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ECHO-RANGING FOR FISH SCHOOLS AND OBSERVATIONS ON TEMPERATURE AND PLANKTON IN WATERS OFF CENTRAL CALIFORNIA IN THE SPRING OF 1946

by

Osgood R. Smith and Elbert H. Ahlstrom

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CONTENTS

Page

Introduction ---------- 1

Area and Time of Survey ---------- 2

Fish Detection by Sonar ---------- 2

Bathythermograph Observations ---------- 4

Plankton Collections ---------- 9

Volume of Plankton ---------- 11

Plankton Organisms ---------- 13

Fish Eggs and Larvae taken in Plankton Hauls --------- 16

Tables ---------- 18

INTRODUCTION

Early in 1946 the owners of sardine processing plants in the San Francisco area, through their San Francisco Sardine Association, arranged to operate a purse seine vessel equipped with echo-ranging gear to explore for sardines and try experimental fishing. Concerned by the poor fishing in recent seasons, the Association wished to find means of making sardine scouting more effective and thus assure a steadier, if not greater, catch of fish.

The purse seiner MS PEARL HARBOR, Captain John Aiello, with full fishing crew and a purse-seine, was chartered to carry on the experiment during the months of April, May, and June. Captain Vince Cardinelli was engaged to supervise the operation for the Association. A special permit to use sardines for reduction was secured from the California Fish and Game Commission, so that any fish caught during the experiment could be processed during the closed season. The Submarine Signal Corporation installed the echo-ranging gear, commonly known as Sonar, and provided a technician to operate it. The Association also made arrangements to make sonar equipment available to any or all boats in the San Francisco fleet, provided the experiments gave promise of success.

At the invitation of the San Francisco Sardine Association a biologist of the U. S. Fish and Wildlife Service accompanied the vessel to observe the operation and to collect as much oceanographic and biological data as possible. The Service assigned Osgood R.Smith to regularly perform the observations and Elbert H. Ahlstrom went on the PEARL HARBOR for the cruise of April 23 to 26 during which the bathythermograph was first put into operation. A biologist of the California Division of Fish and Game also accompanied the vessel as an official observer and at times kindly assisted in the operation of the bathythermograph and plankton gear. J. B. Phillips, W. E. Ripley, J. A. Aplin, and P. Bonnot each served in this capacity at various times.

The oceanographic and biological data collected were not particularly extensive as to kind or area and, lacking previous records from the same area and the same season of the year for comparison, their interpretation is difficult and uncertain. However, the very circumstance which limits their interpretability gives them significance as the first information of the kind for the place and time. Moreover, they relate to spring and early summer conditions prior to the sardine season of 1946-47 which proved later to be an almost complete failure in these waters, San Francisco's catch for this season being down 97% from the previous year. If this sardine fishing failure is related to abnormal oceanographic conditions preceding the season some elements of the abnormality should appear in these data. For these reasons they are recorded in some detail herein. It is hoped that further oceanographic work may take place in the future when perhaps fishing conditions may be more normal and that comparison with these 1946 data may give some clues to the causes of such apparent scarcity of sardines.

AREA AND TIME OF SURVEY

From April to June the PEARL HARBOR scouted over the usual sardine fishing grounds of the San Francisco fleet: south of Point Reyes, between the Farallon Islands and the San Francisco lightship, and southward along the coast to Monterey Bay, largely within 20 or 30 miles of shore. Three trips were made farther seaward: the first, on May 15 to 18, extended 150 miles west from Santa Cruz, with the return line toward the Farallon Islands; the second, on June 6 and 7, extended 80 miles southwesterly from Point Montara; the third on June 13 and 14, 60 miles southwesterly from Bodega Bay, then inbound toward the Farallon Islands. See Charts(2 and 12). Scouting was done five days a week, sometimes at night and sometimes in the daytime. The vessel was at sea a total of 280 hours distributed over 33 days.

FISH DETECTION BY SONAR

The echo-ranging equipment on the PEARL HARBOR was similar to the sonar used on some of the smaller Navy vessels to locate submarines. A projector under the vessel's bottom produced a beam of supersonic impulses or waves, much like a search-light beam. This beam could be directed horizontally through the water and it could be revolved in a complete circle. Any echo that might be returned was received and transmitted to appropriate instruments. In principle, the sonar was like echo sounders in general use, except that the beam was directed horizontally instead of vertically.

The Submarine Signal Company kindly furnished the following description of the installation on the PEARL HARBOR:

SUPER-SONIC ECHO-RANGING: Piezo Electric

Projector: In a streamlined dome, secured to the lower end of a shaft which was mounted through hull. The shaft could be raised or lowered and rotated from inside the vessel.

Receiver-Amplifier: Submarine Signal Company high gain receiver amplifier designed for use with Rochelle Salt projector and marine applications.

Transmitter: Submarine Signal Company designed for the PEARL HARBOR tests.

Indicator: Revolving red light similar in principle to Submarine Signal Company commercial Fathometer indicators, supplemented by simultaneous loud speaker or ear phones.

Available space did not permit as efficient an installation as might be desired. The range indicator (distance of an object giving an echo) was located in the galley, while the direction indicator was out on deck. Communication between the sonar operator in the galley and the bridge was by telephone.

A recording type echo-sounder, "Fathometer" type 896A, was installed in the wheelhouse. This recorded the depth of the bottom, and of course, any echoing material between the vessel and the bottom. It supplemented the sonar by recording the depth of an object, such as a school of fish, when the vessel passed over it.

During most of the period of use the sonar beam was kept stationary, generally at an angle of about 45° off one bow or the other. Sonar searching was done during most of the time at sea that weather permitted, or approximately 175 hours out of the 280 that the vessel was at sea. During this time echoes were received from a few very small schools not large enough to pay to catch. A number of contacts were made with "targets" that may have been fish schools, but they were lost before they could be detected with the echo sounder. The range at which the various targets were first detected was similar to the range, namely, 700 to 1200 yards at which Smith (1947, p.2)1/ reported detecting sardine schools with sonar gear on a Navy vessel of PC type.

Two small schools of fish were detected by sonar and also identified by other means. One was a school of sardines, seen in daylight, in Monterey Bay. The other, just north of Point Reyes was not identified, but "flippers" were heard indicating the presence of fish. In both cases, contact was maintained for a while and then lost. On five occasions small "targets" or objects were located by sonar and then by running over the indicated spot a slight trace was secured on the recording "Fathometer", indicating a small school of fish or other schooling organisms. One of these, located at night, was also evident as a small luminous spot. This spot was identified by the skipper as "feed",--meaning small fish or other organisms that would pass through the meshes of a purse seine. On the same occasion about ten or twelve additional spots of feed were located by sonar and also seen, but only one was dense enough (or deep enough) to show up on the "Fathometer" record.

1/ See Commercial Fisheries Review, vol. 9, no. 1, pp. 1-6, Jan. 1947, Washington, D. C.

During the trip of April 16-19, when we were not on the PEARL HARBOR, a target was recorded for which J. Phillips gave the following description:

"Early on the morning of April 18 the PEARL HARBOR cruised through the squid fishing grounds in shallow water off the Monterey canneries, where the squid boats were making hauls. However, due to echoes from boats, buoys and unloading hoppers, echoes from the schools of squid present could not be properly defined. Therefore, the vessel cruised outside the area where fishing was being conducted to get away from interference and was followed by one squid fishing boat, the "Husky". Echoes were obtained about one mile off Pacific Grove in 35 fathoms, indicating a school of fish or squid. In order to investigate, the "Husky" made a haul with its net and obtained a few squid. It was the impression of the skipper of the "Husky" that there was a school of squid where they set but that the school was too deep for their shallow net."

In view of the lack of sizeable sardine schools in the area covered, the tests by the PEARL HARBOR did not settle the question of whether sonar would or would not prove useful in sardine fishing. The test did show, however, that sonar on a fishing boat can locate subsurface schools of fish. In general the tests corroborated some tests of sonar scouting for fish schools conducted by the Navy off San Francisco during the winter of 1944-45. (Smith 1947 ibid.) The following quotation from this publication applies equally to both the Navy and the PEARL HARBOR trials: "The experiments demonstrated, however, that sonar can locate schools of fish under certain conditions, and sonar may become a valuable tool for commercial fisheries or for fisheries research, or both."

There was no indication that the sonar frightened or disturbed the small schools of fish, whales or porpoises.

BATHYTHERMOGRAPH OBSERVATIONS

The Service secured the loan of two bathythermographs, a winch, and accessories, from the Hydrographic Office of the Navy, through the Scripps Institution of Oceanography, for the purpose of recording water temperatures.

The bathythermograph or "BT", as it is generally called, is an instrument containing a pressure element and a temperature element, so arranged that a stylus will record the temperature in relation to depth on a smoked glass slide. The slide is then viewed or photographed under a properly calibrated grid, with temperature readings on the horizontal scale and depth on the vertical.

One "BT" instrument was for recording temperatures from the surface down to 180 feet (30 fathoms), the other down to 450 feet (75 fathoms). The "BT" may be sent down from a vessel under way by letting the wire to which it is attached pay out faster than the ship is moving. The instruments used were refinements of one described by A. F. Spilhaus. 1/

After April 22, when the Bathythermograph winch was installed, "BT" and plankton samples were taken regularly whenever the vessel was under way and clear of shoals. The three "offshore" cruises yielded the most information about oceanographic conditions along the coast, but even the scattered inshore "BT" records showed significant temperature peculiarities.

The "BT" observations covered too limited an area to indicate the general pattern of offshore conditions, yet without some knowledge of this larger pattern it would be difficult to interpret the present observations. Although the temperature and current patterns off the California coast have not been studied in detail, their broad features are known.

The principal current off the California coast flows toward the southeast. It is a wide, rather sluggish current known as the California Current. According to Sverdrup, Johnson, and Fleming (1942), 2/ it is a southward extension of the Aleutian current of the North Pacific and is found between lat. 48° and 23°N. The California current apparently is located several hundred miles off the coast of Central California, although, at times it is probably closer to shore than this, at other times further seaward. In 1939, when a section off Monterey was surveyed jointly by the Scripps Institution of Oceanography and the Fish and Wildlife Service, this current was 180 to 240 miles offshore in June. Water temperatures in the current are a little higher than in the waters on its shoreward side.

1/ "A Bathythermograph," Sears Found. for Mar. Res., Bingham Oceanogr. Lab. Jour. Mar. Res., vol. 1, no. 2, pp. 95-100, 1938.

2/ "The Oceans," Prentice-Hall, Inc., New York.

Between the California Current and the coast there is a counter current flowing toward the north, known as the Davidson Current. This current can be detected at all seasons of the year at depths below 200 meters, but as a surface current it is present only during the fall and early winter months, particularly during November, December, and January. During the spring and early summer months when north-northwest winds prevail off the coast of California, upwelling takes place, overturning the surface layers and destroying the counter current above a depth of about 200 meters. The over-all current pattern in the region of upwelling seems to consist of a number of long-stretched swirls and not a current flowing consistently in one direction. However, a current may develop which flows in the direction of the wind. Off the California coast this would result in an along-shore current flowing in the same direction as the California Current and in the opposite direction to the counter current, now present at depths below 200 meters.

Upwelling is a term applied to the vertical transport of water from a depth to the surface. It is directly connected with wind action. When the northwesterly winds blow parallel to the coast, the light surface water is transported away from the coast (almost at right angles to the wind direction). The fact that the water veers to the right, instead of moving parallel with the coast, is due to the effect of the earth's rotation. The surface waters, moving offshore, are replaced by heavier subsurface water. Upwelling, apparently, takes place within the upper 100 to 300 meters only. It brings to the surface water of greater density, of lower temperature, and richer in plant nutrients than that replaced. Because upwelled water is rich in plant nutrients, such as phosphates, nitrates and silicates, it is of great importance in increasing the productivity of an area.

In regions of intense upwelling off the California coast, the average surface temperature of the water may be as low during June and July as during December and January. This is well illustrated by figure 1 showing surface temperature along the Pacific Coast (from lat. 25° to 52°N) in December and July. 1/

1/ Surface temperature observations taken by commercial vessels over a period of years have been compiled by the Scripps Institution of Oceanography and used in preparing charts showing surface isotherms (smoothed) for each month of the year off the west coast of North America, north of lat. 25°N. The temperature data, used in preparing figure 1 were obtained from these charts.

The lowest surface temperatures along the whole coast during July occur off Central California, just north of San Francisco. We can assume that ordinarily this is the area of most intense upwelling, although upwelling is a dominant feature along the whole California Coast north of San Pedro.

"BT" observations, although primarily a record of temperatures, can be used to obtain a rough approximation of the current pattern in the area surveyed. The current pattern is ordinarily computed from the distribution of densities, obtained from observations of both temperature and salinity. For an accurate determination of density, it is necessary to know both the temperature and salinity. However, because density in the upper layers of water is usually more dependent upon temperature than salinity, isotherms in a horizontal plane may be used to obtain a rough approximation of the current pattern. The direction of the current is determined as follows: in the northern hemisphere the warmer water lies on the right hand side of an observer looking in the direction of the current, the colder water on the left. 1/ The speed of the current is greatest where density (temperature) changes are greatest and when isotherms are plotted in the horizontal plane we may assume that in the region where the isotherms are closely spaced there would be a marked current.

The current patterns during the seaward cruises of the PEARL HARBOR were determined from temperature isotherms at the 100-foot level. We chose this level for the following reasons: (1) it was deep enough to get below ordinary surface fluctuations in temperature caused by local solar heating and the like, (2) more observations could be utilized than if a somewhat deeper level, say 165 foot (50 meter), was chosen, because many shallow "BT" casts were as deep as 100 feet but not as deep as 165 feet, and (3) the current pattern was well defined at this level.

