregor suggests that only one mode develops due to the poor condition of the females, but he did not examine the ovaries histologically. Foucher and Beamish (1977) reported that only one mode of eggs develops in the Strait of Georgia whiting stock. Soviet scientists report that several modes of eggs in whiting ovaries are apparent (Ermakov et al.[5/]). It must be considered that multiple spawning may occur, but there is no direct evidence. Ovaries average about 8% of the body weight of spawning females. Ripe ovaries contain 80-600 advanced mode eggs per gram of ovary wet weight (MacGregor 1966). An equation relating total fecundity to length of the female is $E = 0.00142*L^3$.

C. Early Life History

1. Egg Stage

Ahlstrom and Counts (1955) describe the eggs of Pacific whiting. They are smooth spheres, have a single oil droplet and are 1.14-1.26 mm in diameter (after accounting for 7% shrinkage due to preservation in formalin). Egg hatching is temperature dependent (Bailey, in press; Zweifel and Lasker 1976). Whiting eggs may be expected to hatch in 100-120 hr at temperatures found at their habitat depth on the spawning grounds, where temperatures range from 11° to 14°C.

Predators capable of eating whiting eggs are numerous, and some invertebrates are listed in Table 3. Whiting eggs are somewhat resistant to tactile and small invertebrate predators because they are motionless and have a very hard cuticle. Ermakov and Kharchenko[6/] report finding the stomachs of threadfin bass, *Anthias gordensis*, full of whiting eggs off Baja California.

Table 3.--Predation experiments on Pacific whiting eggs and yolk sac larvae. Experiments were for 24 h duration (12-light, 12-dark), at 8°C (from Bailey and Yen, in review).

Predators	No. Predators	Eggs added	Eggs recovered	Larvae added	Larvae recovered
Euphausia pacifica (euphausiid)	1	5	5	5	2*
Parathemisto (large) *spp*. (amphipod)	1	5	5	5	4
Parathemisto (small) *spp*.	2	10	10	5	1*
Shrimp larvae	1	5	5	5	5
Crab larvae (large)	1	5	5	5	0*
Crab larvae (small)	2	10	10	5	5
Chaetognath	2	10	10	5	4
Calliopes spp. (amphipod)	1	5	0*	5	0*
Euchaeta elongata (copepod)	2	10	7	5	0*
Phialidium gregarium (leptomedusae)	1	5	1*	5	0*
Phialidium gregarium (leptomedusae)	2	5	3*	5	0*
Pleurobranchia bachei (ctenophore)	1	5	4	-	-
Pleurobranchia bachei (ctenophore)	1	5	1*	5	5
Cyania capillata (schyphomedusae)	1	-	-	5	0*
Cythocaris spp. (amphipod)	1	10	10	5	4
Corycaeus spp. (copepod)	4	10	10	5	5
Sarsia spp. (medusae)	2	5	2 (dead)*	5	4 (dead)*

* probably significant predators

Northern anchovy could also be feeding on whiting eggs, as they consume considerable numbers of their own eggs (Hunter and Kimbrell 1980) and are believed to feed at depths where whiting eggs occur (Holliday and Larsen 1979). However, Hunter (Southwest Fisheries Center, LaJolla, CA 92038, pers. commun.) reported finding no whiting eggs in northern anchovy stomachs.

2. Larval Stage

Ahlstrom and Counts (1955) described the larvae of Pacific whiting. They are distinguished by a pigment band around the tail, pigment spots on the dorsal crown of the head, sturdy bodies, and 51-54 myomeres (Figure 7). Preserved yolk sac larvae are 2.5-3.0 mm standard length. Shrinkage of larvae due to handling is highly variable, from 10-40% depending on the preservative and on the time from death to preservation (Bailey, in press; Theilacker 1981).

Time to absorption of the yolk is temperature dependent (Bailey, in review). At ambient temperatures, absorption of the yolk may take 120-200 h. A mouth develops before the yolk is fully depleted and yolk sac larvae are observed to feed (Sumida and Moser 1980). Larvae take 150-250 h to starve after yolk depletion (Bailey, in press).

Daily growth of whiting larvae is described by counting growth increments on their otoliths (Bailey, in review). Growth in length is slow and constant for the first 20 d, after which it rapidly accelerates (Figure 8).

Predators on yolk sac larvae are more numerous than those on eggs (Table 3). Yolk sac larvae seem to be vulnerable to many abundant invertebrates, such as medusae and predatory copepods. Invertebrate predation on whiting larvae is stage and/or size specific and larger larvae are not as vulnerable to predators as yolk sac larvae (Bailey and Yen, in review).

The diet of larval whiting is composed mostly of copepod eggs, calanoid copepod nauplii, copepodites and adults (Sumida and Moser 1980). Whiting

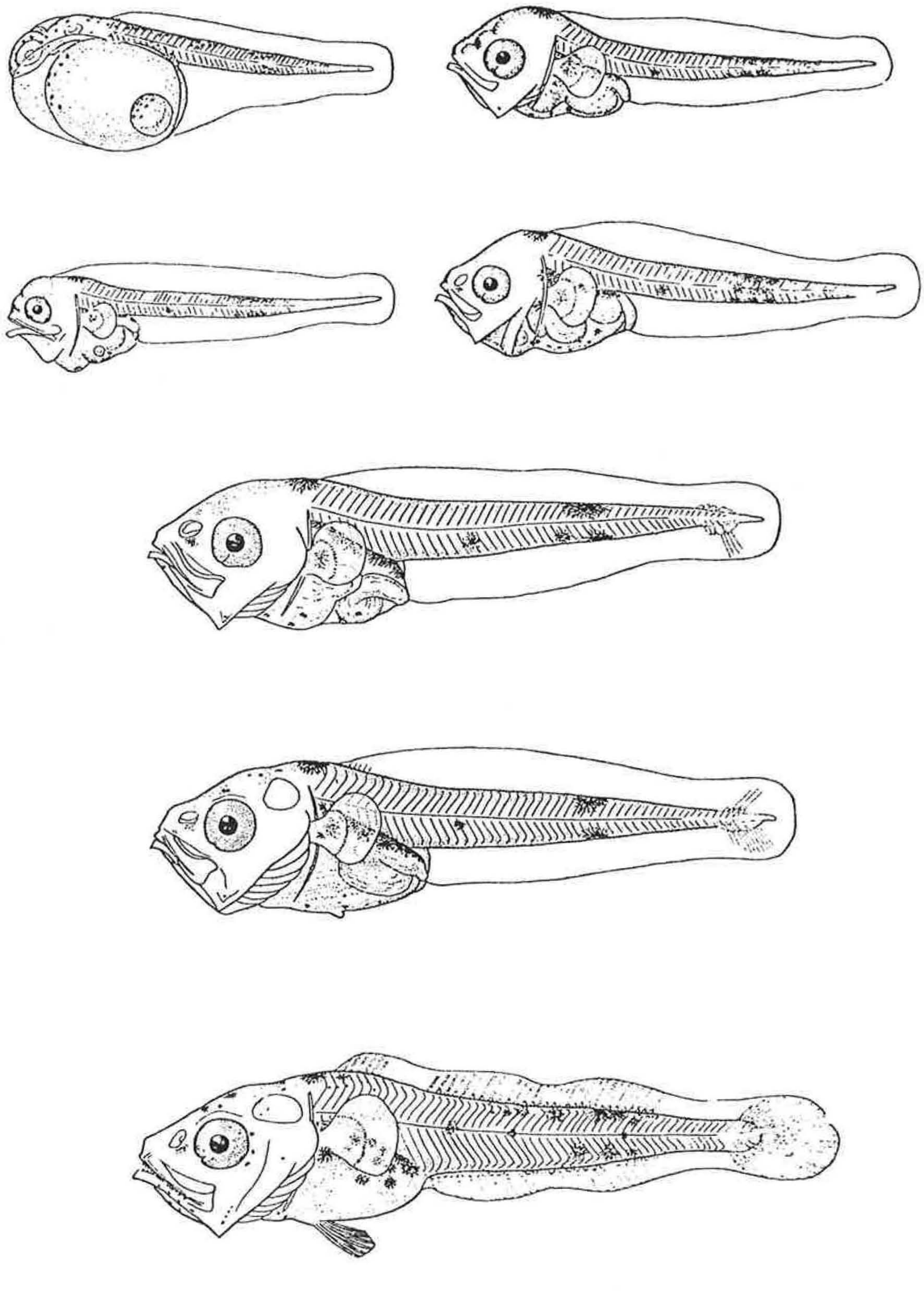

Figure 7.--Stages of Pacific whiting larvae (from Ahlstrom and Counts 1955).

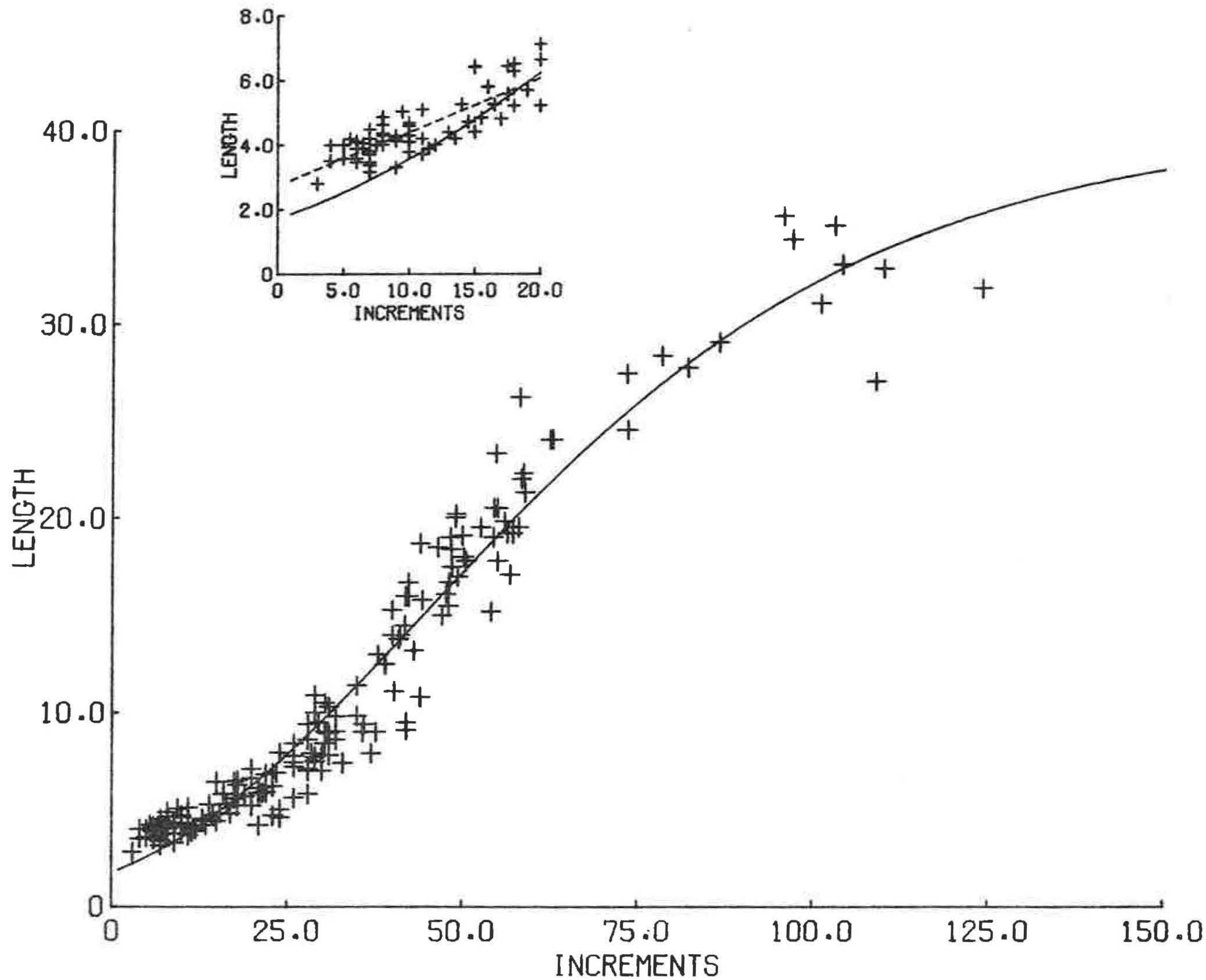

Figure 8.--The growth of larvae caught off southern California determined from otolith increments. A Gompertz curve was fit to the data, Y = 1.72 * exp[3.15 * (1 - exp (-0.02624 * X))]. Insert: daily growth for the first 20 days was better fit with a straight line (Y = 2.75 + 0.16X) (from Bailey, unpubl. manuscr).

larvae have relatively large mouths and feed on a broad size range of prey. First-feeding larvae may ingest prey of 50-400 μm width.

Competitors of whiting larvae in the ichthyoplankton which share the same temporal and spatial distributions are: California smoothtongue, Bathylagus stilbius, and snubnose blacksmelt, Bathylagus wesethi. Overlap in the vertical and horizontal distribution also occurs with Vinciguerria lucetia; rockfish, Sebastes spp.; and jack mackerel, Trachurus symmetricus. Numerous carnivorous invertebrates are also competitors.

3. The Vertical Distribution of Whiting Eggs and Larvae

Eggs and larvae of Pacific whiting are found just below the base of the mixed layer, usually about 40-60 m deep (Ahlstrom 1959). Eggs are released at 130-500 m in spawning and most rise upwards to a depth of neutral buoyancy, usually at the base of the mixed layer. If a strong pycnocline does not exist, eggs and larvae may be distributed through the mixed layer. Some evidence exists that larger larvae may be distributed deeper than small larvae (Bailey, in press).

4. Juvenile Stage

Not much is known about juvenile whiting. Juveniles of 1-3 yr old are found primarily off central and southern California (Figure 9). Most 0-1 yr olds occur inshore of the 200 fathom (fm) isobath, and older fish are distributed somewhat farther offshore than younger fish (Table 4). The food of juvenile whiting is mainly copepods and euphausiids (P. Livingston, in review).

D. Adult Life History

1. Migratory Behavior

The migrations of Pacific whiting are described using survey and fisheries data. Tagging of Merluccidae has not proven feasible (Jones 1974).

