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Abundance of Pelagic Resources Off California, 1963-78, as Measured by an Airborne Fish Monitoring Program

James L. Squire, Jr.

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U.S. DEPARTMENT OF COMMERCE
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John V. Byrne, Administrator
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William G. Gordon, Assistant Administrator for Fisheries

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Abundance of Pelagic Resources Off California 1963-78, as Measured by an Airborne Fish Monitoring Program

JAMES L. SQUIRE, JR.[1]

ABSTRACT

From September 1962 through December 1978 commercial aerial fish-spotter pilots operating off southern and central California and northern Mexico, maintained a flight log indicating the geographical areas searched and an estimate of the quantity of pelagic species observed. These flight logs were analyzed for quantities of the various species observed per block area (10′ longitude by 10′ latitude area). Flights were recorded as surveying all or a portion of 164,753 block areas. A total of 110,375 block areas were surveyed during the day and 54,378 during night operations. An annual index of apparent abundance (arbitrary values) was computed for each of the major species observed, both for day and night aerial observations from selected geographical areas, and for total observations. The index value computed is not directly comparable between species.

During the period of the survey, the apparent abundance index for Pacific sardine, *Sardinops sagax caerulea*, declined from 1.03 in 1964 to 0.00 in 1974, and no significant schools have been observed by aerial surveys since. The northern anchovy, *Engraulis mordax*, night apparent abundance index remained relatively constant from 1963 to 1969 (2.99-4.35), increased substantially in 1973 to 14.99, then declined by 1978 to a level (1.91) near that observed in 1963-69. The day index for Pacific bonito, *Sarda chiliensis*, declined to a low level in 1968-69 (0.43-0.26), increased in 1972 to 1.11 (a year of above average sea surface temperature), and in subsequent years declined again to a low level ($\pm$0.1). Pacific mackerel, *Scomber japonicus*, population biomass was apparently low in 1962 at the start of the surveys, and continued to decline to very low night abundance levels during 1967-75 (undefined range of 0.00 to 0.03). In 1976 a small increase in the overall apparent index was recorded. By 1977 the night index had increased to 2.62, and in 1978 it again increased to a high level of 7.46. Jack mackerel, *Trachurus symmetricus*, showed a declining abundance index value during 1969-75 (0.66-0.40). A small increase in the night index apparent abundance was noted in 1976, and in 1977 the night index increased to 2.77. In 1978 it then increased about 1.5 times to a record high of 4.20.

Downward trends in apparent abundance indexes were noted 1 to 2 yr in advance of declines in the commercial catches for northern anchovy and Pacific bonito. Limitations of collected nonrandom data and variations in sightings and school size estimation between pilots are discussed. The apparent abundance indexes obtained from aerial surveys are compared with measures from larval and acoustical surveys.

A rank correlation analysis was made to measure the agreement between independent estimates of northern anchovy spawning biomass, larval index, and aerial index. Significant correlations were found for the aerial and acoustical survey indices of 1972-78 for the northern anchovy ($r_s = 0.810$, significant at the 0.05 level). During this period only three larval surveys were conducted, insufficient to calculate correlation. For earlier data, 1962-66 and 1968-69, larval vs. aerial index gave a poor correlation (+0.30). A significant correlation was evident for Pacific mackerel aerial index vs. spawning biomass index ($r_s = 1.00$).

INTRODUCTION

The Southwest Fisheries Center, National Marine Fisheries Service (NMFS), initiated an aerial pelagic fish monitoring program in 1962 with the cooperation of fish-spotter pilots active in locating fish for the central and southern California commercial purse seine fishery. The program utilized the services of the aerial fish-spotter pilot as a spin-off from their major occupation. The objective of the monitoring program was to measure and evaluate the apparent abundance of pelagic near-surface schooling fishes.

It was originally hypothesized that basic sighting data for the various species—tonnage estimates, or numbers of schools and their individual tonnage estimates, compared with search effort—would provide a measure of the relative apparent abundance of each species within a fishing area. Such information would be useful in assessment of the available stocks. Since sighting information from the spotter pilots is used as an aid in fishing, the efficiency of the pilot in locating schools and sometimes directing the setting of the purse seine has affected the catch per effort of the purse seiner. Therefore, aerial spotter data may be more useful than fishing vessel records for detecting changes in abundance of intensively fished species. The aerial fish-spotter also records the abundance of pelagic species which may not currently be targeted upon by the fishery. Aerial survey data, therefore, can be particularly useful in evaluating underutilized pelagic near-surface schooling resources.

The first report on the results of the program (Squire 1972) reviewed trends in apparent abundance for data collected from 1962 through 1969. This review updates these data through 1978 using the same analytical methods. Since publication of the first review, considerable changes in the apparent abundance levels of some pelagic species has occurred. The species of interest to this program are all members of a complex, interacting coastal ecosystem, and these data may assist in better defining changes in abundance levels over time which occur within the coastal pelagic resources complex. For a definition of terms used such as abundance, apparent abundance, and relative apparent abundance, see Marr (1951).

[1]Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

The fish species most commonly observed by the commercial fish-spotters while operating off central and southern California, and northern Baja California, Mexico, are the northern anchovy, *Engraulis mordax*; jack mackerel, *Trachurus symmetricus*; Pacific bonito, *Sarda chiliensis*; Pacific mackerel, *Scomber japonicus*; Pacific sardine, *Sardinops sagax caerulea*; and bluefin tuna, *Thunnus thynnus*. Other species such as Pacific barracuda, *Sphyraena argentea*, yellowtail, *Seriola lalandei*, white seabass, *Atractoscion nobilis*, and albacore, *Thunnus alalunga*, are observed by the pilots, and are sometimes caught by the commercial fleet with the aid of aerial spotters. Other animals such as the basking shark, *Cetorhinus maximus*, mammals (whales and porpoise), and invertebrates (squid—*Loligo opalescens*), have been observed and recorded. A total of 20 species of fish have been observed and recorded by the spotter pilots (Squire 1972).

METHODS

Commercial aerial fish-spotters have recorded flight tracks and fish school tonnage estimates for the program since the fall of 1962; 1963, however, was the first complete year of data. The pilots in the program are full-time professional commercial fish-spotter pilots. Participating pilots under contract were advised that all sightings of schooling fish were to be reported. A total of 15 pilots have participated in the program. Observation quality has remained relatively stable since the pilots who have made the major contributions to the program have participated in it throughout its 16-yr period. There has been no attempt to intercalibrate the pilots. The only data gap in the program is for the second half of 1970 (July through December), when contracts for observation data were cancelled.

For a review of the methods and procedures for obtaining and processing the flight log observation data, and for results of the program for the period 1963-69, see Squire (1972). Caruso[2] described by details of computer coding of the aerial observations for future analysis. The general procedure for recording fish sighting observations on flight log charts has not changed from that described by Squire (1972). In 1974 flight log charts were added to cover the northwest coast of Baja California, Mexico. With the addition of charts for the area south of the United States-Mexico border, pilots recorded observation sighting data for summer flights in search of bluefin tuna. The borders of 10′ longitude × 10′ latitude "block areas" and associated "block numbers" were printed on the charts to expedite data coding. The "block areas" referred to are identical to the California Fish and Game statistical grid system. The area from Half Moon Bay, Calif., to Cedros Island, Baja California, Mexico, has six flight log charts. Divisions of this area into "block areas," which were later combined into larger grouped "zones" lettered A through T, are shown in Figure 1.

Pilots recorded their flight paths and school sightings on the appropriate charts. Aerial spotter data was analyzed by using summaries of the number of block areas entered into by the pilots as a measure of observation effort and tonnage estimates of fish.

Approximately 40,000 flight hours of observations were recorded. A total of 164,753 block areas or portions of block areas were surveyed: 110,375 (67%) during the day and 54,378 (33%) during the night (Table 1). A graph of each year's day, night, and total observation effort is given in Figure 2.

From 1962 to 1978, no natural changes in the survey area occurred that could be classed as atypical. However, one unusual event did occur that had a severe local impact and affected the observation of near-surface pelagic species. In late January 1969, a large release of crude oil occurred in the Santa Barbara Channel area. The oil release continued in varying quantities for some months afterward, and affected fishing and aerial fish-spotting operations in the eastern half of the Santa Barbara Channel and around the Channel Islands. Since this was an area where concentrations of anchovy, jack mackerel, and Pacific bonito were previously observed by the aerial spotters and fished by commercial seiners, the oil contamination resulted in a temporary cessation of fishing. During the months when the surface crude oil spill was a problem, however, frequent aerial surveys of the Santa Barbara Channel and Islands area were made by the Union Oil Company, using an aerial spotter pilot who was participating in the NMFS program. Data from these observations were recorded in the same format as the NMFS pelagic fish program and made available to the NMFS for analysis.