During the first seaward cruise, May 15-18, there was a southeasterly drift about 50 miles off the coast between San Francisco and Ano Nuevo (shown in Fugure 3). Below this point the current probably turned eastward toward Monterey Bay. This could have been better demonstrated had there been stations to the south, but lacking these there is support for this interpretation in the vertical temperature gradients. (See temperature profiles in Figure 5). "BT" casts Nos. 15 to 25, taken along the inner half of the southern line, showed a number of complex temperature inversions (colder water overlying warmer water). Inasmuch, as such inversions are said to be typical of (though not limited to) current boundaries, they strongly suggest that the movement in this region was easterly in direction.

1/ Sverdrup, Johnson, and Fleming. The Oceans. pp. 394, 1942.

This probably is an example of the earlier-mentioned southerly flowing current, inshore of the California Current and associated with the upwelling process.

A rather complex pattern of water movements is indicated by the isotherms at the 100-foot level for the two later cruises (combined in Figure 4). The major movement in the area seems to be in the form of a large eddy, the northern portion of which was sampled. The northward movement in the eddy occurred near the outer end of the lines (lower and middle lines) while the flow in the reverse direction (southeast) was nearer shore--just to the west of the Farallon Islands. There were also several secondary eddies (especially on the upper line off Bodega Bay). These are probably examples of the earlier-mentioned elongated swirls occupying the area inshore of the California Current.

These observations on the current pattern prevailing during the seaward cruises should be considered as rough approximations only. Even so, it is evident that no cruise extended as far seaward as the California Current. The current pattern in the area surveyed is probably quite variable during the period of upwelling. Certainly, the pattern changed considerably between the first and second cruises.

This is evident from examination of that portion of the second cruise which extended into the area covered by the first. During the three week interval between the cruises the thermal pattern in this area changed considerably, and the temperature at 100 feet and above was several degrees higher during the later cruise (see temperature profiles, in Figures 6 and 7). This was probably due to the change in the current pattern in this area rather than to an actual warming of the water because, in most areas near shore, there was a gradual cooling of the water during the period of survey. This can be illustrated from a comparison of 4 "BT" tracings ("BT casts no. 47, 52, 66, 86) obtained on different dates between May 23 to June 18 from approximately the same locality about 4 to 6 miles south of Point Reyes. (Illustrated in Figure 9; for clarity, two tracings only are compared in each figure). The temperature change between May 23 and June 6 was small. In the week between June 6 and 13, however, there was a marked rise in temperature of the surface layers (down to about 40 feet), but the water below 60 feet was colder, probably due to an influx of upwelled water. On June 18 the water was nearly as cold in the deeper layer as on June 13, but the cold layer now extended nearly to the surface, representing a marked overall lowering of the temperature. Concurrently with this temperature change the appearance of the water also changed. On June 13, with warm surface water, the water had a brownish tinge, what the fishermen call "salmon water." On June 18, with surface water 5°colder, the water was a clear greenish blue. Undoubtedly, the water mass itself had changed during this period.

The gradual lowering of the temperature of the water in this locality is perhaps better shown by the average temperature from 0 - 150 feet. On the above dates it was as follows:

Date	Average temperature, 0-150 ft.
	of
May 23	49.3
June 6	49.1
June 13	48.9
June 18	48.2

This lowering of the temperature of the water during the spring months is due to upwelling.

There are several "BT" casts that may have been taken in regions where upwelling had recently taken place. We would expect a "BT" cast taken in a region of active upwelling to have a rather uniformly low temperature from the surface to a depth of several hundred feet or more. "BT" observations Nos. 3, 68, 69 and 79 have uniformly low temperatures with but little change between the surface and 150-180 feet. These are probably examples of recently upwelled water. However, to be certain one would need to have salinity data as well as temperature.

Values of temperature at standard depths as read from all of the "BT" records of the Pearl Harbor cruises are given in table 2.

PLANKTON COLLECTIONS

Plankton is the basis of the sardine industry. Plankton not only forms the entire diet of the sardine during its entire life span but sardine eggs and young are passive, free-floating constituents of the plankton itself.

The term plankton is used to refer to small floating plants and animals present in all bodies of water, salt or fresh. The plants in the plankton constitute the basic food in the ocean; they consist principally of microscopic plants, often single-celled, known as diatoms. In addition there are many kinds of animals in the plankton, --in fact, nearly all the principal groups of marine animals have representatives in the plankton. Many of the animals in the plankton are microscopic in size, but some, such as jelly fish, are often quite large. Some animals live their entire lives in the plankton; others are a part of it only while very young, as is the case with the sardine, the anchovy and the commercial crabs and lobsters. The plankton community is a complex aggregation of many kinds of organisms whose numbers and relative importance are in a state of continual flux.

A small net, illustrated in fig. 11, was used to obtain samples of plankton. It was designed to collect samples while the boat was going at normal speed (9 knots). The net is of simple but unconventional design, consisting of three parts: a brass towing head, a short, cylindrical straining surface, and a plankton bucket. The brass towing head is shaped somewhat like an inverted funnel; it is 2-3/4 inches in length, cylindrical in the rear half where the net is fastened and tapering from two inches in diameter, inside measurement, at the cylinder to one inch at the mouth. The straining surface consists of a cylinder, 10 inches long by 2 inches in diameter, made of no. 56xxx bolting silk. A canvas band at either end serves for attachment to the towing head and to the coupling on a plankton bucket. The latter is the more or less standard type used for limnological collection. 1/

Most samples were obtained by towing the plankton net at 9 knots for a period of 20 minutes. Not only did the net tow well at this speed, but the plankton organisms taken in the net were caught in fair numbers and remained in excellent condition.

No instrument was available for measuring the exact amount of water entering the net but a maximum estimate may be derived by assuming that the net strained a cylinder of water oneinch (2.5 cms.) in diameter (the diameter at the mouth opening of the net) and 3 miles in length (the length of the haul). Under these circumstances approximately 2.75 cubic meters (725 gals.) of water would enter the net during a 20 minute haul. Actually, the volume would probably be somewhat lower due to the obstruction of flow by clogging of the net or other causes.

It was estimated that the net fished mostly from the surface to a depth of 34 feet (10 meters) 2/ and that the net went deeper than this only during the time the cable was being freely payed out at the beginning of each haul.

1/ This bucket is sold by several supply houses for the Birge plankton net. We modified it to the extent of substituting a rubber stopper with a wire attached in place of the brass rod stopper.

2/ The average depth of the net during most hauls, based on the angle of stray of the towing wire, was computed to be about 17 feet (app. 5 meters). However, this estimate assumes that the towing wire was straight for its complete length. Actually, it probably curves downward at the end to which the net and weight were attached. Even were the depth twice as great as that computed, however, the net would still have towed at only about 34 feet (10 meters) depth. The length of the towing wire was usually 300 feet. At first a sash weight was used to weight down the net while towing, but later on inoperative "BT", weighing 20 pounds, was substituted because it had much better towing qualities than the sash weight.

The samples of plankton obtained by nets, even when constructed of very fine meshed material, are size selective, allowing a portion of the smaller plants and animals to escape. 1/ The small net used during the Pearl Harbor cruise was constructed of no. 56xxx bolting silk. The opening between threads is approximately 0.3mm. for unused bolting silk of this mesh size and only about 0.2 mm for used nets. 2/ Hence, any organism that would be lost through the meshes of this net would have to be less than 0.2 mm in two of its dimensions.

The volume of plankton retained by the small net was, consequently, smaller than the amount present in the waters sampled. Whether such a loss is important or not depends upon the use to which the collections are to be put. If a person were interested primarily in fish eggs and larvae in the plankton, for example, the sampling would be quite adequate, for the mesh-size is small enough to retain all the eggs and larvae that enter the net. However, if a person were interested primarily in the productivity of an area, the sampling would be inadequate. In any comprehensive survey undertaken in the future, techniques should be developed for fully sampling the smaller constituents of the plankton.

Volume of Plankton

An estimate of the volume of plankton taken by the net during a haul was obtained by straining the plankton from its preserving liquor, and then measuring the volume of the wet plankton in a graduated glass centrifuge tube after plankton had been allowed to drain for several minutes in the fine silk cone used in the separation. Large jelly masses and ctenophores were removed, their volume determined, and subtracted from the total volume. The volumes of plankton are given in table 4 and do not include jelly masses and ctenophores. 3/

1/ Sverdrup, Johnson & Fleming "The Oceans," pp. 377.

2/ The aperture size between threads becomes reduced in a net that has been used for a time in water due to a combination of shrinkage of the material and spreading apart of the fibers in the threads.

3/ Jelly masses were usually fragments of coelenterates or tunicates. The volume of ctenophores was not measured for most samples until several months after collection. At that time many of the ctenophores were disintegrating. For this reason the volume occupied by this group is excluded from the tabulations, but the number present in each haul is listed.

The volume of plankton taken by the net during a haul varied from .1 cc to 10.0 cc (jellies and ctenophores excluded). As previously pointed out, the probable maximum amount of water that the net could have strained during a 20-minute haul was 2.75 cubic meters, hence, the minimal volume of plankton taken per cubic meter of water strained (based on the poorest haul) was at least .04 cc, the largest volume of plankton per cubic meter of water strained (based on the richest haul) was at least 3.65 cc. and the average volume was at least 0.46 cc.

A comparison of these results with volumetric measurements of zooplankton from other areas may be enlightening. Very few data are available from localities in the Pacific Ocean. Material collected in 1941 during pilchard spawning surveys off southern California in May and June yielded approximately .28 cc. of plankton per cubic meter of water strained through a somewhat coarser meshed net than that used during the "Pearl Harbor" cruises. 1/

More data are available on volumetric measurements of zooplankton from the north Atlantic. 2/ The samples were taken by various investigators on both sides of the Atlantic using various types of nets hauled invarious ways, so that they are only roughly comparable. The average volume of plankton at the best season was usually between 0.20-0.35 cc per cubic meter in most areas, although, it was as high as 0.75 cc between Cape Cod and Chesapeake Bay.

The plankton in the area surveyed by the PEARL HARBOR, consequently, would seem to be at least as rich as most--perhaps even somewhat richer than in other areas volumetrically surveyed. Certainly the collection of 3.65 cc of animal plankton per cubic meter in one haul is an example of exceedingly rich plankton, exceeded by very few hauls on record.

1/ The nets used during the 1941 survey were constructed on no. 40xxx grit gauze with an average distance between threads of about 0.3 mm., while the nets used on the "Pearl Harbor" cruises were constructed of no. 56xxx grit gauze with an average distance between threads of about 0.2mm. There was also a difference in the method of obtaining the samples; during the 1941 survey the hauls were taken obliquely from about 75 meters deep to the surface, while during the "Pearl Harbor" cruises the net was towed horizontally.

2/ Summarized in Bigelow and Sears, 1939. Studies of the water of the continental shelf, Cape Cod to Chesapeake Bay. III. A volumetric study of the zooplankton. Mem. Mus. Comp. zool., Harvard U., vol. 54, no. 4, pp. 183-378, esp. pp. 221-228.

Plankton Organisms

The plankton samples were examined under a low power binocular microscope to determine the kinds of organisms present and their approximate volume. Fish eggs and larvae were separated from the plankton, but only pilchard and anchovy eggs and larvae were separately tabulated. The main groups of organisms making up the plankton in addition to fish eggs and larvae were copepods, euphausids, amphipods, decapod crustacea larvae (mostly crab), appendicularians, salps, chaetognaths and siphonophores. 1/ Several other categories were either present in small numbers in many samples or were common in one or two samples--these included cladocerans, ostracods, annelids, and pteropods. However, as these latter categories were usually present in quantities too small to estimate, they are included in the table under the heading of miscellaneous.

Larger organisms such as salps, siphonophores, decapod-crustacea larvae, amphipods, chaetognaths, and the larger euphausids could usually be rather readily separated from the other constituents of the plankton and the volume occupied by each category could be directly determined by measurement. However, with small organisms such as copepods, appendicularians and at times euphausids it would have been too time-consuming to completely separate out each group; hence, the volume of plankton remaining after the categories mentioned above had been removed was measured, and an estimate of the relative proportion by volume of each of the several main groups of organisms composing this residue was made by inspection. These estimated proportionalities were applied to the measured volume of the residue to compute the volume of each category.

Copepods were the most important element in the plankton. in a total of 54 samples they had the largest volume in 32 samples and the second largest volume in 15 others. This importance of copepods and the relative importance of other groups are shown in table 5. Because some groups are taken in larger volume during night time, night hauls and daylight hauls are separately tabulated. This difference between day and night hauls is more clearly evident in tables 6 and 7 which give the volume of the principal groups of animals in the plankton hauls in relation to both time of collection of hauls and to distance from shore.

1/ Illustrations of some of these types of animals may be found on pp. 812 et. seq. of Sverdrup, Johnson and Fleming, 1942).

With regard to the distribution of particular groups of organisms, copepods seem to occur in about equal abundance in night and day hauls, although they are about twice as abundant within 20 miles of shore as beyond. Euphausids, on the other hand, although having a similar relation as regards distance from shore, are much more abundant in samples taken at night than in the daytime. Decapod crustacea larvae were taken in quantity only near shore and amphipods at a distance from shore. Salps were taken in greater quantity at night and at some distance from shore. Appendicularians, which were present in all but two samples, seem to occur in about equal abundance in all parts of the area sampled at whatever time of the day taken.

Reserve should be used in drawing conclusions from tables 6 and 7, however, as they probably carry the refinement of the data further than the basic data warrant. The sampling, in a word, was not random, with respect to date, time of day, and distance from shore, but the data are used in the table as if they were. Nonetheless, they demonstrate beyond doubt these generalities: (1) that night hauls were richer than those taken during daytime and (2) that hauls taken within 20 miles of shore were richer than those taken farther to seaward.