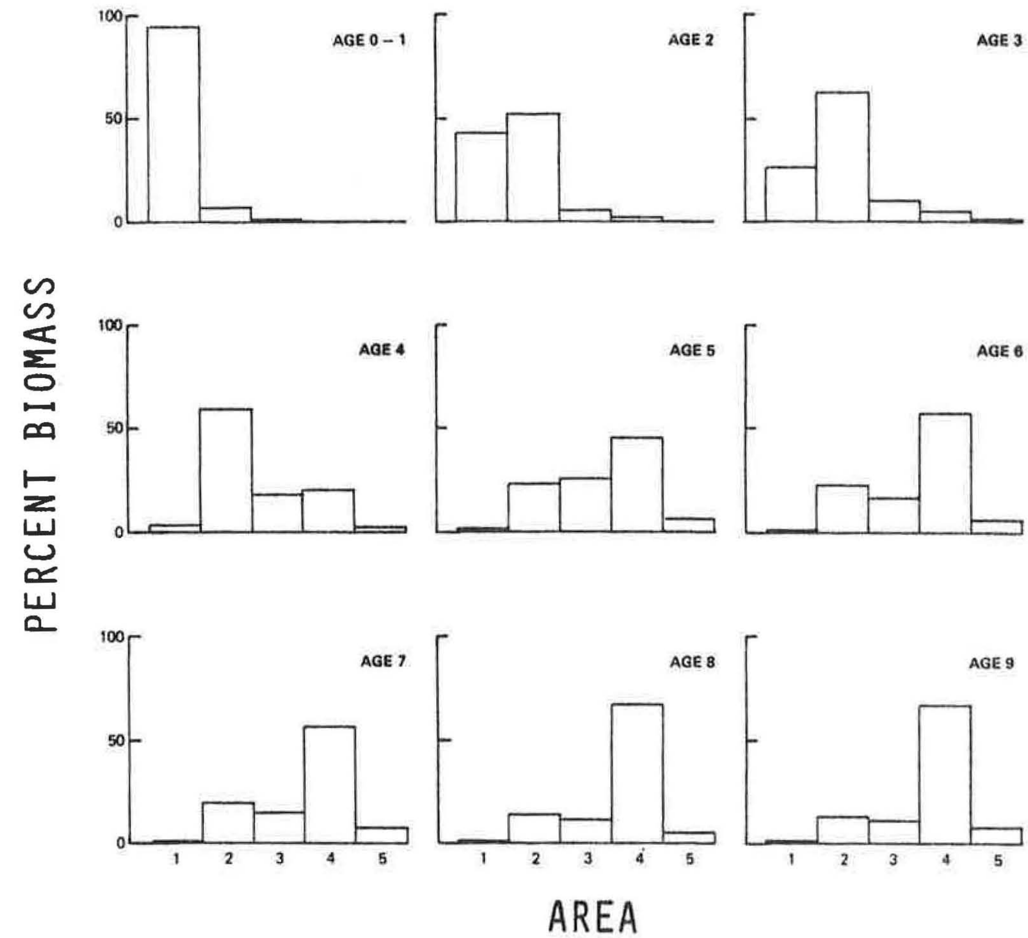

Figure 9.--The distribution of biomass by region for each age class in the 1977 Northwest and Alaska Fisheries Center trawl survey: Area 1, Point Conception; Area 2, Monterey; Area 3, Eureka; Area 4, Columbia; Area 5, Vancouver (from Bailey and Ainley in review).

Table 4.--Percent biomass of juvenile Pacific whiting by depth interval and by age from the summer 1977 Northwest and Alaska Fisheries Center bottom trawl survey.

Depth (fathoms)	Age (yr)			
	0	1	2	3
0-99	95.4	35.8	14.6	30.7
100-199	4.4	63.4	59.6	41.8
150-199	0.2	0.8	25.8	27.5
	100.0	100.0	100.0	100.0

Pacific whiting become scarce in survey catches (Table 5) and in the fishery (Table 6) from autumn until early spring (see also Jow 1973; Best 1963; Alton 1972). These observations led to a hypothesis that adult whiting leave the coastal waters in autumn to migrate from the shelf and southward for spawning in winter, and then return northward in early spring (Alverson and Larkins 1969). This migratory pattern has been verified from more recent data (Ermakov 1974; Dark et al. 1980).

The distance that adult whiting must travel from the midpoint of the spawning range (33°N) to the midpoint of the summer feeding range (45°N) is 1300 km, although larger fish make longer migrations than small ones.

Speeds of migration may be estimated from the sequential appearance of fish up the coast after spawning. Post-spawning accumulations of whiting appear around San Francisco (38°N) in early March (Ermakov 1974; Erich et al. 1980). Whiting schools appeared off southern Oregon (42°N) in the third week of April for 5 consecutive yr, 1966-71 (Ermakov 1974). Fish travelling on this schedule would move about 10 km/d. By May, concentrations appear off Vancouver Island. These estimated speeds compare favorably to speeds obtained from direct observations. Ermakov (1974) concluded from direct observation of a lead school that the northward migration is at speeds of 5-11 km/d.

Pacific whiting make the spawning migration southward in autumn. Ermakov (1974) hypothesized that the timing of this return migration was linked to the seasonal appearance of the Davidson Current off the Oregon-Washington coast. Analysis of the Soviet fishing fleet tends to support this hypothesis. The north-south distribution of the fleet is apparently related to Bakin's (1973) upwelling index, which in turn is related to wind direction and currents. It would appear that the resultant direction of currents influences the distribution of fish (Figure 10). Furthermore, from 1968 to 1972, the fleet left the

Table 5.--Average trawl catches (pound per hour) of Pacific whiting by month and year (Alton 1972).

Year	Jan	March	May	July	August	Sept	Nov	Dec
1961	-	-	-	2,403	-	9,784	-	97
1962	-	45	71	-	11,131	-	425	-
1963	100	-	175	-	4,315	-	450	-
Mean	100	45	123	2,403	7,723	9,784	438	97

Table 6.--The proportion of Soviet catches in the INPFC Vancouver-Columbia area by month, 1973-76.

Month	1973	1974	1975	1976	$\bar{x}$
1	-	-	-	-	-
2	-	-	-	-	-
3	-	.012	-	-	.003
4	.032	.073	-	-	.026
5	.008	.085	.026	.122	.060
6	.106	.049	.163	.207	.131
7	.305	.212	.406	.202	.281
8	.296	.116	.167	.261	.210
9	.158	.453	.136	.188	.234
10	.094	-	.086	.017	.049
11	-	-	.016	-	.004
12	-	-	-	.002	-

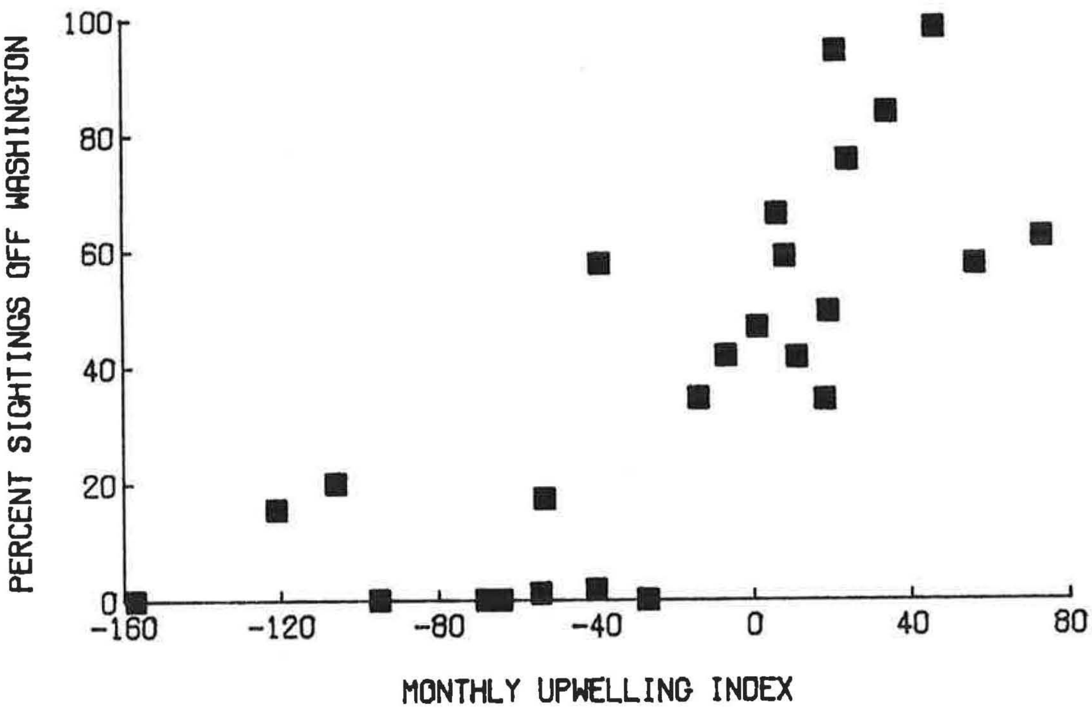

Figure 10.--The average monthly percentage of foreign fishing vessels sighted off Washington in aerial surveys off the Oregon-Washington coast versus the corresponding monthly upwelling index at 45° N. Data is from August-December 1968-72.

Pacific Northwest when the predominant winds made a seasonal shift from an equatorward to a poleward direction (Figure 11). This shift in winds is related to the appearance of the Davidson current (Hickey 1979). Although fleet movement must be a result of many factors, we assume that the availability of fish is most important.

Adult whiting also make seasonal inshore-offshore migrations. Ermakov (1974) reports that in spring and early summer whiting schools concentrate over the continental slope. By mid-June, a large portion of the stock moves inshore to depths less than 100 m. In early August, whiting move offshore and by mid-October they begin to migrate southward for spawning. These bathymetric migrations are also supported by data in Alton (1972) showing that the average depth of catches in bottom trawls decreased in early summer and increased in autumn (Figure 12). These movements could be related to the dynamics of the California Undercurrent, which is located over the continental slope in spring and spreads over the shelf in early summer (Huyer et al. 1975; Huyer and Smith 1976). The migration of whiting is a fertile area of research that is of practical importance.

Adult whiting also migrate on a diurnal schedule. Fish are dispersed from near surface to 20 m depth at night (10 PM to 3 AM). They descend quickly at dawn and form schools. At night they rise to the surface again in 30-40 min (Nelson and Larkins 1970; Ermakov 1974). These diurnal migrations have been compared to the migrations of their primary prey, euphausiids, as a causal mechanism (Figure 13) (Alton and Nelson 1970). Spawning whiting do not appear to migrate vertically.

2. Schooling

Pacific whiting form schools in daytime near the bottom. Schools are sometimes shaped in bands composed of distinct clusters (T. Dark, Northwest

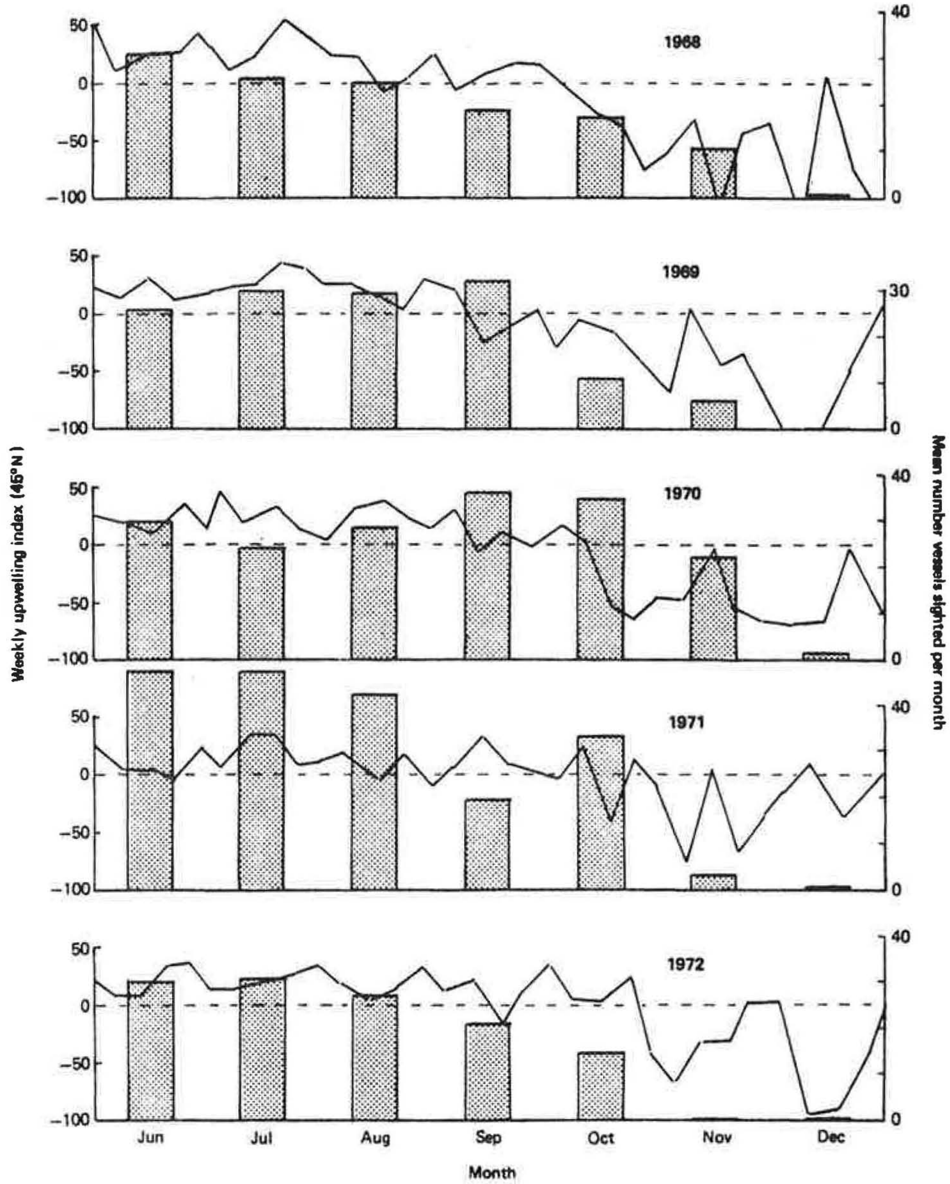

Figure 11.--The average monthly number of foreign fishing vessels sighted off the Oregon-Washington coast by aerial surveys (bars) compared to the weekly upwelling index at 45° N (lines).