Flight log data represent a sample estimate of the apparent abundance of pelagic species schooling in the near-surface layers of the areas surveyed. The selection of flight tracks was nonrandom,

[2]Caruso, J. 1979. Aerial marine resources monitoring system. Data Coding Manual. Admin. Rep. LJ-79-9, 99 p. Southwest Fisheries Center La Jolla Laboratory, NMFS, NOAA, La Jolla, CA 92038.

Table 1.—Observation effort off California for pelagic commercial fish (day/night) in units of block area overflights by zone.

Zone	1962–65	1966–69	1970–73	1974–78	Total
A	443/310	1,271/38	14/0	22/0	1,750/348
B	1,148/600	2,025/113	218/48	180/53	3,571/814
C	2,098/2,207	6,020/2,053	10,508/3,151	6,213/3,475	24,839/10,886
D	1,043/1,190	5,023/1,921	5,075/1,503	4,659/3,801	15,800/8,415
E	151/427	336/287	124/122	743/298	1,354/1,134
F	40/181	166/316	123/732	381/472	710/1,701
G	1,329/1,512	3,583/3,206	4,222/3,899	7,974/8,369	17,108/16,986
H	1,041/967	1,829/1,556	1,612/2,001	3,156/2,595	7,638/7,119
I	1,238/510	2,585/1,215	1,178/1,298	3,356/1,026	8,357/4,049
J	1,599/626	3,538/749	4,208/211	5,353/726	14,698/2,312
K	35/0	315/52	932/72	1,796/38	3,078/162
L	0/0	0/0	1,287/47	5,157/202	6,444/249
M	0/0	0/0	22/3	43/0	65/3
N	0/0	0/0	878/0	3,094/165	3,972/165
O	0/0	0/0	0/0	0/0	0/0
P	0/0	0/0	212/0	618/35	830/35
Q	0/0	0/0	0/0	0/0	0/0
R	0/0	0/0	0/0	161/0	161/0
					110,375/54,378

being determined by past experience regarding the most likely locations for sighting schools of various species, real-time information from fishing boats and other spotter aircraft, and other recent experience. The species identification of the schools was determined during the day by physical characteristics such as shape or color of the fish or school, or by behavior of the fish. During the night, identification was made by the bioluminescent characteristics of the school's shape or its behavioral response to a flash of light. Information from fishing vessels was sometimes used in determining species composition, particularly where "mixed schools" were encountered.

A pilot's estimate of school tonnage is based on many years of observing school size, shape, depth, and quantity as determined by catching the fish observed. It is possible to estimate a school's vertical depth (distance from top of school to bottom) for schools of the larger pelagic species and small schools of such species as the northern anchovy. However, for large schools of the smaller forage species, the actual depth of the school usually cannot be determined from the air. Therefore, information from fishing vessels was frequently used since they could determine the school's vertical depth using an echosounder. The horizontal shape and area of the school could be estimated visually. Aerial spotter pilots are often paid on the basis of tonnage caught, so a close check on tonnage taken by the purse seiner is important to the pilot.

SIGHTINGS AND ABUNDANCE INDEX TRENDS BY SPECIES

Geographical Distribution of Fish School and School Group Sighting

Current and historical records, based on catch or fishing boat logbook data, give some indication of the location of catch, but only by "block area" (a 10′ longitude × 10′ latitude area), which measures about 8 × 10 nmi each at the latitude of southern California. A more detailed description of individual locations of the center of school or school group sightings as observed on each flight (day plus night) for the period 1962 through 1978 is given in Figures 4-61.

An illustration of how the center of sighting was determined is given in Figure 3. The dot on the chart is the geographical center of the sighting, representing one or more animals or schools observed in the area. On some charts having a high density of sightings, an overlap or masking may occur, particularly for anchovy.

Locations of centers of sightings are given for the northern anchovy (Figs. 4-11), Pacific sardine (Figs. 14-18), Pacific bonito (Figs. 20-27), Pacific mackerel (Figs. 30-36), jack mackerel (Figs. 38-45), bluefin tuna (Figs. 47-49), albacore tuna (Figs. 50 and 51), yellowtail (Figs. 52 and 53), Pacific barracuda (Figs. 54 and 55), white seabass (Figs. 56 and 57), basking shark (Figs. 58 and 59), and squid (Figs. 60 and 61).

A review of the sighting distribution charts is given in the following sections for those areas having the most sightings. In many instances the charts for north of Morro Bay and those below the United States-Mexico border are not shown because the observation effort was low, or the effort was not expended in areas where the species of interest would be commonly observed. For example, anchovy charts are not given for the Monterey Bay area because, although anchovies have frequently been observed in the area, the observation effort since the mid-1950's has been low. Most of the flight observation effort south of the United States-Mexico border has been offshore in search of bluefin tuna, and, as a result, nearshore areas commonly having schools of anchovies are rarely surveyed and are therefore not given.

During the survey period, the following total number of sightings of schools or school groups were made: northern anchovy, 8,720; Pacific sardine, 195; Pacific bonito, 3,873; Pacific mackerel, 1,273; jack mackeral, 3,233; bluefin tuna, 1,314; albacore tuna, 200; yellowtail, 94; Pacific barracuda, 138; white seabass, 70; and squid, 384. The observations of schools or school group for the major species observed represent a total tonnage sighted by day and night of 43,013,254 t of northern anchovy; Pacific sardine, 442,644 t; Pacific bonito, 442,644 t; Pacific mackerel 1,364,048 t; jack mackerel 1,869,256 t; and bluefin tuna, 507,366 t.

Apparent Abundance Index Trends

Day and night indices of apparent abundance for each zone and grouped zones have been calculated annually since 1963 for species of northern anchovy, Pacific bonito, jack mackerel, Pacific mackerel, Pacific sardine, Pacific barracuda, and yellowtail. Bluefin tuna indices have been calculated since 1974.

In calculating the index value, one of four arbitrary tonnage ranges for each species was assigned. These cover the range of observed tonnages that might be estimated to occur in any one block area. In order to provide a tonnage range value (x) the midpoint of each range was divided by 100 for the northern anchovy, a species that is observed in larger quantities compared with any others and by 10 for Pacific bonito, jack mackerel, Pacific mackerel, Pacific sardine, and bluefin tuna. The midpoint of the tonnage range for yellowtail and white seabass was not reduced. The range of observed tonnage and resulting x values are given in Table 2. The

Table 2.—Range of tonnage and tonnage range values (X). X is the index value based on the midpoint of the observed tonnage/100 (but not for barracuda or yellowtail).

Species	Observed tonnage	X
Anchovy	0-400	2
	401-1,000	7
	1,001-10,000	55
	10,001-20,000	150
Pacific bonito	0-50	2.5
	51-150	10
	151-1,000	57.5
	1,001-5,000	300
Jack mackerel	1-50	2.5
	51-300	17.5
	301-1,000	65.5
	1,001-2,000	150
Pacific mackerel	0-20	1
	21-100	6
	101-250	17.6
	251-500	37.5
Pacific sardine	0-100	5
	101-500	30
	501-2,000	125
	2,001-4,000	300
Bluefin tuna	0-50	2.5
	51-250	15
	251-1,000	62.5
	1,001-4,000	250
Pacific barracuda	0-10	5
	11-30	20
	31-80	55
	81-160	120
Yellowtail	0-5	2.5
	6-10	7.5
	11-30	20
	31-60	45

following formula was used to calculate annual indices of apparent abundance, day and night, by zone and by species:

$$\text{Index of apparent abundance} = \frac{\Sigma N_1X_1 + N_2X_2 + N_3X_3 + N_4X_4}{N_t}$$

where $N_{1,2,3,4}$ = number of block area flights in which the species occurred at value $X_{1,2,3,4}$,

$X_{1,2,3,4}$ = tonnage range values,

N_t = total number of block area flights in the zone during the year.

The index value, then, represents the relationship between the amount of fish observed (tonnage range value—x), divided by the amount of search effort (number of block area flights) conducted either during the night or during the day. Day and night indices of apparent abundance for each zone, and the annual average day/night indices of apparent abundance for all zones, are listed in Table 3. The boundaries of the zones were selected to outline important geographical areas where fish were commonly observed.

The index trends reviewed here are for the major commercial species of northern anchovy, Pacific sardine, Pacific bonito, Pacific mackerel, jack mackerel, and bluefin tuna. Apparent abundance trends for yellowtail and Pacific barracuda, species which are primarily targets of the recreational fishery, are given in Table 3 but are not reviewed here. During the survey period, sightings of these species were few, and have been much reduced in recent years, with a resultant decrease in indices.