The greater richness of the night hauls is due, in large part, to the vertical movement of animals toward the surface during darkness. Many plankton animals move downward during daylight hours (not uncommonly to depths as great as 500 to 1000 feet), and move toward the surface at night time. The upward migration at night may be for feeding, since food is more abundant in the upper layers. Not all organisms migrate. Most marine plants, for example, have no means of locomotion, and because they require sunlight to carry on photosynthesis, are confined to the upper layers. Many small plankton animals have very little power of locomotion; consequently, they engage in little or no vertical movement. In fact, it is mainly the larger organisms with fairly well developed means of locomotion that migrate for any distance vertically. Using the PEARL HARBOR collections as an illustration, the euphausids taken in day hauls were small, immature individuals only, while euphausids of all sizes up to large mature individuals were present in night hauls.

The hauls taken within 20 miles of shore were richer than those taken farther to seaward, probably because the area near shore was influenced to a greater extent by upwelling. Water temperatures were lower near shore and increased to seaward, and this lends support to the thesis that upwelling (or at least recently upwelled water) was more important in this zone than elsewhere. As mentioned previously, upwelling plays an important role in increasing the productivity of an area by bringing to the surface plant nutrients that have accumulated at a depth.

Most of the plankton samples were obtained during the three seaward cruises. An interesting feature of the plankton distribution on the first of these was the presence of a rich band of plankton sampled on the outward leg at approximately 36° 51'N and 123°02-06'W (sample #11) and on the inward leg at approximately 27° 20'N, 123° 45-42'W (sample #25). The volume of plankton was 3 or 4 times as great in these hauls as in samples taken on either side. Copepods made up the major portion of the volume (approximately 85%). These rich areas were near to, but on the shoreward side of current boundaries.

An increasingly large number of ctenophores was collected during the later cruises. Ctenophores were taken in only one sample during the first cruise (average, 1 individual per haul during the cruise), in 7 out of 10 samples on the second cruise, made three weeks later (average, 2.5 individuals per haul), and in 12 out of 14 samples on the third cruise, made a week later than the second (average 6.0 individuals per haul).

Very few data are available on temporal change in the quantity and type of plankton in a locality. During the cruises identical stations were not revisited, but in a few instances samples were taken at a later date within a few miles of an earlier haul. The data for three such pairs of observations are given in table 8.

In each instance the comparison is based on two hauls, both of which were collected either during daylight or during nighttime. At each locality the later haul was taken at a lower temperature and contained a smaller volume of plankton than the earlier sample. In one comparison (samples No. 31 and 53) the composition of the plankton differed markedly: the earlier haul consisted mainly of copepods, the later of siphonophores and ctenophores. Such marked differences in the composition of the plankton must have been due to a change in the water mass itself at this locality, rather than to changes within the same water mass. These three comparisons, however, are too few to throw much light on this problem.

The relation of the sardine to the plankton has yet to be studied. All types of plankton may not be equally desirable as "fodder." Some plankton organisms, such as ctenophores, probably have little more food value than so much water; others, such as copepods and euphausids, probably have very high food value. We do not know how selectively the sardine feeds. It may avoid certain types of plankton, such as those containing large quantities of diatoms, which might interfere with its respiration, or those containing large amounts of jelly-like organisms. At least there is evidence that European herring do this.

We also need more information on the effects of oceanographic conditions on the production of plankton. The amount of upwelling, for example, is undoubtedly an important factor in plankton production. It is probably more extensive during some years than others, but as yet practically nothing is known about the extent of the annual variation. The influence of currents, both the "California Current," the "Davidson" counter current, and their variations, on plankton production in this area needs also to be investigated.

Because data for other seasons are lacking, it is not possible to determine whether plankton production during the spring of 1946 was poorer or better than average for this area. Similarly, we do not know whether oceanographic conditions were normal or abnormal. Further oceanographic observations covering a period of years are needed to determine average conditions off Central California. Only then could an abnormal condition of plankton abundance or ocean circulation be identified as such, and their relation to sardine scarcities become known.

Fish Eggs and Larvae Taken in Plankton Hauls

A suggestive relationship was noted between water temperature and the occurrence of pilchard eggs. Pilchard eggs were taken in three samples, and in each case the water temperature was 57°F (14°C) or higher in the upper 25 foot zone. 1/ Only 5 plankton hauls were made in water with a temperature as high as 57°F, and the taking of pilchard eggs in three of these and in none of the 49 other hauls strongly suggests that pilchard spawning was taking place in somewhat warmer water than that encountered during most of the survey. This accords closely with observations made during spawning surveys off southern California, where most spawning was found to occur in water of 13.5° to 16.0° C (56.3° to 60.8°F). The three samples containing pilchard eggs were taken about 50 to 75 miles offshore during the second and third seaward cruises (June 7 and June 14), at or near the seaward end of the lines. Hence, it is likely that we sampled only the inner edge of the spawning region. 2/

1/ Although temperature observations were not taken at the time plankton hauls were made, "BT" casts were usually alternated with plankton hauls and an interpolated value for water temperatures in the upper 25 foot zone during a plankton haul could be obtained by averaging the "BT" observation taken just before with that taken soon after a plankton haul.

2/ During a pilchard spawning survey in 1939, a line of stations was taken off Monterey. Sardine eggs were found in greatest abundance at about 150 miles offshore at a temperature of 14.4°C (57.9°F).

The concentration of pilchard eggs at the seaward end of the line on June 7 amounted to approximately 135 million eggs per square mile of sea surface, which is comparable to concentrations of pilchard eggs taken on the inner edge of the spawning zone off southern California in 1940 and 1941.

Pilchard larvae also were found in three samples from the same cruises, but shoreward from the localities where eggs were obtained; the temperature may have been as low as 54.5°F. at one locality, but was over 56.5°F. at the other two.

The temperature of the water from which anchovy eggs were obtained ranged from 52° to 58°F. (11.1° C. - 14.4°C). Anchovy eggs were widely distributed, occurring in 15 samples collected both near shore and to seaward. They were taken throughout the entire period of sampling. In six samples the record consisted of but a single egg, but in 7 samples the numbers of eggs taken were between 22 and 66. This is indicative of rather intensive spawning in this region. 1/ Anchovy larvae were taken in 4 samples, the largest number in a sample being 20.

Other fish eggs were taken in the majority of all samples collected (35), over a wide temperature range. However, the total number of other fish eggs in all samples was less than the number of anchovy eggs. Other fish larvae were obtained in 19 samples with three individuals being the largest number taken in any sample. A record of fish eggs and larvae taken in plankton hauls is given in table 9.

1/ The mere listing of numbers taken by the net may give a mistaken impression of the actual abundance. The net strained, at most, only 2-3/4 cubic meters of water while taking a haul. Because of this fact, it may be well to give an example of abundance in other terms. In a 20-mile wide coastal strip south of San Francisco, centering off Point San Pedro - Point Montara, anchovy eggs were taken in 6 out of 10 samples (between June 6 to 21). The average number of eggs per sample was 14.5. Integrating this number over the area involved, approximately 400 square miles, and assuming eggs to be equally abundant throughout the upper 10 meters of water, the number becomes 725 billion eggs. As the eggs probably take 3 to 4 days to develop to hatching at the temperatures prevailing in this area at the time, the daily number spawned would be about 18 billion eggs.

TABLE 1.-Record of B.T. casts made during the "Pearl Harbor" cruises

BT Cast No.	Date	Time of Collection	Position Lat.- N	Position Long.- W
1	IV - 25	1124	36° 47'	122° 05'
2	IV - 25	1145	36° 51'	122° 05'
3	V - 1	2208	37° 36'	122° 54'
4	V - 7	1034	37° 42½'	122° 54'
5	V - 7	1121	37° 45'	122° 44'
6	V - 15	1328	37° 36'	122° 52'
7	V - 15	1445	37° 31'	123° 00'
9	V - 15	1930	37° 21'	123° 23'
10	V - 15	2135	37° 11'	123° 05'
11	V - 15	2235	37° 11'	122° 52'
12	V - 15	2345	37° 10'	122° 41'
13	V - 16	1125	36° 50'	121° 52'
14	V - 17	0607	36° 56'	122° 13'
15	V - 17	0707	36° 55'	122° 24'
16	V - 17	0807	36° 54'	122° 35'
17	V - 17	0907	36° 53'	122° 46'
18	V - 17	1007	36° 52'	122° 58'
19	V - 17	1107	36° 51'	123° 09'
20	V - 17	1207	36° 50'	123° 20'
21	V - 17	1330	36° 49'	123° 36'
22	V - 17	1430	36° 47'	123° 47'
23	V - 17	1530	36° 46'	123° 58'
24	V - 17	1630	36° 45'	124° 10'
25	V - 17	1730	36° 44'	124° 21'
26	V - 17	1830	36° 43'	124° 32'
27	V - 17	1930	36° 42'	124° 44'
28	V - 17	2030	36° 41'	124° 55'
29	V - 17	2130	36° 40'	125° 07'
30	V - 17	2230	36° 39'	125° 18'
31	V - 17	2330	36° 38'	125° 29'
32	V - 18	0530	37° 00'	124° 35'
33	V - 18	0600	37° 02'	124° 30'
34	V - 18	0800	37° 10'	124° 10'
35	V - 18	0900	37° 14'	124° 00'
36	V - 18	1000	37° 18'	123° 50'
37	V - 18	1100	37° 22'	123° 40'
38	V - 18	1200	37° 26'	123° 30'
39	V - 18	1300	37° 30'	123° 20'
40	V - 18	1500	37° 38'	123° 01'
41	V - 18	1545	37° 40'	122° 54'
42	V - 18	1600	37° 41'	122° 51'
43	V - 18	1645	37° 43'	122° 43'
44	V - 23	1310	37° 41'	123° 05'
45	V - 23	1345	37° 40'	123° 08'
46	V - 23	1620	37° 49'	123° 05'

TABLE 1 (Cont'd) Record of B.T. casts made during the "Pearl Harbor" cruises

BT Cast No.	Date	Time of Collection	Position Lat.- N	Position Long.- W
47	V - 23	1700	37° 54'	123° 01'
48	V - 24	0830	37° 57'	122° 52'
49	V - 24	1200	37° 40'	122° 57'
50	V - 24	1352	37° 36'	122° 48'
51	V - 24	1440	37° 35'	122° 37'
52	VI - 6	0130	37° 55'	122° 57'
53	VI - 6	0255	37° 39'	122° 56'
54	VI - 6	0350	37° 33'	122° 49'
55	VI - 6	0434	37° 31'	122° 42'
56	VI - 6	1855	37° 27'	122° 34'
57	VI - 6	1955	37° 23'	122° 44'
58	VI - 6	2130	37° 19'	122° 53'
59	VI - 6	2235	37° 15'	123° 04'
60	VI - 6	2335	37° 11'	123° 14'
61	VI - 7	0050	37° 06'	123° 26'
62	VI - 7	0150	37° 01'	123° 36'
63	VI - 7	0300	36° 56'	123° 48'
64	VI - 7	1030	37° 30'	123° 08'
65	VI - 13	1715	37° 52'	122° 44'
66	VI - 13	1830	37° 57'	122° 56'
67	VI - 13	1915	38° 00'	123° 04'
68	VI - 13	2020	38° 08'	123° 08'
69	VI - 13	2110	38° 14'	123° 11'
70	VI - 13	2245	38° 10'	123° 20'
71	VI - 13	2345	38° 06'	123° 30'
72	VI - 14	0045	38° 02'	123° 40'
73	VI - 14	0200	37° 57'	123° 53'
74	VI - 14	0245	37° 54'	124° 01'
75	VI - 14	0420	37° 50'	123° 46'
76	VI - 14	0520	37° 48'	123° 35'
77	VI - 14	0630	37° 45'	123° 22'
78	VI - 14	0730	37° 43'	123° 12'
79	VI - 14	0820	37° 41'	123° 03'
80	VI - 14	1325	37° 41'	122° 59'
81	VI - 14	1425	37° 38'	122° 48'
82	VI - 14	1510	37° 37'	122° 39'
83	VI - 14	1625	37° 38'	122° 32'
84	VI - 18	1715	37° 52'	122° 44'
85	VI - 18	1805	37° 55'	122° 51'
86	VI - 18	2055	37° 55'	122° 58'
87	VI - 18	2240	37° 44'	122° 52'
88	VI - 20	2010	37° 41'	122° 42'
89	VI - 20	2110	37° 32'	122° 46'
90	VI - 21	0530	37° 22'	122° 46'
91	VI - 21	0810	37° 31'	122° 32'
92	VI - 21	0930	37° 42'	122° 39'

TABLE 2. Temperature values, in °F, at standard depths from B.T. tracings obtained during the "Pearl Harbor" cruises

