PROGRESS REPORT
1 APRIL 1955 · 30 JUNE 1956

Inquiries concerning the California Cooperative Oceanic Fisheries Investigations should be addressed to the State Fisheries Laboratory, California Department of Fish and Game, Terminal Island, California, or to University of California, Scripps Institution of Oceanography, La Jolla, California

CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

Progress Report, 1 April 1955-30 June 1956

ERRATA

Page 19, left-hand column, line 24. For "1955-56" read "1956-57".

Page 25, left-hand column, line 47. For "Onchorhynchus tshauytscha" read "Oncorhynchus tshawytscha".

Page 28, left-hand column, line 38. Delete sentence beginning "All are small crustaceans...", and substitute "These are small crustaceans and pelagic mollusks found in the upper layers of the ocean".

Page 29, table 11. Phrases "more than" and "less than" should appear in column headed "Number of fish". Phrase "more than" should be deleted from entries from 1938 through 1950.

Page 44, right-hand column, line 26. For "guttara" read "guttata".

PP:vm - 1/7/57 - 6000

LETTER OF TRANSMITTAL

1 July 1956

HONORABLE GOODWIN J. KNIGHT
Governor of the State of California
Sacramento, California

DEAR SIR: We respectfully submit a report on the progress of the California Cooperative Oceanic Fisheries Investigations for the period 1 April 1955 to 30 June 1956.

For several years the agencies cooperating in this program have conducted research on other fishes than the sardine. This work has been only briefly reported on in the past. In this report, we have asked the research agencies, after quickly reviewing their activities during the reporting period, to present individual articles summarizing the status of their knowledge of three important marine fisheries: the anchovy, the jack mackerel, the Pacific mackerel. The report thus contains sections on each of these and a single section on their eggs and larvae. Included in the report is an annotated list of publications which have arisen from research conducted under the investigations during the period 1 January 1955-30 June 1956.

Respectfully,

THE MARINE RESEARCH COMMITTEE
J. G. BURNETTE, *Chairman*
D. T. SAXBY, *Vice Chairman*
RAYMOND CANNON
JOHN HAWK
JOSEPH MARDESICH
ARTHUR H. MENDONCA
JOHN V. MORRIS
W. E. STEWART
G. C. VAN CAMP, SR.

ABSTRACT

In the period 1 April 1955-30 June 1956, the ships of the California Cooperative Oceanic Fisheries Investigations (CCOFI) spent 893 days at sea. In addition to routine oceanographic-biological surveys along the California and Baja California coast, the ships cooperated in the international NORPAC project, the largest single oceanographic survey ever conducted, and made two special cruises to the Gulf of California.

New developments included a very promising technique for electrical fishing and refinements on the method of scouting fish schools from airplanes.

At the close of the reporting period, the outlook for the fisheries was this:

Sardine: Sardines spawned off Southern California again in 1956 and schools appeared off Port Hueneme late in June. None of the year-classes in the fishery approach the strength of the rapidly disappearing 1948 year-class, the last one comprising satisfactory numbers.

Anchovy: The anchovy population off Southern California has probably doubled in numbers since 1951. The airplane spotting surveys in May and June located enormous concentrations of anchovies near shore. The anchovy stock will probably remain at a high level of abundance for several years.

Jack mackerel: The past five years have seen the large jack mackerel become one of the prized sport fishes of California. The catch was 40,000 fish in 1955. During this period it was learned that the jack mackerel spawns extensively off the northwestern coast of the United States during August, eggs and larvae being found far out at sea.

Pacific mackerel: The available Pacific mackerel population is at a low level. Nearly half of some year-classes are caught before they are two years old. The available population in the 1950's is much smaller than in the 1930's and 1940's.

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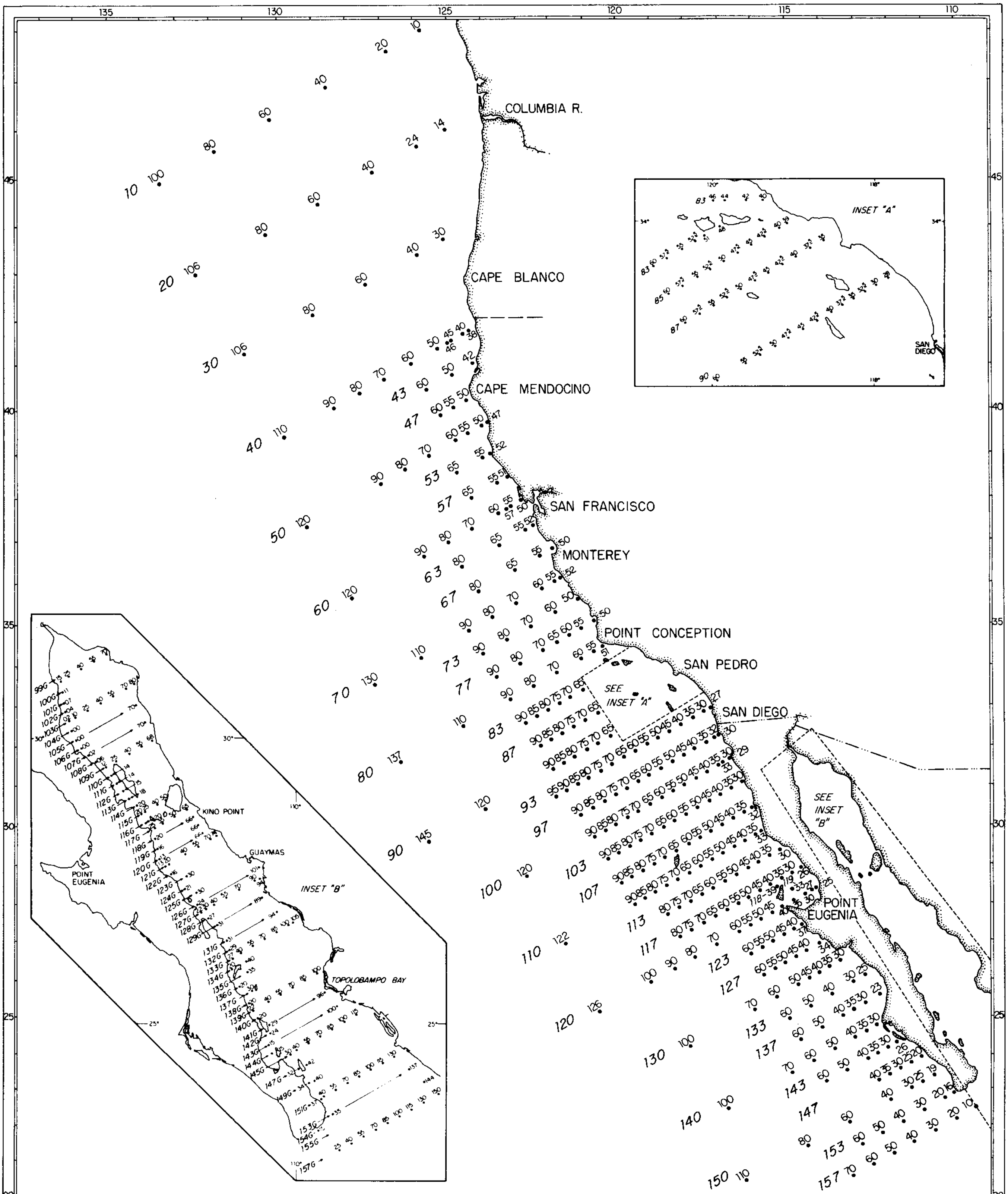


FIGURE 1. Area covered by oceanographic-biological cruises, 1 April 1955 to 30 June 1956 (except during NORPAC project). Numbers in italics indicate lines. Dot indicates station position, numerals indicate station number. To refer to station, the station number is prefaced by the line number; thus Station 97.65 is Station 65 on line 97. Inset "A": Station pattern in Southern California area. Inset "B": Station pattern in Gulf of California.

REVIEW OF ACTIVITIES
1 April 1955-30 June 1956

During the period 1 April 1955 to 30 June 1956 the research vessels participating in the California Cooperative Oceanic Fisheries Investigations spent 893 days at sea. Figure 1 shows the area covered by the hydrographic-biological cruises; Tables 1 and 2 give the stations occupied and the nature of the work done; Figure 2 shows the cruises made by the *Yellowfin* in its surveys to determine the location and abundance of juvenile and adult fishes.

Most of the time at sea was spent in work similar to that done in the past, but three of the cruises were far from routine: they were CCOFI Cruises 5508 (August, 1955), 5602 (February, 1956), and 5604 (April, 1956).

NORPAC PROJECT

The August, 1955, cruise was part of an international project known as NORPAC (NORth PACific). In terms of ships, manpower and area covered this was the largest oceanographic program ever conducted. Figure 3 shows the western half of the area: the region usually covered by CCOFI cruises in August is shaded in to indicate the vast scale of the NORPAC project.

NORPAC called for a considerable extension of the area usually covered in the CCOFI cruises so that information gathered by the Californian vessels could be tied in with that taken by others.

The project was first formally proposed at the Fifth Pacific Tuna conference of November, 1954, which was attended by representatives of all the agencies which subsequently took part except the Japanese. Distinguished Japanese scientists were asked if their country would participate and they agreed at once to do so.

Participants in the project were, from Japan, the Japanese Hydrographic Office, the Central Meteorological Observatory, the Marine Observatory of Hakodate, the Marine Observatory of Kobe, the Marine Observatory of Nagasaki, the Tokai Regional Fisheries Research Laboratory, the University of Hokkaido, the University of Kagoshima, and the University of Fisheries, Tokyo; from Canada, the Pacific Oceanographic Group of the Fisheries Research Board; from Washington, the University of Washington; from Hawaii, the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service; from California, the ships of CCOFI.

Men from these agencies spent all of August and part of July and September making observations in the North Pacific in the areas shown in Figure 4. Nineteen ships comprised the fleet; they sailed approximately 55,000 miles. Eleven of the ships were Japanese. One came from Canada, seven from the United States.

The area explored is about one and one-half times the size of the North American continent. It covers one-sixteenth the surface of the globe. From it are taken every year about 18 billion pounds (almost half the world's total) of commercial food fishes. The catch is worth approximately one billion dollars.

The main features of the oceanography of the region were well known in a general way, and in some areas, such as the CCOFI region, had been extensively explored. On the western side, the warm, narrow, rapid Kuroshio Current sweeps northward from the equator along the eastern shore of Japan. South of the Aleutian Islands it loses much of its warmth and speed. Some of the Kuroshio water eventually descends southward along the Canadian and U. S. coast as the wide, cold, sluggish California Current. South of Baja California it branches and part of it turns westward as the North Equatorial Current which, across the Pacific, feeds into the Kuroshio.

But information about the region as a whole had come from occasional single oceanographic cruises that had lasted for several months at a time—months during which oceanographic conditions at the starting point of the cruise would have changed significantly before the last stations were occupied. What was needed was a rapid, intensive survey over a short period of time. NORPAC provided that, extending to the entire North Pacific Ocean the sort of coverage that has been provided almost monthly for several years over the CCOFI region.

Figure 3 shows one of the first results of the analysis of the NORPAC data, a map of surface temperature over the western half of the North Pacific. Similar charts will be drawn for other oceanographic properties at different depths. Charts, maps, and data will be published, probably in 1957, under the joint auspices of the University of California and the University of Tokyo.

One of the interesting preliminary results of NORPAC was the information that jack mackerel spawning extended to the northernmost part of the CCOFI area and well offshore (see section on Jack Mackerel Larvae).

GULF OF CALIFORNIA CRUISES

Two special cruises (5602 and 5604) were made by the *Black Douglas* into the Gulf of California. The sardine population of the gulf has been inadequately

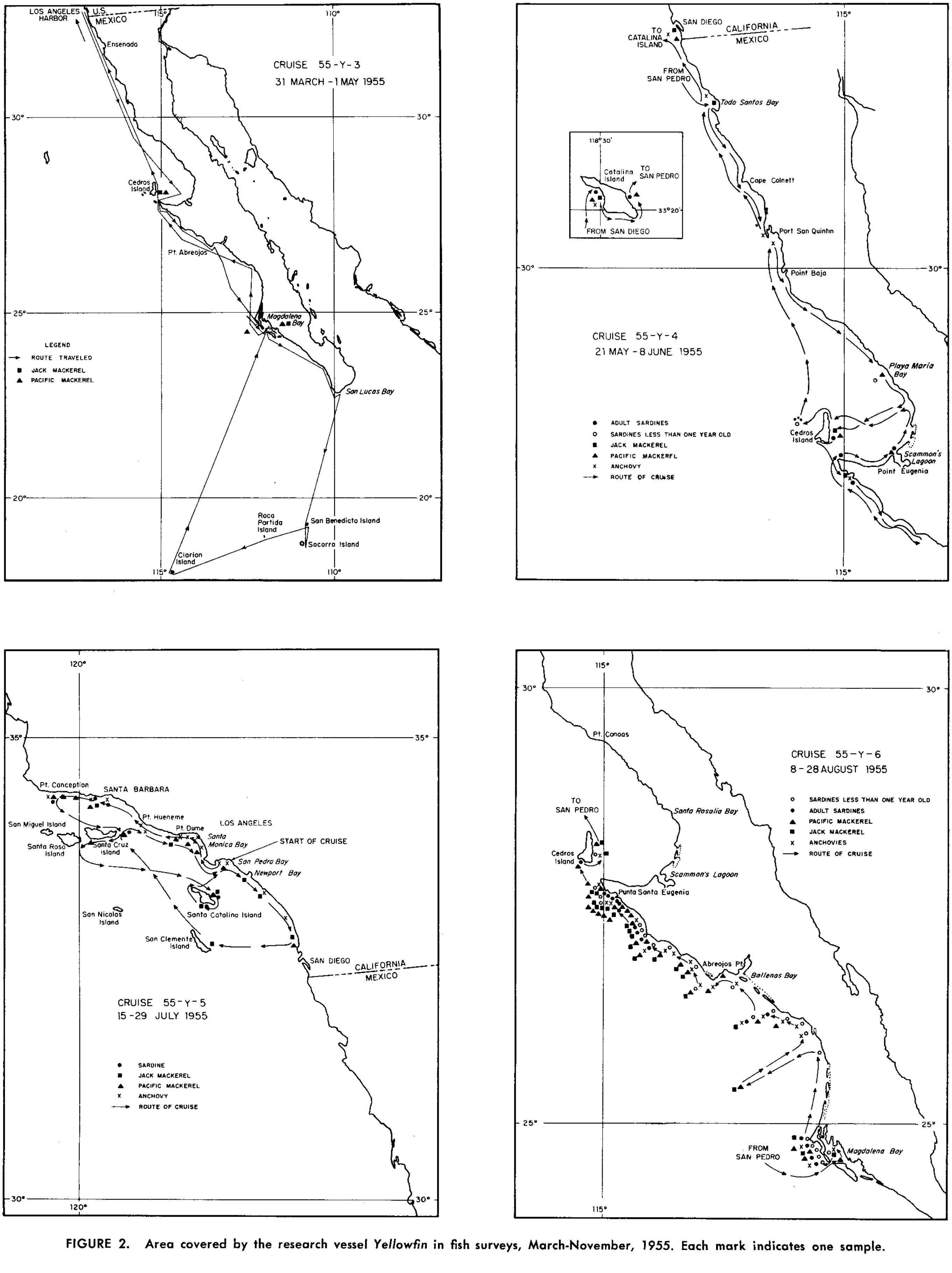
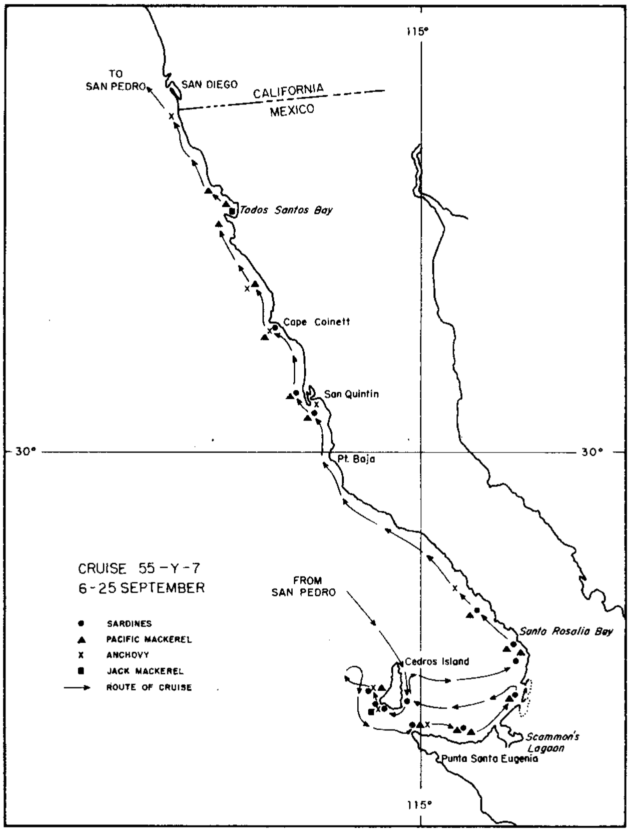
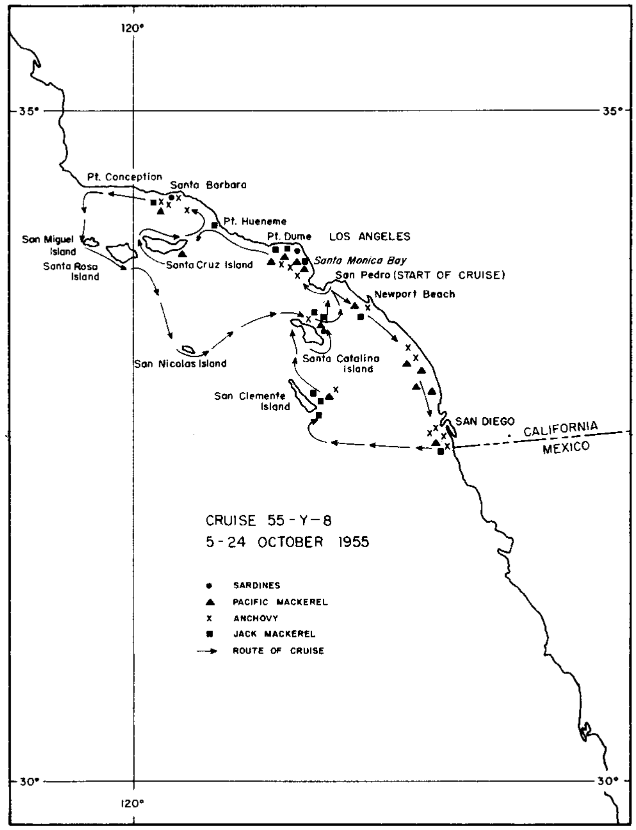
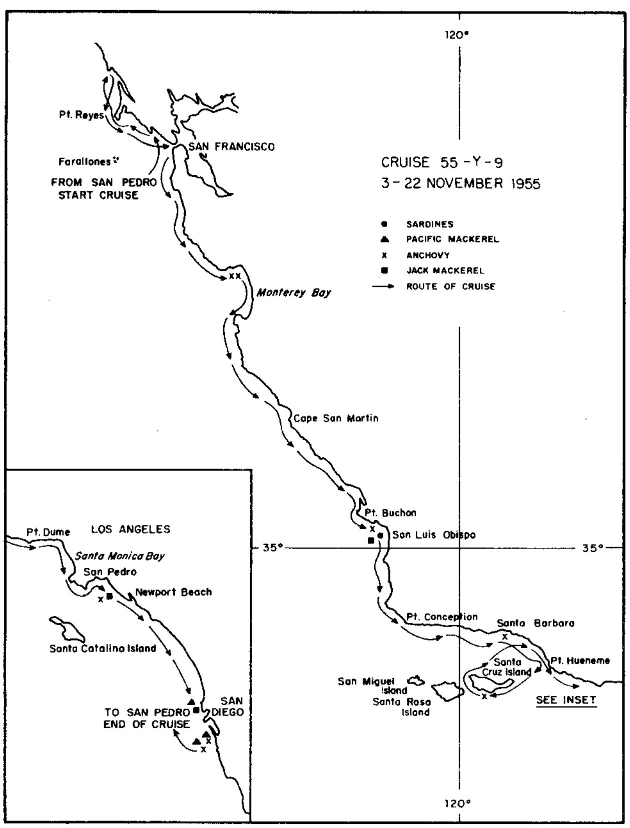


FIGURE 2. Area covered by the research vessel *Yellowfin* in fish surveys, March-November, 1955. Each mark indicates one sample.







studied. It is not known if the fish spawned there ever enter the California fishery, though it is possible that they do.

By the time of writing, the collections from the February cruise had been sorted and identified. They show that in February sardine spawning was widespread. There were sardines all over the gulf, spawning in deep water as well as off the coast. The most eggs were found on line 133G, approximately 80 miles south of Guaymas, the most larvae on line 139G, 60 miles farther south. Larvae were found all the way to the entrance to the gulf.

Since the region is generally considered to be under tropical influence, it was rather unexpectedly that the largest numbers of larvae were found on the Sonora side of the gulf.

Larvae of the Pacific mackerel were extremely abundant. They were found over most of the gulf and in considerable quantities: in this one cruise more Pacific mackerel larvae were collected than are taken in a whole year in the CCOFI area.