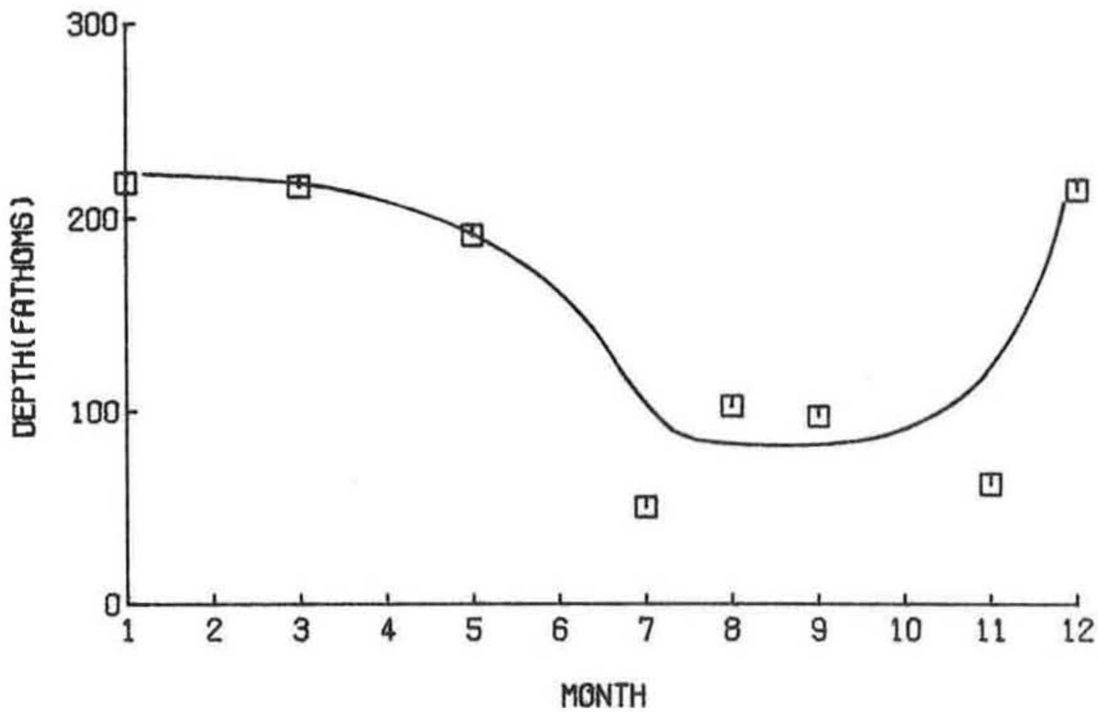

Figure 12.--The average depth of Pacific whiting bottom trawl catches by month, plotted from data in Alton (1972).

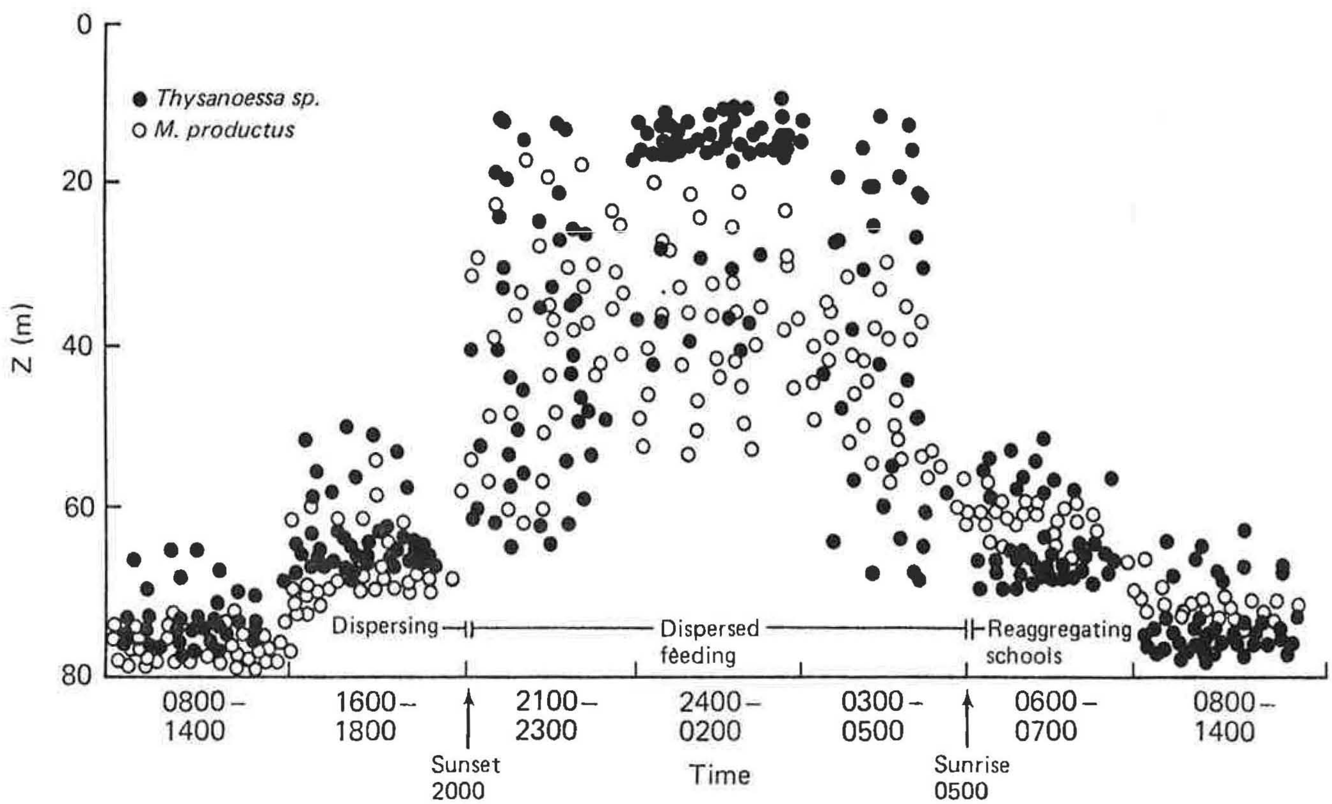

Figure 13.--The diurnal migration of euphausiids compared to those of Pacific whiting.

and Alaska Fisheries Center, Seattle, WA 98112, pers. commun.), and whose long axes are parallel to isobaths (Nelson and Larkins 1970). Soviets reported that schools may be from less than 0.5 km up to 20 km in length and 0.25 to 3.2 km in width. Over the shelf schools are, in general, within 20 meters of the bottom and have heights of 6-12 m. Often the underside to a school is 2 m off bottom. Quite a bit of variability in school size, depth, and structure is observed (M. Nelson, Northwest and Alaska Fisheries Center, Seattle, WA 98112, pers. commun.). School characteristics are more variable and less oriented over the continental slope than over the shelf (Nelson and Larkins 1970).

Ermakov (1974) concluded that schools are formed of similar-sized fish. He reports densities of 15-19 fish/1000 m^3 in daytime and less than 1 fish/ 1000 m^3 at night.

Spawning schools of whiting form dense aggregations in the pelagic layer, ranging in depth from 100 to 500 m (Stepanenko[2]; Ermakov 1974; Nelson and Larkins 1970). Stepanenko[3] reported one school of spawning whiting that was 4.2 miles long and had a biomass of 81 thousand t.

3. Age and Growth

Age compositions of commercial catches are determined from annual growth patterns observed from otoliths. The primary source of data on Pacific whiting age and growth comes from the analysis of commercial age compositions (Dark 1975; Francis in review).

Growth in length is rapid during the first 3 yr after which it slows and approaches an asymptote in the oldest ages (10-13 yr). At about 4 yr of age, females grow noticeably faster and by age 11 may average 3 cm larger than males (Dark 1975). Individual males may reach 66 cm while some females may reach 80 cm in length. Growth in length was analytically described by the von Bertalanffy growth equation:

$$l_t = l_\infty \quad (1-e^{-k(t-to)})$$

where

l_t = body length at age t

and l_∞ , k, and t_o are parameters of the curve.

Table 7 gives values of these parameters estimated for Pacific whiting. Francis (in review) found that between ages 3 and 7 growth in length is not uniform throughout the feeding season (May-October) and that it appears to reach a maximum during mid-summer (June-August).

The length-weight relation empirically fits the following equation:

$$W = a\ l^b$$

where

W = weight in grams, and

l = length in centimeters.

Table 8 gives estimates of a and b for Pacific whiting. By age 3 males have grown to between 50 and 60% of their total weight at age 11, and females to between 40 and 50% of their total weight at age 11. Males attain an average weight of between 900 and 1000 g by age 11 and females between 1100 and 1200 g by age 11. Francis (in review) found that growth in weight is markedly seasonal. During the winter (November-March) spawning season adults between ages 4 and 11 lose a minimum of between 5 and 10% of their total body weight and during the feeding season (April-October) adults between ages 4 and 11 gain a minimum of between 11 and 30% of their initial body weight. He also found that to

Table 7.--Parameters of the von Bertalanffy growth equation.

Source and sex classification	l_∞	k	t_o
Dark (1975)			
Male	56.29	0.39	0.20
Female	61.23	0.30	0.01
Male, female combined	60.85	0.30	0.03
Francis (in review)			
Male, female combined	55.40	0.26	-1.61

Table 8.--Parameters of the weight-length equation $w = a\ l^b$.

Source and sex classification	a	b
Dark (1975)		
Male	.034682	2.55618
Female	.020444	2.69509
Francis (in review)		
Male, female combined	.001815	2.73343

accurately represent the seasonal dynamics of growth a separate weight-length equation needed to be used for each age. Figure 14 gives a comparison of the weight-age relationships arrived at by Dark (1975) for 1964-69 and Francis (in review) for 1976-80.

4. Feeding

The feeding behavior of Pacific whiting has been studied by several investigators but a comprehensive seasonal and geographic examination of feeding is lacking.

Adult whiting probably do not feed on the spawning grounds (Tillman 1968) but begin to feed "ravenously" during the post-spawning migration north (Ermakov 1974). In summer, whiting are observed to feed at night towards the surface (Alton and Nelson 1970); however, if patches of prey are abundant near bottom, whiting may remain there at night to feed (Ermakov 1974).

There are apparent geographic, seasonal, annual, and size-specific differences in feeding behavior. The most frequently occurring prey items in the diet in summer are euphausiids and Pacific sand lance, *Ammodytes hexapterus*, off Vancouver Island (Outram and Haegele 1972) and euphausiids and shrimps from California to Washington (Alton and Nelson 1970; Gotshall 1969a). Ermakov and Kharchenko[6] found that off Washington and Oregon euphausiids decrease in frequency of occurrence in the diet in autumn compared to summer (Table 9). Shrimp and fish sometimes occur frequently. Jackowski[7] found that in summer off Vancouver Island, Pacific herring were important in the diet of whiting (Table 10). In northern California waters where adult and juvenile distributions overlap, cannibalism is often observed (T. Dark, pers. commun.).

Livingston (in review) found that Pacific herring were an important component in the diet of whiting off Oregon-Washington in 1980, composing almost

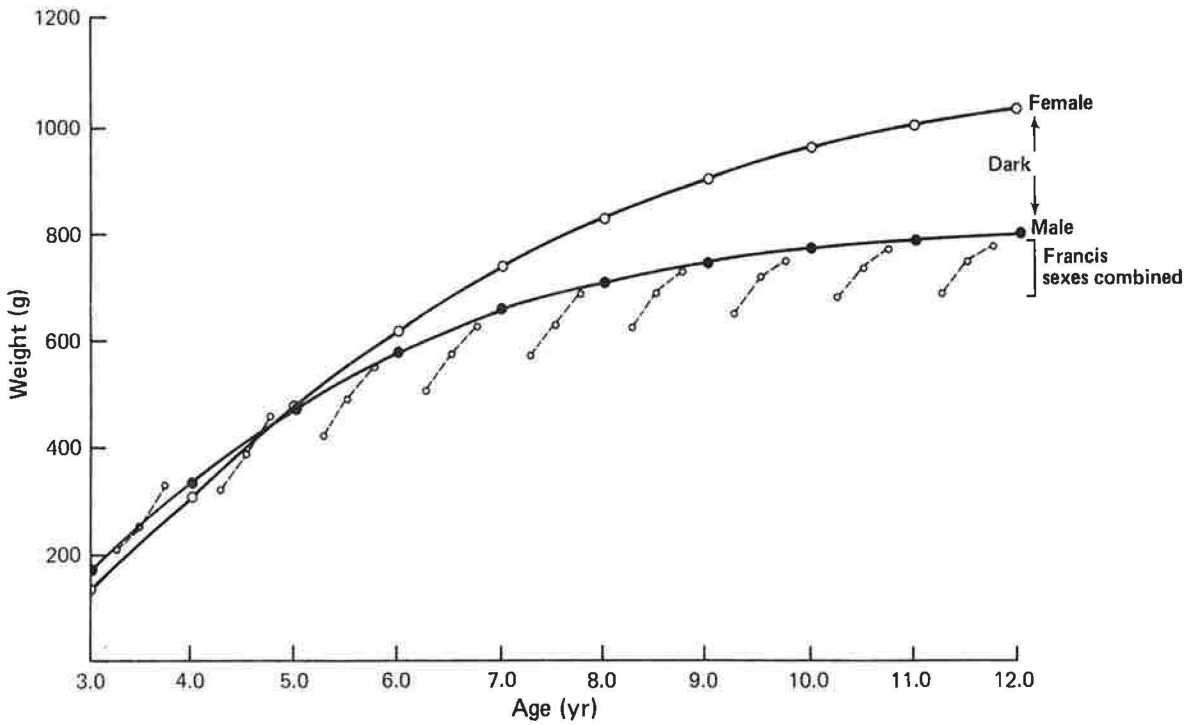

Figure 14.--The annual growth in weight of Pacific whiting (from Dark 1975, solid lines) compared to seasonal estimates of growth by age class (from Francis, unpubl. manuscr., dotted lines).

Table 9.--The percent occurrence of food types in the diet of Pacific whiting determined by Soviet scientists[1/].