B.T. Cast No.	Depth, in feet, of observation								
	0	25	50	75	100	150	200	300	400
	°F	°F	°F	°F	°F	°F	°F	°F	°F
1	53.5	51.3	50.0	49.1	48.8	—	—	—	—
2	53.9	52.6	49.6	48.9	48.7	47.9	—	—	—
3	50.2	49.2	49.4	49.9	49.9	49.6	—	—	—
4	53.1	51.7	48.9	48.8	48.4	47.9	—	—	—
5	53.8	52.4	49.8	48.3	48.2	—	—	—	—
6	52.5	51.4	50.6	50.1	48.1	47.8	—	—	—
7	51.3	50.5	49.5	48.8	48.8	48.4	47.9	47.3	47.1
9	51.6	51.6	51.3	51.2	51.2	51.1	50.0	48.7	47.7
10	53.2	53.1	53.0	51.9	50.3	49.2	49.6	49.0	—
11	52.2	52.1	51.2	50.2	49.9	48.9	48.5	48.1	—
12	52.2	51.7	51.3	51.0	49.6	48.5	—	—	—
13	55.2	54.7	51.2	50.1	49.9	49.2	—	—	—
14	52.3	52.3	51.2	51.1	50.5	49.4	—	—	—
15	53.7	53.1	51.2	50.2	50.9	50.3	49.3	48.7	—
16	54.1	53.9	53.6	52.5	50.1	48.9	48.4	47.7	—
17	54.4	53.3	53.1	53.1	51.8	49.9	48.7	47.9	—
18	54.1	53.6	53.4	51.5	50.1	48.9	49.0	48.1	—
19	54.1	54.0	53.2	53.1	53.2	49.2	49.5	48.5	—
20	53.4	52.7	52.5	53.2	52.4	50.0	48.4	48.2	—
21	55.1	55.1	55.0	54.7	52.6	51.1	49.6	48.3	—
22	54.7	54.5	54.2	54.2	53.9	52.1	49.2	48.0	—
23	54.5	54.5	54.1	53.1	52.9	52.6	51.1	48.9	—
24	54.7	54.6	54.4	53.7	53.4	53.0	50.9	48.8	—
25	53.9	53.8	53.5	53.3	53.3	53.1	53.0	49.0	—
26	54.2	54.2	54.1	54.0	53.8	53.0	51.4	49.2	—
27	54.2	54.2	54.2	54.1	54.0	53.9	53.1	50.5	—
28	54.5	54.4	54.2	54.1	54.0	53.9	53.7	52.0	—
29	54.1	54.1	54.1	54.0	53.8	53.9	53.8	50.9	—
30	54.5	54.5	54.5	54.4	54.3	54.1	53.9	51.4	—
31	54.7	54.6	54.5	54.4	54.4	54.2	54.1	51.8	—
32	54.0	54.0	54.0	54.0	53.9	53.0	52.6	52.5	—
33	54.0	54.0	54.0	54.0	53.9	53.7	52.9	52.1	—
34	54.1	54.1	54.1	54.0	53.8	53.2	51.8	49.5	—
35	52.1	52.1	52.1	52.1	52.1	51.2	49.1	47.9	—
36	51.8	51.6	50.2	50.1	49.8	49.2	49.3	48.4	47.6
37	53.0	52.7	51.4	50.0	49.7	49.7	49.5	48.1	47.8
38	53.1	53.0	51.3	50.6	49.9	49.6	49.3	48.0	47.7
39	52.1	51.6	50.8	50.2	49.9	49.1	48.1	47.8	47.3
40	52.8	51.0	50.1	49.1	48.8	48.6	—	—	—
41	52.1	50.4	49.0	48.8	48.3	—	—	—	—
42	52.4	50.3	49.4	48.3	48.1	—	—	—	—
43	52.9	50.4	48.3	48.0	47.7	—	—	—	—
44	53.8	51.7	51.4	49.9	49.5	48.1	—	—	—
45	54.0	52.7	50.4	48.9	48.7	48.1	47.9	47.5	47.4
46	54.0	51.0	50.1	49.9	49.3	48.1	—	—	—

TABLE 2. (Cont'd) Temperature values, in °F, at standard depths from B.T. tracings obtained during the "Pearl Harbor" cruises

B.T. Cast No.	Depth, in feet, of observation 0	25	50	75	100	150	200	300	400
	°F	°F	°F	°F	°F	°F	°F	°F	°F
47	53.0	50.0	49.4	49.1	48.8	47.7	—	—	—
48	52.9	51.2	50.3	49.2	—	—	—	—	—
49	52.4	52.2	52.1	51.4	50.3	—	—	—	—
50	54.5	53.2	52.0	49.9	48.4	47.8	—	—	—
51	55.3	53.3	49.5	49.1	48.8	—	—	—	—
52	52.3	49.8	49.2	48.3	48.2	48.1	—	—	—
53	54.2	51.5	50.4	48.7	48.1	47.7	—	—	—
54	53.6	53.2	52.1	51.0	49.1	47.9	—	—	—
55	54.1	54.2	50.7	48.9	48.3	47.9	—	—	—
56	56.2	51.2	49.6	47.9	47.4	47.1	—	—	—
57	56.0	52.4	50.5	49.7	49.2	48.7	—	—	—
58	56.9	56.3	55.4	54.7	52.8	50.9	49.7	47.7	46.9
59	57.0	55.1	54.1	53.8	53.2	50.8	50.7	48.6	47.2
60	56.5	55.3	55.2	53.9	52.7	51.9	50.3	47.5	46.9
61	57.8	57.8	55.0	53.3	52.7	50.0	49.2	48.2	46.8
62	57.5	56.9	56.6	55.0	53.6	49.2	48.1	48.6	47.6
63	57.5	56.0	53.2	52.5	51.1	51.8	48.4	48.3	47.8
64	56.1	55.8	54.2	53.2	53.4	51.7	48.9	47.9	—
65	55.0	48.3	47.9	47.2	(47.1)	—	—	—	—
66	56.0	51.6	49.0	47.7	47.2	46.8	—	—	—
67	51.8	49.8	48.8	48.1	48.0	—	—	—	—
68	49.4	48.7	48.4	48.2	48.1	47.3	—	—	—
69	50.1	48.5	48.4	48.3	48.3	47.6	—	—	—
70	52.0	51.9	51.5	49.7	48.7	47.9	47.5	47.0	—
71	54.5	52.1	51.8	51.3	51.2	49.8	49.3	48.7	—
72	56.3	54.3	53.9	51.5	50.7	49.8	49.4	49.3	—
73	56.8	54.5	53.4	53.0	52.9	52.5	50.1	48.9	—
74	54.4	53.6	53.0	52.6	52.1	52.0	50.8	48.5	—
75	58.2	57.5	56.0	54.0	51.4	50.7	49.1	47.7	47.4
76	57.8	56.6	56.5	56.4	55.0	50.2	49.2	47.7	—
77	56.4	56.4	55.3	54.0	52.9	49.0	49.3	48.9	—
78	52.1	51.0	51.0	50.7	50.6	50.5	50.0	49.2	—
79	50.0	49.4	49.4	49.2	49.1	47.7	—	—	—
80	51.3	50.0	49.3	49.0	48.5	—	—	—	—
81	54.1	49.8	50.5	48.3	49.0	—	—	—	—
82	56.6	51.2	48.3	47.7	—	—	—	—	—
83	55.1	49.4	48.4	48.4	—	—	—	—	—
84	53.2	51.2	48.1	—	—	—	—	—	—
85	50.1	48.5	48.3	47.9	46.9	—	—	—	—
86	50.1	48.5	48.3	48.0	47.5	—	—	—	—
87	51.0	50.9	49.4	48.5	47.9	47.0	—	—	—
88	53.0	52.8	50.1	49.0	47.9	—	—	—	—
89	52.1	49.6	49.4	49.3	49.1	47.9	—	—	—
90	52.0	51.2	50.9	50.3	49.9	48.6	48.1	47.2	—
91	53.3	50.8	47.9	47.8	—	—	—	—	—
92	53.2	50.1	48.7	—	—	—	—	—	—

TABLE 3. Record of plankton hauls made during the Pearl Harbor cruises

Plankton haul no.	Month	Day	Time Start	Time End	Position - Start N. Lat.	Position - Start W. Long.	Position - End N. Lat.	Position - End W. Long.
7	May	16	1420	1440	36° 53'	121° 59'	36° 54'	121° 59'
8	"	17	0710	0730	36° 55'	122° 25'	36° 55'	122° 28'
9	"	17	0830	0850	36° 53'	122° 39'	36° 53'	122° 43'
10	"	17	0930	0950	36° 52'	122° 50'	36° 52'	122° 54'
11	"	17	1030	1050	36° 51'	123° 02'	36° 51'	123° 06'
12	"	17	1130	1150	36° 50'	123° 13'	36° 50'	123° 17'
13	"	17	1230	1250	36° 49'	123° 24'	36° 49'	123° 28'
14	"	17	1400	1420	36° 48'	123° 41'	36° 48'	123° 45'
15	"	17	1500	1520	36° 46'	123° 52'	36° 46'	123° 56'
16	"	17	1600	1620	36° 45'	124° 04'	36° 45'	124° 08'
17	"	17	1700	1725	36° 44'	124° 15'	36° 44'	124° 20'
18	"	17	1800	1825	36° 43'	124° 26'	36° 43'	124° 31'
19	"	17	2000	2025	36° 41'	124° 49'	36° 41'	124° 54'
20	"	17	2100	2120	36° 40'	125° 01'	36° 40'	125° 05'
21	"	17	2300	2320	36° 38'	125° 23'	36° 38'	125° 27'
22	"	18	0630	0650	37° 04'	124° 25'	37° 05'	124° 22'
23	"	18	0815	0835	37° 11'	124° 7½'	37° 12'	124° 04'
24	"	18	0930	0950	37° 16'	123° 55'	37° 17'	123° 52'
25	"	18	1030	1050	37° 20'	123° 45'	37° 21'	123° 42'
26	"	18	1130	1150	37° 24'	123° 35'	37° 25'	123° 32'
27	"	18	1230	1250	37° 28'	123° 25'	37° 29'	123° 22'
28	"	18	1400	1420	37° 34'	123° 10'	37° 35'	123° 07'
29	"	23	1630	1650	37° 50'	123° 04'	37° 52'	123° 02'
30	"	24	0845	0905	37° 57'	122° 55'	37° 54'	122° 55'
31	"	24	1315	1335	37° 35'	122° 52'	37° 33'	122° 50'
32	June	6	0145	0205	37° 52'	122° 57'	37° 49'	122° 57'
33	"	6	0400	0420	37° 32'	122° 47'	37° 31'	122° 44'
34	"	6	1906	1926	37° 27'	122° 35'	37° 26'	122° 38'
35	"	6	2050	2110	37° 23'	122° 47'	37° 21'	122° 50'
36	"	6	2155	2215	37° 18'	122° 57'	37° 16'	123° 01'
37	"	6	2300	2320	37° 13'	123° 07'	37° 12'	123° 11'
38	"	7	0001	0021	37° 9½'	123° 18'	37° 08'	123° 21'
39	"	7	0105	0130	37° 02'	123° 29'	37° 01'	123° 31'
40	"	7	0215	0235	36° 57'	123° 40'	36° 56'	123° 42'
41	"	7	0415	0435	36° 51'	123° 58'	36° 54'	123° 55'
42	"	13	1930	1950	38° 02'	123° 04'	38° 05'	123° 06'
43	"	13	2025	2045	38° 10'	123° 08'	38° 13'	123° 11'
44	"	13	2155	2215	38° 13'	123° 13'	38° 11'	123° 17'
45	"	13	2315	2335	38° 08'	123° 25'	38° 07'	123° 28½'
46	"	14	0010	0030	38° 04'	123° 35'	38° 03'	123° 38'
47	"	14	0100	0120	38° 01'	123° 43'	37° 59'	123° 47'
48	"	14	0207	0227	37° 56'	123° 54'	37° 55'	123° 58'
49	"	14	0425	0445	37° 50'	123° 45'	37° 49'	123° 42'
50	"	14	0530	0555	37° 47'	123° 33'	37° 46'	123° 29'

TABLE 3. (Cont'd) Record of plankton hauls made during the Pearl Harbor cruises

Plankton haul no.	Month	Day	Time Start	Time End	Position - Start N. Lat.	Position - Start W. Long.	Position - End N. Lat.	Position - End W. Long.
51	June	14	0640	0700	37° 45'	123° 21'	37° 44'	123° 17'
52	"	14	0740	0805	37° 42'	123° 10'	37° 41'	123° 06'
53	"	14	1340	1400	37° 40'	122° 56'	37° 39'	122° 52'
54	"	14	1430	1450	37° 38'	122° 47'	37° 37'	122° 43'
55	"	14	1515	1535	37° 36'	122° 38'	37° 36'	122° 34'
56	"	18	1725	1745	37° 53'	122° 45'	37° 55'	122° 48'
57	"	18	2112	2132	37° 53'	122° 58'	37° 49'	122° 59'
58	"	20	2015	2035	37° 40'	122° 43'	37° 37'	122° 44'
59	"	20	2120	2140	37° 30'	122° 46'	37° 27'	122° 47'
60	"	21	0820	0840	37° 32'	122° 33'	37° 35'	122° 35'

TABLE 4.- Wet volume, in cubic centimeters, of principal constituents of zooplankton

Plankton haul no.	Copepods 1/ large	Copepods 1/ small	Euphausids large	Euphausids small	Amphipods	Decapod crustacea larvae	Other crustacea	Salps	Siphonophores	Appendicularians	Chaetognaths	Small eggs	Misc.	Total all 2/ groups
7	0.15	0.60		0.15			0.30	P	P	0.15	0.05			1.40
8	.30	.50		.05		P	P	0.10	P	.02	P	P	0.03	1.00
9	.05	.05		.03			P	.25		.02				.40
10	.20	.20		P				.10	P	.05		P		.55
11	1.00	.50		.15	P	P		P	P	.05				1.70
12	.10	.30		P						.05	.05	P		.50
13	.10	.30		P	P				P	.05	P			.45
14	.25	.25		.05	P					.05	P			.60
15	.13	.13		.04	P			.10		.05				.45
16	.15	.10		.05	P			.20		.05	P			.55
17	.08	.08		.08	P			.30		.08	P		.03	.65
18	.10	.25		.10				.55		.20	P			1.20
19	.10	.15	1.85	P	0.25			P		.15	P			2.50
20	P	.15		P	.30			.10		.08	P		.02	.65
21	.10	.15		.10	.15			.10		.05	.05			.70
22	.05	.20		.05	P			P		.05	P			.35
23	P	.05		P						P	P		.05	.10
24	.05	.15		P	P			P		.05		.15	.05	.45
25	.50	1.50		.10	P	P		P		.05		.25		2.40
26	.03	.10		.02				.02		.03		.02		.22
27	.05	.10		.03		.02		P		.02		P	.03	.25
28	.10	.40		P		P		P	P	.10		.30	.10	1.00
29	.20	1.50		.15		P		.05	P	.05		P	.05	2.00
30	.10	.65		.10		.70				.05	P	.10		1.70
31	.50	2.60		.30		.02				.10	.05	.40	.03	4.00
32	2.00	3.20	.40	3.00	P	1.00		P	.05	.20	.05	.10		10.00
33	.35	1.20		.70	P	.10				P	P	P	.05	2.40
34	.30	.65		1.00	P	P	P			P		P	.05	2.00
35	.10	.05		.05	P	P		.60	.05	.05	P	.10	.05	1.05
36	1.00	.10		.35	.03	P		1.20	.05	.05	.05	P	.07	2.90
37	.30	.05		.40	.10	P		.30	.20	.05	P	P	.05	1.45
38	.15	.05		.30	.05	P		.35	.10	.03	P		.07	1.10
39	.12	.04	.04	.12	.04	P		.70	.04	.02	P		.08	1.20
40	.20	.05		.20	.05	P		.40	.07	.03	P	P		1.00
41	.20	.05		.15	P	P		.20	.08	.03	P	P	.04	.75

TABLE 4 (Cont'd).- Wet volume, in cubic centimeters, of principal constituents of zooplankton.