YELLOWFIN SURVEYS

The fish surveys, conducted by the California Department of Fish and Game, were curtailed early in 1956 because of the discovery of dry rot in the *Yellowfin*. Results of the surveys are shown in Figure 2.

TABLE 1

STATIONS OCCUPIED BY CCOFI CRUISES, APRIL, 1955 (CRUISE 5504), TO JUNE, 1956 (CRUISE 5606)

Line	Station No.	5504	5505	5506	5507	5508	5509P	5509BD	5510	5511	5512	5601	5602	5603	5604	5605	5606
10	10					x											
	20					x											
	40					x											
	60					x											
	80					x											
	100					x											
20	14					x											
	24					x											
	40					x											
	60					x											
	80					x											
	106					x											
30	30					x											
	40					x											
	60					x											
	80					x											
	106					x											
40	38															x	x
	40					x										x	x
	45															x	x
	46					x											
	50															x	x
	60															x	x
	70					x										x	x
	80															x	x
	90					x										x	x
	110					x											
43	42															x	x
	50															x	x
	60															x	x
47	50															x	x
	55															x	x
	60															x	x
50	47															x	x
	50															x	x
	55					x										x	x
	60															x	x
	70					x										x	x
	80															x	x
	90					x										x	x
	120					x											
53	52															x	x
	55															x	x
	65															x	x
57	51															x	x
	55															x	x
	65															x	x
60	50														x		
	55			x		x			x						x	x	x
	57					x									x		x
	60			x					x						x	x	x
	70			x		x			x						x	x	x
	80			x					x						x	x	x
	90			x		x			x						x	x	x
	120					x											
63	52		x	x	x				x						x	x	x
	55		x	x	x				x						x	x	x
	65		x	x	x										x	x	x
	80														x		
67	50		x	x	x				x						x	x	x
	55		x	x	x				x						x	x	x
	65		x	x	x										x	x	x
	80														x		
70	52		x	x	x				x						x	x	x
	55		x	x	x	x			x						x	x	x
	60		x	x	x				x						x	x	x
	70		x	x	x	x			x						x	x	x
	80			x	x				x						x	x	x
	90			x	x	x			x						x	x	x
	110					x											
	130					x											
73	50			x	x				x						x	x	x
	60			x	x				x						x	x	x
	70			x	x										x	x	x
	80			x	x											x	
	90			x	x												
77	50		x	x	x				x						x	x	x
	55		x	x	x				x						x	x	x
	60															x	x
	65		x	x	x										x		
	70		x	x	x											x	x
	80		x	x	x											x	
	90		x	x	x												

Line	Station No.	5504	5505	5506	5507	5508	5509P	5509BD	5510	5511	5512	5601	5602	5603	5604	5605	5606
80	51	x	x	x	x				x		x	x	x	x	x	x	x
	55	x	x	x	x	x			x		x	x	x	x	x	x	x
	60	x	x	x	x	x			x		x	x	x	x	x	x	x
	70	x	x	x	x	x			x		x	x	x	x	x	x	x
	80	x	x	x	x				x		x	x	x	x	x	x	x
	90	x	x	x	x	x			x		x	x	x	x	x	x	x
	110					x											
	137					x											
83	40	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	43	x	x	x	x				x		x	x	x	x	x	x	x
82	47												x	x	x	x	x
	48						x	x		x							
83	51	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	52.5						x	x		x							
	55			x	x		x	x		x					x	x	x
	57.5						x	x		x							
	60	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	65			x	x												
	70	x	x	x	x									x	x	x	x
	75			x													
	80	x		x										x	x	x	x
	85			x													
	90	x		x										x	x	x	x
85	39						x	x		x							
	40						x	x		x							
	42.5						x	x		x							
	45						x	x		x							
	47.5						x	x		x							
	50						x	x		x							
	52.5						x	x		x							
	55						x	x		x							
	57.5						x	x		x							
	60						x	x		x							
87	36											x	x	x	x	x	x
	35	x	x	x	x		x	x	x	x	x						
	37.5						x	x		x							
	40	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	42.5						x	x		x							
	45		x	x	x		x	x	x	x						x	x
	47.5						x	x		x							
	50	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	52.5						x	x		x							
	55		x	x	x			x		x						x	x
	57.5							x		x							
	60	x	x	x	x			x	x	x	x	x	x	x	x	x	x
	65			x	x											x	x
	70	x		x	x									x	x	x	
	75			x												x	x
	80	x		x										x	x	x	x
	85			x												x	
	90	x		x										x	x	x	
90	28	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	30	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	32.5						x	x		x							
	35						x	x		x							
	37	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	40						x	x		x							
	42.5						x	x		x							
	45	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	47.5						x	x		x							
	50	x	x	x	x		x	x		x						x	x
	53					x	x	x									
	55		x	x	x		x	x	x	x	x	x	x	x	x	x	x
	60	x	x	x	x				x		x	x	x	x	x	x	x
	65		x	x	x											x	x
	70		x	x	x	x			x		x	x	x	x	x	x	x
	75		x	x	x											x	x
	80	x	x	x	x				x		x	x	x	x	x	x	x
	85		x		x											x	x
	90	x	x		x	x			x					x	x	x	x
	120					x											
	145					x											
93	27	x	x	x	x				x		x	x	x	x	x	x	x
	30	x	x	x	x				x		x	x	x	x	x	x	x
	35		x	x	x											x	x
	40	x	x	x	x				x		x	x	x	x	x	x	x
	45		x	x	x											x	x
	50	x	x	x					x		x	x	x	x	x	x	x
	55		x	x	x											x	x
	60	x	x	x	x				x				x	x	x	x	x
	65		x	x	x											x	x
	70	x	x	x	x								x	x	x	x	x
	75		x	x	x											x	x
	80	x	x	x	x									x	x	x	x
	85		x		x											x	x
	90	x	x		x									x	x	x	x
	95		x														
97	30	x	x	x	x				x		x	x	x	x	x	x	x
	32	x	x	x	x				x		x	x	x	x	x	x	x
	35		x	x	x												

STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

Progress Report

1 April 1955 to 30 June 1956

Cooperating Agencies:
CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DEPARTMENT OF FISH AND GAME
STANFORD UNIVERSITY, HOPKINS MARINE STATION
U. S. FISH AND WILDLIFE SERVICE, SOUTH PACIFIC FISHERY INVESTIGATIONS
UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY

1 July 1956

TABLE 1—Continued

STATIONS OCCUPIED BY CCOFI CRUISES, APRIL, 1955 (CRUISE 5504), TO JUNE, 1956 (CRUISE 5606)

Line	Station No.	5504	5505	5506	5507	5508	5509P	5509BD	5510	5511	5512	5601	5602	5603	5604	5605	5606
97	40	x	x	x	x				x		x	x	x	x	x	x	x
	45		x	x	x											x	x
	50	x	x	x	x				x		x	x	x	x	x	x	x
	55		x	x	x											x	x
	60	x	x		x				x				x	x	x	x	x
	65		x		x											x	x
	70	x	x		x								x	x	x	x	x
	75		x		x											x	x
	80	x	x		x									x	x	x	x
	85		x		x											x	x
	90	x	x		x									x	x	x	x
100	29	x	x	x	x	x			x		x	x	x	x	x	x	x
	30	x	x	x	x				x		x	x				x	
	33												x	x	x		x
	35		x	x	x	x										x	x
	40	x	x	x	x				x		x	x	x	x	x	x	x
	45		x	x	x											x	x
	50	x	x	x	x	x			x		x	x	x	x	x	x	x
	55		x	x	x											x	
	60	x	x		x				x		x	x	x	x	x	x	x
	65		x		x											x	x
	70	x	x		x	x			x		x	x	x	x	x	x	
	75		x		x											x	
	80	x	x		x				x		x	x	x	x	x	x	
	85		x		x											x	
	90	x	x		x	x			x					x	x	x	
	120					x											
103	30	x	x	x	x				x		x	x	x	x	x	x	x
	35	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x				x		x	x	x	x	x	x	x
	45		x	x	x											x	
	50	x	x	x	x						x	x	x	x	x	x	
	55		x	x	x											x	
	60	x	x	x	x						x	x	x	x	x	x	
	65		x	x	x											x	
	70	x	x	x	x									x	x	x	
	75		x	x	x											x	
	80	x	x	x	x									x	x	x	
	85		x	x	x											x	
	90		x	x	x									x	x	x	
107	32	x	x	x	x				x		x	x	x	x	x	x	x
	35	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x				x		x	x	x	x	x	x	x
	45		x	x	x											x	x
	50	x	x	x	x						x	x	x	x	x	x	x
	55		x	x	x											x	x
	60	x	x	x	x						x	x	x	x	x	x	x
	65		x	x	x											x	x
	70	x	x	x	x									x	x	x	x
	75		x	x	x											x	x
	80	x	x	x	x									x	x	x	x
	85		x	x	x											x	x
	90		x	x	x									x	x	x	x
110	33	x	x	x	x	x			x		x	x	x	x	x	x	x
	35	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x	x			x		x	x	x	x	x	x	x
	45		x	x	x											x	x
	50	x	x	x	x				x		x	x	x	x	x	x	x
	55		x	x	x											x	x
	60	x	x	x	x	x			x		x	x	x	x	x	x	x
	65		x	x	x											x	x
	70	x	x	x	x				x		x	x	x	x	x	x	x
	75		x	x	x											x	x
	80	x	x	x	x				x		x	x	x	x	x	x	x
	85		x	x	x											x	x
	90	x	x	x	x	x			x					x	x	x	x
	122					x											
113	30	x	x	x	x				x		x	x	x	x	x	x	x
	35	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x				x		x	x	x	x	x	x	x
	45	x	x	x	x									x		x	x
	50	x	x	x	x						x	x	x	x	x	x	x
	55	x	x	x	x									x		x	x
	60	x	x	x	x						x	x	x	x	x	x	x
	65		x	x	x											x	x
	70	x	x	x	x						x	x	x	x	x	x	x
	75		x	x	x											x	x
	80		x	x	x									x	x	x	x
117	26	x	x	x	x				x		x	x	x	x	x	x	x
	30	x	x	x	x				x		x	x	x	x	x	x	x
	35	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x				x		x	x	x	x	x	x	x
	45	x	x	x	x									x		x	x
	50	x	x	x	x						x	x	x	x	x	x	x
	55	x	x	x	x									x		x	x
	60	x	x	x	x						x	x	x	x	x	x	x
	65		x	x	x											x	x
	70	x	x	x	x						x	x	x	x	x	x	x
	75		x	x	x											x	x
	80		x	x	x									x	x	x	x
118	39											x	x	x	x	x	x
119	33											x	x	x	x	x	x
120	25	x	x	x	x				x		x	x	x	x	x	x	x
	27		x	x	x				x								
	30	x	x	x	x				x		x	x	x	x	x	x	x
	35	x	x	x	x				x		x						
	40	x	x	x	x						x	x	x	x	x	x	x
	45	x	x	x	x	x			x		x	x	x	x	x	x	x
	50	x	x	x	x				x		x	x	x	x	x	x	x
	55	x	x	x	x						x	x	x	x	x	x	x
	60	x	x	x	x	x			x		x	x	x	x	x	x	x
	70	x	x	x	x				x		x	x	x	x	x	x	x
	80	x	x	x	x	x			x					x	x	x	x
	90								x								
	100					x											
	126					x											
123	37	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x				x		x	x		x	x		x
	42												x		x	x	x
	45	x	x	x	x									x			
	50	x	x	x	x				x		x	x	x	x	x	x	x
	55	x	x	x	x						x	x	x	x		x	x
	60	x	x	x	x				x					x	x	x	x
127	34	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x				x		x	x	x	x	x	x	x
	45	x	x	x	x									x		x	x
	50	x	x	x	x				x		x	x	x	x	x	x	x
	55	x	x	x	x						x	x	x	x		x	x
	60	x	x	x	x				x					x	x	x	x
130	30	x	x	x	x				x		x	x	x	x	x	x	x
	35	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x	x			x		x	x	x	x	x	x	x
	45													x			
	50	x	x	x	x	x			x		x	x	x	x	x	x	x
	60	x	x	x	x				x				x	x	x	x	x
	70					x											
	100					x											
133	25	x	x	x	x				x		x	x	x	x	x	x	x
	30	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x						x	x	x	x	x	x	x
	50	x	x	x	x									x		x	x
	60													x			
137	23	x	x	x	x				x		x	x	x	x	x	x	x
	30	x	x	x	x				x		x	x	x	x	x	x	x
	40	x	x	x	x						x	x	x	x	x	x	x
	50	x	x	x	x									x		x	x
	60													x			
140	30										x	x	x		x		
	35										x	x	x		x		
	40					x					x	x	x		x		
	50					x							x				
	60												x				
	70					x											
	100					x											
143	26										x	x	x		x		
	30										x	x	x		x		
	35										x	x	x		x		
	40												x		x		
	50												x				
	60												x				
147	20										x	x	x		x		
	25										x	x	x		x		
	30										x	x	x		x		
	35												x		x		
	40												x		x		
150	19										x	x	x		x		
	25					x					x	x	x		x		
	30										x	x	x		x		
	40					x							x		x		
	60					x											
	80					x											
	110					x											
153	16											x	x		x		
	20											x	x		x		
	30											x	x		x		
	40												x		x		
	50												x		x		
	60												x		x		
99G	15														x		
	25														x		
	40														x		
	55														x		
	70														x		

TABLE 1—Continued

STATIONS OCCUPIED BY CCOFI CRUISES, APRIL, 1955 (CRUISE 5504), TO JUNE, 1956 (CRUISE 5606)

Line	Station No.	5504	5505	5506	5507	5508	5509P	5509BD	5510	5511	5512	5601	5602	5603	5604	5605	5606
100G	11														x		
101G	07														x		
102G	04														x		
103G	02														x		
	10														x		
	25														x		
	40														x		
	55														x		
	70														x		
	80														x		
104G	00														x		
105G	00														x		
	70														x		
106G	00														x		
107G	02														x		
	70														x		
108G	06														x		
109G	12														x		
	25														x		
	40														x		
	55														x		
	68														x		
110G	14														x		
111G	14														x		
112G	15														x		
113G	18														x		
114G	20														x		
115G	20														x		
	25														x		
	40														x		
	50														x		
116G	20														x		
117G	25												x		x		
	35												x				
	50												x		x		
	65														x		
	66												x				
118G	20												x		x		
	66												x				
119G	16												x		x		
	66														x		
120G	13												x		x		
	66												x				
121G	13												x				
	20												x		x		
	40												x		x		
	55												x		x		
	70												x		x		
	74												x		x		
122G	16												x		x		
123G	30												x		x		
124G	21												x		x		
125G	30												x		x		
126G	24												x		x		
	101												x		x		
127G	22												x				
	30												x		x		
	40												x		x		
	55												x		x		
	70												x		x		
	90												x		x		
	94												x		x		
128G	27												x		x		
129G	31												x		x		
	89												x		x		
131G	31												x		x		
	94												x		x		
132G	29												x		x		
133G	27												x		x		
	40												x		x		
	55												x		x		
	70												x		x		
	85												x		x		
	100												x		x		
	105												x		x		
134G	20												x		x		
	40												x		x		
135G	35												x		x		
136G	20												x		x		
137G	30												x		x		
138G	20												x		x		
139G	22												x		x		
	40												x		x		
	55												x		x		
	70												x		x		
	85												x		x		
	100												x		x		
140G	20												x		x		
141G	29												x		x		
	96												x		x		
142G	24												x		x		
143G	15												x		x		
	100												x		x		
144G	15												x		x		
145G	30												x		x		
	40												x		x		
	55												x		x		
	70												x		x		
	85												x		x		
	100												x		x		
	115												x		x		
147G	32												x		x		
	42												x		x		
149G	34												x		x		
	40												x		x		
151G	37												x		x		
	40												x		x		
	55												x		x		
	70												x		x		
	85												x		x		
	100												x		x		
	115												x		x		
	130												x		x		
153G	35												x		x		
	137												x		x		
154G	15												x		x		
155G	144												x		x		
157G	25												x		x		
	40												x		x		
	55												x		x		
	70												x		x		
	85												x		x		
	100												x		x		
	115												x		x		
	130												x		x		
	150												x		x		
157	10					x						x	x		x		
	20											x	x		x		
	30					x						x	x		x		
	40												x		x		
	50					x							x		x		
	60												x		x		
	70					x											

TABLE 2

OCEANOGRAPHIC-BIOLOGICAL CRUISES MADE DURING THE PERIOD 1 APRIL 1955 TO 30 JUNE 1956

Cruise number	Ship	Date	Number stations	Hydrographic stations	Plankton collections	Phytoplankton collections*	GEK observations	Bathythermograph observations	Drift bottles released
5504	*Horizon*	4–19 April (1955)	73	73	73	x	81	233	--
	Crest	6–22 April	54	54	54	x	101	235	647
5505	*Black Douglas*	11 May–8 June	102	--	102	x	59	172	384
	Crest	17 May–2 June	85	--	85	x	101	184	144
5506	*Horizon*	10–28 June	98	63	33	x	112	195	--
	Paolina-T	16–24 June	37	18	37	x	--	44	336
	Crest	10–28 June	57	42	57	x	52	158	356
5507	*Paolina-T*	7–21 July	74	--	74	x	29	63	312
	Crest	7–18 July	44	--	44	x	5	154	299
	Black Douglas	6–22 July	79	--	79	--	92	234	--
5508	*Horizon*	3 August–8 September							
	Black Douglas	3 August–7 September							
	Stranger	9 August–6 September; 14–21 September	162	162	197	x	819	1,162	1,944
	Spencer F. Baird	8 August–19 September							
5509	*Paolina-T*	10–23 September	83	--	83	x	--	202	504
	Black Douglas	13–25 September	86	--	86	x	--	183	589
5510	*Stranger*	14–29 October	56	56	56	--	85	165	--
	Black Douglas	11–30 October	53	53	53	--	80	161	140
5511	*Black Douglas*	8–19 November	76	--	76	--	--	28	504
	Paolina-T	8–20 November	84	22	84	--	--	99	480
5512	*Black Douglas*	2–16 December	42	42	42	--	--	136	--
	Stranger	29 November–16 December	64	63	64	--	96	201	240
5601	*Stranger*	7–19 January (1956)	66	--	66	--	11	177	--
	Horizon	4–14 January	47	--	47	--	82	167	336
5602	*Black Douglas*	2–21 February	93	22	93	--	--	308	174
	Stranger	2–19 February	63	51	63	--	86	184	336
	Spencer F. Baird	2–19 February	69	53	16	x	12	353	--
5603	*Stranger*	2–20 March	82	--	82	--	105	278	--
	Black Douglas	6–19 March	59	--	59	--	--	209	360
5604	*Black Douglas*	4–27 April	128	38	128	x	--	335	228
	Stranger	5–26 April	90	73	90	--	139	403	565
	Spencer F. Baird	5–27 April	89	70	88	--	114	366	432
5605	*Spencer F. Baird*	4–17 May	53	--	53	--	29	278	--
	Black Douglas	4–22 May	94	--	94	--	97	281	432
	Stranger	4–19 May	84	--	84	--	66	262	--
5606	*Paolina-T*	28 May–16 June	67	38	67	--	39	163	276
	Black Douglas	30 May–16 June	85	49	85	--	93	278	--
	Spencer F. Baird	26 May–25 June	62	45	62	--	71	230	444
	Totals		2,640	1,087	2,556	--	2,656	8,281	10,462

* Total number of collections not available. "x" indicates collections were taken.

AIRPLANE SPOTTING

For the third year, the Department carried out a program of aerial spotting of fish schools. The results are shown in Figure 5. The most striking phenomenon is of course the appearance of masses of anchovies off the coast in the spring months of 1956: no such concentrations have been seen before. Spawning studies corroborate the apparent increase in anchovies by indicating that the population may have doubled in the period 1951 to 1955.

Methods of spotting and measuring fish schools from the air are still being worked out. Within the past few months, a method much less subjective than that used before has been tested and it has now become possible to estimate with considerable confidence the total area covered by fish schools. Methods of determining from the air the density of fish within a school have not yet been developed.

ELECTRICAL FISHING

The loss of the *Yellowfin* to the program has meant that the State's very promising experiments with electrical fishing gear have been cut short. The department has contracted with the inventor of a specially designed switch which has been attached to collecting gear of various designs. Results of one of the most successful tests are shown in Figure 6. The aim of the experiments has been to develop gear that would work at sea by dragging or by attracting fish with a light. The fish in the photograph were attracted by a light.