	Washington-Oregon				California				
	Month				Month				
Food type	5	6	9	10	3	4	5	6	11
Euphausiids	81.6	99.6	1.2	40.2	83.3	83.1	99.8	84.0	93.5
Shrimp	4.9	0.4	17.3	1.3	-	-	-	-	15.2
Squid	-	-	-	1.3	-	-	-	-	-
Fish	14.3	-	12.4	37.7	5.6	0.9	1.4	1.4	10.9

1/ Ermakov, Y., and A.M. Kharchenko. 1976. Biological characteristics of Pacific hake and the estimation of its abundance in 1975. Unpubl. manuscr. Pacific Scientific Research Institute of Marine Fisheries and Oceanography (TINRO), Vladivostok, USSR.

Table 10.--The percent by weight of food types in the diet of Pacific whiting determined by Polish scientists[1/] in summer 1979.

	Region		
Food type	Eureka	Columbia	Vancouver
Euphausiids	94.2	94.0	85.6
Juv. rockfish	1.0	1.6	-
Pacific herring	-	-	5.9
Juv. Pacific herring	-	-	6.6
Osmerids	-	0.4	-
Pacific whiting	0.5	-	-
Sablefish	-	2.0	0.1
Flatfish	-	0.4	-
Squid	0.7	-	-
Shrimp	-	1.6	-
Other fish	3.2	-	1.7
Other	0.4	-	0.1

1/ Jackowski, E. 1980. Biological characteristics of Pacific whiting from Polish surveys of the west coast of the U.S.A. and Canada in 1979. Unpubl. manuscr., presented at the U.S.-Poland bilateral meetings, 1980.

70% of the diet (by weight) of whiting greater than 55 cm and 50% of the diet of whiting less than 55 cm. Alton and Nelson (1970) found that in the spring and summer of 1965 and 1966 euphausiids, mostly Thysanoessa spinifera, composed 57% of the biomass of whiting stomach contents. Fish, mostly deepsea smelts or Osmeridae spp., composed another 34% of stomach contents.

Gotshall's (1969a) study demonstrated considerable seasonality in the diet of whiting off northern California. Crustaceans, which are the major food in spring and summer, decline in the diet in winter, and are replaced by fish as the dominant food (Figure 15). In spring and summer an average of 50-60% of the stomach contents of whiting was ocean shrimp; however, these results should be viewed conservatively as the sample size was small.

Larger whiting more frequently eat fish and less frequently eat euphausiids compared to smaller whiting (Figure 16). Larger whiting also appear to consistently eat more shrimp than smaller whiting (Figure 17).

The question of feeding by whiting on ocean shrimp as a significant factor in shrimp population dynamics has provoked some controversy. Catches of shrimp off the Oregon-Washington coast have increased significantly since the late 1960s, and this increase appears to be correlated to the harvest of whiting (Figure 18). It has been hypothesized that removing large whiting by fishing has reduced predation pressure on the shrimp population. This same trend has occurred off the California coast. The harvest of whiting off California since the mid-1970s has been accompanied by an increase in shrimp catches (Figure 19). However, other factors, such as increasing fishing effort or normal changes in abundance, cannot be ruled out as being responsible for the increase in shrimp catches, and the question of a whiting-shrimp interaction deserves more rigorous examination.

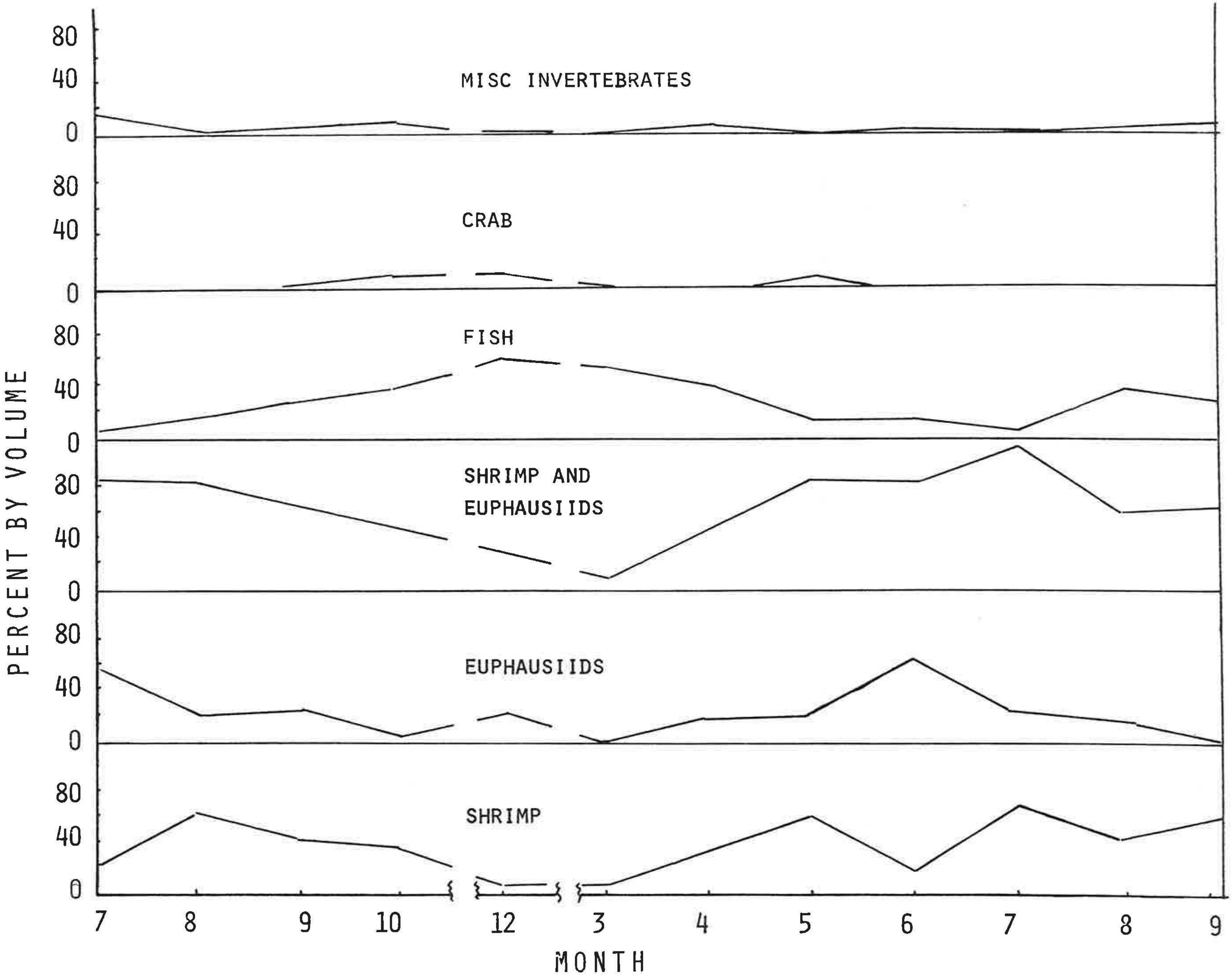

Figure 15.--The percent (by volume) of different food types in the diet of Pacific whiting by month (data from Gotshall 1969[a]).

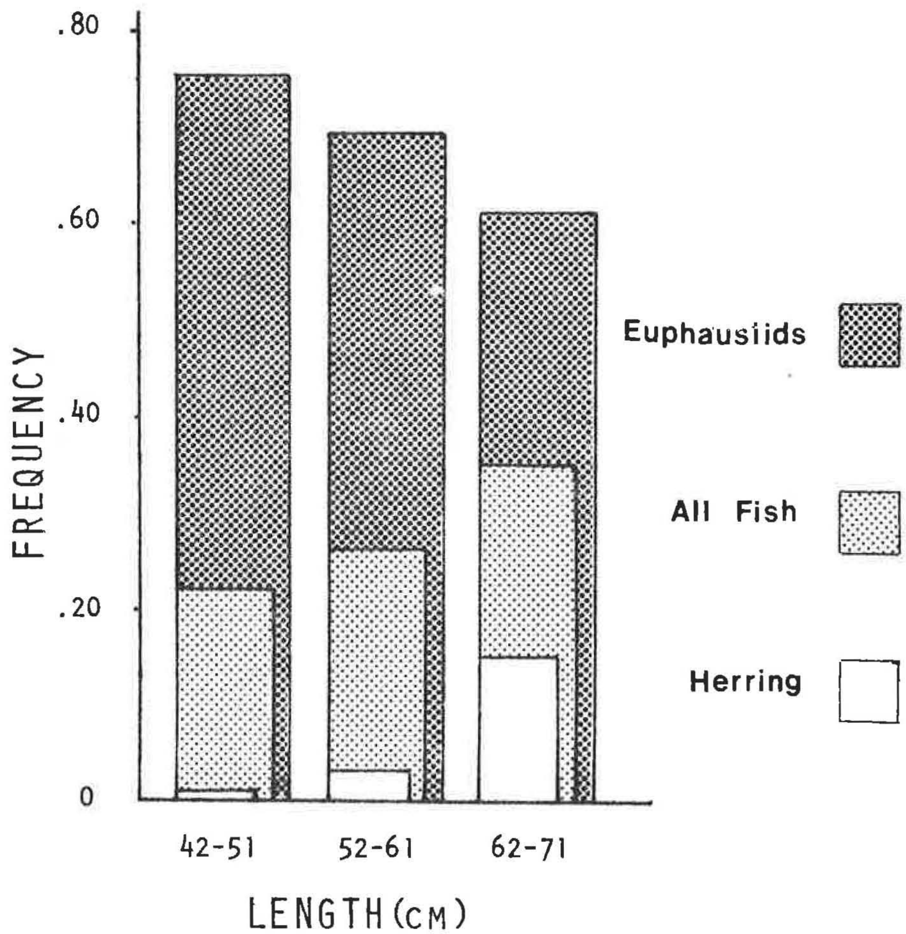

Figure 16.--Frequency of occurrence of prey types in different Pacific whiting size classes off Vancouver Island (data from Outram and Haegele 1972).

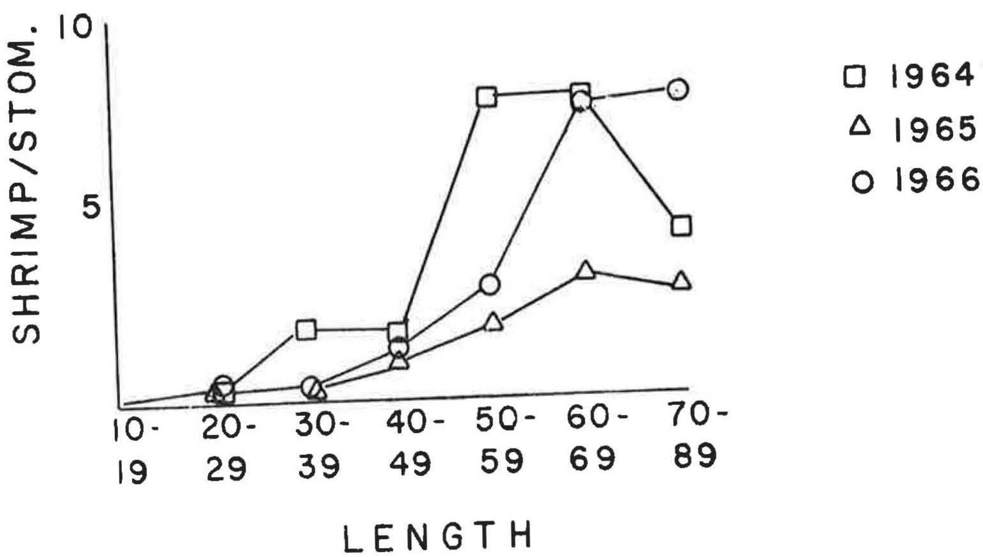

Figure 17.--The number of ocean shrimp per stomach of Pacific whiting off Vancouver Island (data from Gotshall 1969b).

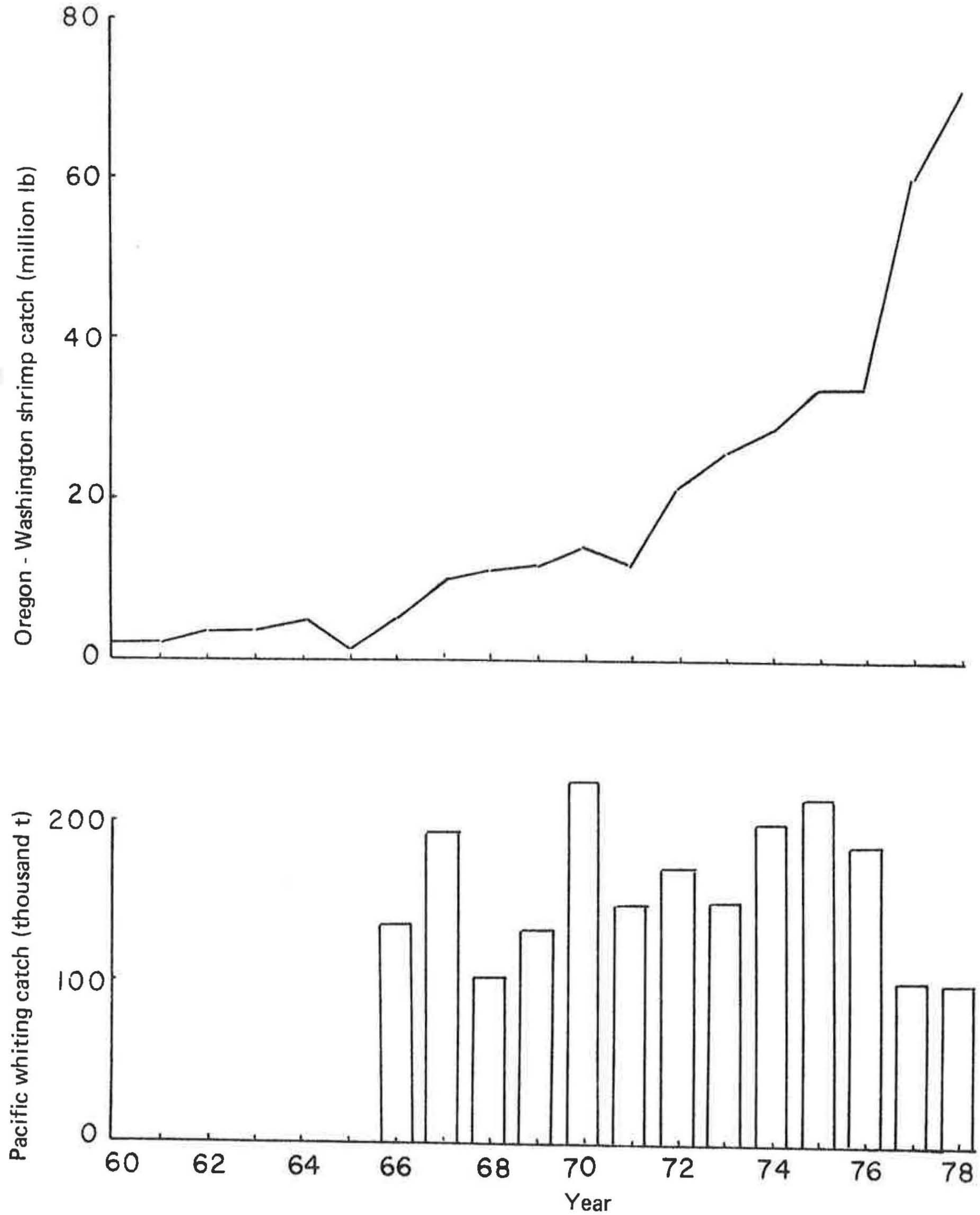

Figure 18.--Shrimp catches off the Oregon-Washington coast and catches of Pacific whiting.