Plankton haul no.	Copepods 1/ large	Copepods 1/ small	Euphausids large	Euphausids small	Amphi-pods	Decapod crustacea larvae	Other crusta-cea	Salps	Siphon-ophores	Appen-dicu-larians	Chaetog-naths	Small eggs	Misc.	Total all 2/ groups
42	P	0.05		P	P						P	P	0.05	0.10
43	0.40	.05		0.20	P					P	P	P	.05	.70
44	.20	.10		.15	P				P	P	P	P	.05	.50
45	.30	.10	0.30	.15		P		0.15	0.05	P	P	P	.05	1.10
46	.10	.05		.25	0.05			1.30	.05	P	P	P	.05	1.85
47	.30	.10	.40	.25	P		P	.40	.25	P	P	P	.05	1.75
48	.15	.05	.05	.15	.05	P		.05	.05	P	P		.05	.60
49	.10	.03		.10	.03			P	P	0.05	0.03	P	.06	.40
50	.08	.03		.06	P				.20	.05	P	P	.03	.45
51	.20	.05		.10	P			P	.15	.05	P	.40		.95
52	.02	.02		P	P				.08	P	P	.16	.02	.30
53	.05	.05		P	P	P		P	.35	P		P	.05	.50
54	.03	.30		.02	P	0.05			.05	P	P	P	.05	.50
55	.10	.90		.20	P	.10	P			P	P			1.30
56	.02	.30		.03		P						.05		.40
57	.25	.05	2.00	.05		P				P		.05		2.40
58	.30	.30	.90	.25	P	.25				.05	.05	P		2.10
59	.30	.30	.35	.25	P	.60	P		P	.02	P	.25	.03	2.10
60	P	.25		.05	P	.05			.03	P		.10	.02	.50

1/ Under large copepods are placed copepods as large as, or larger than, Calanus finmarchicus in the adult or late copepodid stages. Under small copepods are included all small-sized species as well as Nauplii and early copepodid stages of the larger-sized species.

2/ Total volume exclusive of jelly masses and ctenophores.

TABLE 5

Relative importance of the several groups of animals taken in the plankton hauls as shown by the number of instances of dominance and by the groups' percentage of total volume.

Group	Hauls taken during daylight			Hauls taken at night			All hauls		
	Dominant	Sub-dominant	Percentage of total volume 1/	Dominant	Sub-dominant	Percentage of total volume occupied	Dominant	Sub-dominant	Percentage of total volume occupied
	No.Samples	No.Samples		No.Samples	No.Samples		No.Samples	No.Samples	
Copepods	23	6	64	9	9	35	32	15	46
Euphausids	—	5	7	8	7	35	8	12	25
Salps	3	4	7	6	1	15	9	5	11
Siphonophores	1	1	3	—	—	3	1	1	3
Amphipods	—	—	P	1	1	3	1	1	2
Macro-crustacean larvae	—	1	3	—	1	4	—	2	4
Appendicularians	—	1	6	—	—	2	—	1	3
Cladocerans	—	1	P	—	—	P	—	1	P
Small eggs (euphausid or copepod)	3	6	7	—	—	1	3	6	3
All others	—	—	3	—	—	4	—	—	3
Total	30	—	100	24	—	102	54	—	100

1/ Total volume exclusive of jelly masses and ctenophores. "P" signifies presence in quantity too small to be measured.

TABLE 6

Average volume, in cubic centimeters, of the principal groups of animals in the daytime plankton hauls grouped according to distance from shore.

GROUP	Distance of haul from shore			Average Daytime Hauls (30 hauls)
	0 - 20 miles (10 hauls)	20 - 40 miles (7 hauls)	over 40 miles (13 hauls)	
	cc.	cc.	cc.	cc.
Copepods	0.91	0.41	0.39	0.57
Euphausids	.10	.05	.04	.06
Amphipods	P	P	P	P
Decapod Crustacea larvae	.09	P	P	.03
Small eggs (copepod or euphausid)	.07	.12	.03	.06
Salps	.02	.05	.09	.06
Siphonophores	.04	.06	P	.03
Appendicularians	.04	.05	.06	.05
All other 1/	.06	.02	.02	.03
Total	1.33	0.76	0.63	0.89

1/ All other animals taken in the plankton hauls except jelly masses and ctenophores.

TABLE 7

Average volume in cubic centimeters, of the principal groups of animals in the nighttime plankton hauls grouped according to distance from shore

GROUP	Distance of haul from shore			Average-night hauls (22 hauls)
	0 - 20 miles (9 hauls)	20 - 40 miles (5 hauls)	over 40 miles (8 hauls)	
	cc.	cc.	cc.	cc.
Copepods	1.03	0.48	0.21	0.61
Euphausids	.92	.42	.37	.61
Amphipods	P	.04	.11	.05
Decapod Crustacea larvae	.22	P	P	.07
Small eggs (copepod or euphausid)	.06	P	P	.02
Salps	.07	.67	.24	.27
Siphonophores	.01	.12	.04	.05
Appendicularians	.04	.02	.05	.04
All other 1/	.02	.06	.04	.04
Total	2.37	1.81	1.06	1.76

1/ All other animals taken in the plankton hauls except jelly masses and ctenophores.

TABLE 8. A comparison of plankton hauls taken 2 to 3 weeks apart in approximately the same localities.

	10 miles south of Pt. Reyes		6-10 miles SE of Farallone Islands		15 miles west of Pt. Montara	
	F32	F57	F31	F53	F33	F59
	VI-6	VI-18	V-24	VI-14	VI-6	VI-20
	1:50AM	9:20PM	1:25PM	1:50PM	4:10AM	9:30PM
Plankton Group	52.0°F 1/	49.2°F	54.0°F	51.5°F	53.8°F	50.8°F
	cc.	cc.	cc.	cc.	cc.	cc.
Copepods	5.20	0.30	3.10	0.10	1.55	0.60
Euphausids	3.40	2.05	0.30	P	0.70	0.60
Amphipods	P	—	P	P	P	P
Decapod crustacea larvae	1.00	P	0.02	P	0.10	0.60
Salps	P	—	—	P	—	—
Siphonophores	0.05	—	—	0.35	—	P
Appendicularians	0.20	P	0.10	P	P	0.02
All other	0.15	0.05	0.48	0.05	0.05	0.28
Total volume 2/	10.00	2.40	4.00	0.50	2.40	2.10
	No.	No.	No.	No. 3/	No. 4/	No.
Ctenophores	3	—	1	25	9	1
Anchovy eggs	—	—	—	—	55	—
Other fish eggs	2	—	—	9	4	9
Other fish larvae	1	—	1	—	1	—

1/ Average temperature, 0-25 feet.
2/ Total volume exclusive of jelly masses and ctenophores.
3/ Occupied approximately 1.8 cc.
4/ Occupied approximately 1.3 cc.

TABLE 9. Record of fish eggs and larvae taken in plankton hauls

Plankton haul no. 1/	Pilchard Eggs	Pilchard Larvae	Anchovy Eggs	Anchovy Larvae	Other Eggs	Other Larvae
	no.	no.	no.	no.	no.	no.
7			1		1	
10			1		2	
11			1		1	
12			1		7	
13					18	
14					7	
15					2	
16					4	
17					1	
18			1		1	
19					1	1
21					1	
22					1	
24					3	
25					2	2
28					3	1
29					1	1
31						1
32					2	1
33			55		4	1
34			24			
35			3			1
36		3	1		26	1
37				7	37	3
38					4	
39					7	1
40	5			1	4	
41	6					
47					1	1
48						2
49	1		66	5	7	1
50		1	47	20	3	3
51		1	22		3	2
52						1
53					9	
54			32		6	1
55			3		3	
56					2	1
58					2	
59					9	
60			28		6	

1/ Hauls in which neither eggs nor larvae were found are omitted.

33641

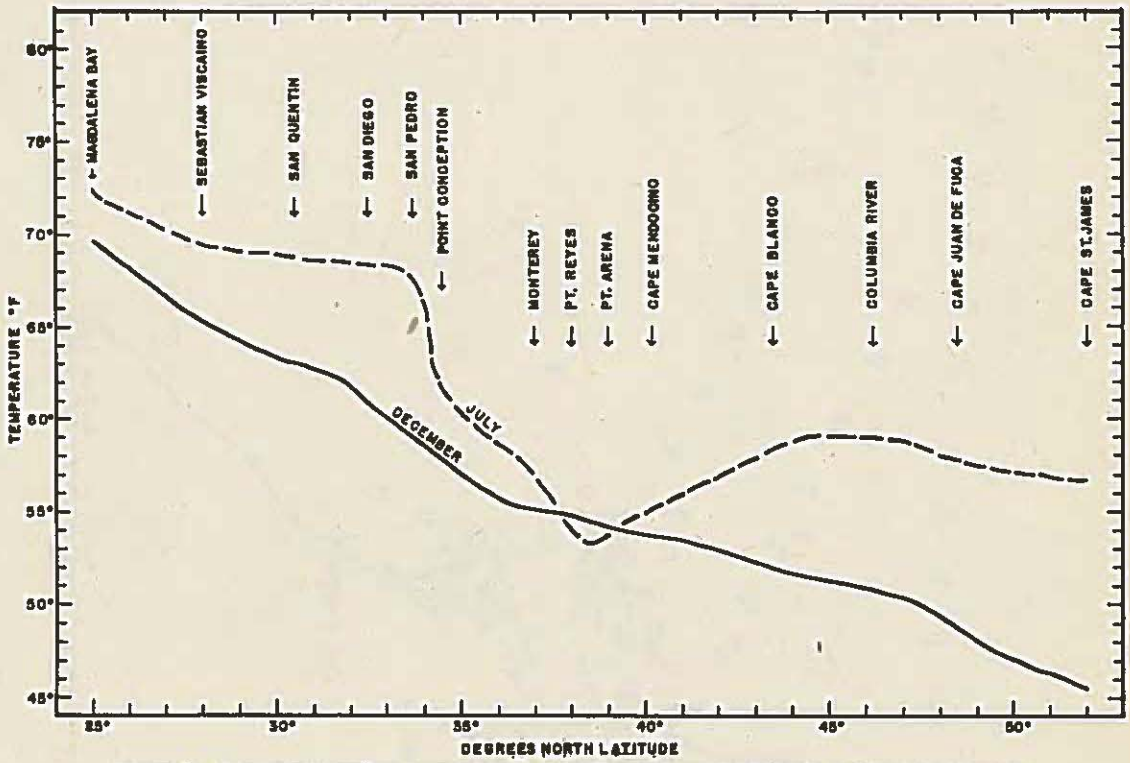

Figure 1. Average sea surface temperatures along the west coast of North America from latitude 25° to 52° north in December and July.

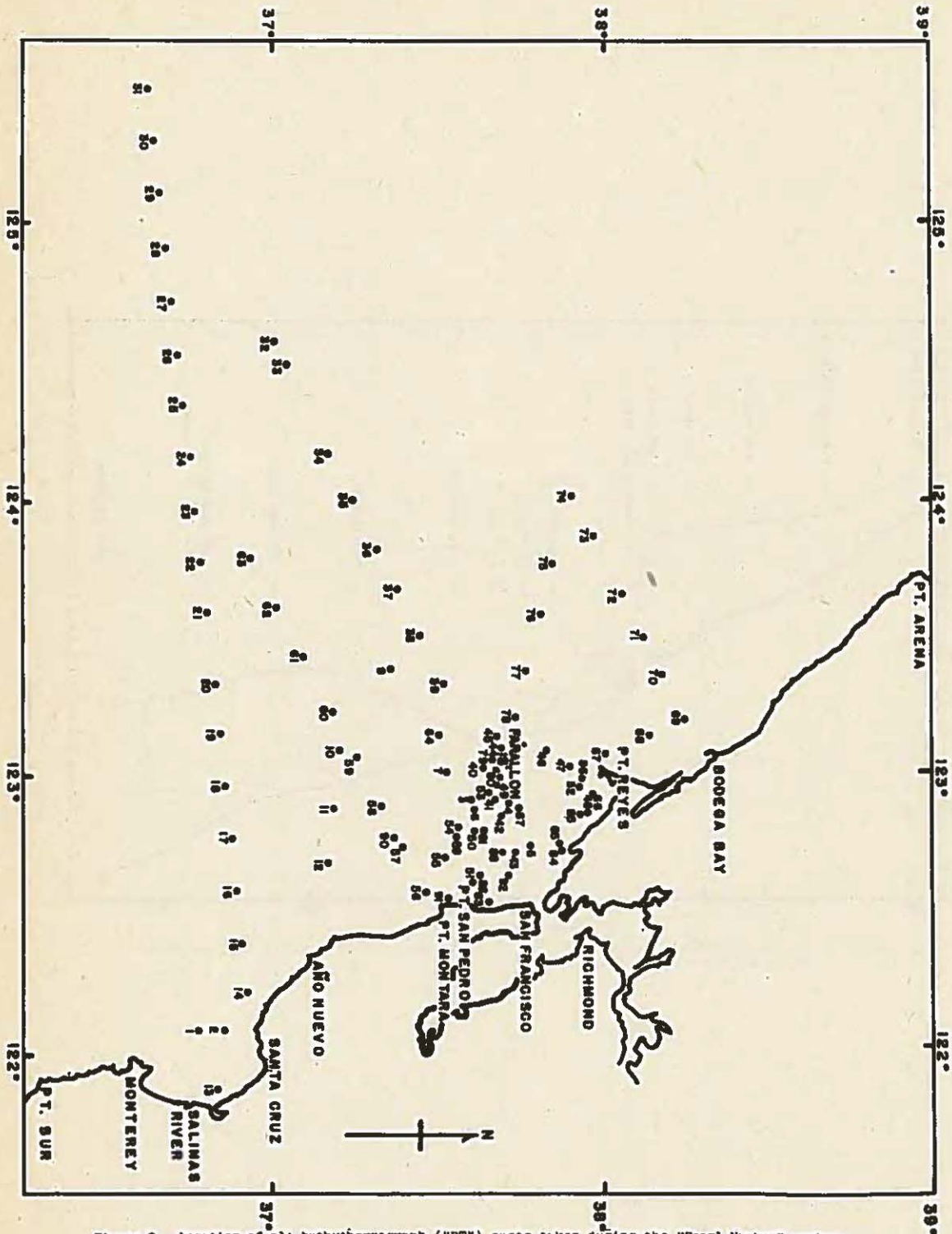

Figure 2. Location of all bathythermograph ("BT") casts taken during the "Pearl Harbor" cruises. The "BT" cast numbers are preceded by a letter F in the files of the Scripps Institution of Oceanography, but this prefix has been omitted here for lack of space.