It has long been known (see previous progress reports) that in the presence of an electrical field established by a pulsating direct current, fishes are impelled toward the positive pole. But implementation of that theory in the field has lagged, so far as marine fishes are concerned. The best results achieved so far

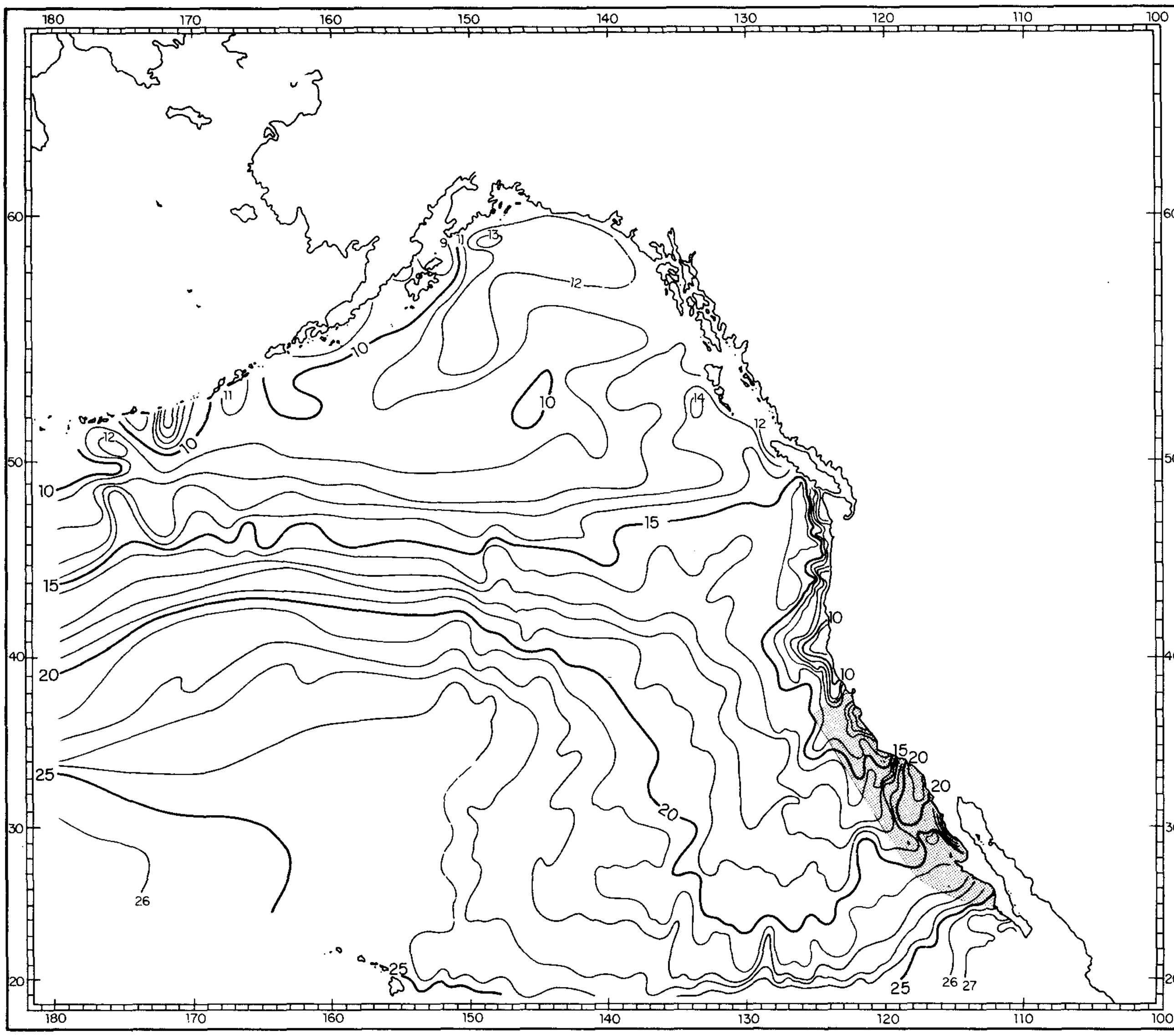


FIGURE 3. Surface temperature of the eastern half of the North Pacific, August, 1955, as shown by NORPAC project. Data for western half were not available at time of drafting, but will be published. Shaded in is the area usually covered by CCOFI surveys during August.

are those obtained by the Department of Fish and Game. Fishery biologists who have worked with the present gear believe it can attract fish of any size at any depth. So far, however, it has been used on small fish (anchovy, sardine, jack mackerel, and Pacific mackerel) close to the surface.

OCEANOGRAPHY OF MONTEREY AREA

The Hopkins Marine Station of Stanford University has continued its studies of the oceanography of the Monterey region. Waters off Monterey are cooler now than they were five years ago and the data suggest that this is the expression of a fairly well-defined long-term trend. The subnormal temperatures cannot be the result of anomalous local weather conditions since they are not limited to the superficial layers but are noticeable to a depth of 500 meters or about 250 fathoms. Practically all of the water mass normally occupied by the great majority of the commercially important fishes in this region is becoming progressively colder.

Since ocean temperatures are characterized by a vertical gradient, the changes in the marine climate may be expressed by plotting the depths below the surface of the various isotherms. The jagged solid line in Figure 7, based on approximately 250 sets of observations taken at weekly intervals off the mouth of Monterey Bay, shows the average depth of the 8° C. (46.4° F.) isotherm by months during the five-year period 1951-55. While there appears to be a general upward trend of the line toward the right (meaning that cold water is nearer the surface), its

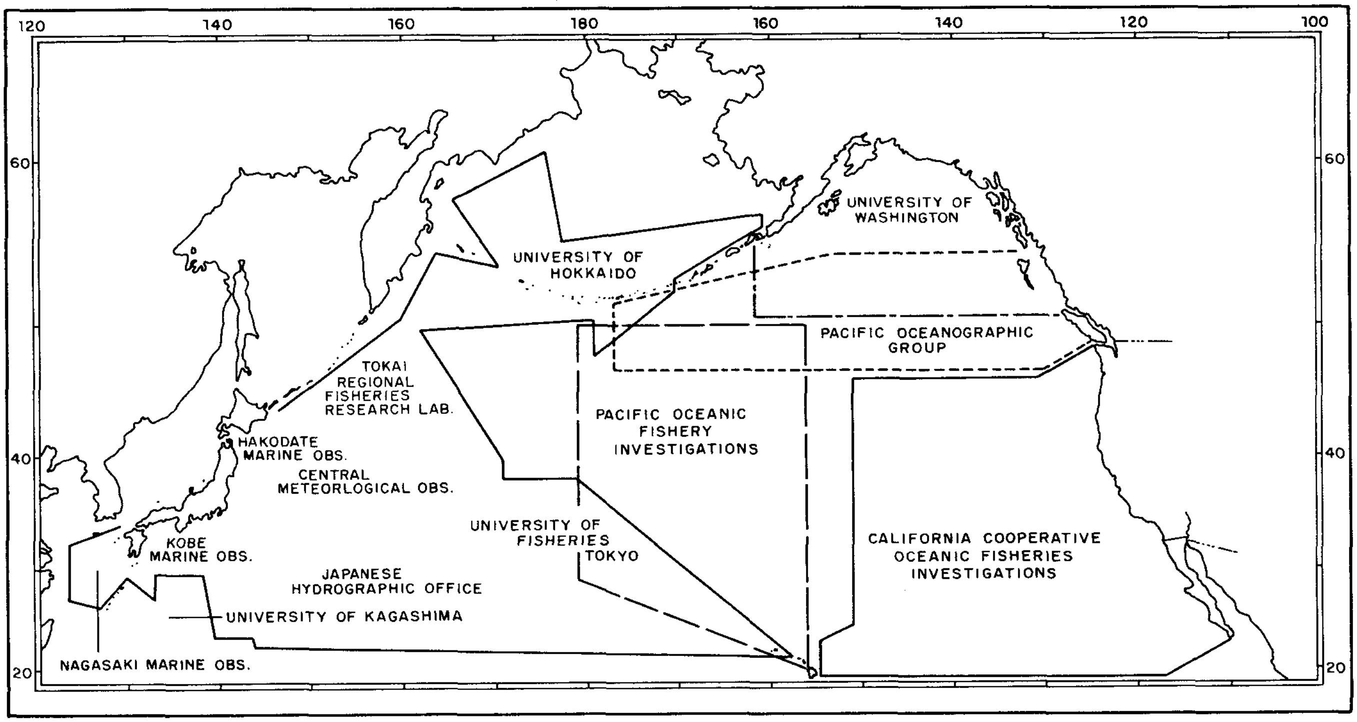


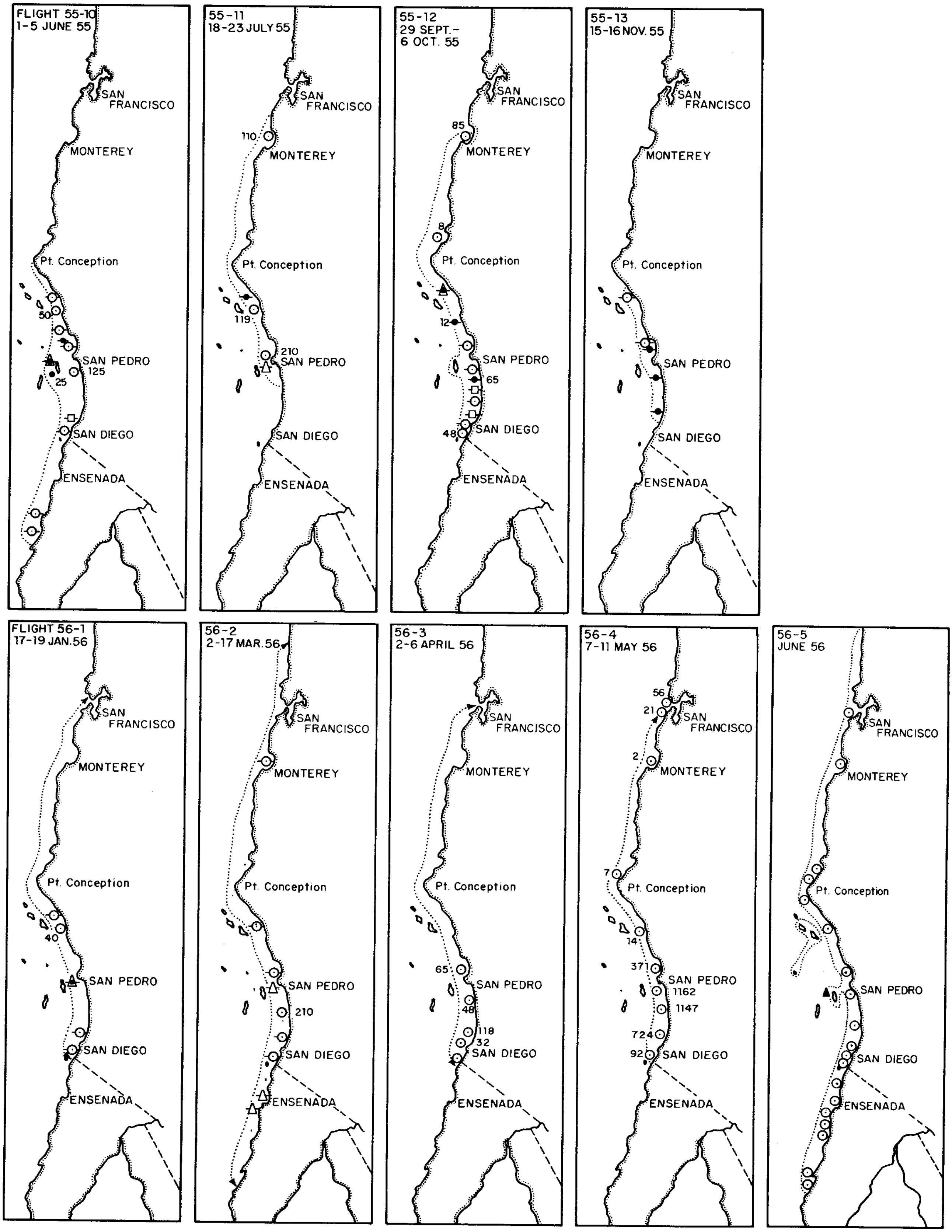
FIGURE 4. Areas covered by different agencies participating in NORPAC project.

magnitude is difficult to estimate because of the irregularities of seasonal fluctuation. The magnitude does, however, become clear if the values are expressed in yearly averages. These are shown by the dashed line extending from the 250-meter level in 1951 to the 220-meter level in 1955. The progressive elevation of the 8° C. water traces a practically straight line between these levels. The almost perfect linear relationship is probably fortuitous, but that the slope of the line is significant is indicated by similar general slopes of the other more irregular isotherms depicted in the same figure.

Marine organisms in general are restricted to specific depths. In some cases the bathymetric range is narrow, in others it is wide, but no organism can occupy all depths. Within the fixed vertical limits of its habitat each organism is restricted in its horizontal distribution by biological, chemical and physical factors, among which temperature is considered to be of prime importance. The northern and southern limits of distribution are usually not marked by sharp physiographic features, but by critical points on gradual temperature gradients—points which fluctuate in latitudinal position from year to year. While other factors such as varying intensity of population pressure may be responsible, it is possible that invasions of new territories, or retreat from old ones previously occupied, may be due to responses to slight changes in ocean climates such as those indicated above. Recent southern extension of the ranges of such fishes as the cod (*Gadus microcephalus*) which are now occasionally being taken in the Monterey area, is correlated with and may be due to the apparently insignificant temperature changes noted. It is possible, although by no means proved, that the apparent shift of the sardine population toward the south has been influenced in some degree by the still more subtle changes in the more superficial layers.

Enrichment of surface waters by upwelling and its effect on the production of phytoplankton, the primary basic food source in the sea, is illustrated by a comparison of Figures 8A and 8B. The latter figure also shows how the physical characteristics of the water and the quantity of plankton production may be used to interpret the patterns of water flow.

During the winter, when upwelling is at a minimum, temperature and salinity are comparatively uniform. On 4 February 1955, at the six stations in Monterey Bay which are indicated by the histograms in Figure 8A, the temperature (dotted bars extending above a base line of 10° C.) showed a range of only 0.69° C., while that of the salinity (white bars extending above a base line of 33°/oo) was only 0.18°/oo. The phytoplankton production (black bars representing wet volume in cc), as indicated by similar net hauls at each station, was low and relatively uniform throughout the area. This particular day yielded volumes approaching the minimum but represents and stresses the conditions found in winter, not only in Monterey Bay but along the entire coast.



● Sardine ⊙ Anchovy △ Jack mackerel □ Pacific mackerel

FIGURE 5. Results of airplane spotting surveys of fish schools. Numerals indicate estimated numbers of schools of fish. A crossbar through a symbol denotes that no estimate was made. Dotted line shows north-south extent of area, but greatly exaggerates distance from shore.

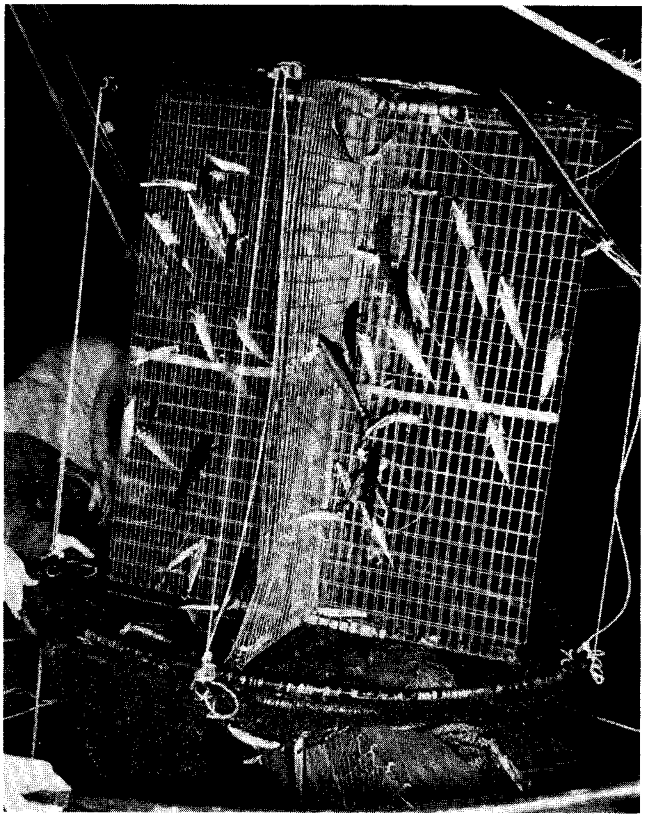


FIGURE 6. Result of an experiment with electrical fishing gear. In this test Pacific mackerel and anchovies were attracted with suffіcent force to firmly lodge themselves in the wire mesh of the electrode. The majority of the captured fish are in the webbing at the bottom of the device. In use, a movable ring draws this webbing from bottom to top to completely enclose any fish attracted to the electrode.

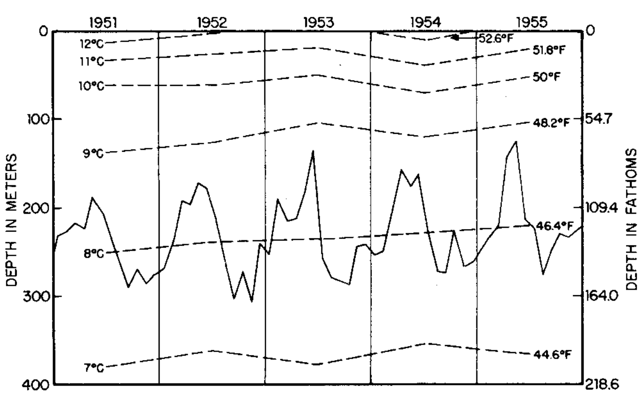


FIGURE 7. Average depth of isotherms, Monterey Bay, 1951-55. The solid line shows monthly values of 8° C. isotherms, the dashed lines, annual averages.

The strikingly different picture presented by Figure 8B shows the situation in summer. During this season the Monterey Submarine Canyon serves to channel the strongly upwelling water which comes to the surface along its course and, depending on local conditions, at various distances from shore. On 7 July 1955, station A, in the major local area of upwelling, gave low temperature and high salinity values indicating water of recent subsurface origin. As the upwelled water spreads over the surface it becomes warmer, owing to solar radiation, and less saline, as a result of mixing with surface layers. The degree of temperature rise and salinity decline provides an index by means of which the comparative length of time which has elapsed since the water reached the surface can be roughly deduced. Stations B and C show a progressive increase in temperature and decline in salinity toward the south and, correlated with these, an increase in phytoplankton volumes; the value of 32 cc at station C indicates rapid growth of the plankton over a considerable period of time. Toward the north, the water at stations D and E, with salinities equal to that at station B, has probably been subjected to the same degree of mixing as that at the latter station, but the higher temperatures indicate that it has been on the surface for a longer period and has had more time to absorb solar energy. This conclusion is strengthened by the rich phytoplankton which surpasses even that found at station C. The physical characteristics of the water at station F, particularly the high temperature, show that it has been on the surface for a comparatively long time. In this case, however, the phytoplankton production is low. The explanation lies in the fact that the water at the extreme northern end of the bay revolves in a relatively permanent eddy and has been at the surface so long that the nutrients derived from the depths have been depleted. As a result the phytoplankton has passed the peak of its bloom and declined.

BEHAVIOR STUDIES

Investigations at the California Academy of Sciences have centered about two problems: (1) whether or not the color of a light is a factor in its attractiveness to sardines, and if so what preference the fish show between various colors; and (2) whether sardines exhibit preference for a definite temperature. If sardines show a marked color preference, this fact should be useful in collecting at sea with a night light. If they show a marked temperature preference, this should be related to where they are most likely to be found at sea.

Experiments were made with white, green, blue, and red lights (all of equal intensity), in which the sardines were given a chance to swim freely from one lighted area into another. The fish showed a definite preference for blue or green light rather than white, but there was no difference in the attractiveness of blue or green. Red light was definitely avoided except when the choice was between red light and darkness. To sum up, the sardines preferred blue and green light to white; blue, green, and white were preferred to red; and all colors tested were preferred to total darkness.

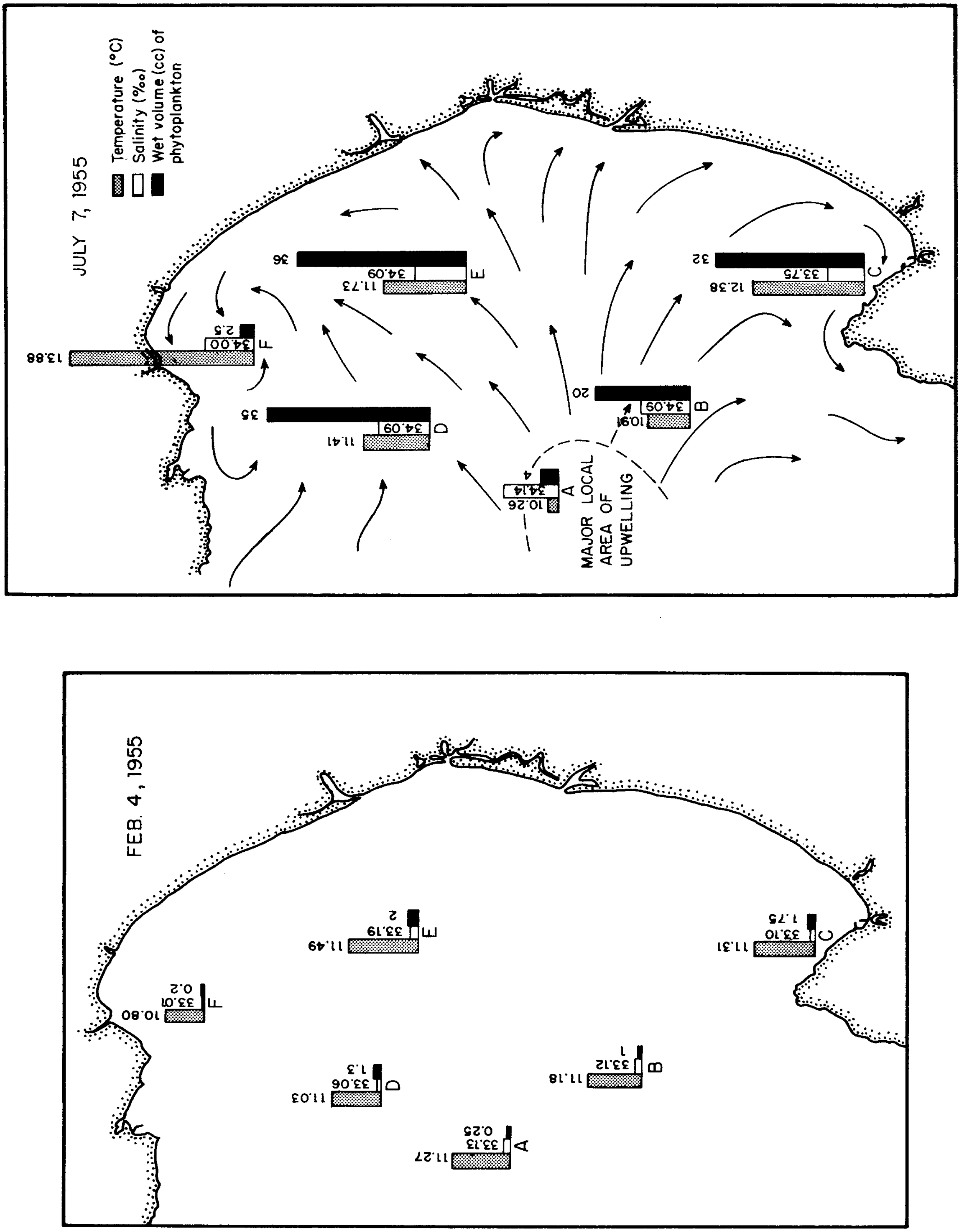


FIGURE 8. Phytoplankton production, Monterey Bay. (A) 4 February 1955; (B) 7 July 1955.