An analysis of sightings by day or night and of tonnage observed (Squire 1972), indicated that the northern anchovy, Pacific mackerel, jack mackerel, and Pacific sardine were observed more frequently and in greater quantity during the night. Pacific bonito and bluefin tuna were observed in greater quantity in the day. The selection of the index that is most representative of the apparent abundance of each species is based on the 1972 study.

In the following sections, total effort and observations by year are shown in graphic displays of day/night index values and U. S. fishery catch trends during 1963-78 for each species, along with a review of areas of high sighting density during 1962-78.

Northern Anchovy

Morro Bay to San Nicolas Island.—1962-65, Fig. 4; 1966-69, Fig. 5; 1970-73, Fig. 6; and 1974-78, Fig. 7.

The sighting effort north of Pt. Conception was greatly reduced after the 1962-65 period. Anchovy schools were commonly observed off Morro Bay and Avila, the latter area being a location where schools were commonly observed. The Santa Barbara coast from Gaviota eastward, and into the eastern end of the Santa Barbara Channel, had a high level of anchovy sightings, with the major area of sighting located offshore between the cities of Santa Barbara and Ventura. In 1974-78, the center of sighting appeared to be slightly farther offshore between Santa Barbara and Ventura, but in 1978, the center of sighting appeared about equidistant between the two cities and much nearer shore than observed in previous years.

Pt. Hueneme to San Diego.—1962-65, Fig. 8; 1966-69, Fig. 9; 1970-73, Fig. 10; 1974-78, Fig. 11.

In 1962-65, anchovy sightings were evenly distributed between Pt. Hueneme and Dana Point, in the Catalina Channel, and about Catalina Island. Sightings were less frequent south of Dana Point to San Diego. From 1966 to 1969, the observations were centered in the Catalina Channel and numerous observations were also made off the coast from Long Beach to Newport Beach.

From 1970 to 1973, the major observation areas were again near the center of the Catalina Channel, with sightings extending northwest from the Channel south of Pt. Dume.

Sighting occurrences for 1974-78 appeared to "clump" in the Catalina Channel area, extending from southeast of Long Beach to near Pt. Dume. 1978 sightings were more scattered throughout the area, except for high density areas of sightings southeast of Pt. Dume.

Index Trends.—The northern anchovy night index trend (Figs. 12, 13) was somewhat constant during 1963-69, with an average night index level of 3.50. The commercial catch increased sharply in 1969 and 1970, then declined in 1972. A period of warm sea surface temperatures which were well above average, occurred from August to December 1972 in the northeastern Pacific (Miller and Laurs 1975), and anomalous warm temperatures may have affected anchovy availability.

The index rose to 14.99 in 1973, and the commercial catch increased to near 117.9×10^3 t. Then, in 1974, a decline in index level and catch was evident. In 1975 the index increased to 11.38 and the catch increased to a record peak of 146.9×10^3 t. The catch decreased slightly in 1976 and 1977, then dropped to a very low level of about 16.3×10^3 t in 1978.

The aerial apparent abundance index declined in 1973-78 (see inspection fitted average line, Fig. 12), and this downward trend preceded the decline of the fishery. In 1975, the peak year of catch, the apparent abundance was not as great as it had been in 1973. However, sufficient fish were available in 1975, at an index level of 11.38, to meet the needs of the fishery. The 1978 apparent abundance index level of 1.91 was slightly below the index levels observed during the 1963-69 period. The total catch of anchovy in the central stock area, of which the southern California fishery is a part, was greater than the catch totals given in Figure 12, due to substantial quantities of anchovy landed and processed at Ensenada, Baja California, Mexico.

Night indices observed for the major fishing areas from near Santa Barbara to Dana Point, including the Channel Islands and San Pedro Channel, are shown in Figure 13. Zones G and H, the Catalina Channel, and the Catalina/14 mile bank area, were the major producing areas, and the highest indices were recorded for these areas. In 1978, a season of much reduced catches, the apparent abundance index increased for the Santa Barbara coastal area (zone C), the only anomalous trend observed.

Pacific Sardine

Morro Bay to San Nicolas Island.—1962-65, Fig. 14; 1966-69, Fig. 15.

The Pacific sardine fishery in the Monterey Bay area failed in the late 1940's. By the time the aerial monitoring survey program was started, little observation effort was being expended along the central California coast north of Morro Bay. In 1962-65, some flights were made along the coast from the south, to, and into, Monterey Bay. A few sardine schools were sighted in Monterey Bay but most were sighted along the coast south of Pt. Sur to Cape San Martin. Some schools were sighted from Morro Bay north (Fig. 14).

The last major catch of sardines off southern California was made near San Nicolas Island (lower right corner, Fig. 14), on opening day of the season, 1 September 1964. Prior to the season opening, aerial spotters estimated a maximum of about 9.1×10^3 t of sardines in the area. After the start of fishing, the sardine school group, which had been observed in the fishing area for 2 wk or more before the season opening, appeared to immediately start migrating southeast. After 2 d of fishing and a catch of about 2.7×10^3 t, only a few additional tons were taken in the San Nicolas Island area. During 1966-69 (Fig. 15), only a few small schools were sighted along the coast off Morro Bay, Avila, and Santa Barbara.

Pt. Hueneme to San Diego.—1962-65, Fig. 16; 1966-69, Fig. 17; 1970-73, Fig. 18.

During 1962-65, sardines were most frequently sighted in the San Pedro Channel south of Los Angeles Harbor, and near Catalina Island. In 1966-69, only six sightings were recorded off the Los Angeles area and southwest of San Clemente Island. The 1970-73 chart shows a small number of sightings off La Jolla, near San Diego. Since 1974, the aerial spotters have not sighted any individual schools of sardines.

Index Trends.—The pelagic resource aerial monitoring program was started after the major decline in sardine abundance occurred. However, the aerial index gives an insight into the last declining years of a once major resource (Fig. 19). In 1964, the catch was only about 6.4×10^3 t and the night index value was about 1.00; it was the last year sardines were caught in any quantity off southern California. In 1965, the index level declined to a very low level and has remained at a 0.00 level since. No individual schools of sardines have been recorded since 1973.

Pacific Bonito

Morro Bay to San Nicolas Island.—1962-65, Fig. 20; 1966-69, Fig. 21; 1970-73, Fig. 22; 1974-78, Fig. 23.

The geographical distribution of Pacific bonito sightings in this area changed little during the survey period. They were frequently sighted along the coast from east of Pt. Conception to near Ventura, around Anacapa Island, Santa Cruz Island, and near the southeast side of Santa Rosa Island. They were more frequently observed along the south side of Santa Cruz Island. During 1974-78, the frequency of sightings decreased, but the general distribution of sightings remained the same.

Pt. Hueneme to San Diego.—1962-65, Fig. 24; 1966-69, Fig. 25; 1970-73, Fig. 26; 1974-78, Fig. 27.

The geographical distribution of sightings changed little in this area from 1962 to 1978. As in the case of the northern anchovy, the distribution pattern of Pacific bonito since the mid-1960's has become more restricted, with sightings being found closer to the mainland coast and islands. The frequency of sightings peaked during 1966-69, with the major sighting area being from the Coronado Islands, Mexico, to Dana Point. In 1970-73, however, they were more commonly observed off San Diego. Sightings of Pacific bonito were fewer in number during 1974-78, and the 1978 sightings were primarily off Dana Point, Newport Beach, and Pt. Dume.

Index Trends.—Pacific bonito increased in abundance off California during the warm years of 1957-58 and was fished lightly between that time and 1965. Due to decreases in the availability or abundance of the Pacific sardine, Pacific mackerel, and jack mackerel, Pacific bonito became a target species. Catches off California more than doubled between 1965 and 1966, peaking with a catch of about 9.2×10^3 t.

The day apparent abundance index (Fig. 28) remained at an average level of 1.44, 1963-67, then decreased sharply to 0.43 in 1968, and to 0.26 in 1969. The catch declined about one-third during this period. No data was available for June-December 1970, but the first half-year data (normally low) indicated few schools were observed. The index increased to a peak of 1.11 in 1972, possibly due to an anomalous warm period in the northeastern Pacific during the summer and fall of 1972, which may have caused an increased migration of Pacific bonito into southern California from off northwestern Mexico. The index declined sharply in 1973 to 0.39, while catches off California increased to a level of about 8.2×10^3 t. The day index continued to decline over the years 1973-78 to a very low level, 0.12. Catches declined sharply in 1975 to the 1.8 to 2.7×10^3 t level and remained low, with a California catch of 1.2×10^3 t reported in 1978.