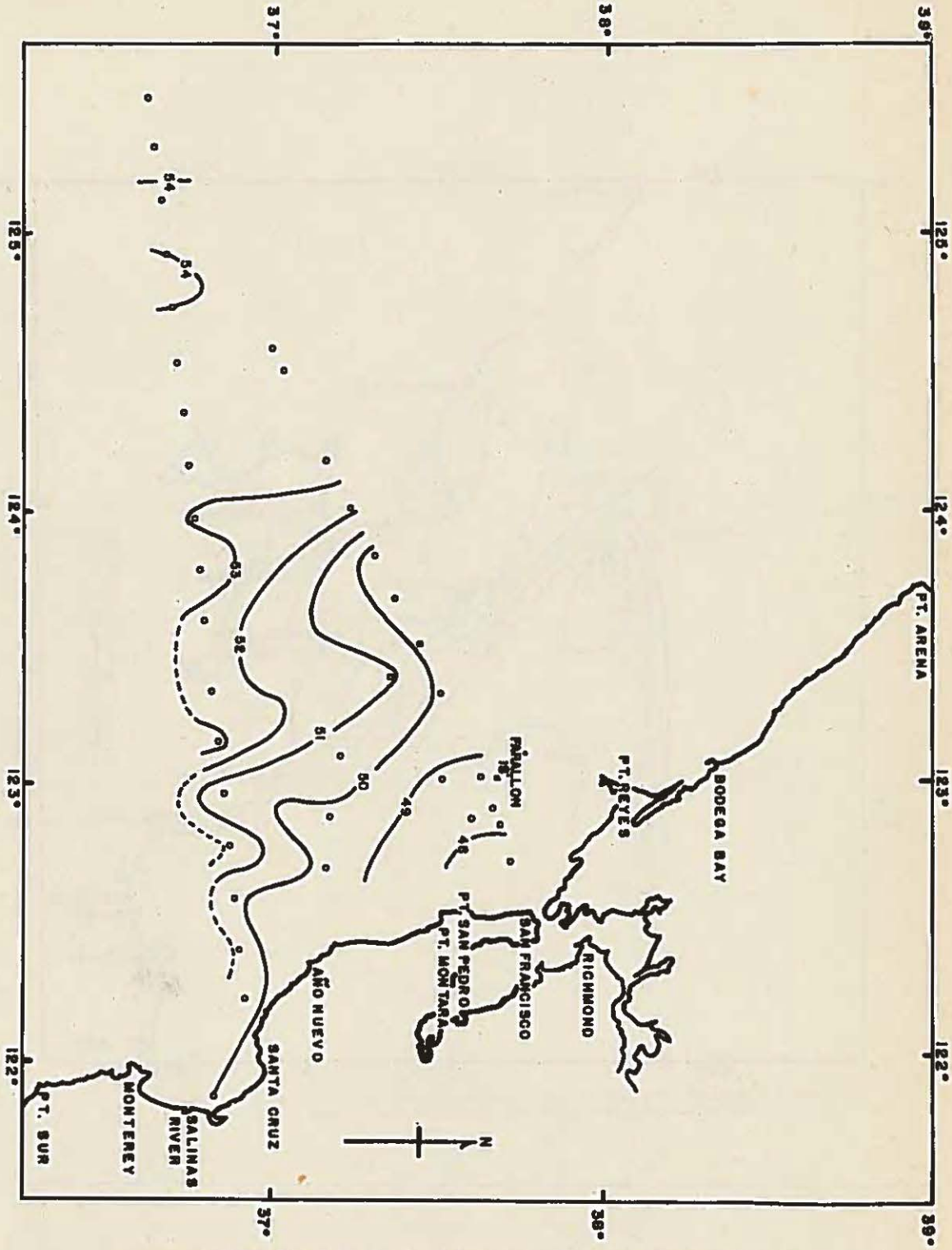

Figure 3. Isotherms (°F) at 100 foot level during the cruise of May 15 to 18. Location of "BT" casts indicated by open circles.

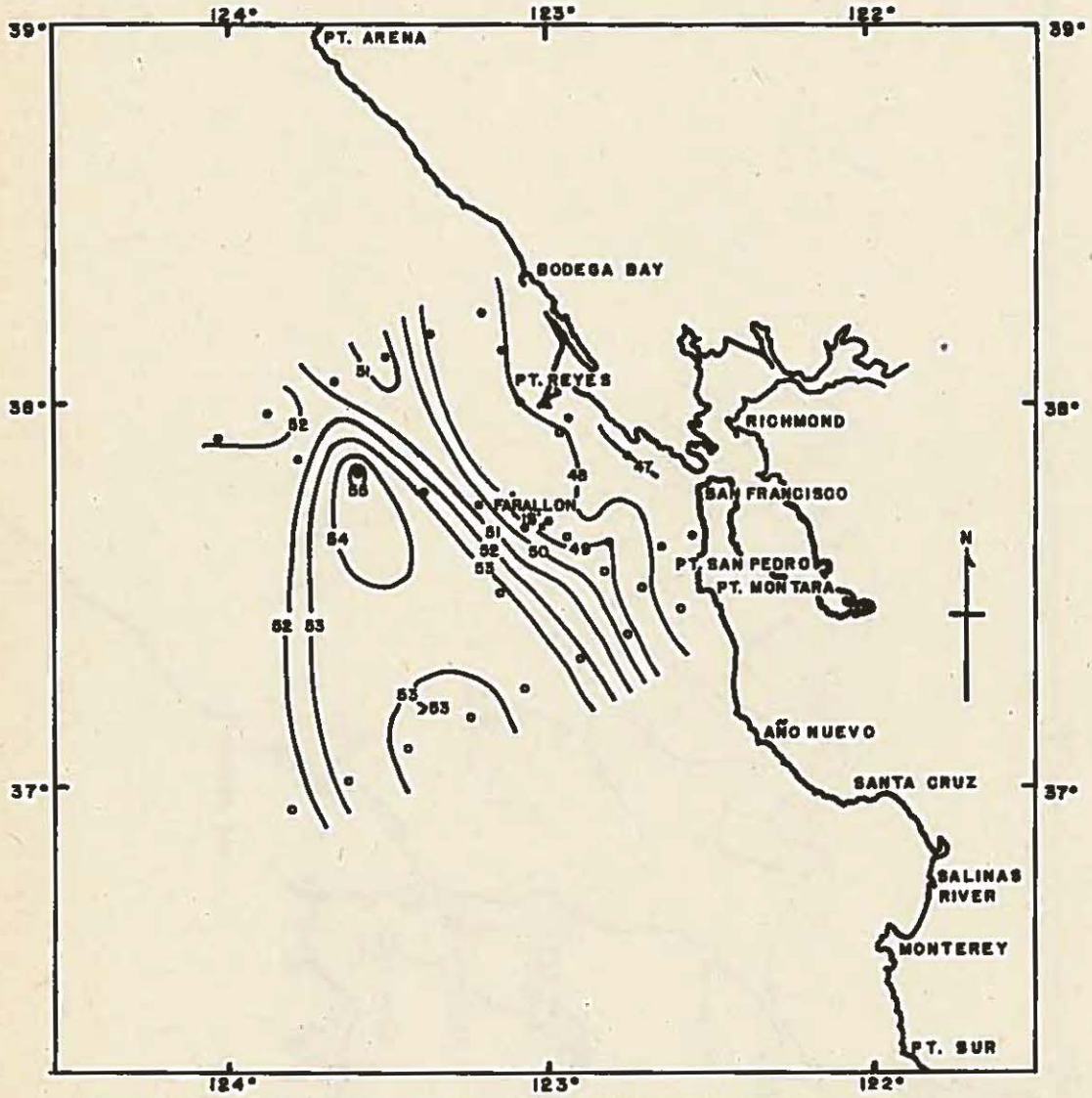

Figure 4. Isotherms (F) at 100 foot level during cruises of June 6-7 ("BT" casts indicated by open circles) and June 13-14 ("BT" cast indicated by black dots).

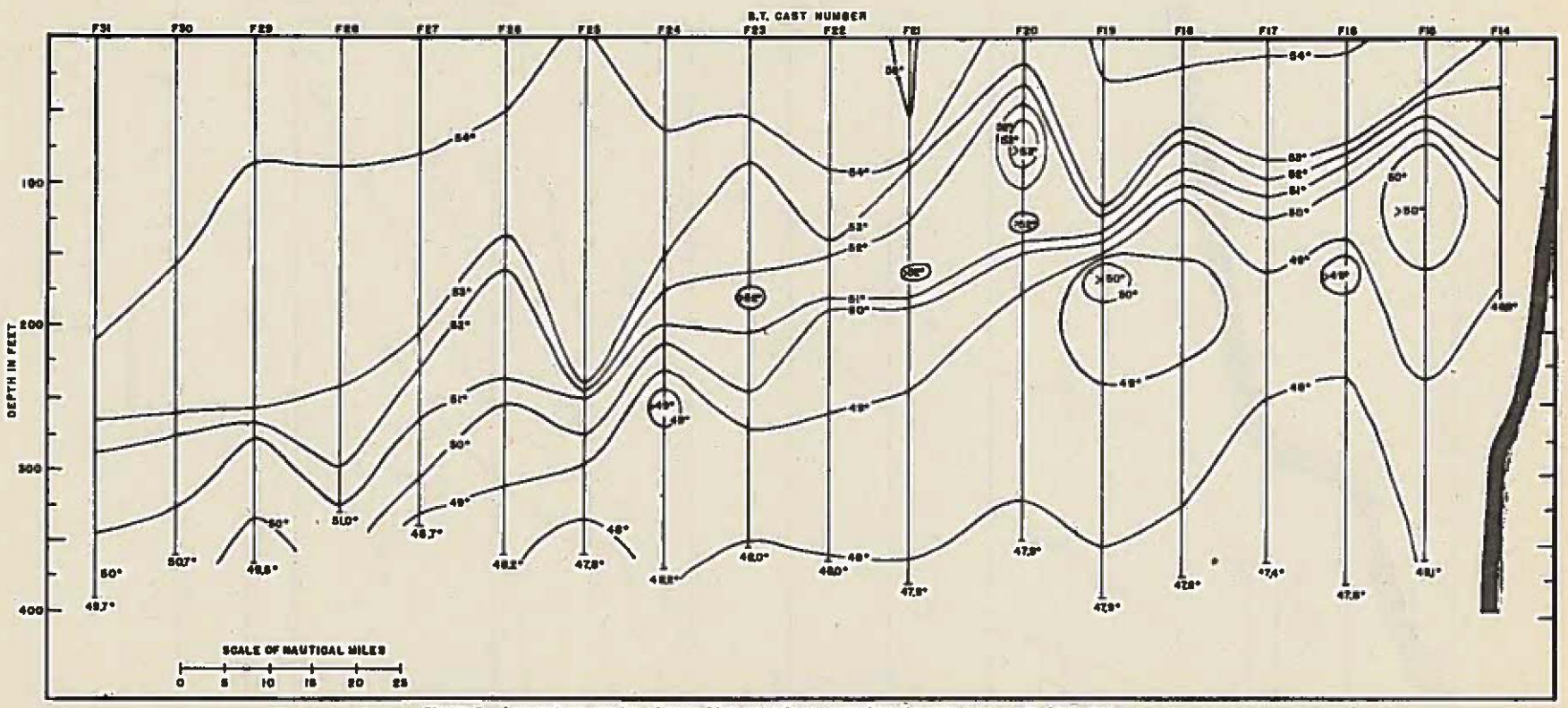

Figure 5. Temperature section along a line extending approximately west from Santa Cruz, taken on May 17-18. For exact location of line refer to figure 2. Temperature in °F. Shaded area represents ocean bottom.