Equipment set up in the laboratory to determine temperature selection consisted of a tank one meter deep in which the temperature varied from 4° C. at the bottom to 34° C. at the top. When placed in this test tank sardines most frequently occupied the 18° C. to 22° C. region. These fish were from aquarium holding tanks where the temperature ranged from 17° C. to 19° C.

Attempts to acclimate sardines to lower temperatures were inconclusive because of a shortage of fish for the experiment, but the role of acclimation in temperature selection was successfully investigated in a similar study of several thousand young anchovies. Anchovies which were acclimated to a temperature of 12° C. most frequently occupied an area in the test tank of 12° C. to 14° C. Those which had become accustomed to a temperature of 17° C. in holding tanks were observed most frequently in the 15° C. to 18° C. area of the test tank, while those which were acclimated to a temperature of 22° C. selected the 18° C. to 20° C. portion of the test tank.

The results indicate that both sardines and anchovies tend to avoid abrupt changes in temperature.

FORECAST FOR 1955-56 SARDINE SEASON

Meeting at La Jolla on 29 June, one day before the end of the reporting period, the Marine Research Committee heard from members of its Technical Advisory Committee that preliminary results on the 1956 sardine spawning indicated widespread spawning off Southern California as far north as San Pedro, in a pattern resembling that of 1955, and that on 25 June, one day later than last year, schools of adult sardines had appeared off Point Hueneme, just as they did in 1955, when a total of 77,000 tons was taken. (Table 3 gives the monthly landings of sardines, anchovies, jack mackerels, and Pacific mackerels in California for the years 1952 to 1955.) It was too early to forecast the results of the coming season in any but the most general terms; however, experts were agreed that none of the year-classes since 1948 has equalled the one of that year, with the weak 1952 year-class the most prominent since.

TABLE 3

LANDINGS OF SARDINE, ANCHOVY, JACK MACKEREL, AND PACIFIC MACKEREL IN CALIFORNIA, 1952-55, INCLUSIVE, IN TONS

	1952	1953	1954	1955
Sardine				
January	1,437.9	458.0	318.4	525.8
February	212.7	137.7	39.0	46.7
March	133.7	91.1	35.6	61.2
April	230.2	73.3	51.0	32.2
May	220.9	20.7	94.6	85.9
June	166.1	136.3	151.6	101.0
July	177.2	212.1	257.9	115.6
August	294.1	174.1	423.9	206.4
September	260.9	577.3	897.4	312.6
October	2,264.8	2,004.5	29,101.2	13,807.8
November	1,033.6	751.0	28,838.9	37,072.5
December	733.1	98.3	8,042.5	20,436.1
Total	7,165.2	4,734.4	68,252.0	72,803.8
Anchovy				
January	9.6	3,113.8	1,810.0	2,670.2
February	44.4	4,908.6	2,531.2	2,324.0
March	0.9	2,485.2	809.4	3,510.8
April	313.1	3,711.9	2,063.5	2,960.2
May	663.7	7,755.5	2,044.5	3,820.4
June	1,809.8	7,881.4	829.0	1,402.7
July	3,134.1	1,999.0	1,752.5	1,479.0
August	3,009.2	1,818.4	2,558.3	1,659.7
September	1,264.1	3,205.1	2,994.1	436.9
October	9,778.8	1,793.0	1,271.9	234.7
November	5,852.8	2,618.2	1,086.4	967.0
December	2,010.5	1,627.6	1,454.3	879.9
Total	27,891.0	42,917.7	21,205.1	22,345.5
Jack Mackerel				
January	2,745.8	701.3	31.8	53.0
February	277.3	121.6	136.6	647.0
March	1,191.2	2,037.2	444.0	512.0
April	3,842.3	7,685.6	427.1	578.5
May	2,922.1	2,448.8	279.8	237.8
June	2,548.2	5,145.1	98.5	134.4
July	4,209.5	5,819.5	3,454.4	4,096.4
August	8,612.4	548.8	2,462.2	2,049.7
September	19,180.0	1,647.9	804.6	316.3
October	9,645.2	1,001.7	0.5	720.0
November	16,486.6	675.1	158.2	3,601.6
December	1,600.2	42.8	369.1	4,930.6
Total	73,260.8	27,875.4	8,666.8	17,877.3
Pacific Mackerel				
January	198.7	53.2	47.7	48.5
February	9.4	31.8	10.8	524.4
March	25.6	0.2	383.9	1,011.5
April	51.8	7.1	313.3	80.1
May	463.7	3.8	188.7	577.5
June	962.9	12.4	144.4	770.7
July	3,142.0	65.3	1,614.7	1,436.4
August	1,797.5	91.8	2,201.6	1,827.4
September	1,108.9	190.6	2,518.0	850.3
October	1,603.9	1,233.6	527.8	1,188.9
November	861.6	1,915.5	3,314.9	1,368.3
December	76.3	145.8	1,430.5	1,971.1
Total	10,302.3	3,751.1	12,696.3	11,655.1

ANCHOVY

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Anchovies were not fished in any great quantities along the Pacific Coast until 1946. In Canada, Washington, and Oregon the catch has been used for reduction and dead bait. Canada's peak catch occurred in 1941 (over 7,000 tons); Washington's in 1949 (over 450 tons); Oregon's in 1953 (84 tons). With the decline of the Pacific sardine stocks, however, the anchovy has been extensively fished off California.

There are two distinct fisheries: live bait and commercial. Each fishery is represented by different fleets of boats using different types of gear, and the statistical records of each are compiled separately. Each is treated individually in the historical discussion which follows.

THE COMMERCIAL FISHERY

Catch Records

The California commercial anchovy catch is utilized for the following purposes: dead fish-bait (fresh, frozen, salted, and chemically treated), fresh market fish, reduction into meal and oil, canning for both human consumption and pet food, "chum" for use in the Pacific mackerel scoop fishery, and fish food used in state fish hatcheries.

The year 1916 marks the inception of tabulation of fish and fishery products landed in California ports. From then to 1956 about 200 tons of anchovies have been landed yearly as dead bait for use in the sport fishery and in the commercial salmon and albacore fisheries. Any appreciable increase in the catch above this quantity can be attributed to increased demands for other commercial purposes. Several periods of increased catch are indicated in Table 4.

TABLE 4

CALIFORNIA ANCHOVY LANDINGS BY PORT, 1916-55 (IN TONS)

Year	Eureka	San Francisco	Monterey	Santa Barbara	Los Angeles	San Diego	Total
1916	--	119.8	125.7	--	20.1	--	265.6
1917	--	50.1	187.8	--	26.4	--	264.3
1918	--	134.2	270.2	--	24.7	4.9	434.0
1919	--	153.0	352.5	--	288.4	10.8	804.7
1920	--	110.6	156.9	--	2.3	15.1	284.9
1921	--	87.6	741.4	--	5.2	139.1	973.3
1922	--	75.4	68.2	--	182.4	0.2	326.2
1923	--	92.0	42.5	--	19.0	--	153.5
1924	--	5.3	148.5	1.7	17.9	--	173.4
1925	--	13.0	0.7	--	32.8	--	46.5
1926	--	1.7	24.3	--	4.1	--	30.1
1927	--	139.1	28.3	--	16.1	0.6	184.1
1928	--	62.8	87.7	--	27.9	0.3	178.7
1929	--	119.8	41.0	--	30.4	--	191.2
1930	--	130.9	21.7	--	5.2	1.9	159.7
1931	--	82.3	52.4	--	18.9	0.1	153.7
1932	--	73.8	60.0	--	15.8	--	149.6
1933	--	92.5	45.4	--	20.7	--	158.6
1934	--	33.5	63.7	--	31.5	--	128.7
1935	--	37.2	38.2	--	14.0	--	89.4
1936	1.0	66.5	15.1	--	14.9	--	97.5
1937	--	51.0	22.1	--	40.0	--	113.1
1938	--	125.9	17.0	--	224.6	--	367.5
1939	--	107.4	6.0	--	960.5	--	1,073.9
1940	--	6.9	18.7	--	3,125.9	7.3	3,158.8
1941	--	0.3	16.6	16.6	2,019.1	--	2,052.6
1942	--	2.7	74.5	--	769.7	0.2	847.1
1943	--	39.4	99.2	--	646.8	--	785.4
1944	--	55.0	424.0	--	1,465.1	1.4	1,945.5
1945	0.2	146.0	63.9	--	598.3	--	808.4
1946	--	131.9	124.0	2.5	702.2	0.2	960.8
1947	2.2	195.1	7,747.9	99.7	1,423.5	1.8	9,470.2
1948	6.8	190.1	3,627.8	102.1	1,486.2	4.9	5,417.9
1949	--	108.2	741.4	240.8	566.6	4.1	1,661.1
1950	0.4	169.3	1,273.3	145.9	850.1	0.3	2,439.3
1951	--	142.0	2,525.0	100.8	703.2	6.4	3,477.4
1952	--	2,915.5	19,867.8	3,516.8	1,578.7	12.6	27,891.4
1953	--	1,536.3	6,847.5	17,367.6	17,164.9	1.4	42,917.7
1954	0.7	130.9	122.6	8,403.7	12,546.0	1.2	21,205.1
1955*	--	103.4	3,441.7	1,630.8	17,166.6	3.2	22,345.7

* Preliminary figures.

The first increase of catch occurred during the period from 1918 to 1921 when anchovies were reduced for oil and meal in Central California. In 1922 there was an immediate halt to this activity for in 1921 "teeth" were put into a law enacted in 1919 that made it illegal to reduce any fish (other than a certain percentage of sardines) without a special permit issued by the Fish and Game Commission.

During the period from 1922 to 1939 the annual catch remained around 150 to 200 tons, the bulk being used in Central California for dead bait. The second marked increase of the commercial catch commenced in 1939 with the expansion of the anchovy fishery in Southern California, where only small poundages had been landed before. In 1939 there was a marked increase in the take of anchovies, which were ground and used as "chum" in the Pacific mackerel scoop fishery. In the period 1939 through 1941 between 1,000 and 3,000 tons per year were so used. During World War II fishing activity was limited and the catch of anchovies dropped. The bulk was still used in Southern California in the mackerel fishery.

With the decline of stocks of Pacific mackerel and sardines off the coast of California, an immediate need arose for packs of other species to supply domestic and foreign markets. Inasmuch as anchovy stocks appeared large enough and could be taken with current fishing methods, many experimental packs were made. Domestically, they encountered serious sales resistance, but the anchovy "sardine style" pack in tomato sauce was favorably received in several Asiatic and South American countries. The industry then centered its activities on processing fish that could sell readily on the export market. The catch increased from about 1,000 tons in 1946 to over 9,000 tons in 1947. In 1948, in response to this rapidly expanding use of anchovies, the then Division of Fish and Game placed case pack requirements upon the canners to insure proper handling of the fish and to prevent excessive reduction of whole fish during the canning process.

In 1949 and 1950 sardines temporarily "returned" to Californian waters; as a result there was lessened interest in anchovies and the catch lessened. However, when the sardines declined rapidly in 1951, anchovies were again desired and permanent markets for anchovy products were sought, for it now seemed that the sardine population was indeed at a very low level of abundance. In 1952 the remaining Central California plants went into nearly full production, utilizing anchovies taken along the coast from Monterey to Point Reyes. In early 1953 the anchovy concentrations off Central California became very limited and fishing activity was centered in the Port Hueneme-Santa Barbara area. The export market continued to serve as an outlet for anchovy packs and domestic sales also increased.

Coincident with the development of anchovy canning in 1946 was the increased use of fishery products in pet foods. Pacific and jack mackerel were the main constitutents of these packs, but in 1953 and in 1954 a ready supply of these species was not available and anchovies were used for pet food. The combined use of anchovies for dead bait and canning brought about an all-time peak commercial catch of over 42,000 tons in 1953.

The decrease of the catch in 1954 and 1955 can be attributed to several factors, the principal one being limited orders for export packs, partly because of the competition with "sardine style" packs produced in South Africa and Japan. There was also considerable speculation in 1953 and it is probable that reserve inventories on hand in 1954 contributed to the smaller take. Sardines again appeared in commercial quantities off Southern California in 1954 and in 1955 and during the sardine season little interest was paid to anchovies, thus contributing further to the decrease in catch.

It is doubtful whether the yearly commercial catch has ever been limited by the supply of fish. It is known that variations in abundance and distribution of anchovy stocks have limited operations in certain areas but this has usually resulted in a mere shift of operations to other areas and the state-wide yearly tonnage has probably not been affected.

Since anchovies have become commercially important and live-bait catches are increasing yearly there has been a growing concern about the possibility of over-exploitation of the anchovy stocks along the coast of California.

In 1955 legislation was enacted as follows:

"During the period from September 1, 1955 to March 31, 1956, the total amount of anchovies which may be taken or received for canning, including canned pet food, shall not be more than 21,000 tons. During the period from April 1, 1956, to March 31, 1957, the total amount of anchovies which may be taken or received for canning, including canned pet food, shall be not more than 35,000 tons."

The 35,000-ton figure was arrived at by averaging the total catches for the years 1952 and 1953.

To insure that young, immature anchovies are not processed the following regulation also was enacted in 1955:

"No anchovies less than five inches in length measured from tip of snout to tip of tail may be purchased for any purpose except for use as bait; provided, that the allowable percentage of undersized anchovies which may be contained in any load or lot purchased shall be not more than 25 percent by weight of all anchovies in said load or lot."

Fishery Methods

From 1916 to 1946 anchovy fishing was conducted almost solely by fishermen using "Monterey style" lampara nets. "Half-ring" and purse seine nets were occasionally used to take anchovies, but these nets were primarily used in the sardine and mackerel fisheries. With the advent of anchovy canning, large tonnage hauls were desired by the processors and more net boats using purse seines were employed. Efficiency and expediency were desired, for even though export orders were large, they were limited, and the operation that could pack the most fish made the most profit.

In 1946 a postwar daytime fishery developed in the Port Hueneme-Santa Barbara area when jack mackerel became important. For several years thereafter three or four aerial spotters worked in conjunction with six to ten boats developing new fishing techniques and becoming familiar with the behavior of many commercially important species, including the anchovy. A new style lampara net (named the Porter seine after one of the principal inventors) was developed to catch fish more efficiently under the guidance of an aerial observer. Thus, when the market for canned anchovies developed in Southern California, in 1952, the daytime operation came into its own and proved to be more efficient than the purse seine nighttime operation that had worked so successfully in Central California. Within a year many more boats adopted the Porter seine or a net of similar construction and in 1954 as many as eight aerial observers were known to be operating at one time in Southern California.

Transport of small pelagic fish caught in areas 80 to 100 miles from the processing plant has always been an economic hardship to the fishing industry. Most boats cannot efficiently carry loads of fresh fish for long distances because of spoilage and/or mechanical breakdown. To solve this problem, trucking was undertaken when long distances were involved. This method was used first in 1946 when sardines became scarce in Central California waters. It was sufficiently successful to warrant its use in late 1952 and early 1953 when a commercially important concentration of anchovies appeared in the Port Hueneme-Santa Barbara area. These fish were trucked to Central California and to the Los Angeles-Long Beach area on a grand scale. This era was short-lived, however, for in mid-1954 concentrations of anchovies appeared near the ports where the processing plants were located, enabling the fishermen to bring the fish directly to the cannery. Some short-distance trucking still continues but only to inland canneries having no boat landing facilities.

LIVE-BAIT FISHERY

The live-bait fishery of Southern California has increased steadily since the first records were obtained in 1939. These records, which include the total number of scoops and the number of hauls per year for each boat in the fleet, have been tabulated since 1939 except for a three-year period during World War II (1943-45). Anchovies have always been the mainstay of the live-bait fishery. Prior to 1951, 15 to 20 percent of the live-bait catch consisted of young sardines but since that date only traces of sardines have been mixed with the anchovies. The yearly live-bait catch has ranged from 1,500 tons in 1939 to nearly 7,000 tons in 1952 (see Table 5).

TABLE 5

LIVE-BAIT CATCH OF ANCHOVIES IN SOUTHERN CALIFORNIA, 1939-55 (CATCH FROM 1942-45 NOT RECORDED)

Year	Catch (tons)
1939	1,503.2
1940	2,006.0
1941	1,587.7
1942	257.5
1943	--
1944	--
1945	--
1946	2,748.1
1947	2,854.0
1948	3,725.5
1949	2,802.4
1950	3,823.8
1951	5,141.9
1952	6,810.4
1953	6,391.5
1954	6,686.0
1955	6,122.3

The most common current method of attracting anchovies for live bait is with a bright light suspended from a skiff at night. This light attracts the fish and causes them to concentrate near the surface around the skiff. The skiff is usually placed in bays or semi-protected coves in late evening and when sufficient fish have been concentrated, a boat using a small "bait" net encircles them. After they are crowded into a small section of the net they are scooped out with a long-handled brail into live-bait tanks on sport boats en route to the sportfishing grounds or are transported short distances in bait tanks to floating bait receivers situated near the centers of sportfishing activity. "Scoops" range from nine pounds per scoop at San Clemente City to 20 pounds per scoop at San Diego. Live bait is also taken in the early morning hours by boats making "sets" on visible surface schools. Within the past few years daytime catches of live bait have been made by boats working in conjunction with aerial observers.

The market for live bait has not been subject to the economic instability characteristic of the anchovy commercial market. There is a demand for live bait throughout the sportfishing season in Southern California (April through October) and if anchovies are present there is a limited but steady market.

The live-bait fishery is, however, dependent upon local stocks of anchovies as live fish are difficult to transport over long distances without specialized equipment and even then it is a costly operation. On the other hand, the commercial fishery utilizes anchovies from anywhere along the coast.

The use of live bait for sportfishing originated in the southern part of the state and has spread slowly to the north. At present the northernmost live-bait operation is at Morro Bay.

LIFE HISTORY

The northern anchovy, *Engraulis mordax mordax,* is one of the most abundant of the schooling pelagic fishes along the Pacific coast of North America. Adults of this species have been collected from Magdalena Bay, Baja California, to the north end of Vancouver Island; eggs and larvae have been found as far offshore as 300 miles. This species is more "shore-bound" than most of the other schooling pelagic fishes. Seldom are concentrations of adult anchovies found farther than 20 miles from shore. Apparently the distribution and behavior of the spawning adults offshore is quite unlike that exhibited by anchovies when they school in the inshore continental shelf area. Adult anchovies have not been observed schooling near the surface offshore nor have they been readily attracted to a light at night.

Subpopulations

Of primary interest are the problems regarding the existence of more than one population of anchovies within the range of their distribution, the probable geographic boundaries of these subpopulations, and the extent of intermingling between them.

Subpopulation studies (McHugh, 1952) based on meristic counts of fin rays, gill rakers, and vertebrae revealed the probable occurrence of at least three subpopulations along the Pacific coast: one extending from British Columbia to Northern California, one off Southern California and northern Baja California, and one off central and southern Baja California. An additional meristic study has substantiated the previous work. An anchovy population which inhabits San Francisco Bay has been given the subspecific name of *E. m. nanus* by Hubbs (1925).

There is a fairly continuous offshore distribution of anchovy eggs and larvae between San Francisco and Magdalena Bay. This fact tends to cast doubt upon the validity of the subpopulations delimited by McHugh because there does not seem to be a separation either in space or time of the spawning adults. Most structures used in meristic studies are formed during the egg and very early larval stage. If there was homogeneous spawning throughout the entire distributional range and if survival of the young from this spawning was relatively equal throughout, there would be little chance of detecting a subpopulation by this method. However, the fact that there are persistent, significant meristic variations between stocks along the coast stimulates the need for additional studies on the life history of the anchovy, especially movements between the areas mentioned.