The major sighting areas for Pacific bonito (Fig. 29) were the Santa Barbara coast and Channel Islands (zones C and D) and the coastal area from near San Diego to Dana Point (zone J). The south coastal zone (J) had high index levels in 1963 and 1966 (record high for any one area) through 1971. The Santa Barbara coast and Channel zone (C) was the high index area for 1964, 1965, 1972, 1974, and 1975. Since 1972, index values for all areas declined to the low levels observed in 1977. In 1978, the night index increased to 0.94 as Pacific bonito were observed in greater quantities at night than during the day, a situation that occurred only in one other year, 1973.

Pacific Mackerel

Morro Bay to San Nicolas Island.—1962-65, Fig. 30; 1966-69, Fig. 31; 1974-78, Fig. 32.

In the area of Morro Bay to San Nicolas Island, Pacific mackerel were commonly sighted in the Santa Barbara Channel area and about the Channel Islands during 1962-65. Concentrations were sighted along the coast from east of Pt. Conception to near Ventura, with a center of sighting near Santa Barbara. Some schools were sighted along the north coast of Santa Cruz Island and the south side of Anacapa, and on the north side of San Nicolas Island. During 1966-69, only 21 schools or school groups were sighted, most of which were along the Santa Barbara coast. No schools were recorded for 1970 and 1974, but in 1977 and 1978, Pacific mackerel schools were again sighted about the Santa Barbara Channel Islands in large numbers, as shown on the 1974-78 charts. Between 1974 and 1977, 54 schools or school groups were recorded; in 1978, 74 were sighted.

During the 1962-65 period which preceded the decline of the Pacific mackerel resource to a very low level, most schools were sighted most frequently along the Santa Barbara coastline, and less frequently around Santa Cruz and Anacapa Islands. In contrast, during 1977 and 1978, only 11 schools or school groups were sighted along or near the Santa Barbara coast, while 117 schools or school groups were sighted off the north and southeast coasts of Santa Cruz Island and about Anacapa Island, indicating a shift in distribution pattern from the coast to about the Santa Barbara Channel Islands.

Pt. Hueneme to San Diego.—1962-65, Fig. 33; 1966-69, Fig. 34; 1970-73, Fig. 35; 1974-78, Fig. 36.

During 1962-65, the principal centers of sighting were around the east end of Catalina Island, and south of Long Beach. Pacific mackerel were also sighted at scattered locations along the coast from San Diego to Pt. Hueneme, and around San Clemente Island, Santa Barbara Island, and Cortez Bank. Few schools or school groups were sighted during 1966-69 or 1970-74, but a substantial

Table 3.—Annual indices of abundance for day and night observations. A dash (-/-) indicates no flight observations in the zone, 0.00 indicates observation effort in four places.

Zone	1962	1963	1964	1965	1966	1967	1968	1969	1970 (Jan. thru June)
NORTHERN ANCHOVY									
A	0.51/1.22	10.98/13.28	0.80/7.32	2.51/2.48	2.02/ 6.33	1.15/-	0.2820/-	0.00 /0.00	-/-
B	3.25/3.18	6.17/13.02	4.08/3.08	1.85/5.75	0.29/15.31	0.28/ 0.30	0.7346/-	0.0317/0.00	0.0714/-
C	0.05/0.99	0.40/ 2.70	0.90/2.85	1.82/8.63	0.27/ 2.79	2.91/ 3.03	0.0476/1.7637	0.8769/1.9387	0.3240/ 0.6387
D	0.00/2.97	1.24/10.02	0.23/4.75	0.48/3.67	0.14/ 6.73	0.63/ 5.12	0.0453/3.2438	0.4124/1.9662	0.0300/ 0.8163
E	-/0.00	0.00/ 1.05	0.00/3.14	0.00/0.12	1.09/ 0.23	3.15/ 0.11	0.1881/0.1284	0.3218/0.6701	0.6666/ 0.00
F	-/0.00	3.66/ 1.71	5.75/0.37	0.00/0.58	0.00/ 2.61	0.00/ 0.00	0.00 /0.6000	0.00 /0.00	-/ 0.00
G	-/1.00	0.51/ 1.81	0.54/6.21	1.42/3.23	2.24/ 1.78	2.40/ 8.32	0.5518/2.1056	5.0145/3.5780	31.7112/17.5166
H	-/-	0.14/ 0.12	0.38/1.00	0.05/1.90	2.28/ 1.43	5.45/ 1.60	0.6469/0.5820	6.3597/3.2604	17.9724/ 0.9949
I	-/-	0.14/ 0.00	0.05/0.11	0.02/0.34	0.28/ 2.53	2.87/ 0.71	0.1801/0.2116	0.7862/0.4971	0.00 / 0.8288
J	-/-	0.78/ 0.67	0.85/6.08	0.00/8.00	0.45/ 1.55	0.16/20.16	0.5282/1.1156	0.5536/3.3989	1.6282/46.5483
K	-/-	0.00/-	0.00/-	0.00/-	0.00/ 0.22	0.00/ 0.70	2.4400/0.0625	0.00 /0.00	-/-
L									
M									
N									
O									
P									
Average all zones	1.79/1.99	1.64/2.99	1.03/3.90	0.96/4.18	0.84/3.62	1.78/4.30	1.3274/1.4599	1.3043/4.3562	6.6325/8.8341
Average D+N						2.54	0.7183	2.4393	
PACIFIC BONITO									
A	0.00/0.00	0.00/0.00	0.50/0.00	0.00/0.00	0.04/0.00	0.07/-	0.0099/-	0.00 /0.00	-/-
B	0.01/0.00	0.00/0.01	0.06/0.01	0.02/0.00	0.43/0.00	0.01/0.00	0.00 /-	0.00 /0.00	0.00 /-
C	0.62/0.25	3.63/1.51	2.40/0.82	2.18/0.40	1.38/0.83	0.51/1.02	0.3617/1.3603	0.2994/0.2715	0.00 /0.0806
D	0.83/0.63	0.65/1.88	1.40/0.12	0.85/0.10	1.27/0.54	0.38/0.80	0.5285/0.1549	0.2433/0.2300	0.0057/0.5867
E	-/0.00	0.02/1.15	0.50/0.00	6.81/0.00	4.30/0.00	0.00/0.00	0.00 /0.0229	0.00 /0.00	0.00 /0.00
F	-/0.00	0.00/0.00	0.43/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	-/0.00
G	-/0.00	0.31/0.37	0.30/0.00	0.50/0.01	1.19/0.16	0.67/0.39	0.1196/0.1302	0.1258/0.1666	0.0048/0.00
H	-/-	0.85/0.22	2.12/0.53	2.06/0.32	0.03/0.00	0.00/0.02	0.6805/0.2398	0.0907/0.0607	0.0689/0.0761
I	-/-	0.00/0.45	3.46/0.54	0.40/0.13	0.06/0.02	0.12/0.00	0.0275/0.0330	0.0203/0.0574	0.00 /0.1801
J	-/-	3.67/0.23	1.10/0.06	1.71/0.46	4.96/0.11	3.27/0.12	1.7038/0.6872	0.6464/0.0518	0.00 /0.00
K	-/-	0.13/-	0.00/-	0.00/-	0.00/0.00	45.73/0.00	0.2666/0.00	0.7547/0.00	-/-
L									
M									
N									
O									
P									
Average all zones	0.23/0.19	1.62/0.68	1.62/0.28	1.26/0.19	1.34/0.35	1.35/0.34	0.4325/0.3477	0.2682/0.1815	0.0059/0.1000
Average D+N						1.05	0.4032	0.2359	
JACK MACKEREL									
A	0.00/0.08	1.81/ 0.00	8.32/2.89	0.78/ 1.67	4.29/25.72	0.81/-	0.9153/-	0.0290/ 0.00	-/-
B	0.02/0.00	3.48/ 1.37	6.65/6.67	1.03/ 1.22	0.74/ 8.78	0.78/ 1.34	0.6966/-	0.00 / 0.00	0.00 /-
C	1.59/0.45	0.96/ 0.49	0.83/0.56	0.14/ 0.33	0.06/ 0.03	0.04/ 0.33	0.1319/ 0.0238	0.1150/ 0.1725	0.3065/ 0.3225
D	0.00/1.45	1.79/13.77	2.72/5.36	1.44/ 1.40	0.24/ 1.62	0.41/ 0.24	0.2064/ 0.1962	0.1544/ 0.3300	0.0607/ 0.1785
E	-/0.00	0.27/ 4.74	0.93/2.31	0.72/ 1.55	0.16/ 7.38	0.00/ 2.15	0.2475/ 4.0917	0.00 / 4.4175	0.00 / 0.00
F	-/2.91	11.16/39.70	1.63/2.31	0.00/17.41	0.00/27.91	0.00/38.84	10.8714/27.7731	3.5696/13.0833	-/12.3148
G	-/-	1.23/ 1.76	0.64/0.99	0.02/ 0.29	0.00/ 1.05	0.00/ 0.10	0.0239/ 0.0072	0.1394/ 0.2673	0.0339/ 0.0119
H	-/-	0.56/ 1.34	0.01/1.11	0.71/ 0.43	0.04/ 2.18	0.01/ 0.33	0.00 / 0.2665	0.00 / 0.5998	0.0172/ 0.3045
I	-/-	2.11/ 5.53	0.17/1.86	1.35/ 0.75	0.19/ 2.37	0.04/ 3.27	0.0045/ 1.2764	0.0489/ 1.5833	0.4090/ 0.7432
J	-/-	0.67/ 0.54	0.72/1.51	0.86/ 0.96	0.00/ 0.06	0.00/ 0.03	0.0855/ 1.0799	0.0616/ 0.3058	0.6410/ 2.1129
K	-/-	0.00/-	0.00/-	0.00/-	0.00/ 0.00	0.00/ 1.75	0.00 / 1.0937	0.00 / 0.00	-/-
L									
M									
N									
O									
P									
Average all zones	0.51/0.46	1.41/2.98	1.62/2.18	0.71/1.36	0.28/1.94	0.20/1.41	0.3044/2.2488	0.1119/0.6562	0.1648/0.5843
Average D+N						0.56	0.9754	0.3143	