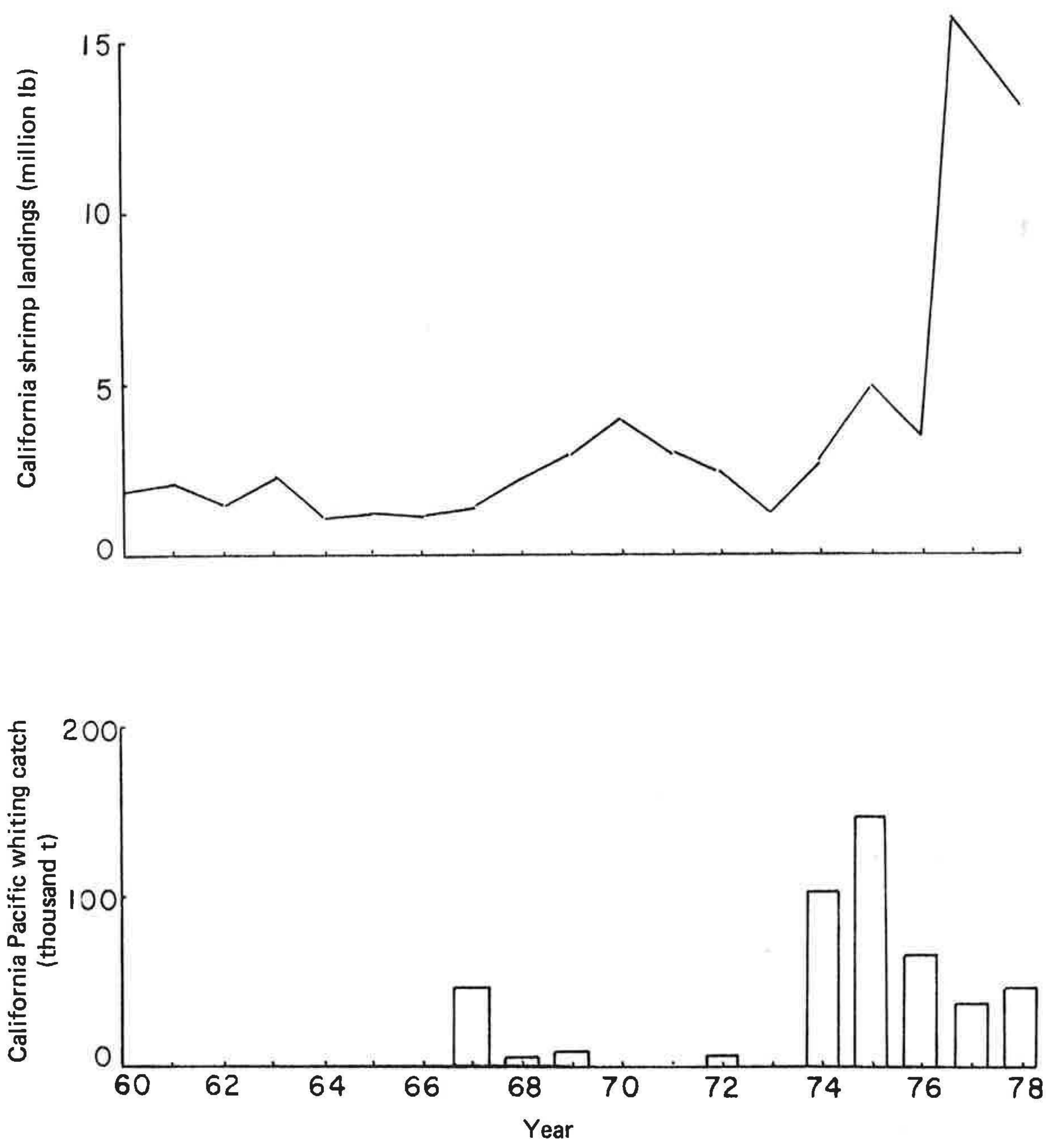

Figure 19.--Shrimp catches off the California coast and catches of Pacific whiting off California.

5. Competitors

Competitors with Pacific whiting for food resources are numerous. Among competitive fishes are: other Gadidae; flatfish, Pleuronectidae; soles, Bothidae; smelts, Osmeridae; Cottidae; Pacific herring; albacore, *Thunnus alalunga*; Hexagrammidae; lingcod, *Ophiodon elongatus*; Myctophidae; rockfish, Scorpaenidae; sablefish, Anoplopoma fimbria; and Salmonidae. Numerous marine mammals may also be competitors, including: the rough-toothed dolphin, *Steno bredanensis*; gray whale, *Eschrichtius robustus*; minke whale, *Balaenoptera acutorostrata*; Bryde whale, *B. edeni*; sei whale, *B. borealis*; fin whale, *B. physalus*; blue whale, *B. musculus*; humpback whale, *Megaptera novaeangliae*; and right whale, *Balaena glacialis* (Fiscus 1979).

6. Predators

Predators of Pacific whiting reported in the literature include: the great white shark, *Carcharodon carcharias*; soupfin shark, *Galeorhinus zyopterus*; Pacific electric ray, *Tetranarce californica*; bonito, *Sarda chiliensis*; albacore; bluefin tuna, *Thunnus thynnus*; rockfish; sablefish; lingcod; dogfish, *Squalus acanthias*; and arrowtooth flounder, *Atheresthes stomias* (Best 1963; Nelson and Larkins 1970; Pinkas et al 1971). Marine mammals that feed on whiting include the California sea lion, *Zalophus californianus*; northern elephant seal, *Mirounga angustirostris*; Pacific whiteside dolphin, *Lagenorhynchus obliquidens*; killer whale, *Oreinus orca*; Dall porpoise, *Phocoenoides dalli*; and sperm whale, *Physeter macrocephalus* (Fiscus 1979).

Bailey and Ainley (in review) analyzed otoliths collected from California sea lion scats for 4 yr, 1974-78, at the Farallon Islands. They describe the seasonal and annual dynamics of sea lion feeding on Pacific whiting. Sea lions fed most heavily on whiting, and primarily on juveniles, in spring and summer. They estimated that sea lions may consume about 185 thousand tons of whiting each year.

IV. Population Dynamics

A. Size of Stocks

The abundance of the Pacific whiting stock has been assessed from trawl-hydroacoustic surveys. In 1980 the abundance of whiting from central California to southern Vancouver Island over the continental shelf was estimated by scientists of the Northwest and Alaska Fisheries Center to be 1.52 million metric tons (t). Most of this biomass was composed of juveniles off the coast of central California. From similar surveys in 1975 and 1977, stock biomass was estimated at 0.44 million and 1.20 million t (Table 11). Based on earlier surveys by the U.S. Bureau of Commercial Fisheries, Alverson (cited in Tillman 1968) calculated about 0.68 million t of whiting. Estimates of whiting abundance based on hydroacoustic methods (Kramer and Smith 1970; Dark et al. 1980), however, have limitations. Critical problems include: 1) the difficulty in calibrating target strength, 2) the failure to identify species by acoustic signals, and 3) the detection of whiting near the bottom (Thorne[8/]. Regardless of these problems, whiting offer one of the more optimum circumstances for hydroacoustic assessment compared with many other species.

Soviet scientists have determined that the average biomass of whiting from 1967-73 was 1.36 million t (Efimov[9/], Ermakov and Kharchenko[6/], Vologdin[10/]). They estimated 1.40 and 1.86 million t of whiting in 1974 and 1975, respectively. The Soviets conducted two surveys in 1979 with resulting estimates of 1.20 and 2.88 million t.

Estimates of spawning biomass of whiting determined from egg and larval surveys are considerably higher than those stated above. Ahlstrom (1968) calculated that the spawning biomass of whiting was 1.8 to 3.6 million t. Stepanenko[2/],[3/] estimated that the spawning biomass of whiting was 2.4 million t in 1977 and 2.65 million t in 1979.

Table 11.--Distribution of Pacific whiting biomass from three Northwest and Alaska Fisheries Center surveys.

Year	Source	Vancouver	Columbia	Eureka	Monterey and Conception	Total
		metric tons				
1975 1/	Midwater	3,791	165,941	25,596	42,020	237,348
	%	2	70	41	18	
	Bottom	667	189,630	7,222	10,107	207,626
	%	-	91	3	5	
	Total	4,458	355,571	32,818	52,127	444,974
	%	1	80	7	12	
1977	Midwater	343,821	316,440	360,944	108,087	1,129,292
	%	30	28	32	10	
	Bottom	6,560	32,917	9,501	20,662	69,640
	%	9	47	14	26	
	Total	350,381	349,357	370,445	128,749	1,198,932
	%					
1980	Midwater	322,335	260,476	182,783	578,841	1,344,435
	%	24	19	14	43	
	Bottom	16,678	16,938	13,579	127,647	174,832
	%	10	10	8	73	
	Total	339,013	277,404	196,362	706,488	1,519,267
	%	22	18	13	47	

1/ 1975 areas do not correspond to 1977 and 1980 survey areas.

Estimates of spawning biomass from egg and larval surveys are extremely crude in the case of whiting because the size composition and fecundity of the spawners is relatively unknown, the stage duration of eggs and larvae was not utilized for these approximations, fecundity schedules of adults are based on very little data, and whether whiting are multiple spawners is unknown. Estimates are further confounded by the extreme patchiness of eggs and larvae of whiting.

In spite of these problems ichthyoplankton surveys are useful to assess the relative abundance of the stock, and the California Cooperative Oceanic Fisheries Investigations (CalCOFI) ichthyoplankton surveys conducted since 1950 have been useful to monitor changes in the spawning potential of the population. Estimates of larval abundance from Stauffer and Smith[4/] are presented in Table 12. The spawning stock appears to have decreased in the late 1960s and early 1970s compared to earlier years, but has recently increased to previous levels.

Bailey (1981) has presented another estimate of relative larval abundance. Since Stauffer and Smith's calculations assume that a constant proportion of larvae are found in the survey each month, variability in spawning time or egg-hatching time can result in significant errors from months when no surveys were taken. This is especially the case since 1960 when only January and April were usually surveyed. A ratio of larvae in April:January was used to correct for temporal availability in the January abundance. His estimates are also given in Table 12. In most cases, the two different methods compare fairly well. Both methods show that increases in larval production occurred in 1966, 1975, and 1978--reflecting large spawning populations. These large spawning populations correspond to the appearance of very strong year classes in the population as 5 yr olds. These strong year classes were spawned in 1961, 1970, and 1973.

Table 12.--Annual estimates of larval Pacific whiting abundance.

	Stauffer and Smith[1/]	Bailey (1981)
	X 10^{12}	X 10^{12}
	------------No. of fish-----------	
1951	43.3	-
1952	42.7	-
1953	55.3	-
1954	19.2	-
1955	23.8	8.0
1956	57.4	-
1957	47.9	-
1958	31.8	-
1959	9.9	-
1960	10.3	2.1
1961	-	2.6
1963	-	5.0
1964	-	4.0
1965	-	8.3
1966	20.7	19.2
1968	-	13.3
1969	13.0	3.7
1972	16.6	1.1
1975	36.1	8.2
1978	-	14.6
1979	-	6.0

1/ Stauffer, G.D., and P.E. Smith. 1977. Indices of Pacific hake from 1951-1976. Southwest Fish. Cent. Admin. Rep. LJ-77, Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, P.O. Box 271, LaJolla, CA 92038.

B. Reproduction Rates

Pacific whiting adults are very fecund, consequently egg and larval production by the population is high, ranging from about 10 to 60 x 10^{12} larvae/yr. Survival rates of early life stages have not been determined, but are undoubtedly quite low.

The population's intrinsic rate of natural increase, r, which is a measure of the growth potential of the population, and the net reproductive rate, R, which represents the average number of eggs produced over the life span of an individual female, may be estimated from data on life history traits (Pielou 1974). For purposes of comparison, these parameters are also presented for two other whiting stocks of the northeastern Pacific (Table 13). In this comparison, the coastal whiting stock has a delayed maturity and low mortality relative to the other stocks; consequently r is relatively low. However, when maturity is reached, spawning females are large and fecundity is high, resulting in a higher R. These values indicate that the coastal stock is more stable than the other two stocks but has less ability to increase rapidly if drastic population declines occur.

The factors most often considered to affect reproductive success of marine fishes are cannibalism, food supply, predation, and larval transport. Although cannibalism is observed sometimes, since the majority of adult whiting spend a limited time in the spawning area (1-3 mo), cannibalism is probably fairly low. Sumida and Moser (1980) found that some large larvae eat smaller larvae. A few reports of adult predation on juveniles exist, but spatial segregation of size classes must minimize this interaction.

Bailey (in press) found that the food requirement of whiting larvae is low because of relatively low growth and metabolic rates. The large mouth size of larvae enables first-feeding larvae to ingest a wide spectrum of food

Table 13.--Life history parameters of the three Pacific whiting stocks. L_x is the survival rate, m_x is the fertility rate.