Commercial and live-bait catch records and sampling localities from the *Yellowfin* have aided in clarifying the picture but as yet the data are insufficient to justify positive determination of the subpopulations, as distinguished by McHugh. The following summary of anchovy life history data is pertinent to the subpopulation problem:

(1) By following locations of catches and by noting movements of fish through aerial survey it has been found that the anchovy does not exhibit an extended latitudinal migratory behavior as does the Pacific sardine. Concentrations of anchovies in Central California have been studied for several years and no movement to the south in late fall and winter has been noted. Actually there was some evidence that anchovies in Monterey moved north along the coast to the San Francisco region in late fall and winter of 1952.

(2) There is a significant break in the inshore distribution of adult and juvenile anchovies in Central California (Figure 9). Over the past six years no samples of anchovies have been taken on the *Yellowfin* in the area between Monterey and Cape San Martin. Similarly no commercial or live-bait catches have been made in this area.

(3) Age and growth studies of the commercial catch indicate a high degree of heterogeneity of anchovy stocks in Central and Southern California. When anchovies decreased in abundance in early 1953 in Central California there was a coincidental increase

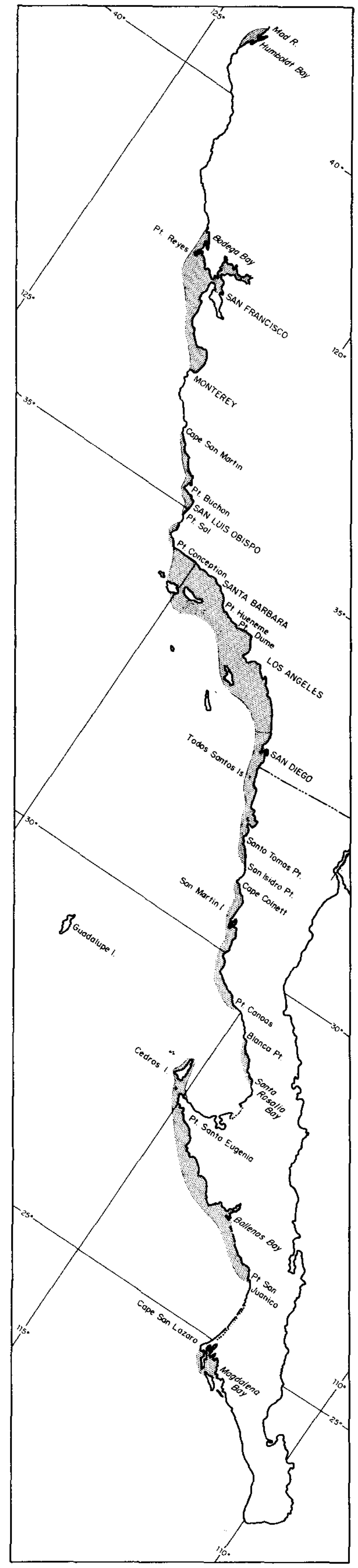

FIGURE 9. Adult anchovy distribution inshore. Data from commercial and live-bait catches; *Yellowfin* samples, 1949-53; and aerial observations, 1952-55.

in the stocks off Southern California a few months later. Consequently it was thought by many that these observations represented a mass movement of the fish from Central California to the southern part of the state. Analyses of samples collected in both regions proved this not so. It was found that 49 percent of the anchovies caught off Central California in February and March, 1953, were of the 1949 year-class and older, whereas only 3.7 percent of the fish in the Santa Barbara region from April to July, 1953, were of these year-classes. Thus the fish that "disappeared" off Central California obviously did not reappear off Southern California. The age composition of the 1952-53, 1953-54, and 1954-55 commercial catch (Figure 10) demonstrates considerable differences in the ages of the Southern and Central California stocks.

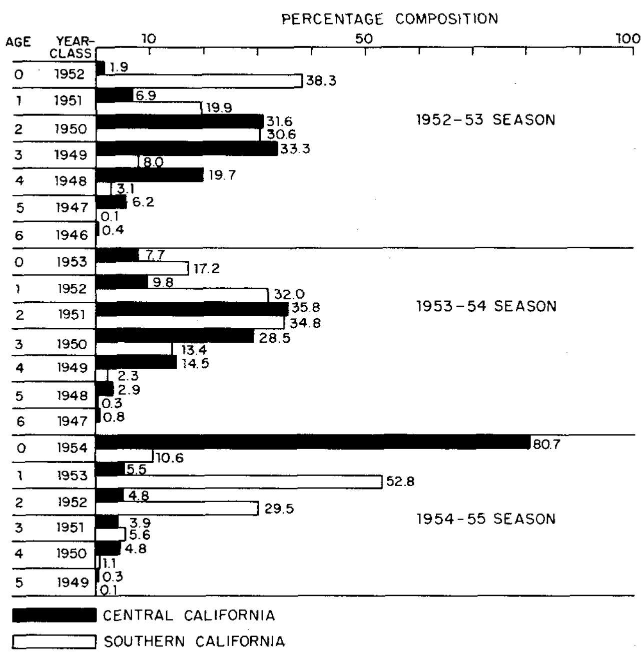

FIGURE 10. Age composition of the 1952-53, 1953-54, and 1954-55 California commercial anchovy catch. The anchovy season extends from 1 April to 31 March of the next year.

(4) Heterogeneity of stocks in the Southern California region is evident when one examines the results of the 1955 live-bait sampling program. Although no significance tests have been applied to the data, preliminary analyses reveal indications of local stocks and of possible mass movements of fish along the Southern California coast. The 1954 year-class made up only 7.0 percent of the live-bait anchovy catch at San Diego in April and May (Table 6) whereas all fish at Santa Barbara were of the 1954 year-class during this same period. Except for a large percentage of 1954 year-class anchovies at Oceanside there was a progressive increase in strength of the 1954 year-class to the north or, conversely, a progressive decrease in the 1953 and 1952 year-class strength from San Diego to Santa Barbara in April and May, 1955. By comparing year-class strength (grouped in two-month intervals from April through November) of anchovies caught at San Diego, Port Hueneme, and Santa Barbara evidence is found of a movement either upcoast or inshore (or both) of a stock of anchovies consisting mainly of 1953 and 1952 year-class adults. There was a continuing increase in the percentage of these older fish in the Port Hueneme and Santa Barbara areas (Table 7) whereas at San Diego the relative percentages of the 1952, 1953, and 1954 year-classes remained fairly constant throughout the entire period from April through September, 1955. It is hoped that with increased sampling of both the live-bait and commercial fisheries and the development of a systematic airplane-boat survey, seasonal movements and changes in abundance can be measured and followed more accurately.

TABLE 6

PERCENTAGE AGE COMPOSITION OF LIVE-BAIT ANCHOVY CATCH, APRIL AND MAY, 1955

Port	Year-Class			
	1955	1954	1953	1952
San Diego	--	7.0	73.5	19.5
Oceanside	0.3	68.8	30.3	0.6
San Clemente	--	35.6	58.8	5.6
Newport	--	51.8	41.7	6.5
Los Angeles	0.4	58.0	38.4	3.2
Santa Monica	--	87.8	11.5	0.7
Port Hueneme	--	76.4	20.4	3.2
Santa Barbara	--	100.0	--	--

TABLE 7

AGE COMPOSITION BY TWO-MONTH INTERVALS OF THE LIVE-BAIT ANCHOVY CATCH AT THREE PORTS IN 1955

Months	Year-Class				
	1955	1954	1953	1952	1951
A. San Diego					
April-May	--	7.0	73.5	19.5	--
June-July	1.7	20.2	68.5	9.6	--
August-September	18.9	17.9	57.2	6.0	--
B. Port Hueneme					
April-May	--	76.7	20.1	3.2	--
June-July	16.5	60.3	14.7	8.5	--
August-September	15.1	52.0	25.2	7.7	--
October-November	2.0	38.0	48.0	11.0	1.0
C. Santa Barbara					
April-May	--	100.0	--	--	--
June-July	--	90.6	8.3	1.1	--
August-September	19.7	57.7	18.5	4.1	--
October-November	12.0	43.0	44.0	1.0	--

Abundance

For many years fishermen have stated that anchovies are unpredictable as to where they will appear and how many will be there when they do appear. At times during the years of heavy sardine fishing, certain areas along the coast were avoided because of the concentrations of anchovies present. During other years it was reported that there was apparently little intermingling between sardines and anchovies on the fishing grounds. Research conducted in 1938, 1939, and 1940 (Phillips and Radovich, 1952) pointed out that large numbers of anchovy schools were present in the inshore young sardine nursery areas.

It is difficult to estimate either a relative or absolute abundance of anchovy stocks prior to 1946 for little effort was made by fishermen and research agencies to learn about their movements or to take note of changes in abundance. Since 1946, more attention has been given the anchovy by researchers and the fishing industry and with the advent of aerial observations concentrations are now readily discovered and the news is quickly circulated. The apparent increase in anchovy stocks since 1950 may be attributed in part to the increased attention given to anchovies and to the relatively large size of the anchovy stocks in comparison to the scarcity of stocks of other species, but studies under way do suggest that there was an actual increase in Southern California stocks, especially in 1952, 1953, and 1954, and a decrease in these same years in Central California.

Since 1952, records of movements of anchovies entering the Southern California inshore area suggest that there is an increase of adult anchovies in the early spring (March-April), a peak of abundance sometime in June, July, or August, and a decrease in numbers in the fall and winter months. In Central California the occurrence of concentrations or school groups has been more erratic and there is little suggestion of a seasonal pattern as has been observed in Southern California. The population has been much smaller in Central California and consequently the movements of the fish have been more difficult to follow.

Fluctuations in abundance and seasonal changes in availability are exhibited by all schooling pelagic species, particularly anchovies. The anchovy is a comparatively short-lived fish. Few ever attain six years of age, indicating a very high natural mortality rate. Recent food studies of larger predatory fishes have disclosed that anchovies constitute a major food item. Stomach analyses of ocean-caught adult king salmon (*Onchorhynchus tshauytscha*) have disclosed that anchovies made up 36 percent of the yearly feed of salmon sampled off San Francisco in 1955.

In view of the fact that anchovies are very short-lived, sudden decreases in total abundance are certain to occur if, by chance, there should be several consecutive years in which spawn survival was poor. A constant recruitment would be necessary to maintain a continuous high-level population but such consistency is unknown among pelagic fishes. In heavily fished Central California the local stocks of comparatively old fish (three-, four-, and five-year-olds) decreased very rapidly in the spring of 1953. Age readings of the commercial catch and routine plane and boat censuses indicated that the 1951, 1952, and 1953 year-classes were weak off Central California and that total mortality was probably considerably greater than recruitment during these three years. Conversely, the 1951, 1952, and 1953 year-classes were strong off Southern California and despite a heavy catch the anchovy population has remained at a high level of abundance. Apparently recruitment was greater than or as great as total mortality in Southern California.

For a look into the future, the anchovy stocks of Southern California will probably remain at a high level of abundance for several more years, since estimates of the 1954 year-class indicate that it is as strong as or possibly stronger than any year-class measured since 1952, when intensive research was started on the anchovy. The 1954 year-class has already contributed materially to the comeback of the Central California fishery (Figure 5) and aerial censuses indicate an increasing buildup of anchovy stocks in Monterey Bay and off San Francisco.

Reproductive Potential

As with all animals subjected to high mortality and a consequent short life the anchovy has a high reproductive capacity. The presence of developing intermediate modes of eggs in the mature ovary, similar to that of the Pacific sardine (Clark, 1934), indicates that an anchovy spawns more than once a season. Of special significance is the fact that anchovy spawning takes place during every month of the year along the California and Baja California coast (Bolin, 1936, and Ahlstrom, 1950). Material supplied by research on the *Yellowfin* (Cruise 53-Y-8) showed an abundance of young 1953 year-class anchovies in Baja California in September and October of that year. These young fish apparently originated from two distinct spawnings since two modes show in the length-frequency data (Figure 11). Most records of young fish concentrations indicate that the spawning during early winter and spring contributes most to the annual recruitment of young fish.

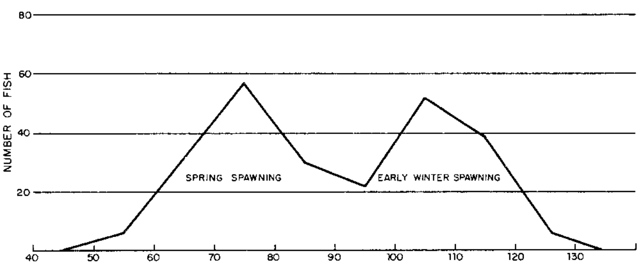

FIGURE 11. Number of anchovies by length grouping of the 1953 year-class in September and October, 1953, off Northern Baja California (data from Cruise 53-Y-8).

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JACK MACKEREL

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HISTORY OF THE FISHERY

The early history of the jack mackerel fishery is at best obscure. Records are scanty for the years prior to 1926 and often mention simply "mackerel"—meaning either jack or Pacific or both.

Records of the State of California commence in 1916, but through 1925 do not distinguish between Pacific and jack mackerel. During this period the total catch of the two did not exceed 1,000 tons, and probably consisted mostly of Pacifics.

Commencing in 1926, landings of Pacific and jack mackerel were segregated in the catch statistics. The Los Angeles region has been the dominant area of landing throughout the entire history of the jack mackerel fishery, but substantial landings have been made on occasion also at Monterey and Santa Barbara.

From 1926 through 1932 the state-wide catch did not surpass 350 tons. Landings increased in 1933 and 1934 and then rose sharply to nearly 5,000 tons in 1935, virtually all of which was delivered in the Los Angeles regions.

After 1935, landings dropped considerably, falling to a low of 717.5 tons in 1940. During the next six years, catches were much more substantial, surpassing 7,500 tons in 1946. It was in 1947 that the fishery experienced its tremendous expansion. Landings reached nearly 65,000 tons, of which 56,500 were delivered in the Los Angeles region. It has been of major importance since; in 1950, the peak year, nearly 67,000 tons were landed state-wide.

Records of catch by gear are not available for early years; however, it is assumed from statements made by various researchers that the bulk of the commercial catch has always been taken with encircling nets—lamparas, ring nets, and purse seines.

Jack mackerel have always been taken in limited numbers by rod and reel anglers fishing off Southern California. From 1947 until 1952 the number of jack mackerel caught by sportfishermen ranged between 200 and 4,500 (Table 8).

TABLE 8

JACK MACKEREL SPORT CATCH

Year	Number	Best month
1947	4,500	September
1948	2,400	August
1949	2,900	August
1950	600	July
1951	200	July
1952	4,400	May
1953	196,300	August
1954	19,400	June
1955	39,600	May

Only during 1950 and 1951 were fewer than 2,400 reported. In 1953, quantities of large jack mackerel appeared in the inshore waters off Southern California and they became a much sought-after species. As a result, nearly 200,000 were caught on hook and line. In 1954, the catch dropped about 20,000 but rose to around 40,000 in 1955. These fish are all large, ranging in length from 18 to 30 or more inches and in weight to five pounds. They appear in quantity in the inshore waters only for a month or two each summer and the season is accordingly short. They are excellent fighters and the flesh is of fine flavor.

In the very early years of the commercial fishery, jack mackerel commanded a slightly higher price per pound than Pacifics. All were sold on the fresh-fish market. Since the advent of canning and the attendant increase in jack mackerel landings, they have usually ranged in value somewhere between the prices paid the fishermen for Pacific mackerel and sardines. The price climbed rather steadily from $6 per ton in 1935-36 to $60 in 1947. Since 1947, the price has fluctuated rather widely, both between and within seasons. Jack mackerel have never brought more than the $80 per ton realized for a short time during the 1953 season.

In general the Southern California fishing grounds for jack mackerel have been the same as those for Pacifics and sardines; the mainland coast from Point Conception to the Mexican boundary and offshore to include the Channel Islands. At Monterey, most of the catch has been made within the boundaries of the bay and delivered to canneries at Monterey and Moss Landing.

Most of the fish in the commercial catch since 1947 have measured from about 8 to 15 inches in total length. These sizes are almost identical to those given for fish taken in the early 1890's. On rare occasions catches are made which consist entirely of extremely large individuals ranging upward to 30 inches in total length. The distribution of adult jack mackerel appears to correspond closely to that given for eggs and larvae. For that and other reasons it is thought that the fishery is exploiting only an inshore margin comprised of the younger age groups of the jack mackerel population.

Adult jack mackerel have been taken along the mainland coast of North America from British Columbia south to Cape San Lucas. Juveniles have been captured south of Cape San Lucas at the Revillagigedo Islands by departmental research vessels and at Acapulco and in the Gulf of Tehuantepec, Mexico, by others. Although the occurrence of the species at localities south of Cape San Lucas is unquestionable, there is considerable doubt that jack mackerel have ever occurred in commercial quantities any great distance south of Magdalena Bay, Baja California. Offshore, adult jack mackerel have been captured in quantity around all of the various islands and near-shore fishing banks and to a lesser extent in much of the area 600 miles and more from the nearest point of land off Southern California.

Routine sampling of the commercial catch commenced in July, 1947. This phase of the work provides information as to the sizes and ages of the fish entering the commercial catch. The otoliths (ear bones) have been found satisfactory for age determination. Examination of several thousand sets of otoliths shows that the commercial fishery is almost entirely dependent upon fish less than six years of age. The sport-fishery generally captures larger fish and some of these have been aged reliably at over 30 years.

Fifty percent of the female jack mackerel 250 mm long (to the fork of the tail) are sexually mature. These fish are two years old. Not until age three (length, 350 mm) are 100 percent of the female jack mackerel mature. Although spawning takes place from March through October, peak spawning does not occur until May and June. Individual females spawn more than once during a season.

FOOD

In carefully conducted food studies on juvenile and adult jack mackerel it was found that over 90 percent by numbers of the identifiable items consisted of three types of animals: euphausiids, large copepods, and pteropods. All are small crustaceans found in the upper layers of the ocean. It was determined by these studies that the jack mackerel, unlike the sardine, is a selective feeder, that is, the food is taken by a definite act of capture on the part of the jack mackerel. General observations of fish sampled at the cannery unloading docks indicate that at times jack mackerel feed heavily and almost exclusively upon juvenile squid and anchovies. On the other hand, the stomachs of large jack mackerel taken considerable distance offshore were found to be filled with lantern fishes, which live at some depth in the ocean. These mackerel were attracted to a bright light suspended from the stern of a vessel at night and probably had eaten the lantern fish (also attracted to the light) at the surface rather than at depths. The sport-caught jack mackerel are usually taken on hooks baited with large, adult anchovies.

RESEARCH UNDER WAY

Routine Sampling of the Commercial Catch

This is a continuous study carried on throughout the fishing season when fish are being caught. Considerable information is obtained from the fishermen at the time of sampling and measurements, weights, and sex determinations are made on the fish in the sample. Otoliths are saved from some specimens for use in age determinations.

Compilation of Catch Statistics

This is a continuing project carried on by the Department's statistical unit. Annual catches are compiled by boat, by locality, by date, by gear, etc.

Age Composition of the Commercial Catch

Otoliths are on hand for all seasons from 1947 to the present. Over half of these have been aged and when the remainder have been determined publication of the results can be made.

Relationship of the California Jack Mackerel to Those Found in Other Areas and Oceans of the World

As material becomes available an attempt is being made to determine whether and/or how *Trachurus symmetricus* can be distinguished from the dozen or more species of *Trachurus* known throughout the world.

Vessel and Plane Surveys

Departmental research vessels and planes are used throughout the year to survey the fishing areas and other inshore waters in an attempt to evaluate the quantity of jack mackerel available to the fishery. Samples are taken of the schools encountered and these data enter into the measures of population density.

Sampling Device Evaluation

Every effort is being made continuously to improve sampling techniques, particularly from aboard the Departmental research vessels. The entire success or failure of a population estimate depends upon the adequacy of the sampling program. To insure best results requires continual evaluation and refining of established methods and searching for or developing new or improved techniques, gear, etc.

PACIFIC MACKEREL

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THE FISHERY

The Pacific mackerel, *Pneumatophorus diego*, is a true mackerel. (The jack mackerel is a member of another family, the Carangidae, or jacks; the yellowtail and scad also belong to this family.) Like all members of its family the Pacific mackerel is a pelagic, schooling fish with erratic migratory habits. The range of the Pacific mackerel is at least from southern Alaska to the tip of Baja California into the Gulf of California, and along the mainland coast of Mexico to Banderas Bay. It is not readily distinguishable from either *P. peruanus*, found from Panama to Chile and at the Galapagos Islands, or *P. japonicus* in the western Pacific and its exact relationship to these is not at present completely understood.

Because of their erratic migratory habits mackerel are not continually abundant at any one spot, nor are they equally abundant at all times of the year. There are definite periods of abundance and scarcity which occur every season at about the same time. They are not abundant north of Monterey Bay and those occurring south of central Baja California probably are not important to the California fishery. The fishery is centered in Southern California with the great bulk of the catch delivered at ports in the Los Angeles region (Redondo Beach, San Pedro, Long Beach and Newport Beach). These ports have accounted for from 83 to 99 percent of the annual state-wide catch. Table 9 gives the total catch from 1926-27 to 1955-56, inclusive.