zone but no fish sighted. Indices given as day/night. 1962 to 1967 data inconsistent regarding number of decimal places, all to two places plus; after 1968 all carried to

1971	1972	1973	1974	1975	1976	1977	1978
-/-	-/-	0.2857/-	0.00 /-	-/-	-/-	-/-	-/-
0.2592/0.00	0.00 /0.00	1.1111/ 7.6222	0.00 /-	0.1250/ 0.00	0.00 / 0.3030	0.304 /0.00	0.00 /-
0.6580/3.0459	0.8916/1.9063	0.5449/ 8.0520	0.2983/ 7.1637	4.1790/ 5.3511	3.6930/ 4.0366	4.23 /2.913	0.3478/8.3585
0.1368/2.1839	0.3668/0.7927	1.8384/ 1.7935	1.4139/ 5.2212	1.6621/ 4.0351	1.2133/ 4.1187	4.678 /6.34	7.5962/1.9864
0.2295/0.00	0.00 /0.1346	0.1200/ 0.00	0.7010/ 0.00	0.00 / 0.00	0.00 / 0.00	0.00 /0.054	0.8298/0.00
0.00 /0.00	0.00 /0.0674	16.2553/ 0.00	6.3235/ 1.3113	0.00 / 0.00	0.00 / 0.00	0.00 /0.00	0.00 /0.00
6.5099/8.7620	5.7211/3.5333	8.0516/25.7464	7.5068/11.3228	10.9772/18.1811	3.3894/ 8.4065	3.794 /6.6817	1.3494/1.1229
3.1002/1.1379	0.7711/0.0522	6.5606/18.8580	4.7102/ 6.8398	1.4856/ 2.0287	2.2903/ 3.0512	1.408 /2.059	1.3961/0.1747
0.3917/0.1228	0.5371/0.1363	2.1185/ 7.2598	0.3564/ 2.6627	0.2514/ 0.00	0.00 / 0.8730	0.4216/0.1498	1.6298/0.5993
0.7907/0.0555	1.5934/0.00	0.4207/ 9.2647	1.3235/ 0.1707	0.9050/ 1.3255	0.4436/10.0188	1.3015/2.253	2.3155/0.0354
0.00 /-	0.00 /0.00	0.2732/ 0.00	0.1403/ 4.0588	0.00 /-	0.00 / 0.0952	0.028 /-	0.8249/-
		0.1996/ 0.00	0.00 /-	1.3075/-	0.0080/ 0.0615	0.1430/2.307	3.1106/-
		0.00 / 0.00	0.00 /-	0.00 /-	0.00 /-	0.00 /-	0.00 /-
		0.00 /-	0.3216/-	0.00 /-	0.3265/ 0.00	0.9308/0.6909	0.00 /-
		-/-	0.00 /-	-/-	-/-	-/-	-/-
		0.1273/-	0.00 /-	0.00 /-	0.0293/ 0.00	2.765/0.2413	0.00 /-
1.1893/2.3107	1.3155/1.4058	2.4401/14.9912	2.0443/7.9060	3.9212/11.3889	1.5046/5.3696	2.1849/4.639	2.0742/1.9153
1.5962	1.3486	5.8869	3.8738	6.0923	2.2800	3.4003	2.0118
-/-	-/-	0.00 /-	0.00 /-	-/-	-/-	-/-	-/-
0.00 /0.00	1.7808/0.00	0.5158/0.00	3.5294/-	0.00 /0.00	0.00 /0.00	0.00 /0.00	-/-
0.1971/0.8846	2.0008/0.6135	1.0244/0.9090	0.8467/1.0172	0.4319/0.00	0.2324/0.0076	0.1741/0.00	0.1085/0.00
0.1732/0.0324	0.4746/0.1506	1.3562/0.8664	0.0776/0.0075	0.4005/0.0067	0.1595/0.00	0.00 /0.00	0.00 /1.9514
0.0409/0.00	0.00 /0.061	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.008 /0.0253	0.00 /0.00
0.1627/0.0094	0.0036/0.0031	0.1318/0.0707	0.0043/0.0098	0.0014/0.0035	0.0118/0.00	0.0109/0.00	0.1039/0.6735
0.00 /0.0029	0.00 /0.0672	0.0220/0.0453	0.0051/0.0188	0.00 /0.00	0.0067/0.00	0.0109/0.00	0.00 /0.0075
0.0128/0.00	0.00 /0.0239	0.0098/0.0196	0.0166/0.00	0.00 /0.00	0.0129/0.00	0.00 /0.5381	0.00 /0.0177
2.6452/0.8333	0.0102/0.00	0.8039/0.0490	0.3975/0.00	0.0035/0.00	0.1817/0.00	0.1020/0.053	0.8451/6.2247
0.2857/-	0.00 /0.00	0.00 /0.00	0.0054/0.00	0.00 /-	0.00 /0.00	0.00 /-	0.00 /-
		0.1068/0.00	0.0710/0.00	0.00 /-	0.0013/0.00	0.00 /0.00	0.00 /-
		0.00 /0.00	0.00 /-	0.00 /-	0.00 /-	0.00 /-	0.00 /-
		0.0056/-	0.1444/0.00	0.00 /-	0.00 /0.00	0.00 /0.00	0.00 /-
		-/-	0.00 /-	-/-	-/-	-/-	-/-
		0.00 /-	0.00 /-	0.8928/-	0.00 /0.00	0.00 /0.00	0.00 /-
0.5530/0.1516	1.1171/0.1993	0.3944/0.3902	0.2492/01775	0.0860/0.0027	0.0748/0.0021	0.0390/0.0386	0.1268/0.9380
0.4073	0.7807	0.3932	0.2268	0.0608	0.0602	0.0388	0.4455
-/-	-/-	0.00 /-	0.00 /-	-/-	-/-	-/-	-/-
0.00 / 0.00	0.00 /0.00	0.00 /0.00	0.00 /-	0.00 / 0.00	0.00 /0.00	0.00 / 0.00	-/-
0.0267/ 0.0600	0.0024/0.0050	0.0018/0.00	0.00 /0.0948	0.00 / 0.0413	0.00 /1.4669	0.0223/ 0.5589	0.0089/ 0.00
0.0632/ 0.0216	0.0071/0.2349	0.00 /0.00	0.0032/0.0151	0.00 / 0.0067	0.3110/1.2332	0.2959/ 3.1454	0.1687/ 1.8643
0.00 / 5.4017	0.00 /0.0961	0.00 /0.00	0.00 /6.1830	0.00 / 0.6250	0.00 /0.00	0.00 / 1.3949	0.00 / 0.9315
3.3700/10.4297	0.00 /6.4061	0.3723/0.6862	1.3088/3.3473	0.00 /37.5000	0.7614/4.0483	0.00 /27.2615	9.1818/14.6290
0.0180/ 0.1581	0.0036/0.0534	0.0156/0.0415	0.0172/0.0984	0.00 / 0.0172	0.0768/0.1725	0.3359/ 1.5846	2.4415/ 4.9477
0.00 / 1.3275	0.00 /0.3417	0.00 /0.0075	0.0357/0.1190	0.2396/ 2.0881	0.0271/1.5528	0.2008/ 3.6547	2.3239/10.8547
0.0128/ 1.1978	3.5087/0.3480	0.00 /1.0669	0.0367/0.9224	0.6814/ 5.7410	0.1077/1.6349	0.7458/ 0.7779	5.2704/ 1.8989
0.0148/ 0.00	0.0205/0.00	0.0012/0.00	0.0051/0.00	0.00 / 0.00	0.1362/0.00	0.1275/ 0.2298	0.00 / 0.00
0.00 /-	0.0641/0.00	0.0206/0.00	0.00 /0.00	0.00 /-	0.00 /0.00	0.0354/-	0.00 /-
		0.00 /0.00	0.00 /-	0.00 /-	0.00 /0.00	0.00 / 0.00	0.00 /-
		0.00 /0.00	0.00 /-	0.00 /-	0.00 /-	0.00 /-	0.00 /-
		0.00 /-	0.00 /-	0.00 /-	0.00 /0.00	0.00 / 0.00	0.00 /-
		-/-	0.00 /-	-/-	-/-	-/-	0.00 /-
		0.00 /-	0.00 /-	0.00 /-	0.00 /0.00	0.00 / 0.00	0.00 /-
0.0449/0.9225	0.1325/0.7388	0.0066/0.0603	0.0274/0.4350	0.0761/0.4013	0.0817/0.8735	0.1944/2.7751	1.1847/4.2077
0.3633	0.6983	0.0213	0.1546	0.1708	0.2406	1.4726	2.3724