	COASTAL		PUGET SOUND		DWARF	
Age	L_x	$m_x(10^5)$	L_x	$m_x(10^4)$	L_x	$m_x(10^3)$
0	1.000	-	1.000	-	1.000	-
1	.522	-	.427	-	.333	4.900
2	.272	-	.183	-	.111	9.260
3	.142	-	.078	5.200	.037	14.430
4	.074	1.260	.033	6.410	.012	20.430
5	.039	1.300	.014	7.320	.004	28.680
6	.020	1.590	.006	8.030	.001	37.110
7	.011	1.730	.003	8.720	-	-
8	.006	2.330	.001	9.520	-	-
9	.003	2.600	-	-	-	-
10	.002	2.690	-	-	-	-
11	.001	2.850	-	-	-	-
R =	22,500		8,035		3,591	
r[1] =	1.85		2.32		4.18	

[1]r was estimated as: $\dfrac{(\sum_x L_x m_x)[\ln(\sum_x L_x m_x)]}{\sum_x x L_x m_x}$ (Pielou 1974)

particles, including juvenile and adult copepods (Sumida and Moser 1980). Bailey (in press) calculated that a first-feeding whiting larvae can satisfy growth and metabolic requirements by ingesting 31 copepod nauplii, 6 small calanoid adult copepods, or 0.6 *Calanus* copepodites per day. By comparison a first-feeding northern anchovy larvae, with its small mouth, must capture at least 200 *Gymnodinium* cells per day to satisfy metabolic (and excluding growth) requirements alone (Hunter 1977). It was concluded that starvation from first-feeding failure is probably not as variable for whiting larvae as it appears to be for northern anchovy and that whiting may not be as dependent on finding patches of prey, as has been found for northern anchovy (Lasker 1975).

Predation on eggs and larvae is a difficult problem to assess and is poorly understood. A wide variety of invertebrate organisms are capable of feeding on whiting eggs and larvae (see Table 3). Yolk-sac stages are most vulnerable to predation by invertebrates (Bailey and Yen, in review). Predation by invertebrates may be important in cold years when development is slow through the most vulnerable stages.

Oceanographic conditions appear to play a major role in the recruitment of Pacific whiting (Bailey 1981). The distance from shore of larvae is apparently positively correlated to indices of wind-driven Ekman transport (Figure 20). Although there is a good deal of variability in this relationship, it is statistically significant and indicates that larvae may be transported offshore in years of high upwelling. Since the juvenile nursery is inshore over the continental shelf, advection of larvae offshore is expected to be detrimental to survival. In fact, Ekman transport during the spawning months is negatively correlated to year class strength (Figure 21).

Sea surface temperature also influences recruitment, possibly due to the predation temperature interactions noted above and the previously described

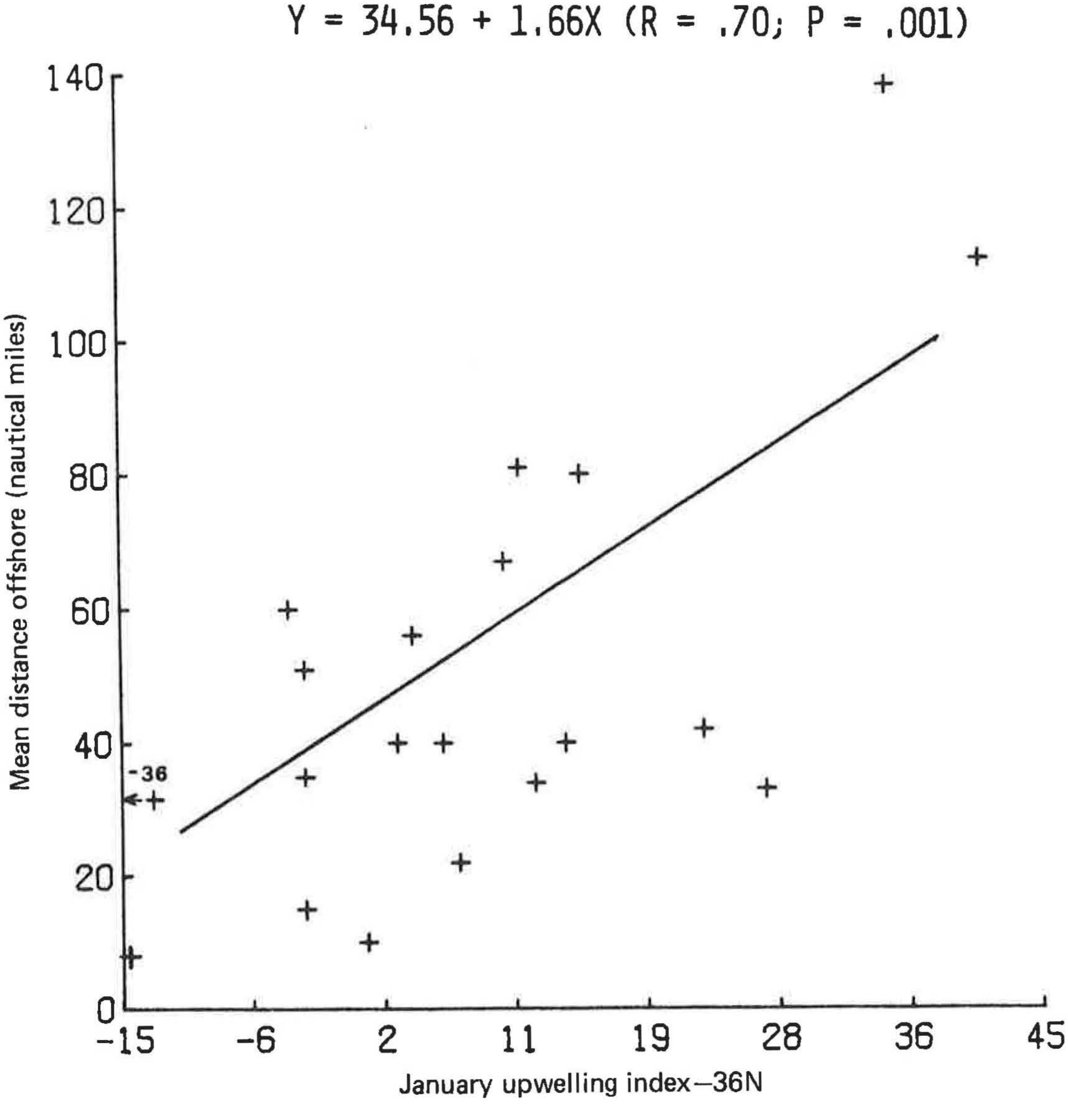

Figure 20.--The distribution of larvae offshore in January-February surveys versus the January upwelling index, 1950-79 (linear correlation coefficient, r = 0.70, P = 0.001) (from Bailey 1981).

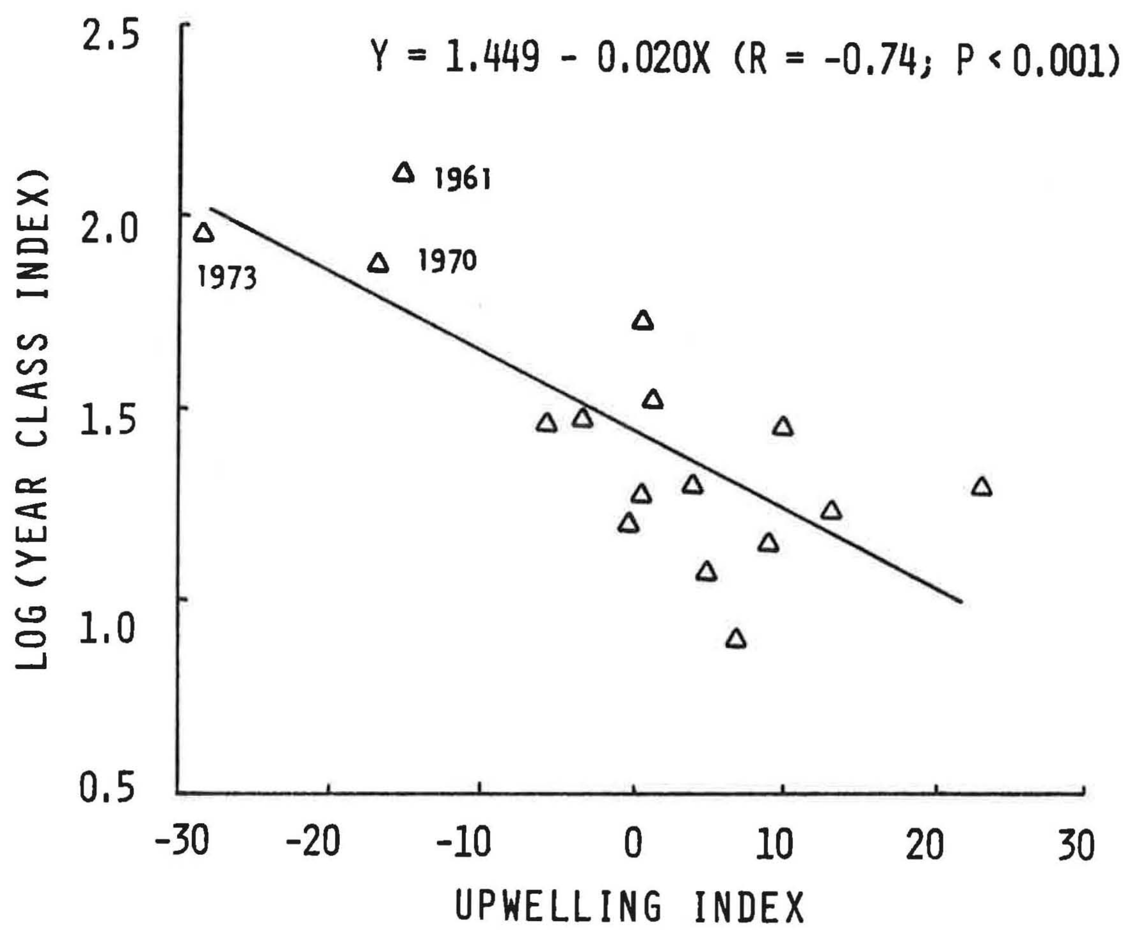

Figure 21.--Log of the year class index against the January upwelling index (from Bailey 1981).

influence of temperature on the location of spawning. Together with Ekman transport these two factors account for 68% of the observed variation in an index of year class strength (Figure 22). There is no apparent relationship between spawning biomass of the population and recruitment.

Recruitment of the exploited stock occurs at 3-6 yr of age. This age depends on the location of fishing due to the spatial distribution of age classes. Inter-annual variations in recruitment are very great, as exemplified by the dominance of the age composition of the stock by strong year classes for several consecutive years (Figure 23).

C. Mortality

Estimates of annual instantaneous natural mortality rates range widely. These estimates, as well as several estimates for fishing and total mortality rates are presented in Table 14. A cohort analysis performed by Francis (in review) on the 1973-80 catch by age data gives estimates of age-specific fishery mortality (catchability) as well as recruitment of the exploited stock at age 3.

D. Dynamics of the Population

Over the past 200 yr the Pacific whiting population has experienced some major changes in abundance (Soutar and Isaacs 1974). At the turn of the last century the population was almost an order of magnitude larger than recent abundance levels. These changes in abundance have been correlated to changes in abundance of the northern anchovy (Soutar and Isaacs 1974) and are inversely correlated to offshore Ekman transport (Bailey 1981).

Several mathematical models have been constructed that simulate changes in the whiting population. These include models by Francis (In review), Francis et al. (In review), Bernard (Oregon State University, Newport, OR),

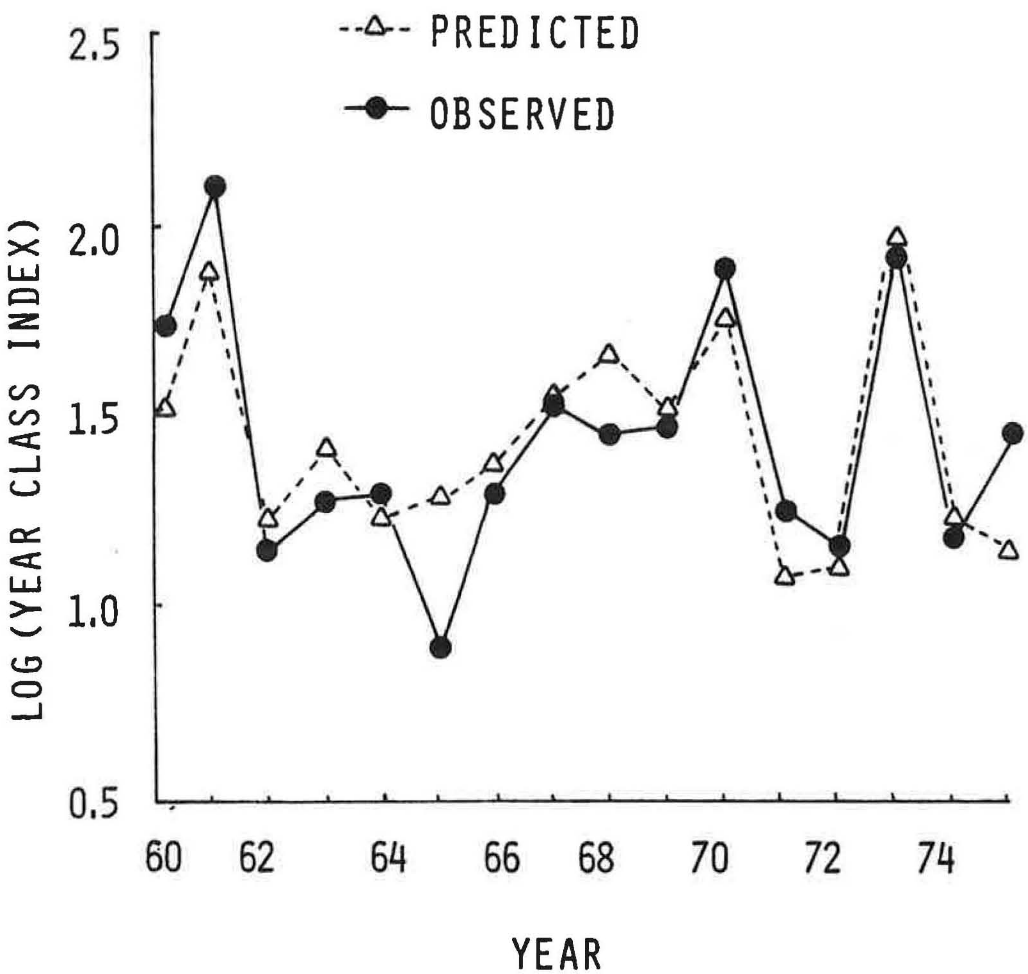

Figure 22.--Observed index of year class strength compared to the predicted index from the multiple regression model (from Bailey in press).