TABLE 9

PACIFIC MACKEREL LANDINGS BY SEASONS, 1926-27 TO 1955-56

Season	Catch (tons)	Season	Catch (tons)
1926-27	1,797.9	1941-42	35,877.3
1927-28	3,227.5	1942-43	24,110.1
1928-29	19,702.5	1943-44	38,926.5
1929-30	28,347.3	1944-45	40,392.7
1930-31	6,402.9	1945-46	26,001.4
1931-32	7,567.2	1946-47	29,448.9
1932-33	5,425.2	1947-48	19,813.7
1933-34	36,436.9	1948-49	19,101.4
1934-35	56,732.1	1949-50	25,030.8
1935-36	73,193.7	1950-51	16,945.0
1936-37	50,372.6	1951-52	15,952.4
1937-38	35,222.8	1952-53	9,380.9
1938-39	38,032.3	1953-54	3,806.3
1939-40	49,980.4	1954-55	13,359.5
1940-41	53,777.0	1955-56*	13,500.0

* Preliminary figures.

Of the nearly 25,000 Pacific mackerel for which ages have been determined, the oldest was in its 12th year when caught. Fish over eight years of age always have been extremely uncommon in the commercial catch and in recent years fish over six years of age seldom have been observed.

Although the fish grows rather rapidly, nearly three years must elapse before a mackerel reaches a foot in length and a weight of three-fourths of a pound. The largest Pacific mackerel on record, nearly 25 inches long and weighing 6⅓ pounds, may have been a freak. In general, one-, two-, and three-year-old mackerel have made up the bulk of the catch (see Table 10).

TABLE 10

NUMBER OF FISH EACH AGE FURNISHED FOR THE SEASONS 1939-40 THROUGH 1954-55

Age	Number of fish
0	29,663,000
1	273,246,000
2	329,778,000
3	212,694,000
4	92,991,000
5	23,340,000

Since 1938, three year-classes, 1938, 1941, and 1947, have made outstanding contributions to the fishery (see Table 11). Over 125,000,000 fish were taken from each of these groups. The smallest contribution was made by the 1950 year-class, which furnished only 2,800,000 fish. Preliminary estimates indicate that the 1951 and 1952 year-classes will be poor. Although data are not complete for the years prior to 1938, there is every reason to believe that during the 11-year period

TABLE 11

NUMBER OF PACIFIC MACKEREL FURNISHED BY EACH YEAR-CLASS 1934 THROUGH 1953

Figures for years prior to 1938 and after 1950 are estimates based upon over-all trends.

Year-Class	Number of fish
1934 more than	70,000,000
1935 more than	70,000,000
1936 more than	70,000,000
1937 more than	70,000,000
1938 more than	126,600,000
1939 more than	71,600,000
1940 more than	45,200,000
1941 more than	130,400,000
1942 more than	48,400,000
1943 more than	45,100,000
1944 more than	52,700,000
1945 more than	19,400,000
1946 more than	10,500,000
1947 more than	149,500,000
1948 more than	65,800,000
1949 more than	9,900,000
1950 more than	2,800,000
1951 less than	1,700,000
1952 less than	7,000,000
1953 less than	70,000,000
1954 less than	10,000,000

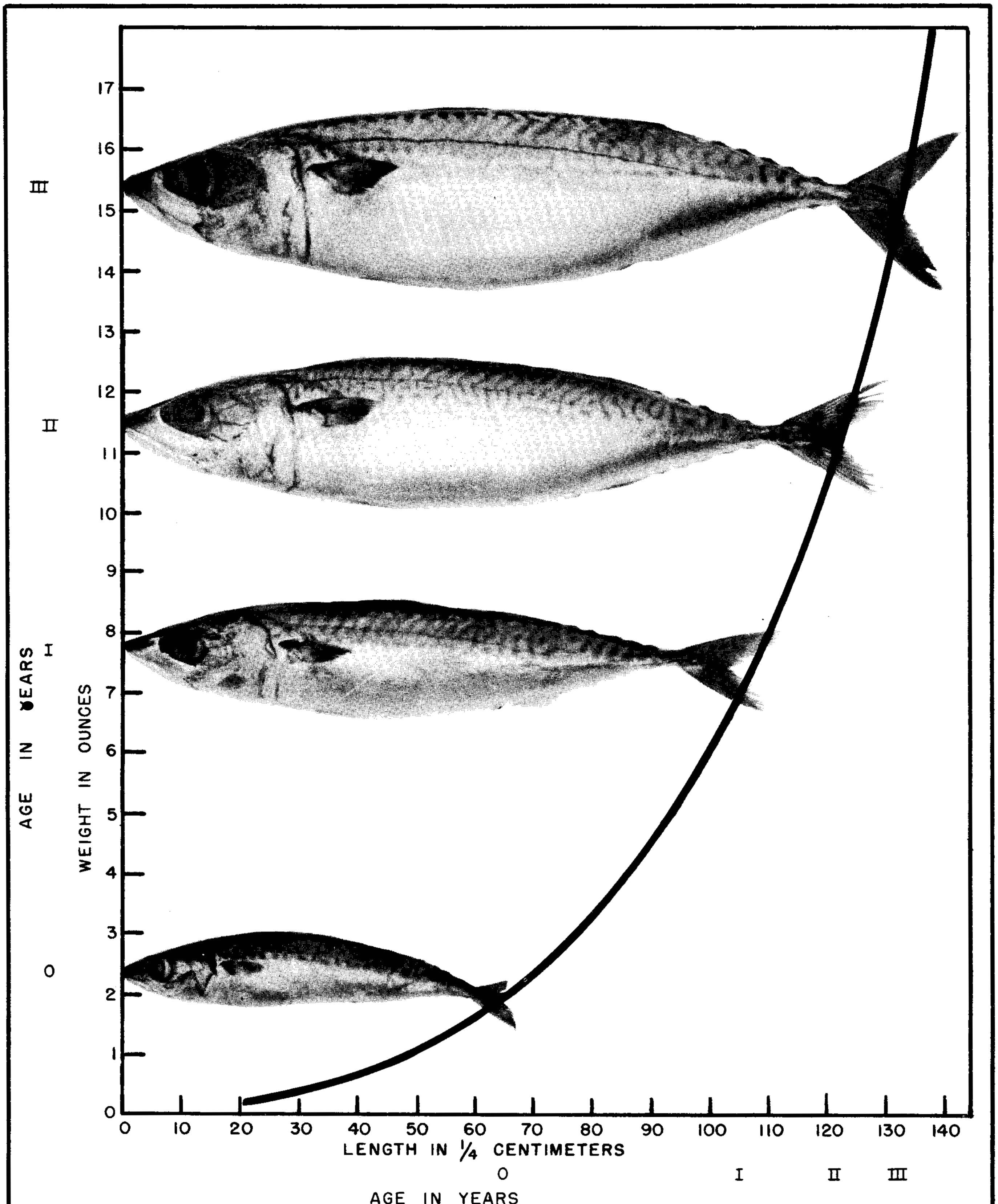

FIGURE 12. Growth curve of Pacific mackerel.

1934-44 no single year-class furnished fewer than 45,000,000 fish. Similarly, data are incomplete for the years succeeding 1950. Regardless, it is obvious that during the 11-year period 1945-55 only three year-classes, 1947, 1948, and 1953, contributed or will contribute more than 20,000,000 fish each.

A factor of prime importance in keeping the Pacific mackerel population at a low level is their capture for canning purposes at an early age. Nearly one-half of the 149,500,000 fish furnished by the 1947 hatch were caught before they had a chance to reach age two. The weight-length chart (Figure 12) graphically illustrates the potential economic loss to everyone concerned when Pacific mackerel are not permitted to reach an age of two or three. At age three they could have spawned once or twice and thus enhanced the possibility of maintaining a stable population level. Twofold or threefold weight increase (including the fish spawned) would mean an identical or similar increase in value. Additional important considerations are: consumer demand for larger, meatier fish, relative ease in handling larger fish on the packing line, etc.

Since 1947, between one-third and one-half of the total number of fish contributed by any single year-class were captured before they had reached an age of two years. Prior to 1947, fish less than two years of age contributed on the average about 35 percent of the catch, whereas since 1947 the contribution of these young fish has been about 45 percent. The 1949, 1950, and 1951 year-classes, which yielded 1,219,000 fish weighing 699 tons during the 1953-54 season, were able to produce only 279,000 fish weighing 162 tons during 1954-55.

TAGGING

Between July, 1935, and March, 1943, a total of 76,038 mackerel were tagged. These fish were captured and released at various localities from Magdalena Bay, Baja California, to Tillamook Head. Oregon (Figure 13). Though one of the 11 fish tagged north of Monterey Bay (Tillamook Head) was recovered in the Los Angeles harbor area, none of those tagged south of San Roque Bay, Baja California, was ever retaken. This tagging program showed that there was considerable interchange of fish from Central and Southern California. Recoveries were made in the Monterey-San Francisco area of fish tagged off central Baja California and one fish tagged in the Monterey area was retaken at Ensenada, Baja California.

Racial analyses indicate that within the range of the mackerel along our coast there might be as many as five reasonably distinct populations among which little mingling occurs. However, the tagging experiments demonstrated that many of the fish from the northern and some from the central Baja California groups ultimately entered the California fishing grounds.

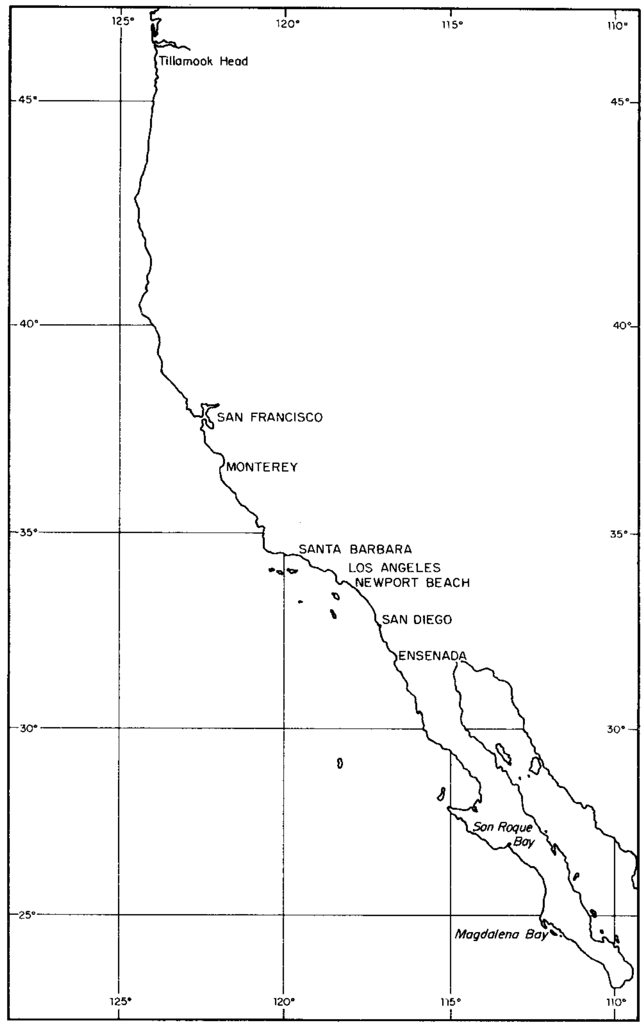

FIGURE 13. Extent of Pacific mackerel tagging program. Map shows localities at which fish were tagged or recovered.

From tagging it was calculated that the mortality rate for Pacific mackerel was between 74 and 78 percent per year for seasons 1940-41 through 1942-43. In the age work, mortality rates for fish two years of age and older were calculated for two separate five-year periods, 1938-42 and 1943-47. For the period 1938-42, the rate was calculated at 48 percent between ages two and three, 62 percent between three and four, and 70 percent between four and five. For the five-year period 1943-47 the mortality rate increased and was 55, 77, and 80 percent per year for two-, three-, and four-year-old fish.

Critical examination of 228 stomachs from Pacific mackerel collected between Point Conception, California, and Santa Maria Bay, Baja California, revealed larval and juvenile fish as the most important item. As much as 30 percent by volume consisted of fish remains. Mysids, nereids, crab larvae, euphausiids, and copepods made up much of the remaining food. Squid were rarely found.

THE FISHERY

Although Pacific mackerel were canned on an experimental basis as early as 1904, it was not until 1928 that the present-day industry got its start. The fishery is and has been centered in Southern California. Commercial landings outside the Los Angeles area have been made at San Diego, Santa Barbara, Port Hueneme, Monterey, and San Francisco, but only at San Diego did these landings ever exceed 5 percent of the annual state-wide catch. Since 1944, deliveries to the Los Angeles region have exceeded 95 percent of the annual state-wide catch.

Fishing methods employed by Los Angeles region fishermen have changed greatly over the years and mackerel can be and have been taken by many types of gear. Prior to 1928, the fishery was conducted almost exclusively for the fresh-fish trade. Hook-and-line fishing could not, however, provide fish in bulk, and the canners' demands were met initially by lampara boats. With the expansion of the industry in 1933, purse seiners found the fishery profitable and by 1937 lamparas had virtually disappeared from the fishery. Catches by these net boats had fallen off by 1939 to the point of being unable to meet the demand. The gap was filled by a large fleet of small boats carrying crews of one to three men who employed the methods of striker fishing and scooping. This scoop fleet, numbering in its heyday into the hundreds, accounted for over half of the total mackerel catch between 1939 and 1952. Since 1952, purse seiners have again come into prominence in the mackerel fishery and the scoop fleet has faded into insignificance.

The price for Pacific mackerel rose from $10 per ton at the start of the 1933 season to $15 in 1935, $18 in 1936, $21 in 1937, and $21.50 in 1941. During the war years, 1942-45, the price was set at $40. Since 1945 there have been marked fluctuations within and between seasons. For a short period during 1953 the price rose to $85 per ton but for the most part it has remained below $60.

From 1916 until the 1927-28 fishing season the total annual catch of Pacific mackerel in California was less than 2,500 tons. Landings increased to about 3,250 tons in the 1927-28 season, to 19,750 in 1928-29, and 28,250 during the 1929-30 fishing season. The drop to around 5,500 tons in the next three years was generally attributed to a poor pack and the economic depression which affected the entire United States. By 1933-34 new canning methods came into use and consumer demand became practically unlimited. Although the catch jumped to over 73,000 tons in just three seasons it has never again attained such a poundage and has been dropping steadily ever since. The most recent low occurred during the 1953-54 season when the 3,800 tons composed the poorest landing in 26 years.

RESEARCH UNDER WAY

Food Studies

Qualitative and quantitative analysis of mackerel stomachs are being performed to determine exactly the items important in their diets. When the results of this study are eventually realized we should know the role that the Pacific mackerel plays in the ecology of marine fishes.

Fecundity Studies

These are being carried on to determine the number of eggs spawned by mackerel at any given size and age. Such information is necessary when attempting to determine the size of the population from egg surveys.

Routine Sampling of the Commercial Catch

This is carried on continuously. It is especially important in determining seasonal or other trends in size composition, catch localities, age composition, etc.

Determination of the Age Composition of the Commercial Catch

This is being carried on continously.

Races

Some effort is being directed at determining the differences if any between our California mackerel and those which are found off the tip of Baja California at the Revillagigedo Islands, those found off Central and South America, those found off Japan and other areas in the Indo-Pacific.

Abundance and Distribution

Abundance of mackerel schools is noted throughout their range during various cruises of departmental research vessels and during aerial surveys with departmental planes. Samples of these fish are taken for the various biological studies being carried on by the Department and cooperating agencies. These surveys are concerned primarily with sardines but distribution and abundance of anchovies and Pacific and jack mackerel is similarly worked out.

Statistical Studies

Catch statistics are being compiled continuously by the statistical section of the Department. These reports include records of catch by boat, day, locality, species, gear, etc.

EGGS AND LARVAE OF ANCHOVY, JACK MACKEREL, AND PACIFIC MACKEREL

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ANCHOVY

The eggs and larvae of anchovy are pelagic. They float passively in the upper layers of the ocean, seldom deeper than 300 feet. Anchovy eggs differ from the eggs of most pelagic fishes in that they are ovoid rather than spherical.

The eggs and early larval stages of the northern anchovy were first described by Bolin (1936). According to Bolin, anchovies spawn at approximately the same hour each night. He estimated that spawning takes place at about 10 p.m. In this respect, the anchovy is similar to the Pacific sardine, which spawns mostly during the four-hour period, 8 p.m. to midnight, with 10 p.m. taken to represent the midtime of spawning (Ahlstrom, 1943).

Fertilization of the eggs takes place in the water immediately after they are spawned. Fertilization in nature is so successful that an unfertilized egg is seldom encountered. Anchovy eggs require from two to four days to develop to hatching, depending on the temperature of the water in which they develop. During development, the eggs float with the long axis perpendicular to the surface of the water. The eggs are colorless and translucent (Figure 14). They blend so well with the water in which they develop that only by the most careful observation can living eggs be distinguished in a sample. The eggs of the anchovy are not unusual in this respect. The eggs of most pelagic fishes are clear and translucent. However, most fishes develop some pigment on the embryo before hatching, but the anchovy does not. The anchovy at hatching is colorless, lacking pigment on the body and in the eyes.

The larvae of the northern anchovy are quite similar in appearance to the larvae of the Pacific sardine (see Figure 15). They are elongated, transparent, threadlike organisms that at hatching measure only 2.5 to 3.0 mm in length, i.e., about one-tenth of an inch. They are so slender after they have absorbed their yolk material that they could literally swim through the eye of a needle. They do not begin to look like an anchovy until they grow to about an inch long. Until reaching this size, they have a terminal mouth, similar in appearance to that of the sardine. (In the adults, the mouth is underslung.) In fact, if it were not for a slightly shorter intestine and the location of the dorsal and anal fins on anchovy larvae, it would be difficult to distinguish them from sardine larvae. Even so, it is sometimes difficult or impossible to distinguish damaged specimens of the two species.

The Area of Heavy Anchovy Spawning

Anchovy spawning, although it occurs from off British Columbia to below Magdalena Bay, Baja California, has been abundant in recent years only between Point Conception and Point San Juanico, Baja California (station lines 80-137, Figure 1). Between 1951 and 1955 there has been a steady increase in the number of anchovy larvae in this area. In fact, the number of anchovy larvae taken in 1954 and 1955 was double the number taken in 1951 (Table 12). It is assumed that the size of the spawning population has also doubled during the same period.

TABLE 12

COMPARATIVE ABUNDANCE OF ANCHOVY LARVAE, 1951-55
(Average monthly census estimates, in billions)

Area	Census estimate				
	1951	1952	1953	1954	1955
North of Pt. Conception (lines 60-77)	84	19	1	108	8
Southern Calif. (lines 80-93)	398	155	427	988	820
N. Baja Calif. (lines 97-107)	101	127	302	447	981
Upper central Baja Calif. (lines 110-120)	424	600	1,103	716	1,764
Lower central Baja Calif. (lines 123-137)	805	1,156	778	1,577	424
Total	1,812	2,057	2,611	3,836	3,997

Area	Percent of total				
	1951	1952	1953	1954	1955
North of Pt. Conception (lines 60-77)	4.64	0.95	0.02	2.81	0.20
Southern Calif. (lines 80-93)	21.96	7.54	16.36	25.76	20.51
N. Baja Calif. (lines 97-107)	5.57	6.17	11.58	11.66	24.55
Upper central Baja Calif. (lines 110-120)	23.40	29.16	42.25	18.66	44.12
Lower central Baja Calif. (lines 123-137)	44.43	56.20	29.79	41.11	10.62
Total	100.00	100.02	100.00	100.00	100.00

The area between Point Conception and Point San Juanico has a north-south extent of approximately 720 miles. It is convenient to divide the area into two equal parts, the northern sector being bounded by station lines 80-107 and the southern sector by station lines 110-137. These sectors are identical to the ''northern'' and ''southern'' spawning centers of the Pacific sardine. If it is desirable to further subdivide the area, the northern sector can be divided into the Southern California area (lines 80-93) and the northern Baja California area (97-107); the southern sector can be divided into the upper central Baja Cali-

[1] Published by permission of the Director, U. S. Fish and Wildlife Service.