Table 3.—*Continued.*

Zone	1962	1963	1964	1965	1966	1967	1968	1969	1970 (Jan. thru June)
PACIFIC MACKEREL									
A	0.00/ 0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/-	0.00/-	0.00/0.00	-/-
B	0.30/ 0.03	0.00/1.56	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/-	0.00/0.00	0.00/0.00
C	0.00/ 3.15	0.23/0.37	0.03/0.30	0.04/0.28	0.01/0.35	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
D	0.50/ 0.30	1.41/2.20	0.49/0.23	0.05/0.08	0.00/0.01	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
E	-/ 3.75	0.43/0.67	0.02/0.74	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.0366	0.00/0.00	0.00/0.00
F	-/ 0.00	5.40/6.59	3.15/3.62	0.00/0.23	0.00/2.95	0.00/0.00	0.00/0.0051	0.00/0.00	0.00/0.00
G	-/18.75	0.79/0.46	0.78/0.13	0.00/0.44	0.00/0.04	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
H	-/-	2.19/1.62	0.14/0.36	0.00/0.02	0.00/0.02	0.00/0.00	0.00/0.0042	0.00/0.0347	0.00/0.0050
I	-/-	0.76/0.40	0.01/0.53	0.00/0.11	0.00/0.09	0.00/0.02	0.00/0.00	0.00/0.0402	0.00/0.0180
J	-/-	0.83/1.44	0.75/0.29	0.00/0.36	0.00/0.06	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
K	-/-	1.94/-	0.00/-	0.00/-	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	-/-
L									
M									
N									
O									
P									
Average all zones	0.17/1.26	0.79/0.91	0.33/0.33	0.01/0.19	0.00/0.14	0.00/0.00	0.00/0.0022	0.0001/0.0096	0.00/0.0028
Average D+N						0.0020	0.0007	0.0036	-
PACIFIC SARDINE									
A	0.00/ 0.00	1.40/3.78	1.22/0.05	0.04/0.00	0.00/0.00	0.00/-	0.00/-	0.00/0.00	-/-
B	0.05/ 2.13	0.31/0.00	0.26/1.63	0.00/0.00	0.00/0.38	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /-
C	0.04/ 0.00	0.02/0.00	0.00/0.05	0.07/0.02	0.00/0.00	0.00/0.03	0.00/0.00	0.00/0.00	0.00 /0.00
D	0.00/ 0.28	0.07/2.36	0.23/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00
E	-/12.50	2.22/0.83	1.75/7.87	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00
F	-/ 0.00	0.00/0.00	13.47/1.62	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	-/0.00	0.00 /0.00
G	-/ 0.00	0.08/0.30	0.17/0.13	0.03/0.00	0.00/0.09	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00
H	-/-	0.06/0.67	0.00/2.27	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.0213	0.00/0.00	0.00 /0.00
I	-/-	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.02	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00
J	-/-	0.12/0.05	0.22/0.01	0.00/1.09	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.2564/0.00
K	-/-	0.00/-	0.00/-	0.00/-	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	-/-
L									
M									
N									
O									
P									
Average all zones	0.04/1.00	0.22/0.50	0.27/1.03	0.02/0.05	0.00/0.04	0.00/0.0078	0.00/0.0022	0.00/0.00	0.0067/0.00
Average D+N						0.0023	0.0007	0.0000	
PACIFIC BARRACUDA									
A	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/-	0.00 /-	0.00 /0.00	-/-
B	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.24/0.00	0.00/0.00	0.00 /-	0.00 /0.00	0.00 /-
C	0.00/0.00	0.34/0.43	0.45/0.48	0.25/0.00	0.02/0.00	0.02/0.00	0.0382/0.0119	0.0422/0.00	0.0199/0.00
D	0.00/0.00	0.00/0.00	0.00/0.01	0.00/0.00	0.01/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
E	-/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
F	-/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	-/0.00
G	-/0.00	0.00/0.11	0.00/0.00	0.02/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
H	-/-	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.11/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
I	-/-	0.15/0.00	0.00/0.31	0.40/0.00	0.02/0.00	0.01/0.00	0.00 /0.00	0.0016/0.00	0.00 /0.00
J	-/-	0.04/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.0429/0.00	0.00 /0.00
K	-/-	0.00/-	0.00/-	0.00/-	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	-/-
L									
M									
N									
O									
P									
Average all zones	0.00/0.00	0.08/0.15	0.08/0.12	0.10/0.00	0.03/0.00	0.00/0.00	0.0077/0.0016	0.0183/0.00	0.0084/0.00
Average D+N						0.0035	0.0056	0.0115	

1971	1972	1973	1974	1975	1976	1977	1978
-/-	-/-	0.00/-	0.00/-	-/-	-/-	-/-	-/-
0.00 /-	0.00 /0.00	0.00/0.00	0.00/-	0.00 /0.00	0.00 /0.00	0.00 / 0.00	0.00 /-
0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	0.006/ 0.021	0.0092/ 0.0658
0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.0394	0.357/ 1.31	1.1879/ 5.0309
0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.1292/0.00	0.00 / 0.00	3.4574/23.8452
0.6744/0.00	0.00 /0.2932	0.00/2.2058	0.00/0.00	0.00 /0.00	0.00 /0.00	0.223/ 8.0	2.7273/18.1452
0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	0.006/ 0.82	1.1853/ 4.4186
0.0990/0.1315	0.00 /0.0047	0.00/0.00	0.00/0.00	0.00 /0.00	0.00 /0.00	5.45 / 8.41	9.6584/13.3682
0.0025/0.0451	0.00 /0.0492	0.00/0.00	0.00/0.00	0.0446/0.00	0.4707/0.00	3.61 /13.89	8.4372/30.2404
0.0005/0.00	0.0041/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.0068/0.00	0.009/ 0.062	0.6338/ 4.9126
0.00 /-	0.00 /0.00	0.00/0.00	0.00/0.00	0.00 /-	0.00 /0.00	0.00 /-	0.00 /-
		0.00/0.00	0.00/-	0.00 /-	0.00 /0.00	0.00 / 0.00	0.00 /-
		0.00/0.00	0.00/-	0.00 /-	0.00 /-	0.00 /-	0.00 /-
		0.00/-	0.00/-	0.00 /-	0.00 /0.00	0.00 / 0.00	0.00 /-
		-/-	0.00/-	-/-	-/-	-/-	-/-
		0.00/-	0.00/-	0.00 /-	0.00 /0.00	0.00 / 0.00	0.00 /-
0.0042/0.0028	0.0003/0.0338	0.0000/0.0282	0.00/0.00	0.0035/0.00	0.0285/0.0066	0.907/2.62	2.1831/7.4608
0.0233	0.0126	0.0077	0.00	0.0025	0.0241	1.754	4.2566
-/-	-/-	0.00 /-	0.00/-	-/-	-/-	-/-	-/-
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/-	0.00/0.00	0.00/0.00	0.00/0.00	0.00/-
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.00 /0.1000	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.0207/0.00	0.0205/0.00	0.0102/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.00 /-	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/-	0.00/0.00	0.00/-	0.00/-
		0.00 /0.00	0.00/-	0.00/-	0.00/0.00	0.00/0.00	0.00/-
		0.00 /0.00	0.00/-	0.00/-	0.00/-	0.00/-	0.00/-
		0.00 /-	0.00/-	0.00/-	0.00/0.00	0.00/0.00	0.00/-
		-/-	0.00/-	-/-	-/-	-/-	-/-
		0.00 /-	0.00/-	0.00/-	0.00/00.0	0.00/0.00	0.00/-
0.0030/0.0008	0.0015/0.00	0.019/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
0.0023	0.0010	0.0013	0.00	0.00	0.00	0.00	0.00
-/-	-/-	0.00 /-	0.00 /-	-/-	-/-	-/-	-/-
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /-	0.00 /-	0.00 /0.00	0.00/0.00	0.00/-
0.0125/0.00	0.00 /0.00	0.0037/0.00	0.2688/0.00	0.0252/0.00	0.0396/0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.0856/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	0.00 /-	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
0.00 /0.00	0.00 /0.00	-/-	0.0068/0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
0.00 /-	0.00 /0.00	0.00 /-	0.00 /0.00	0.00 /-	0.00 /0.00	0.00/-	0.00/-
		0.00 /0.00	0.00 /-	0.00 /-	0.00 /0.00	0.00/0.00	0.00/-
		0.00 /0.00	0.00 /-	0.00 /-	0.00 /-	0.00/-	0.00/-
		0.00 /-	0.00 /-	0.00 /-	0.00 /0.00	0.00/0.00	0.00/-
		-/-	0.00 /-	-/-	-/-	-/-	-/-
		0.00 /-	0.00 /-	0.00 /-	0.00 /0.00	0.00/0.00	0.00/-
0.0055/0.00	0.0190/0.00	0.0004/0.00	0.0407/0.00	0.0030/0.00	0.0053/0.00	0.00/0.00	0.00/0.00
0.0035	0.0120	0.0003	0.0260	0.0021	0.0042	0.00	0.00