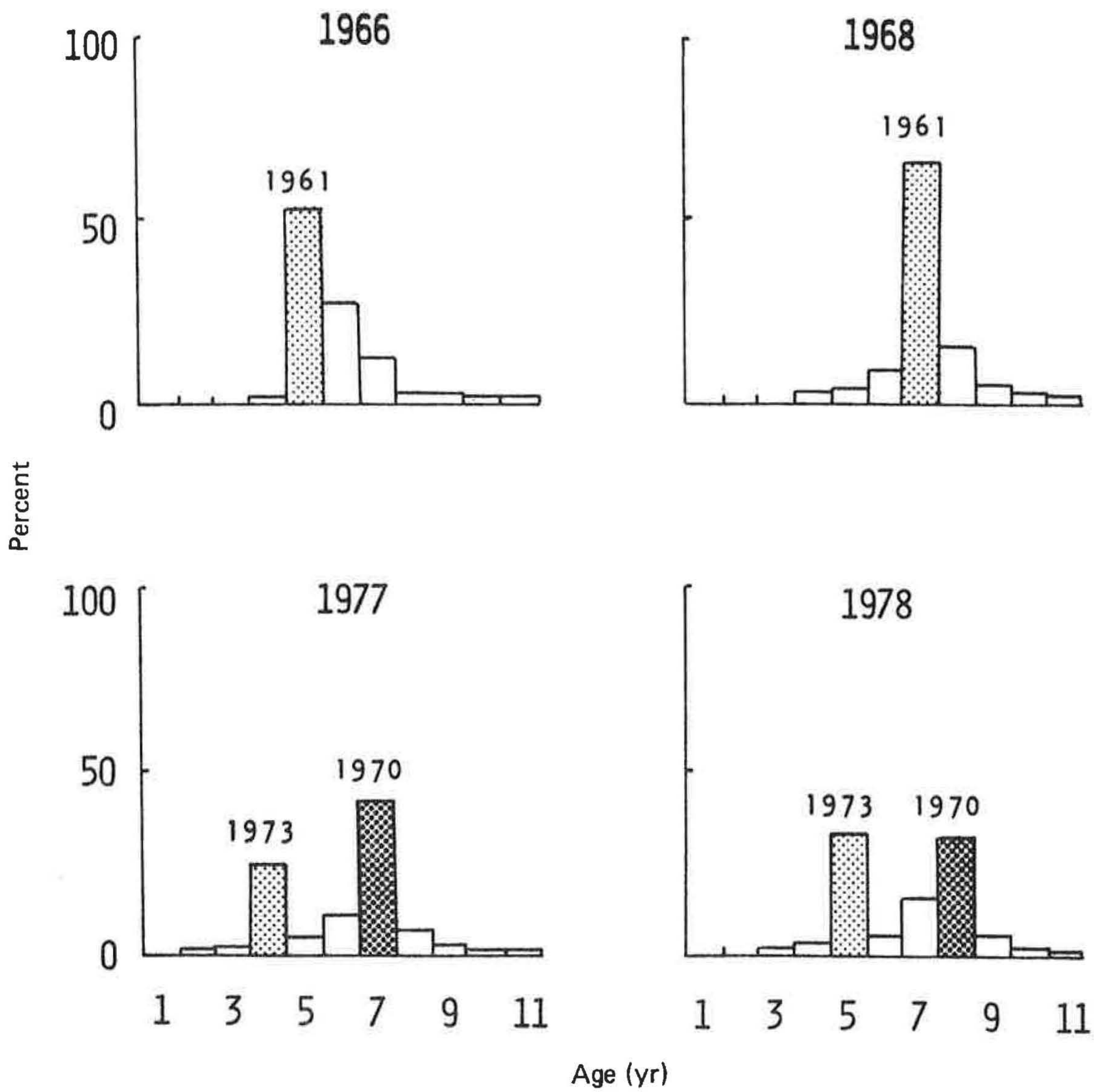

Figure 23.--Age compositions of Pacific whiting caught off Oregon and Washington from research surveys (1966 and 1968) and from U.S. observer fishery data (1977 and 1978) (from Bailey 1981).

Table 14.--Estimates of annual instantaneous mortality rates of Pacific whiting.

Investigators	Males	Females	Both sexes
M: natural mortality			
Tillman (1968)	0.72	0.62	$\bar{x}$=0.67
Nelson and Larkins (1970)			0.56
Efimov (1974)1/			0.35
PFMC2/			0.30-0.60
Janusz and Jackowski (1979)			0.30
Ehrich, et al (1980)			0.56
Low (1978)11			0.50
Francis (in prep)			0.19-0.86 (variable age-specific natural mortality)
F: fishing mortality			
Efimov (1974)1/			0.30
Ehrich, et al (1980)			0.67
Z: total mortality			
Efimov (1974)1/			0.65
Ehrich et al. (1980)			1.23

1/ Efimov, Y.N. 1974. The size of stocks and status of fishery of Pacific hake. Unpubl. manuscr. Pacific Scientific Research Institute of Marine Fisheries and Oceanography (TINRO), Vladivostok, USSR.

2/ Pacific Fishery Management Council. 1980. Pacific coast groundfish plan. Draft report. Pacific Fishery Management Council, 526 S.W. Mill St., Portland, OR 97201.

Stevens and Goodman (Scripps Institution of Oceanography, La Jolla, CA), Tillman (1968), and Riffenburgh (1969).

V. The Pacific Whiting Fishery

A. Historical Catches and Effort

Pacific whiting has been the target of a large foreign fishery off the west coast of the United States and Canada (Table 15). A Soviet fishery for whiting began in 1966 with a catch of 137 thousand t. From 1973-76 Poland, West Germany, East Germany, and Bulgaria joined fishing operations for Pacific whiting. Reported catches peaked in 1976 at 237 thousand t. The average annual all-nation reported catch from 1966 to 1980 was 162 thousand t. (These catches were compiled from data at the Northwest and Alaska Fisheries Center.)

A small domestic fishery for whiting, used in the manufacture of pet food, has existed since at least 1879 (Jow 1973). This fishery has been rather insignificant with catches in the range of 200-500 t/yr. However, in recent years the domestic fishery has become important; U.S.-foreign nation joint venture fishing caught 9 thousand t and 28 thousand t in 1979 and 1980, respectively.

Historical effort statistics for the fishery, excluding Canadian waters, were calculated from weekly aerial surveillance data from the NMFS Enforcement Division (supplied by Bill Dickenson, NMFS, Northwest Regional Office, Seattle, WA). Effort for two classes of vessels, large Soviet BMRT stern trawlers and smaller Soviet SRT side trawlers (see descriptions below) were calculated in vessel-days on the fishing grounds. Effort by the SRT trawlers was greatest in 1966 and declined steadily (Table 16). Effort by the BMRT trawlers was greatest in 1975 and 1976.

To obtain a rough estimate of overall catch per unit of effort (CPUE) for the foreign fishery in U.S. waters, SRT effort was converted to effective BMRT

Table 15.--Annual all-nation catches of Pacific whiting (x 10^3 t) in U.S. and Canadian[1/] waters.

Year	U.S.S.R.	Poland	Domestic/ joint venture	Other	Total
1966	137.00	-	-	-	137.00
1967	206.1	-	-	-	206.1
1968	103.8	-	-	-	103.8
1969	161.8	-	-	0.12	161.9
1970	226.2	-	-	2.3	228.5
1971	151.8	-	-	1.4	153.2
1972	150.8	-	-	0.4	151.2
1973	143.8	2.00	-	5.1	150.8
1974	173.7	44.3	-	8.4	226.5
1975	155.4	57.2	-	5.1	217.7
1976	158.0	25.7	-	53.0	236.8
1977	111.0	19.5	-	1.9	132.4
1978	70.9	27.3	2.7	3.4	104.2
1979	96.8	22.3	13.1	3.6	135.9
1980	0.1	49.0	40.8	0.8	90.7

1/ Zyblut, E. 1981. Dept. of Fisheries and Oceans, Govt. of Canada, Vancouver, B.C. Personal communication.

Table 16.--Historical effort statistics for the U.S.S.R.-Poland foreign Pacific whiting fishery (solely) in U.S. waters.

Year	BMRT vessel days	RST vessel days	Standard BMRT days P_{ST}=0.31	Catch (1000 t)	CPUE (t/BMRT Day)
1966	2,670	14,490	7,128	137.0	19.2
1967	2,730	10,350	5,915	195.1	33.0
1968	5,677	2,079	6,317	68.0	10.8
1969	5,607	1,589	6,096	109.0	17.9
1970	7,847	658	8,049	200.8	24.9
1971	7,245	651	7,445	146.7	19.7
1972	5,131	518	5,290	111.3	21.0
1973	5,904	-	5,904	141.1	23.9
1974	7,717	-	7,717	201.1	26.1
1975	10,401	-	10,401	196.9	18.9
1976	6,917	-	6,917	177.8	25.7
1977	4,076	-	4,076	127.2	31.2
1978	2,779	-	2,779	96.9	34.9
1979	4,452	-	4,452	114.9	25.8
1980	1,553	-	1,553	44.0	28.3

Assumptions - P_{ST}=0.31

P_{BMRT}(Poland)=1.00

CPUE = catch per unit effort

effort by assuming a relative fishing power of P_{SET} = 0.31 from the ratio of average horsepower of SRT vessels to BMRT vessels (1150 HP).

Catch/standard BMRT day indicates that the highest rates occurred in 1967 and from 1977 to 1979. Since the latter period coincides conspicuously with passage of the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA) and observer coverage, these statistics indicated that actual catches were possibly under-reported from 1968 to 1976.

B. Technical Aspects

As the major country fishing for whiting, the Soviet Union's whiting fleet has improved in sophistication considerably since initial efforts. In 1966 the fleet was mainly medium-sized side trawlers of about 500 gross tons. The proportion of large stern trawlers with freezing capacity (BMRTs) has gradually increased to replace the side trawlers. The typical BMRT is 3170 gross tons, has a crew of 22-26 and uses a midwater trawl with a headrope length of 97 m. The daily production capacity is 30-50 t of frozen fish and 20-35 t of meal and oil. Support vessels in the fishery include factoryships, refrigerated transports, oil tankers, personnel carriers, tugs, and patrols.

The Soviet fishery is a well-coordinated expedition, and acoustics are used to guide the net over fish concentrations. Prior to 1976, about 100 BMRTs would typically participate in the fishery (Pruter 1976), but lately the fleet has been reduced to about 39 trawlers. In early years of the fishery most whiting were filleted, and small fish were reduced to meal. Recently the average size of hake has become considerably smaller, and an increasing proportion of the catch is frozen whole.

Several reports (Gulland 1956; Robles, et al. 1980) cover gear selectivity, and this topic will not be further reported here.

The foreign fishery is closely tied to the migratory movements of the whiting population. Historically, the fishery began in waters off Oregon in April and moved northward as schools made their way up the coast in summer. This was documented from aerial sightings of the Soviet fishery (Figure 24). In autumn, as fishing activity halted, hake began to migrate offshore and southward for spawning. More recently, fishing has been restricted by treaty to the period from June until October. Based on aerial surveillance records and Ermakov's (1974) analysis of the fishery, rich fishing grounds appear to be associated with prominent geographical sites, such as banks, sharp "curves" in the continental slope, and in front of canyons. Especially productive grounds are found near the Heceta Banks, Yaquina Head, Cape Flattery, Cape Blanco, and Destruction Island.

The whiting fishery normally occurs over the middle continental shelf and the upper continental slope (Table 17). Alton (1972) reported seasonal changes in the depth of whiting catches in research bottom trawls (see Figure 12), which is consistent with reports of the Soviets (Ermakov 1974). In April-May whiting are mostly located over the slope. In mid-June they move inshore over the middle shelf, and in autumn they move offshore again.

C. Management

Prior to implementation of the MFCMA in 1977, management of the foreign fishery was by bilateral agreement. Since 1977 management has been directed by a Preliminary Management Plan (PMP)[12/] for groundfish prepared by the Department of Commerce. Subsequently, the Pacific Fishery Management Council has prepared a fisheries management plan (FMP) for groundfish, including whiting, which is currently under review. A conservative estimate of maximum sustained yield in the plan is 175.5 thousand t. The FMP specifies geographic

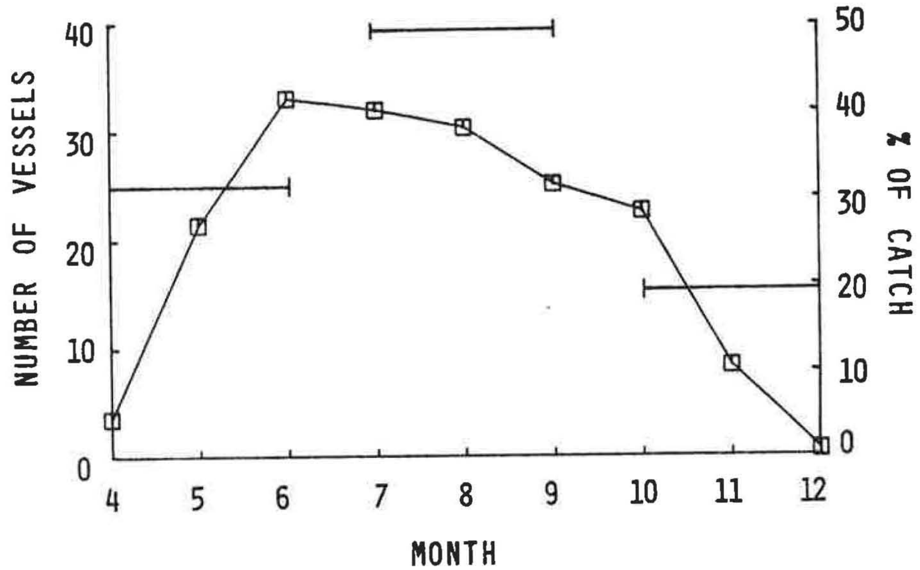

Figure 24.--The average monthly number of foreign vessels fishing Pacific whiting sighted in aerial surveys, 1967-72 (squares) and the average percent of the catch in 3-mo periods for the same years.