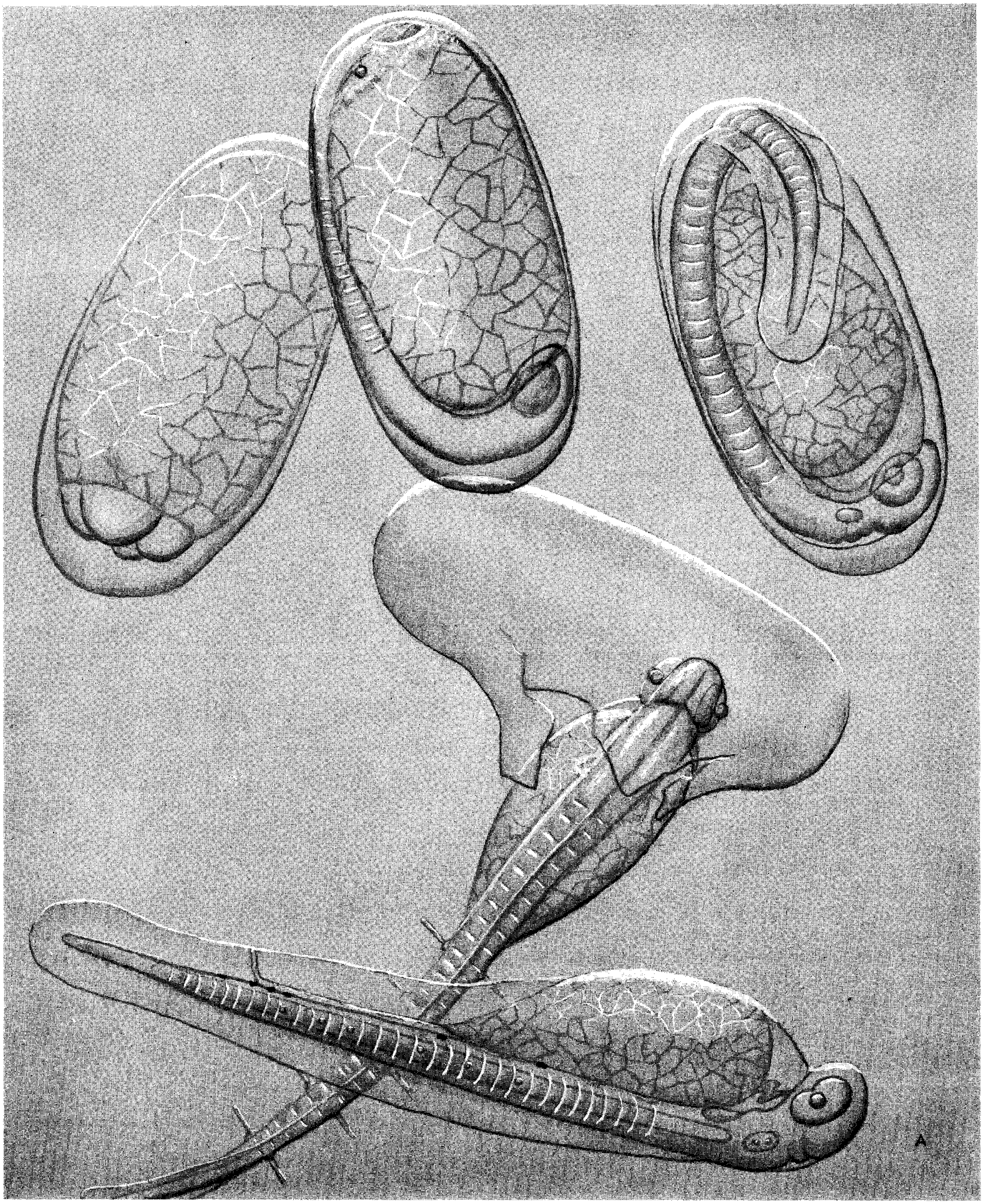
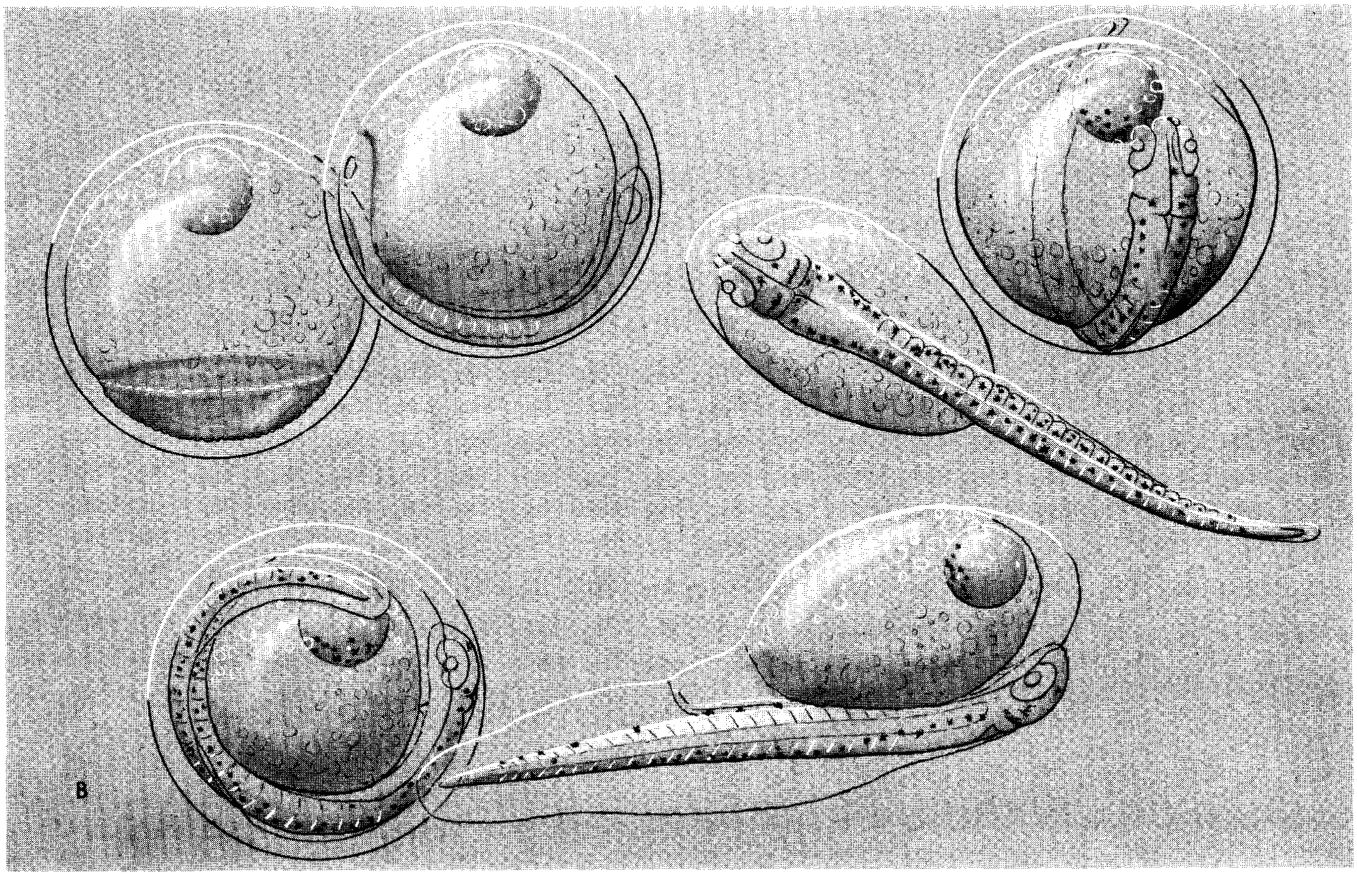


FIGURE 14. Eggs and yolk-sac larvae of (A above) anchovy, (B opposite page, upper) jack mackerel, and (C opposite page, lower) Pacific mackerel. The diameter of a jack mackerel egg is approximately one twenty-fifth of an inch. Drawings by George M. Mattson, U. S. Fish and Wildlife Service.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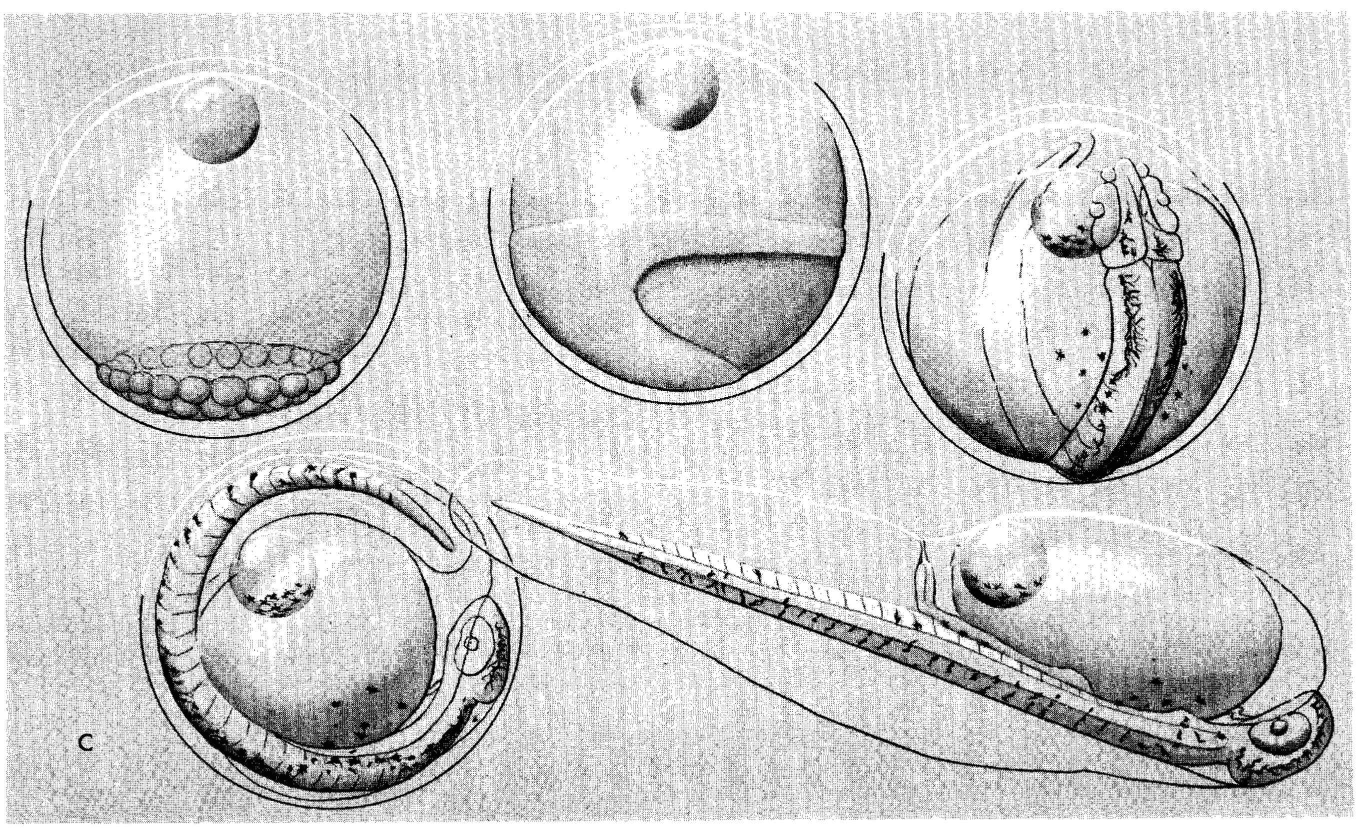
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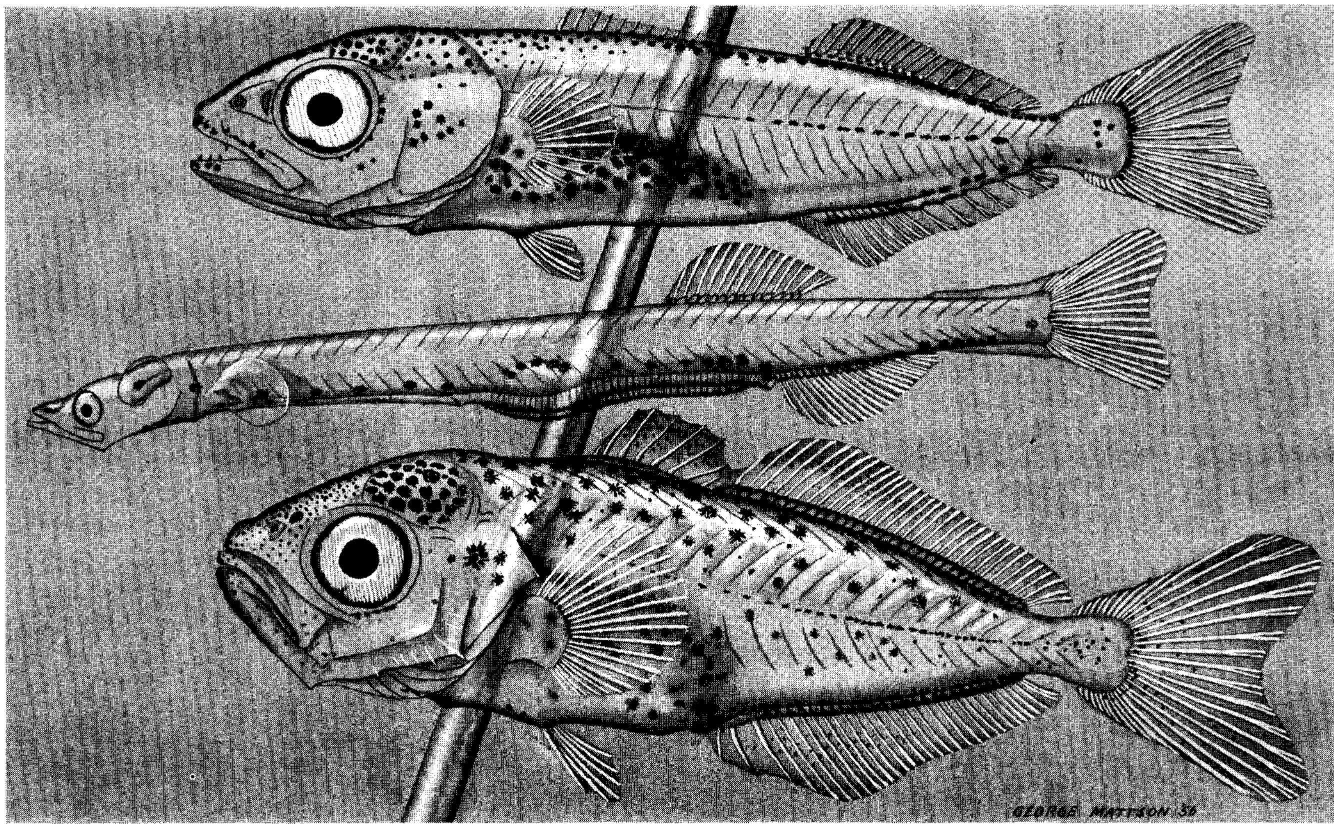

FIGURE 15. Larvae of (A) Pacific mackerel, (B) anchovy, and (C) jack mackerel. The column in the background is a section of No. 8 nylon fishing leader, drawn to scale. Note transparency of larvae. The jack mackerel larva is approximately three-fifths of an inch long. Drawings by George M. Mattson, U. S. Fish and Wildlife Service.

fornia area (lines 110-120) and lower central Baja California area (lines 123-137).

The southern sector has consistently had a larger portion of anchovy eggs and larvae than the northern sector. The relative importance of the two sectors during the past five years can be seen in Table 13.

The northern sector had the smallest percentage of anchovy larvae in 1952, and since then there has been a consistent gain in the portion of the larvae found in this sector.

TABLE 13

PERCENTAGES OF ANCHOVY LARVAE FOUND IN DIFFERENT SECTORS OF CCOFI AREA, 1951-55

Year	Northern sector (lines 80-107) (percent)	Southern sector (lines 110-137) (percent)	Other sectors (percent)	Total (percent)
1951	27.5	67.8	4.7	100.0
1952	13.7	85.4	0.9	100.0
1953	27.9	72.0	0.1	100.0
1954	37.4	59.8	2.8	100.0
1955	45.1	54.7	0.2	100.0

As can be seen by referring to the distribution charts of anchovy larvae for 1954 and 1955 (Figures 16 and 17), the greatest abundance of larvae occurs near shore. A similar condition obtains for anchovy eggs. The zone of heavy concentration is within 60 miles of the coast, although some spawning occurs as far offshore as 200 to 250 miles.

It will be noted from the 1955 distribution chart (and Table 12) that the abundance of larvae (and eggs) was markedly less off lower central Baja California (station lines 123-137) in 1955 than in any recent year. Only about 11 percent of the larvae were taken in this area in 1955, while between 30 and 56 percent of anchovy larvae were taken in the area in the years between 1951 and 1954. The lowered abundance was probably associated with anomalous conditions in the area—increased upwelling, colder temperatures, and heavy concentrations of plankton. Anchovies spawn throughout the year in the area between Point Conception and Point San Juanico (lines 80-137). However, spawning is not equally heavy during all seasons. Since 1953, the peak of abundance has occurred during the winter and early spring months, January through March or April, and the period of lowest abundance has been in late summer and early fall. During the period of lighter spawning, most of the eggs and larvae are taken quite close inshore, in contrast to a more widespread distribution offshore in the period of heavy spawning.

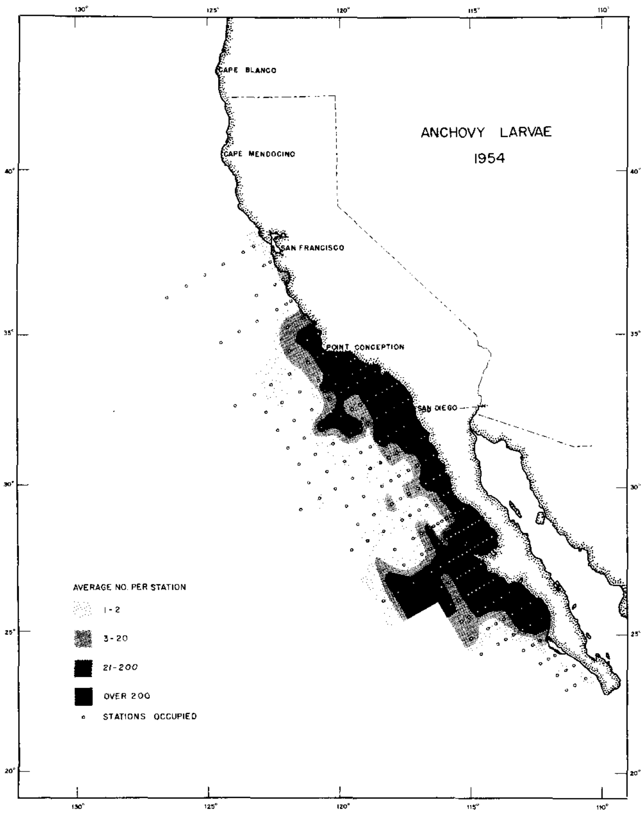

FIGURE 16. Distribution of anchovy larvae, 1954.

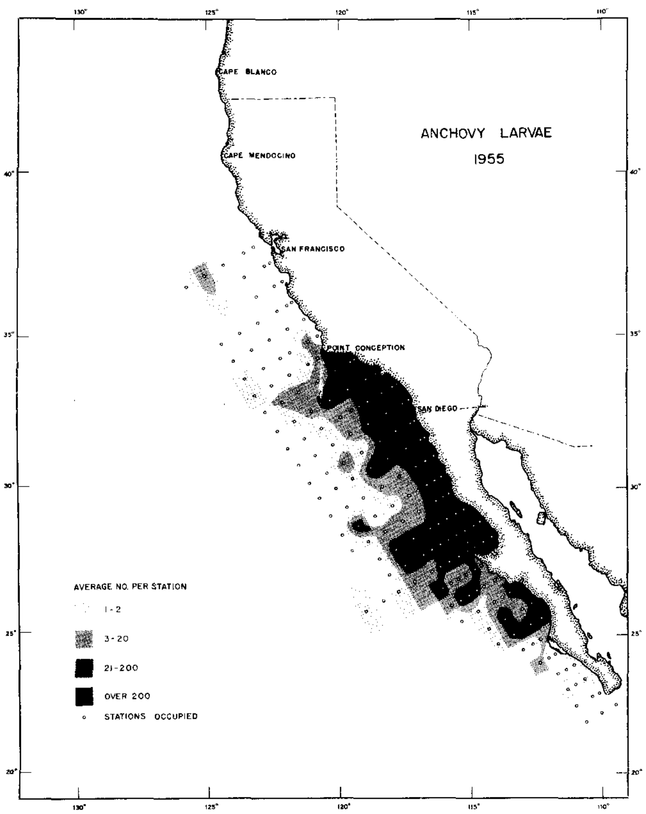

FIGURE 17. Distribution of anchovy larvae, 1955.

Anchovy Spawning to the North of Point Conception

In recent years anchovy spawning to the north of Point Conception has been variable in amount. It was heavy off central California in 1950, especially off Monterey, and lesser in amount but widely distributed in 1951 and light in 1952. Spawning may occur at considerable distances from shore in the central California area. In both 1950 and 1951 some spawning took place as far seaward as 200 miles. In 1953, anchovy spawning to the north of Point Conception was negligible in amount. In 1954, on the other hand, spawning was fairly heavy on line 77, about 40 miles north of the point (see Figure 16). I assume that anchovies from south of Point Conception moved into this area for spawning in 1954. A more marked northward shift was noted in spawning sardines in 1954, but in the latter species the shift was from central Baja California to Southern California; there was no evidence of sardine spawning to the north of Point Conception in 1954. There was very little anchovy spawning above Point Conception in 1955. It should be noted that the area to the north of Point Conception has not been regularly surveyed during the winter months and in other areas these have comprised the period of maximum spawning.

Anchovy Spawning Off Southern Baja California

Except in 1956, anchovy larvae have not been taken in abundance off southern Baja California (station lines 140-157). The area is not routinely occupied, but has been surveyed on one or more cruises per year since 1950. The most systematic coverage of the area was made in 1951, with cruises in March, June, and September, and in 1955, with cruises in January, February, March, and December. In the other years, coverage was limited to one or two cruises. During the period 1950-1955 only 362 anchovy larvae (standard haul totals) were taken off southern Baja California in 266 plankton hauls. This averages less than 1.5 larvae per haul.