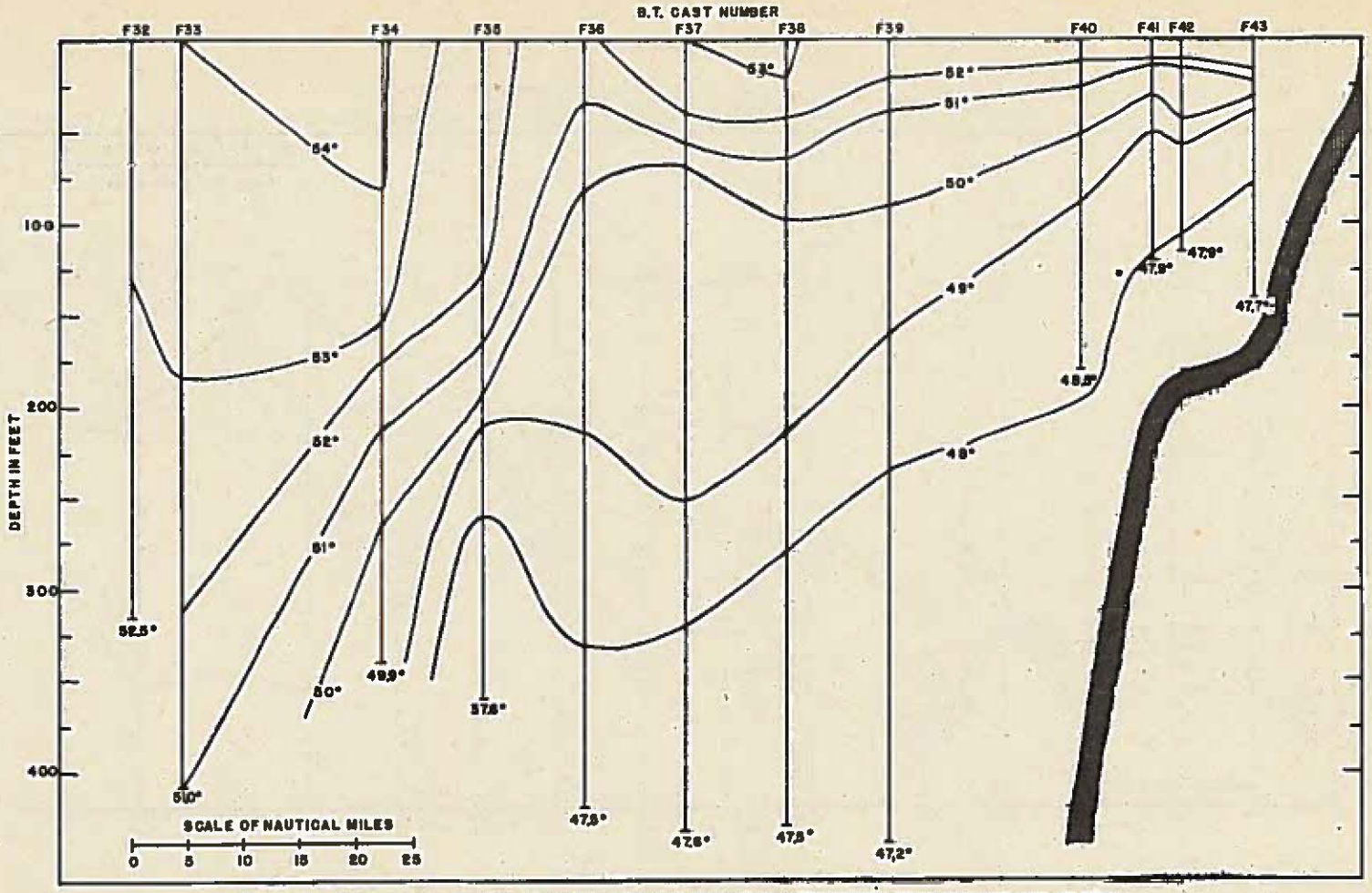

Figure 6. Temperature section along line headed toward San Francisco from seaward end of line shown in figure 5. Taken on May 18. Temperature in °F. Shaded area represents ocean bottom.

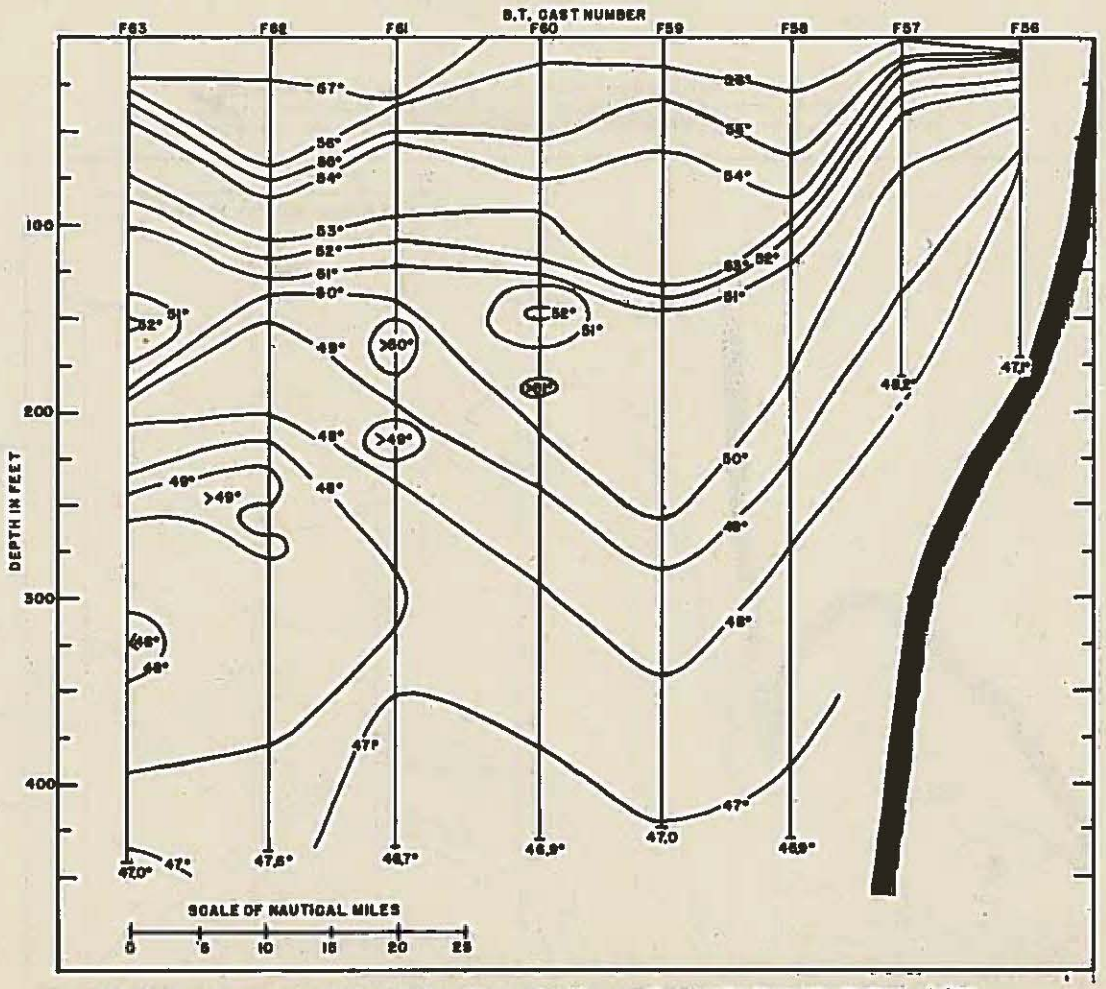

Figure 7. Temperature section along a line extending southwesterly from Pt. Montara, taken on June 6-7. (See figure 2 for exact location of line). Temperature in °F. Shaded area represents ocean bottom.

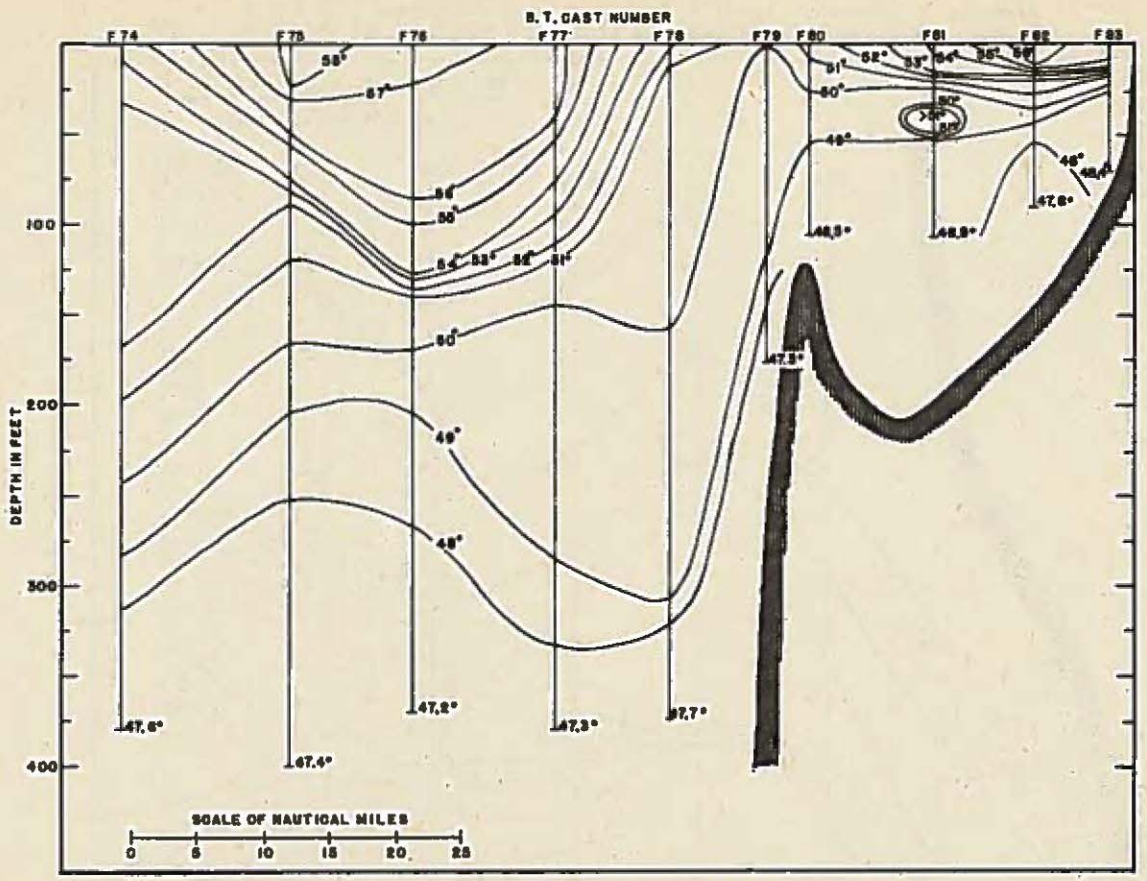

Figure 8. Temperature section along a line extending from about 50 miles west of Pt. Reyes to near Pt. San Pedro, taken on June 14. (See Figure 2 for exact location of line). Temperature in °F. Shaded area represents ocean bottom.

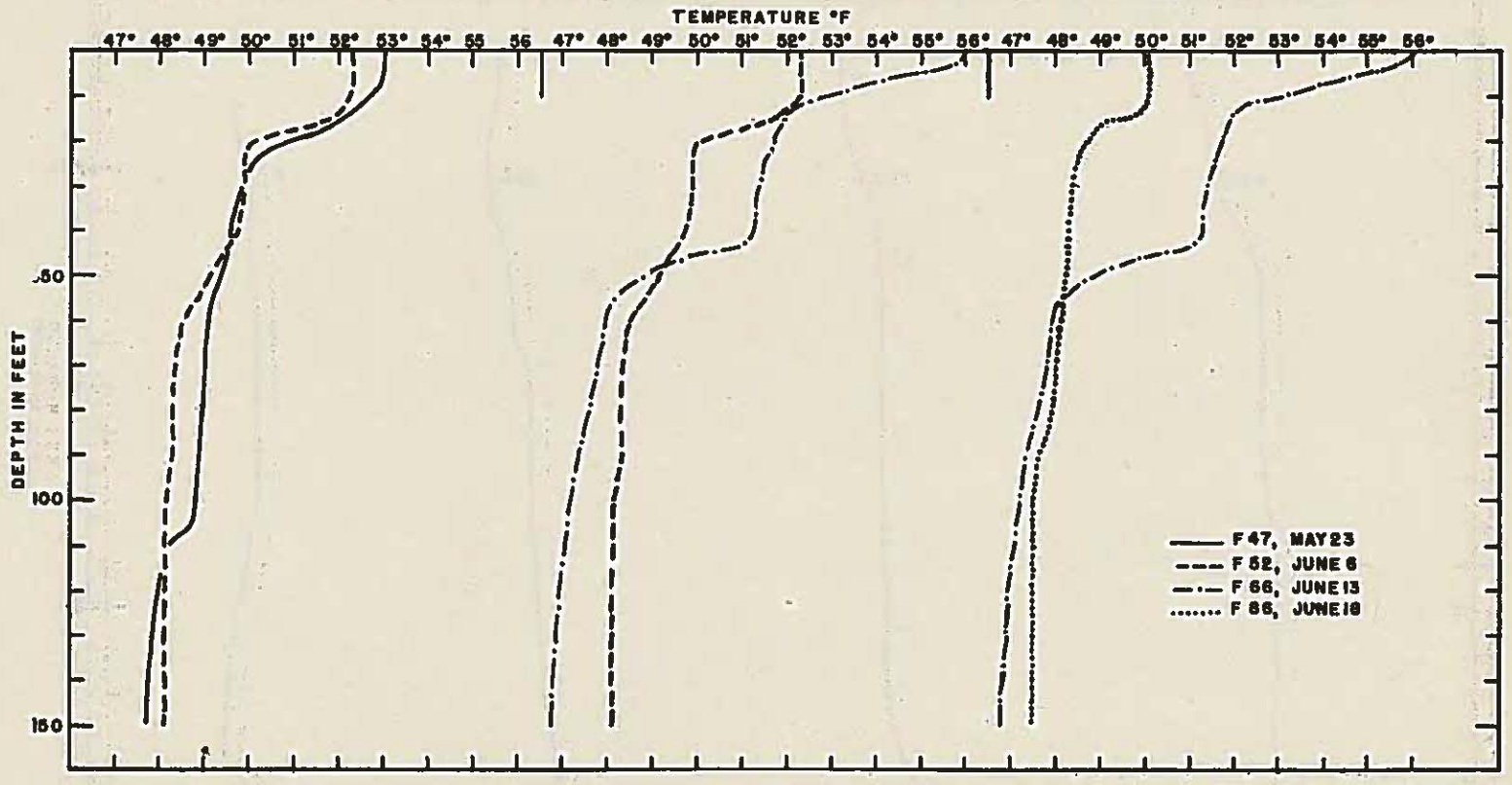

Figure 9. Comparison of 4 "BT" tracings obtained from approximately the same locality (10 miles south of Pt. Reyes) on the dates indicated in legend.