Table 17.--Catch (percentage) by depth strata of Pacific whiting taken by foreign trawlers in 1979 (from French et al.[1]).

Depth (m)	0-99	100-199	200-299	300-399	400-499	>500
Percentage	15.7	47.7	26.2	6.9	2.3	1.2

1/ French, R., R. Nelson Jr., and J. Wall. 1980. Observations of foreign and joint venture fishing fleets off the coast of Washington, Oregon, and California, 1979. Unpubl. rep. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

and seasonal restrictions, mesh size, incidental catch levels, and an optimal yield (in the form of quotas). Under the MFCMA only the Soviets and Poles have been granted licenses as the major foreign interests that may fish for Pacific whiting. Recently, U.S. fishermen have become involved in the whiting fishery through joint ventures in which U.S. trawlers harvest whiting for delivery to foreign processing vessels.

D. Effects of the Fishery on the Population

Commercial fisheries may affect the abundance and recruitment of marine fish populations in several ways. The effects of removing a stock's largest and oldest fish, besides reducing the total spawning biomass of the population, include: 1) the quality of the spawning product suffers if offspring from smaller fish are less fit (Hempel 1979); 2) the number of age classes that contribute to spawning is reduced, thus the maintenance of healthy levels of spawning stock depends on successful recruitment from fewer age classes (Smith 1978); and 3) the distribution of spawning changes if size or age differences in the location of spawning exist.

The spawning potential of the whiting population has had no discernible effect on recruitment from 1960 to 1975 (Bailey 1981), partly because of the overwhelming effects of environmental factors. For example, the 1961 year class arose from an extremely low spawning stock (Table 12), but under favorable environmental conditions it became a very strong year class. Similar situations gave rise to the strong 1970 and 1973 year classes. Intuitively, if the spawning stock was high and environmental conditions were favorable, enormous recruitment should result. However, density dependent processes related to the carrying capacity of the environment and to the feeding behavior of predators may be important but are little understood.

The long life of *Merluccius* spp., as well as of other gadids, is probably an adaptation to stabilize the stock from the effects of recruitment variability. Reduction in the number of spawning age classes by heavy fishing must be a destabilizing influence. If recruitment failure occurred in a succession of years, the probability of a stock collapse would be increased. This type of interaction appears to have influenced the recruitment of other stocks. In an analysis of the population dynamics of the Pacific sardine, *Sardinops sagax*, Murphy (1968) concluded that after the reduction of the number of spawning age classes by fishing, several years of recruitment failure caused catastrophic population declines. However, it should be noted that the Pacific sardine is a shortlived fish compared with Pacific whiting.

Since the mid-1960s, a change in the spawning grounds of Pacific whiting has occurred. Larvae have become much less abundant off Baja California and more abundant off central California compared to earlier years (Figure 25). In addition, the deposition of scales from young whiting markedly declined off Baja California from 1965 to 1969 compared to earlier periods (Soutar and Isaacs 1974). Smith[15/] first suggested that this change was related to an intensive fishery for adults beginning in 1966. He suggested that large adults spawn farther south and that harvesting this component of the population has resulted in the decrease in spawning in the southern end of the spawning range. Bailey's (1980, 1981) analysis supports an interaction between the spawning distribution and the fishery. Although the spawning location of whiting is related to temperature, the recent change in spawning is independent of temperature changes. An analysis of covariance indicated significantly different slopes and intercepts for pre- and post-spawning periods (Figure 26). Bailey (1980, 1981) presented a model suggesting that a fishery for large adults could account for the observed changes in larval distribution.

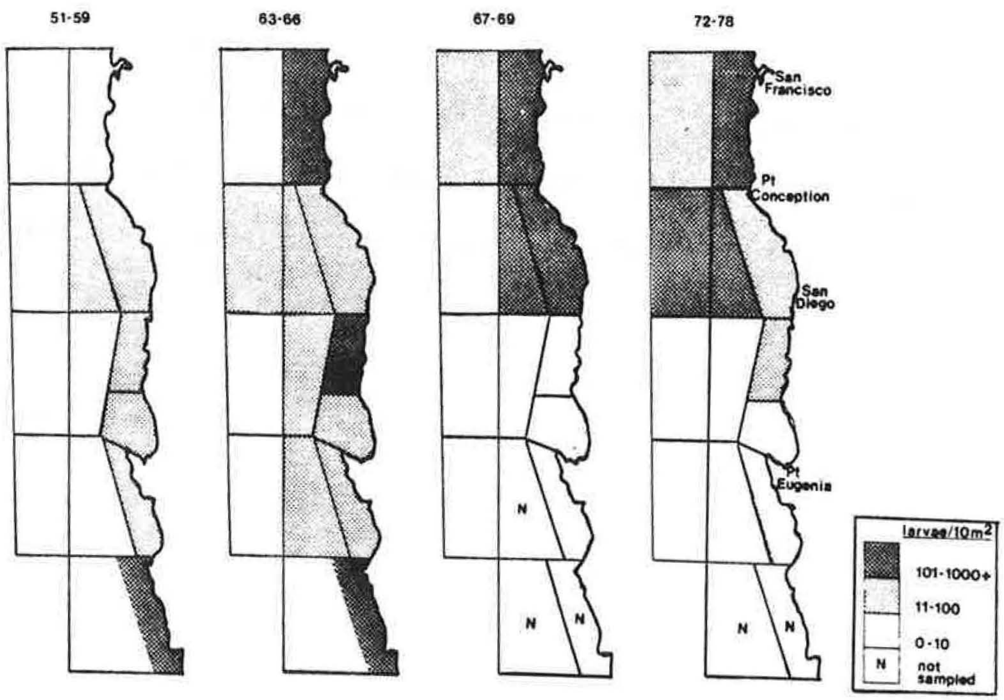

Figure 25.--Historical changes in the distribution of Pacific whiting larvae from January surveys (from Bailey 1980).

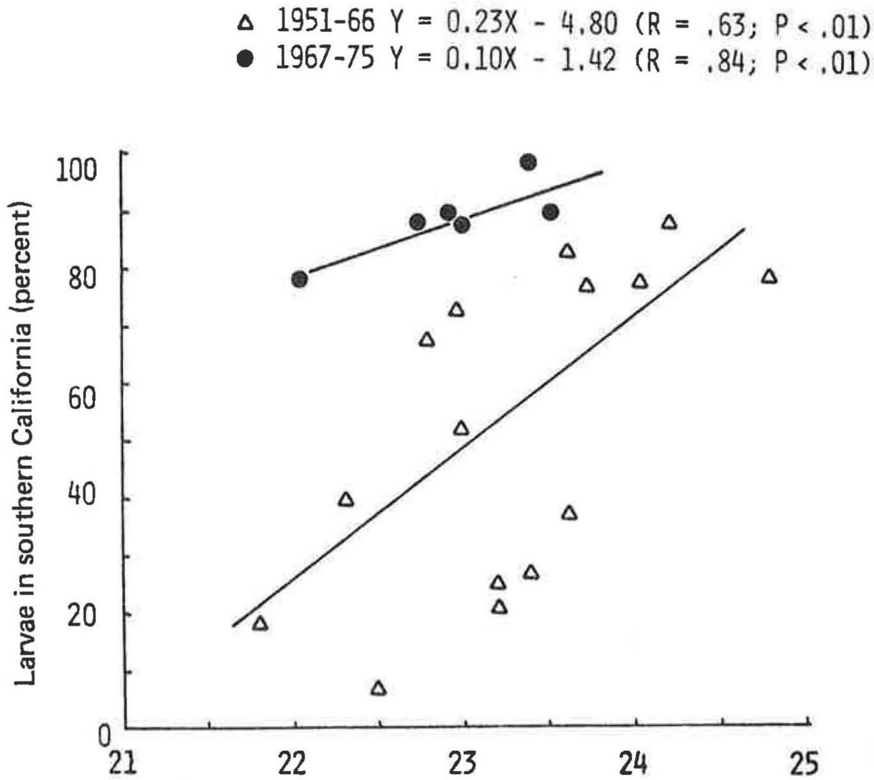

Figure 26.--Regressions of the percent of Pacific whiting larvae off southern California compared to Baja California against the mean January-March sea surface temperature off Baja California for the pre- and post-fishing periods, 1951-66 and 1967-75.

He also presented data indicating that large adults do spawn farther south (Figure 27) and that large adults are presently less abundant compared to the early years of the fishery (Figure 28). Since larger adults are distributed farther north, an increase in catches in the southern end of the range indicates increased fishing on younger fish due to decreases in the abundance of large adults.

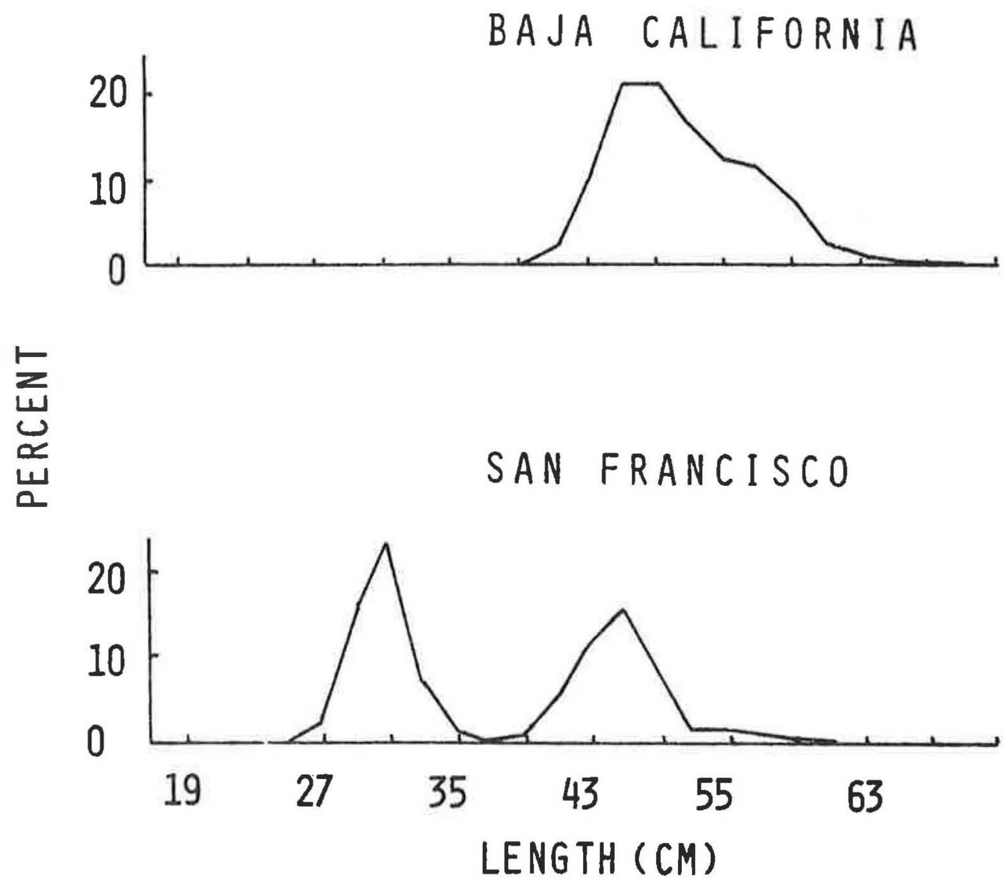

Figure 27.--Length frequencies of Pacific whiting caught off Baja California (upper) and off San Francisco (lower) sampled by West German researchers in March 1975 (from Erich et al. 1980).

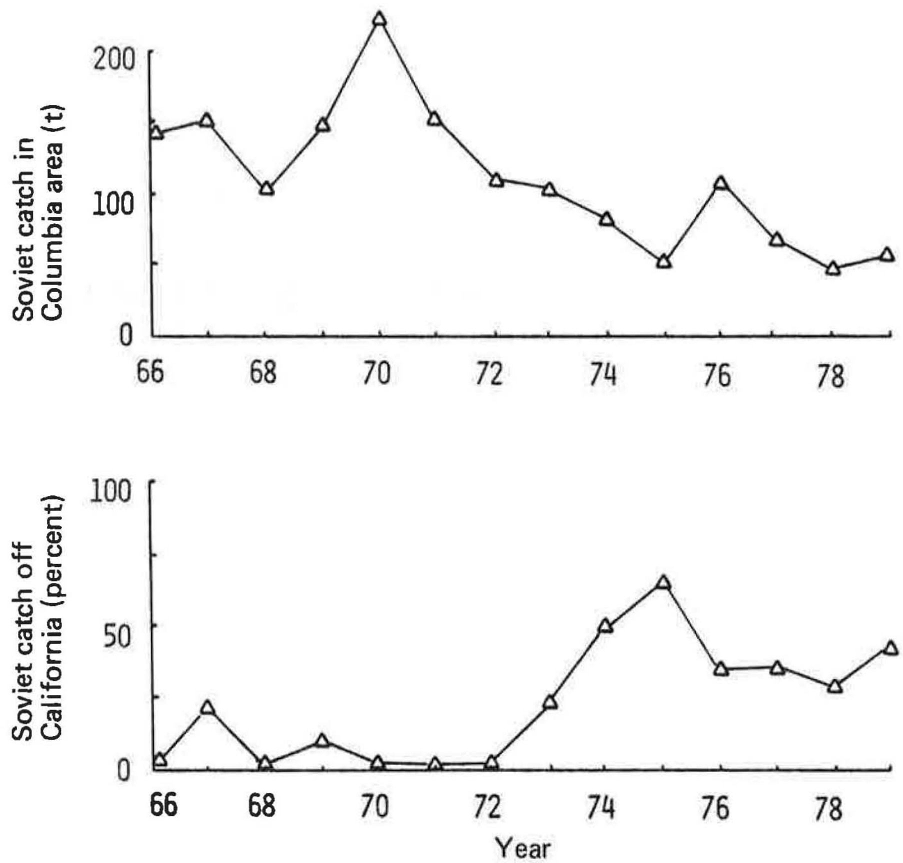

Figure 28.--Changes in the Soviet Pacific whiting catches: a) catches in the International North Pacific Fisheries Commission Columbia area from 1966-79 and b) the percent of catches off California.

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