Anchovies moved into this area in 1956. During January and February over 19,000 anchovy larvae (standard haul totals) were taken off southern Baja California in 49 plankton hauls. The majority were taken on line 140, but the larvae occurred at a number of stations on lines farther south (143 to 150). The southward shift in the spawning population may not represent a shift of more than 40 to 80 miles, but it is good evidence that such movements in the spawning population do occur.

Relation of Anchovy Spawning to Temperature

A fish that spawns over an extensive area during all seasons of the year must, of necessity, spawn over a wide range of temperatures. The temperature range over which anchovy eggs were taken during 1953 and 1954 was from 9.9° to 23.3° C., a range of 13.4° C. (Table 14). I have used the temperature at 10 meters' depth as representative of the temperature in the upper mixed layer in which anchovy eggs occur.

TABLE 14

TEMPERATURE RANGE OVER WHICH ANCHOVY EGGS WERE TAKEN IN 1953 AND 1954

(Temperature at 10 meters depth)

Temperature degrees C.	1953	1954	Total
9.5	1		1
10.0	3		3
10.5			0
11.0	5	3	8
11.5	8	1	9
12.0	8	5	13
12.5	7	6	13
13.0	15	13	28
13.5	21	32	53
14.0	32	44	76
14.5	15	34	49
15.0	17	30	47
15.5	19	36	55
16.0	14	12	26
16.5	9	11	20
17.0	6	10	16
17.5	13	7	20
18.0	6	10	16
18.5	5	5	10
19.0	2	2	4
19.5		7	7
20.0		3	3
20.5	1		1
21.0			0
21.5	1	1	2
22.0			0
22.5		1	1
23.0		1	1
Total	208	274	482

A wide range in temperatures was encountered at the same station at different times during the spawning season (Table 15). This was more marked at inshore than at deep-water stations. The point can be illustrated by giving the temperature range found at several inshore stations off Southern California in 1954.

TABLE 15

TEMPERATURE RANGE AT SEVERAL INSHORE STATIONS OFF SOUTHERN CALIFORNIA IN 1954

Station	Position		Temperatures at which anchovy eggs were taken (degrees C.)		
			Minimum	Maximum	Range
87.35	33°50′N	118°37.5′W	13.34	19.34	6.00
90.28	33°28.5′N	117°46.7′W	13.87	23.26	9.39
93.27	32°56′N	117°19.2′W	13.30	23.03	9.73
97.30	32°15.4′N	117°08.8′W	13.21	20.33	7.12

The temperature range over which anchovies spawn off Southern California is considerably greater than the range over which sardines ordinarily spawn in this area. One reason for this is that sardines spawn only in the period February through July, with heavy spawning confined to April through June, while anchovies spawn throughout the year in this area. Also, anchovies tend to spawn closer inshore than sardines, and, as noted above, inshore stations are subject to more marked temperature fluctuations than offshore stations. Perhaps the most marked difference in the spawning of the two species concerns the lower or threshold temperature. In the sardine, 13.0° C. has been shown to be a limiting temperature below which spawning ordinarily does not take place. The threshold temperature is lower in the anchovy; about 10 percent of the spawning sampled in 1953 and 1954 was at temperatures below 13.0° C.

JACK MACKEREL

The eggs of the jack mackerel are spawned in the open ocean far from shore. Like most pelagic fishes, the jack mackerel spawns in the upper mixed layer of water. This layer, which is seldom more than 300 feet thick and often much shallower, is both warmer and better supplied with food than the deeper zones. The egg of the jack mackerel is spherical in shape and moderate in size. Twenty-five eggs placed in a row would extend only one inch. Like the anchovy egg, the jack mackerel egg in nature is colorless and translucent (see Figure 14). The yolk mass is segmented and contains a single large oil globule. Many fish eggs contain one or several oil globules. Sardine, hake, and Pacific mackerel are examples of other common species that have an oil globule. However, the eggs of the northern anchovy, Pacific halibut, and round herring lack oil globules, so this structure must play only a secondary role in the development of fish eggs. It may aid the egg to float, for the oil globule is situated at the top of the jack mackerel egg as it ordinarily floats in the water, while the embryo develops on the under side of the egg. During development, pigment forms on the under side of the oil globule and along the back and belly of the embryo. The oil globule is situated in the forward part of the yolk sac on hatching, just under the unpigmented eyes. This is an unusual placement for the oil globule.

The newly hatched jack mackerel larva is a small, defenseless organism. It is barely a twelfth of an inch in length, lacks fins for swimming, pigmented eyes for seeing, and even a mouth for feeding. In the two or three days that the yolk material remains after hatching the young larva develops rapidly, however, so that by the time the yolk is gone it has a functional mouth, pigmented eyes, and paired pectoral fins.

The larva of the jack mackerel is very different in appearance from the larva of the sardine or anchovy (see Figure 15). It is a stubby larva with a big head and a big mouth. The big mouth is useful in capturing and swallowing larger plankton organisms, particularly copepods, than the young stages of sardine or anchovy can eat. In fact, a jack mackerel larva that is only a fifth of an inch long can utilize food material that a sardine larva could not ingest until it became two or three times this long. Hence, jack mackerel larvae do not directly compete with small sardine or anchovy larvae for food, but they do compete with older larvae.

The young stages of jack mackerel larvae seem to have definite food preferences. They are especially partial to a small, brightly colored copepod to which has been given the scientific name of *Microstella norvegica*. This copepod is considered to be truly cosmopolitan. It occurs everywhere in the oceans, though seldom in large numbers. The jack mackerel larvae are very adept at capturing it, as well as several other kinds of widely distributed "colored" copepods. This preference for cosmopolitan food items may be one of the reasons why jack mackerel larvae are able to "make a living" in offshore waters.

Jack mackerel spawn over a much more extensive area than the Pacific sardine, northern anchovy, or Pacific mackerel. Within the area routinely surveyed on CCOFI cruises, there are few stations at which jack mackerel eggs or larvae are not taken during a season, and these are located either close inshore or at the southern end of the survey area. The center of greatest abundance of the eggs and larvae is located off Southern California and adjacent Baja California (Point Conception to San Quintín), as is shown in Figure 18. Abundance falls off sharply to the south of the center and also decreases in amount to the north as well. However, we know from our early surveys off Oregon (1949) and from the extensive coverage of NORPAC that some spawning occurs as far north as Washington and as far offshore as 150° W. Actually, the offshore extent of spawning has never been adequately delimited. Jack mackerel eggs and larvae have been taken as far north and as far seaward as our cruises have extended.

Jack mackerel eggs and larvae ordinarily are found at some distance from shore; in fact, the center of their abundance appears to be between 80 and 240 miles off shore. A tendency has been noted for the center of spawning to move closer inshore as the spawning season draws to a close.

The season of spawning off California and Baja California is mostly confined to the five-month period, March through July. There is some spawning at other times, but it is small in amount (between 1 and 5 percent of the season total). The peak of spawning has occurred as early as April (1951) and as late as June (1953 and 1954).

Spawning begins as early in the year off Southern California as it does off Baja California, but a gradual northward progression of spawning occurs above Point Conception. In 1950, for example, spawning occurred off Northern California in June and July. In 1949, when stations were regularly occupied off Oregon, spawning was found to occur in that area from July through September. In August, 1955, on the extended coverage afforded by NORPAC, jack mackerel eggs and larvae were taken at a number of stations off Oregon and Washington (Figure 19). In contrast, jack mackerel eggs and larvae were taken in only a few hauls off California and Baja California on NORPAC, representing in these areas the tag ends of spawning. A more detailed account of the distribution and abundance of jack mackerel larvae is given in Ahlstrom and Ball (1954).

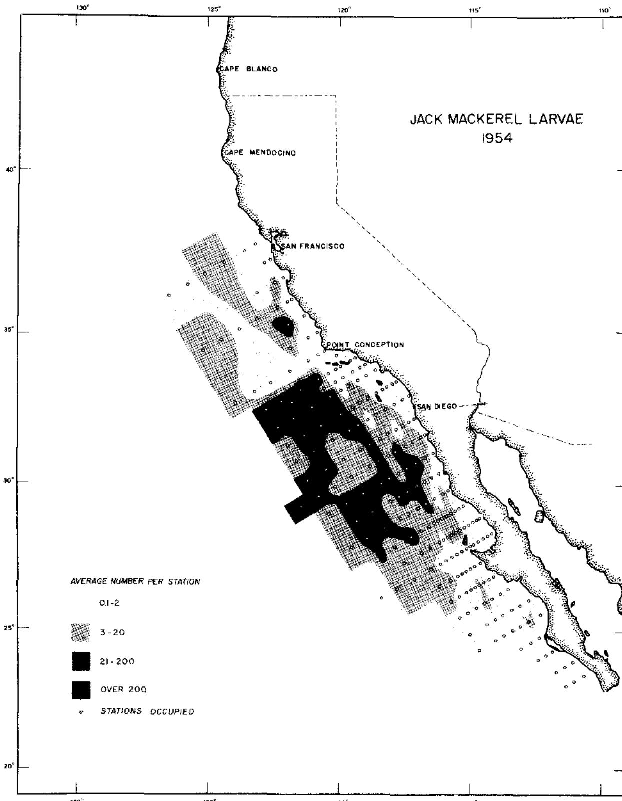

FIGURE 18. Distribution of jack mackerel larvae, 1954.

Rate of Development

The eggs of Pacific mackerel and jack mackerel take longer to develop to hatching than those of the Pacific sardine. The rate of development of all kinds of fish eggs is directly related to the temperature at which development takes place. Incubation of sardine eggs, for example, requires approximately $4\frac{1}{3}$ days at 12° C., a little less than three days at 15° C. and only about $1\frac{1}{2}$ days at 20° C. The relation of temperature to the length of the incubation period of sardine eggs is known in detail, but our knowledge of the rate of development of other species is less complete. However, work is being done on a number of other species, as this information is a prerequisite in determining the amount of spawning and the survival rate of eggs and larvae. Recently, incubation experiments have been conducted on jack mackerel and Pacific mackerel

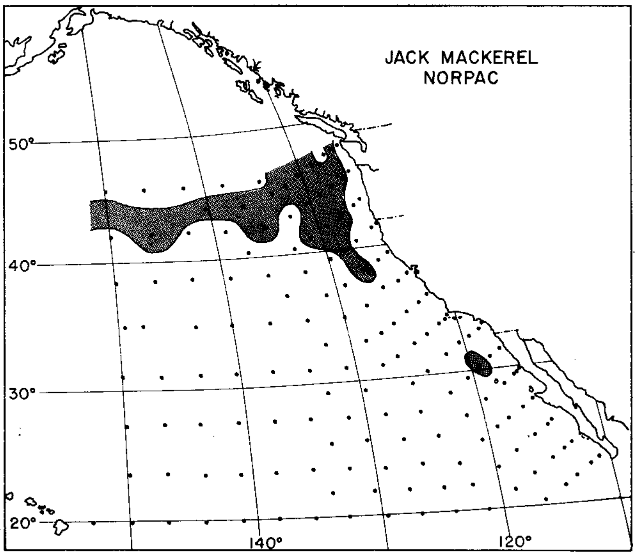

FIGURE 19. Distribution of jack mackerel eggs and larvae, NORPAC project.

eggs. The eggs, collected at sea about 150 miles off San Diego, were incubated at about 14.3° C. The jack mackerel eggs required approximately four days to develop to hatching at this temperature, the Pacific mackerel eggs 4½ days. For comparison, the sardine requires less than 3¼ days to develop at this temperature. Interestingly enough, the rate of development of Pacific mackerel eggs at this temperature is almost identical to that reported for the Atlantic mackerel by Worley (1933).

Depth Distribution

We have made a number of studies on the depths at which fish eggs and larvae occur in the water. For most species, the distribution is limited to the upper mixed layer above the thermocline and to the upper portion of the thermocline. The depth of the upper mixed layer varies with latitude, with distance from shore, with season, and with wind conditions; hence it is a layer of variable thickness. In our area it is seldom more than 300 feet deep, and often much shallower. In some places it is as shallow as 50 feet or even less.

The depth distributions of fish eggs and larvae show a corresponding variation, and, in addition, larvae may have a different position within the upper mixed layer during night-time as compared to the day. Hence for every species, there is a variable depth range at which eggs and larvae may occur, but for most species the lower limit of the distribution is seldom deeper than 300 feet.

The depth distributions of the larvae of five common species of fish are given in Table 16. These data represent the summation of a number of depth distribution series, and it should be noted that there was considerable variation in the depth distribution for all species from series to series. Larvae of the Pacific mackerel, sardine, and anchovy occurred in greatest abundance in the upper 23 meters, jack mackerel had their greatest abundance between 24 and 48 meters, hake larvae occurred in greatest abundance between 65 and 88 meters.

TABLE 16

DEPTH DISTRIBUTION OF FISH LARVAE: PERCENT TAKEN IN DIFFERENT DEPTH STRATA

Depth stratum (meters)	Pacific mackerel (percent)	Sardine (percent)	Anchovy (percent)	Jack mackerel (percent)	Hake (percent)
0-23	75	68	46	30	2
24-48	24	25	33	49	2
49-64	1	4	16	5	8
65-88	0	3	5	13	71
89-122	0	less than 0.1	less than 0.1	2	5
123 and below	0	0	0	0	12

PACIFIC MACKEREL

The eggs and larvae of the Pacific mackerel are superficially similar in appearance to those of the jack mackerel (see Figures 14 and 15). The eggs of both species are spherical, they have a single oil globule of similar size, and in both there is very little space between the yolk mass and the outer unsculptured shell membrane. The larvae of both species are stubby and big-headed; they develop their fins at about the same sizes and transform into juveniles when only about three-fifths inch in length.

However, a practiced eye finds little difficulty in distinguishing between the young stages of the two species. There are a number of small differences between the eggs of Pacific mackerel and jack mackerel. The Pacific mackerel eggs are somewhat larger; 1.15 mm as opposed to 1.0 mm in diameter. This difference may seem slight, but actually a mixture of eggs of the two species can be readily separated on the basis of size alone. A more striking difference is in the character of the yolk, which is irregularly segmented in jack mackerel, but homogeneous in the Pacific mackerel. Two differences that can be used in distinguishing later stage eggs are body segment or myomere number and pigmentation. The number of myomeres corresponds to the number of vertebrae which will later develop: Pacific mackerel almost always has seven more than the jack mackerel; 31 as compared to 24. There are a number of differences in pigmentation of late stage eggs. There is considerable pigment on the forward part of the head of the developing Pacific mackerel embryo and little or none on the jack mackerel embryo. Another difference is the presence of some pigment on the yolk of Pacific mackerel eggs, while none develops on the yolk of jack mackerel eggs. There are additional differences in the distribution of pigment over the body of the embryos, which I will not attempt to describe in detail. The eggs and early larval stages of the Pacific mackerel have been described by Fry (1936), the larvae by Roedel (1949).

One of the things that makes it difficult to associate the egg and larval stages of pelagic fishes is the marked difference in pigmentation that is usually found between eggs and larvae. In many species of fish, the embryonic pigment is distributed along the dorsal surface or back, while the larval pigment is mainly or entirely confined to the ventral or belly side. The change is accomplished by an actual migration of pigment. The change usually takes place during the yolk sac stage after hatching from the egg, although in some species (including the Pacific mackerel) the migration may commence before hatching. The migration and rearrangement of the pigment is usually completed before the end of the yolk sac stage.

On the newly hatched Pacific mackerel larvae, the pigment, which had been dorsal until soon before hatching, is streaming down the sides of the body between the myomeres. Within a couple of days the larval pigment pattern has appeared. It consists essentially of pigment in three areas: (1) a cap of pigment spots on top of the head; (2) pigment along the peritoneal cavity; and (3) a row of ventral spots, extending from behind the anus to the end of the notochord. Several differences between the newly hatched larvae of jack mackerel and Pacific mackerel might be pointed out. Perhaps the most conspicuous difference is in dorsal pigmentation. The jack mackerel larva retains considerable pigment on the back, while the Pacific mackerel does not. A striking difference is in the position of the oil globule, which is located at the anterior end of the yolk sac in newly hatched jack mackerel larvae, and at the posterior end of the yolk sac in Pacific mackerel larvae. A third difference is in the position of the anus, which is much farther forward in the Pacific mackerel than in the jack mackerel larva. The newly hatched larvae of jack mackerel are slightly smaller than those of Pacific mackerel, but the difference is not great enough to be of help in differentiating the two forms.

Distribution of Pacific Mackerel Spawning

Although adult Pacific mackerel are known to occur from northwest Alaska to the Gulf of California, eggs and larvae have not been taken to the north of Point Conception. Some spawning occurs off Southern California and northern Baja California, but the bulk of spawning occurs off central and southern Baja California (see Figure 20), and in the Gulf of California.

There is a striking similarity between the distribution and season of Pacific mackerel spawning and that of the Pacific sardine. Off Southern California and northern Baja California the spawning of both species

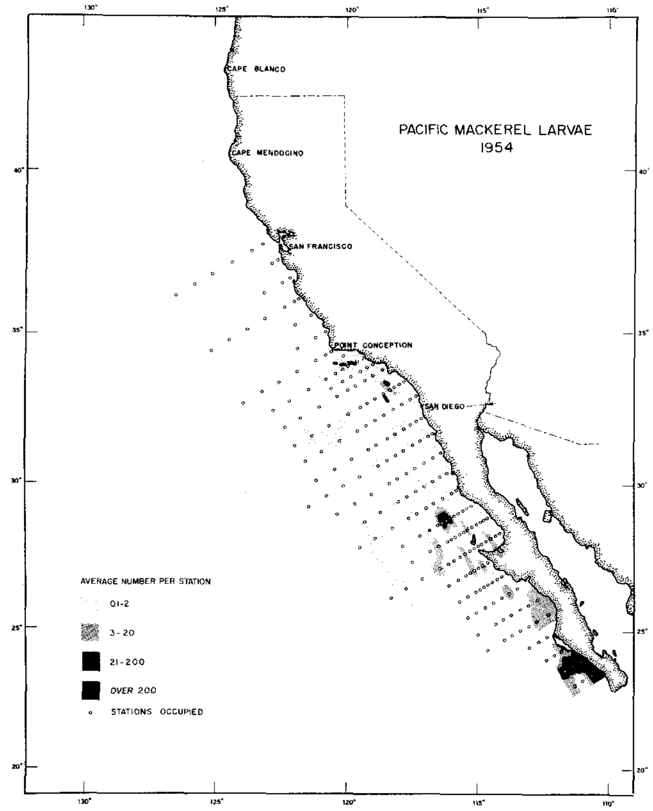

FIGURE 20. Distribution of Pacific mackerel larvae, 1954.

may occur at considerable distances from shore, and the season of spawning is similar (March through July). Pacific mackerel, like the sardine, spawn throughout the year off central Baja California. The number of Pacific mackerel larvae taken off central Baja California has been four to six times as large as the number occurring off Southern California and northern Baja in most recent years. The ratio was nearly 20 to 1 in 1953, a season with unusually low water temperatures.

The area off southern Baja California has not been routinely occupied, but has been surveyed on 12 cruises during a six-year period (1950-1955). Pacific mackerel larvae have been taken in this area on most cruises, and occurred in considerable abundance in January, 1954. No systematic coverage of the Gulf of California was attempted prior to the current season (1956), when the gulf was surveyed on two occasions (Cruises 5602 and 5604). The collections of the earlier of the two cruises have been worked up, and Pacific mackerel larvae were taken at many stations in the gulf. The distribution and abundance is shown in Figure 21. Judging from abundance found on this cruise, there must be a larger spawning population in the gulf than on the outer coast.

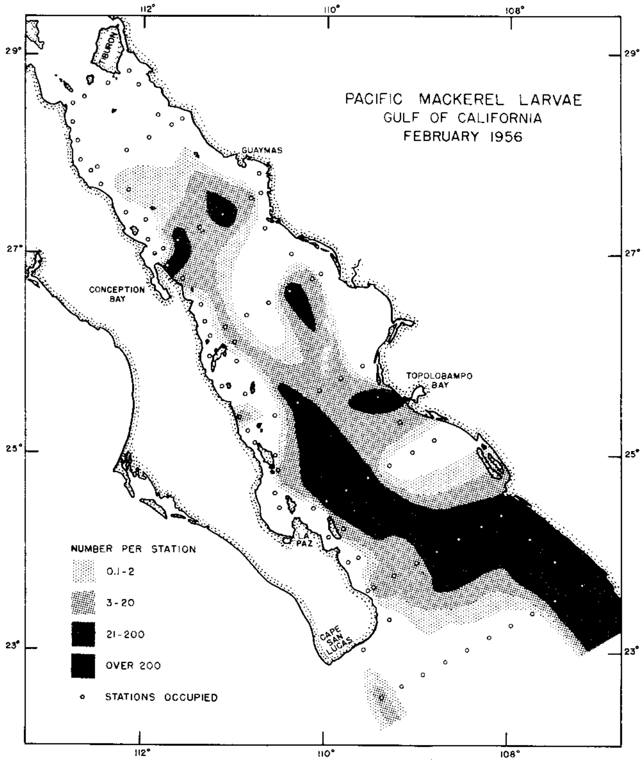

FIGURE 21. Distribution of Pacific mackerel larvae, Gulf of California, February, 1956.

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The eggs, larvae, and early development of the hake are described. Data on the abundance and distribution of hake larvae in 1951 and 1952 are given. Information on vertical distribution and temperatures at which larvae are found is also included.

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