Table 3.—*Continued.*

Zone	1962	1963	1964	1965	1966	1967	1968	1969	1970 (Jan. thru June)
YELLOWTAIL									
A	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/-	0.00 /-	0.00/0.00	-/-
B	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.07/0.00	0.00/0.00	0.00 /-	0.00/0.00	0.00/-
C	0.00/0.00	0.03/0.04	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00/0.00	0.00/0.00
D	0.00/0.00	0.36/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00/0.00	0.00/0.00
E	-/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00/0.00	0.00/0.00
F	-/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00/0.00	-/0.00
G	-/0.00	0.00/0.00	0.00/0.00	0.01/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00/0.00	0.00/0.00
H	-/-	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00 /0.00	0.00/0.00	0.00/0.00
I	-/-	0.55/0.64	0.13/0.04	0.34/0.07	0.39/0.00	0.09/0.00	0.00 /0.00	0.00/0.00	0.00/0.00
J	-/-	0.63/0.10	0.00/0.00	0.16/0.00	0.00/0.00	0.00/0.00	0.0037/0.00	0.00/0.00	0.00/0.00
K	-/-	0.00/-	0.00/-	0.00/-	0.00/0.00	0.00/0.00	0.00 /0.00	0.00/0.00	-/-
L									
M									
N									
O									
P									
Average all zones	0.00/ 0.00	0.19/ 0.06	0.01/ 0.00	0.06/ 0.00	0.04/ 0.00	0.00/ 0.00	0.0004/ 0.00	0.00/0.00	0.00/0.00
Average D+N						0.0023	0.0002	0.0000	—

increase in sightings occurred in this area during 1976-78. In 1976, 11 sightings were made about San Clemente Island, and 3 northwest of San Diego. In 1977, sightings totaled 210 with concentrations about Catalina and San Clemente Islands, and a small group of sightings about Cortez Bank and along the coast near Pt. Dume. Most of the increase in numbers of sightings occurred in the late summer and fall of 1977. In 1978, 321 sightings were made, and were concentrated about the southern California islands, including Santa Barbara Island. An increasing number of sightings occurred in the Catalina Channel south of Long Beach, and along the coast both east and west of Pt. Dume.

In recent years, Pacific mackerel have been sighted in many of the same areas as during the 1962-65 period, the exception being that sightings are not as common in the San Diego to Oceanside area.

Index Trends.—The aerial pelagic resource monitoring program was started after the major decline of the Pacific mackerel fishery had occurred. However, about the time the survey program was started (1963), and in the years following, a sequence of severe recruitment failures helped reduce the population to a very low level (MacCall et al. 1976). The biomass estimate in 1962 was about 99.8×10^3 t. By 1963, it had declined to about 54.4×10^3 t, and to a level of about 7.3×10^3 t in 1967. A catch moratorium was placed on the commercial fishery in 1970. In later years, this was modified and catches off California in 1977 and 1978 amounted to 3.8 and 13.2×10^3 t, respectively. The night index (Fig. 37) declined from about 0.91 in 1963 to 0.00 in 1967 and remained at a very low level through an 8-yr period, from 1967 to 1975. The catch also declined sharply from 18.1×10^3 t in 1963 to about 2.3×10^3 t in 1965. Historical records would indicate the Pacific mackerel is subject to rather severe fluctuations in recruitment. In 1976, a small increase in the index level was evident, and in 1977 the index level had increased dramatically to a level of about 2.62. In 1978, the 1977 level increased 2.8 times, to a level of 7.46. Within a 3-yr period, the Pacific mackerel went from zero observations of pure schools in 1974, to a condition in 1978 where it was one of the species frequently observed in substantial tonnage.

Jack Mackerel

Morro Bay to San Nicolas Island.—1962-65, Fig. 38; 1966-69, Fig. 39; 1970-73, Fig. 40; 1974-78, Fig. 41.

Jack mackerel were frequently sighted along the coast from Avila northward to Pt. Sur, and from Pt. Conception eastward in the Santa Barbara Channel, with centers of sightings in the Channel southeast of Santa Barbara about the eastern half of Santa Cruz Island, and Anacapa Island. Observations on the flight log charts, from 1962 through 1969, showed little change in areas and numbers sighted. Fewer sightings were made during 1970-73 about the Santa Barbara coast, Channel, and Islands, and this may have been related to the oil discharge in the Santa Barbara Channel in early 1970. During this period, less search effort was expended north of Pt. Conception, but the effort that was expended failed to note any concentrations. During 1976-78, jack mackerel were sighted in increasing numbers at the eastern end of the Santa Barbara Channel, and about Santa Cruz and Anacapa Islands, in the same areas as observed during 1962-69.

Pt. Hueneme to San Diego.—1962-65, Fig. 42; 1966-69, Fig. 43; 1970-73, Fig. 44; 1974-78, Fig. 45.

For the area from Pt. Hueneme to San Diego, there has been little change in the major sighting areas since 1962. Sightings declined during 1970-73, as in the Santa Barbara Channel area. In 1976-78, the sightings increased along the coast and about the islands and on Cortez Bank. During this period, the coastal area from southwest of Pt. Dume to Pt. Hueneme appeared to have a greater number of sightings than during 1962-65.

Index Trends.—The aerial night index level (Fig. 46) was about 2.98 in 1963, with a catch of 42.6×10^3 t. In 1964-67, the catch declined about one-third, but the aerial index did not show a declining trend. In 1969, the index dropped sharply to a 0.65 level and continued to decline through 1975 (0.40). In 1976, a small increase in the index was noted (0.87), rising to 2.77 in 1977. It then increased 1.5 times in 1978 to a record high of 4.20. The substantial increase in index level in 1977 and 1978 parallels, but does not equal in magnitude, the increase in the Pacific mackerel index. Both day and night indices for jack mackerel increased in 1978.