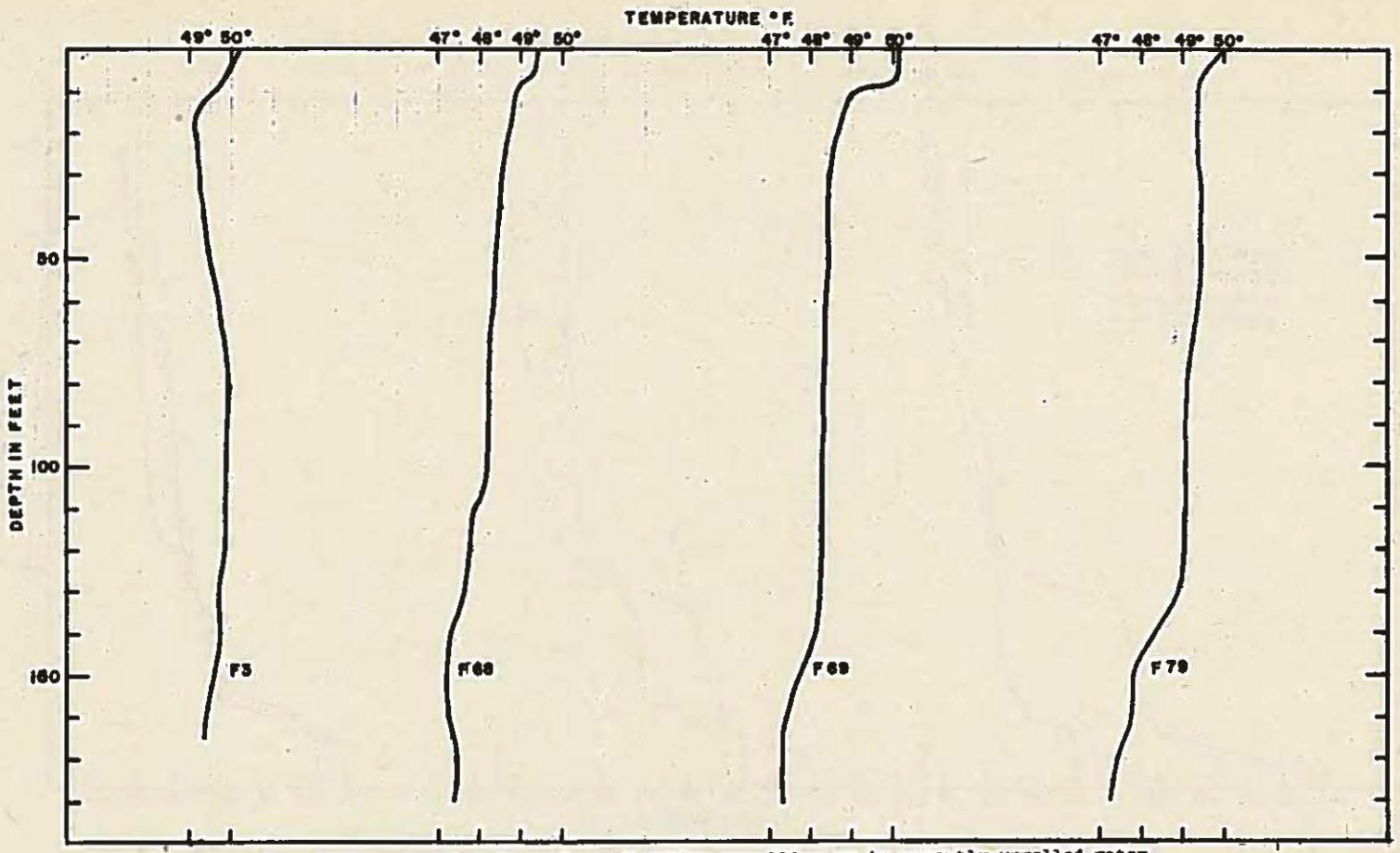

Figure 10. "B1" casts taken in regions of active upwelling or in recently upwelled water.

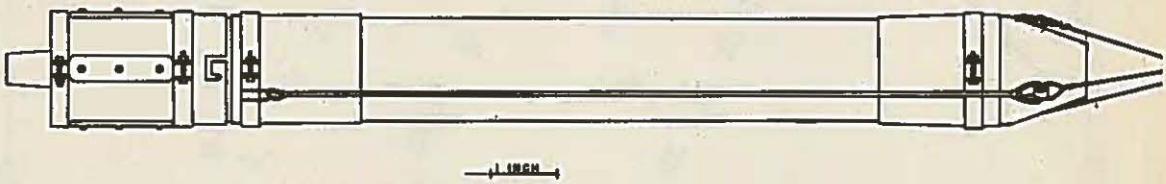

Figure 11. Sketch of plankton net used during the "Pearl Harbor" cruises. Total length of net, without bridle, approximately 16.5 inches.

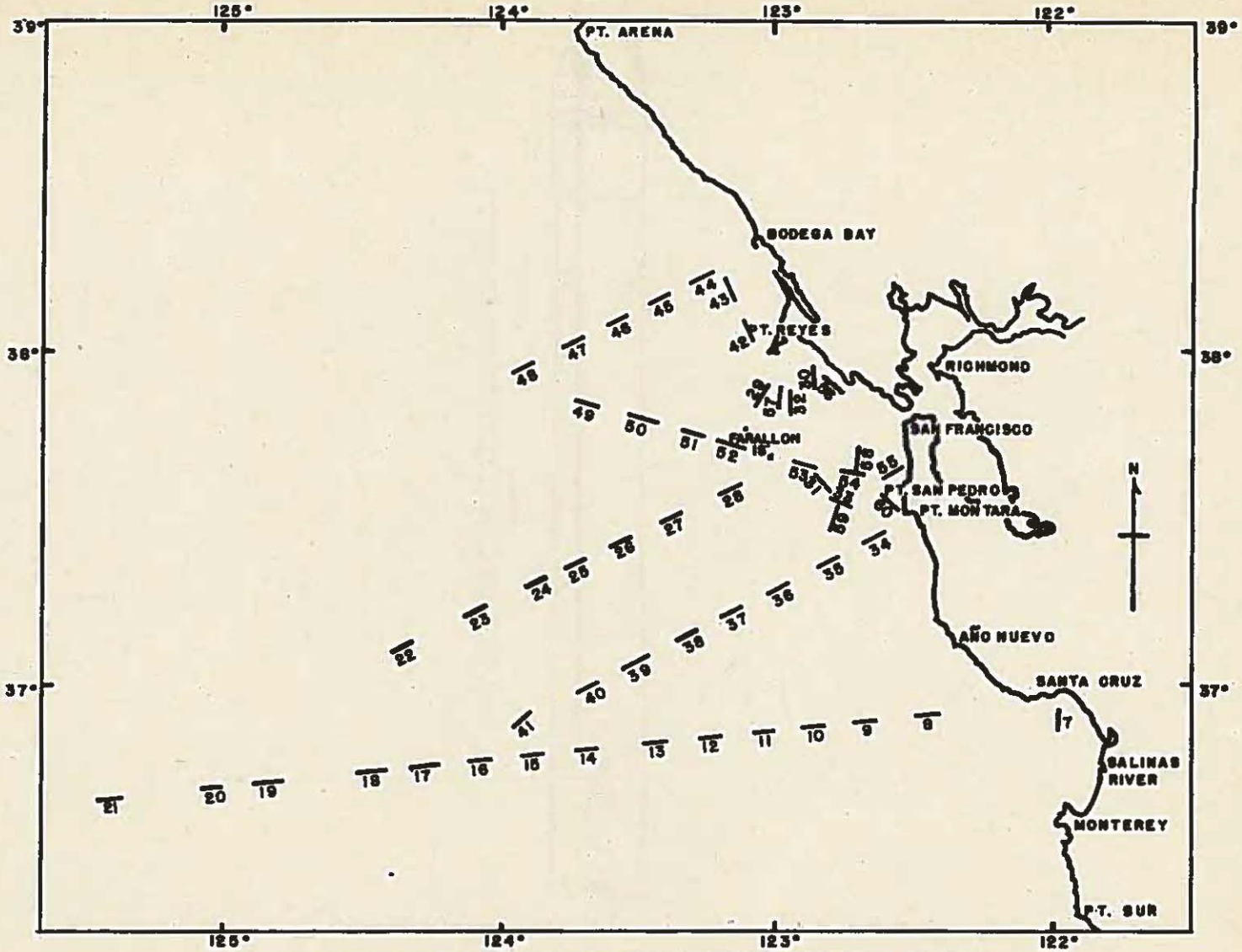

Figure 12. Location of all plankton hauls taken during the "Pearl Harbor" cruises. The dashes represent the approximate length and direction of hauls.

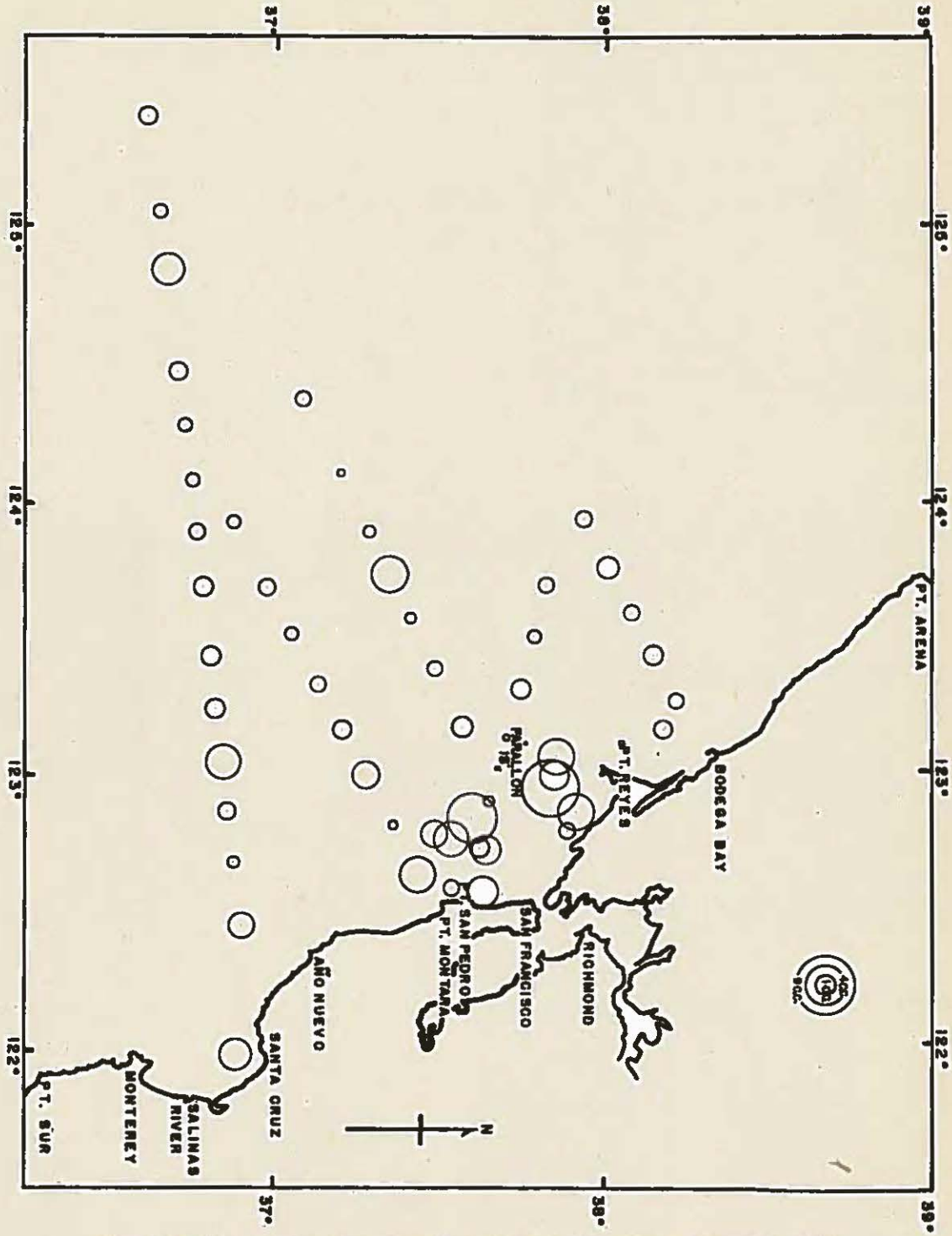

Figure 13. Relative abundance of crustacea (all types) in plankton hauls. Day and night hauls adjusted to a comparable basis. Abundance in cc per sample indicated by size of circle (note scale in upper right corner).