	1971	1972	1973	1974	1975	1976	1977	1978
	-/-	-/-	0.00 /-	0.00 /-	-/-	-/-	-/-	-/-
	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /-	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/-
	0.00/0.00	0.0664/0.00	0.0074/0.00	0.0044/0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.0014/0.00	0.00/0.00	0.00/0.00
	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.0873/0.6451	0.00/0.00	0.00/0.00
	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/0.00
	0.00/0.00	0.0109/0.00	0.00 /0.00	0.00 /0.00	0.0047/0.00	0.00 /0.00	0.00/0.00	0.00/0.00
	0.00/-	0.00 /0.00	0.0460/0.00	0.2364/0.00	0.00 /0.00	0.00 /0.00	0.00/0.00	0.00/00.0
	0.00/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /-	0.00 /0.00	0.00/-	0.00/-
			0.00 /0.00	0.0106/-	0.00 /-	0.00 /0.00	0.00/0.00	0.00/-
			0.00 /0.00	0.00 /-	0.00 /-	0.00 /-	0.00/-	0.00/-
			0.2847/-	0.00 /-	0.00 /-	0.00 /0.00	0.00/0.00	0.00/-
			-/-	0.00 /-	-/-	-/-	-/-	0.00/-
			0.00 /-	0.00 /-	0.00 /-	0.00 /0.00	0.00/0.00	0.00/-
	0.00/0.00	0.0035/0.00	0.0213/0.00	0.0470/0.00	0.0004/0.00	0.0015/0.0056	0.00/0.00	0.00/0.00
	0.0000	0.0022	0.0155	0.0323	0.0003	0.0024	0.00	0.00
Bluefin tuna								
A			0.00 /-	0.00 /-	-/-	-/-	-/-	-/-
B			0.00 /0.00	0.00 /-	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
C			0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
D			0.00 /0.00	0.0226/0.00	0.0386/0.00	0.00 /0.00	0.00 /0.00	0.00 /0.00
E			0.00 /0.00	0.0257/0.00	0.3281/0.00	0.0545/0.00	0.00 /0.00	0.00 /0.00
F			0.00 /0.00	0.6127/0.0449	0.00 /0.00	0.0458/0.7258	0.00 /0.00	0.00 /0.00
G			0.00 /0.00	0.0797/0.0410	0.0241/0.00	0.00 /0.0021	0.00 /0.00	0.00 /0.00
H			0.00 /0.00	0.0306/0.00	0.0279/0.00	0.0067/0.00	0.0072/0.00	0.00 /0.00
I			0.2667/0.00	0.2603/0.00	0.1228/0.00	1.2857/0.0396	0.034 /0.00	0.00 /0.00
J			0.0408/0.00	0.7556/0.00	0.0779/0.00	0.7330/0.00	0.00 /0.00	0.00 /0.00
K			3.0506/1.2878	1.9407/0.00	0.1034/-	1.6140/0.2380	0.14 /-	4.145/-
L			1.1499/0.5319	1.9779/-	0.3642/-	1.6190/0.00	0.00 /0.00	0.328/-
M			2.9545/0.00	0.00/-	0.00 /-	0.00 /-	0.00 /-	0.00 /-
N			2.4402/-	5.3768/-	0.7735/-	1.7961/0.00	4.44 /0.00	9.482/-
O			-/-	0.00/-	-/-	-/-	-/-	-/-
P			16.3561/	14.3181/-	0.00 /0.00	0.2495/0.00	0.037/0.00	2.142/-
Q						-/-	-/-	-/-
R						24.7204/0.00	-/-	-/-
Average all zones			0.9462/0.0276	0.7972/0.0202	0.1324/0.00	0.8766/0.0091	0.424/-	0.7183/0.00
Average D+N			0.6940	0.5547	0.0938	0.7026	0.2139	0.4361

Tunas

Bluefin tuna.—Sightings of bluefin tuna for all years 1962 through 1978, are given for the areas north of the United States-Mexico border (Figs. 47, 48), and for the area from San Diego south into Mexico (Fig. 49). Flight log charts for areas south of the border (see dotted line on Fig. 49) were not used by the program until 1974.

Figure 47 shows that the major sighting area for bluefin tuna in the Santa Barbara Channel and Channel Islands area was along the south side of Santa Cruz and Santa Rosa Islands, with a few sightings made near San Nicolas Island and along the Santa Barbara coast. Figure 48 shows that sightings were widely scattered west and southwest of San Diego. Bluefin tuna were frequently sighted about San Clemente Island, and along the coasts off Oceanside and Redondo Beach. In the southern area of fishing off Mexico (Fig. 49), sightings were more concentrated west and northwest of Ensenada. Aerial spotter operations were seldom conducted south of Pta. Baja, Mexico.

Index Trends.—For the period 1973-78 day index (Table 2), the index trend shows 1975 to have been the lowest in relative apparent abundance (0.13). The highest level was recorded in 1973 (0.95).

Albacore tuna.—For albacore tuna sightings, Figure 50 gives locations for all years 1962 through 1978. Figure 51, from the Coronado Islands, Mexico, southward to Pta. Baja, indicates sightings for the years 1974-78.

Albacore were sometimes sighted west and southwest of San Diego (Fig. 50), but few sightings were made north of this area. A total of 124 sightings were made during the survey period. Figure 51 indicates that 76 sightings were made west to northwest of Ensenada, but few were made in this area south of a line drawn west from Cabo Colnett, Mexico.

Other sightings

Although yellowtail, Pacific barracuda, white seabass, basking shark, and squid are not of primary interest to the commercial aerial fish spotter, records were maintained and are given for these species because they are of interest to the recreational or commercial fisheries of southern California.

Yellowtail.—Areas of sighting were about the Coronado Islands, Mexico, north to near Newport, along the northeast side of San Clemente Island (Fig. 52), and along the coast from Santa Barbara to Pt. Conception (Fig. 53)

Pacific barracuda.—Small numbers of sightings were made along the coast, from north of San Diego to near Long Beach, and off the northeast side of San Clemente Island (Fig. 54). Barracuda were also sighted along the coast from near Pt. Conception to Ventura (Fig. 55).

White seabass.—This species was more commonly sighted by the aerial spotters near Pt. Conception, along the north side of Santa Cruz Island (Fig. 56), and to the north off Avila, Morro Bay (Fig. 57), with some sightings recorded in the northern half of Monterey Bay.

Observations of basking shark (Figs. 58, 59) and of squid (Figs. 60, 61) are of interest to the commercial fishery and are given. Index values are not given for these species.

Basking shark.—Although many species of sharks were sighted, most were not indentified by the spotter pilots as to species. The exceptions were the large sharks, such as the basking shark which was the subject of a commercial fishery in the late 1940's and early 1950's. Aircraft were used in this fishery to locate basking sharks and, on occasions, great white sharks were observed (Squire 1967).

Basking sharks were quite common in coastal waters in the late 1940's and early 1950's, and at that time were fished commercially in California. They were sighted frequently off Avila and Morro Bay (Fig. 58) along the coast south of Pt. Sur, but most frequently in the central and northern half of Monterey Bay (Fig. 59). Few were observed in the mid- to late-1960's and early 1970's. Recently, more basking sharks were being sighted north along the coast from the Santa Barbara area west to Point Conception. A total of 1,911 basking sharks were recorded by the aerial spotters.

Squid.—The only invertebrate animal reported as being sighted in surface schools was the squid. Schools were most common about the eastern half of Santa Cruz Island and Anacapa Island (Fig. 60), and in the coastal area from Pt. Hueneme to Pt. Dume. They appeared most common about Catalina Island (Fig. 61), with larger concentrations along the southwest side. Distribution of sightings about San Clemente Island were grouped at the northwest and southeast ends.

DISCUSSION

Evaluation of Index Data

The aerial observation program relies on the assistance of commercial aerial spotters who, for a modest fee, provide flight log data. The limitations of the data must be recognized since they are nonrandom, and influenced by many variable factors.

Sighting.—The probabilty of sighting a school may be affected by a number of physical factors, some of which are common to both day and night operations, others to day or night (see Table 4). Economic factors are also very important in determining target species for search and location of area searched. In recent years, the demand for anchovy has increased and additional emphasis has been placed on searching areas where anchovy are commonly observed. However, these areas are frequently the same areas where other species are observed.

Table 4.—Physical factors affecting the probability of sighting a school. X = important, — = less important, and 0 = not a factor.

	Day	Night
Area observed	X	X
Angle of viewing	X	—
Sun position	X	0
Moon phase	0	X
School size	X	X
School depth	X	X
School density	X	—
Bioluminescence levels	0	X
Weather		
clear	X	0
overcast	X	0
haze	X	—
Configuration of aircraft	X	X
Ground speed differences	—	—

Identification.—The detection of near-surface schools during the day is dependent upon the pilot's ability to distinguish subtle color and light intensity differences in the water. Detection of schools at night is possible only during the dark phase of the moon, and depends on the pilot's ability to discern gradation of light intensity. Bioluminescence of planktonic organisms agitated by schooling fish indicates by a dull glow the location and size of the school.

Species are identified during the day on the basis of a combination of two or more of the following characteristics: color of school or individual fish, shape of school, and behavior and size of individuals within the school. At night, species identification is based on shape of the luminous area and behavior of the schooling fish under undisturbed conditions, or by the behavior of the school after being subjected to a stimulus from an external source such as a flash from the aircraft's landing light. A light flash causes a response or movement of the fish, which agitates the plankton, resulting in bioluminescence. The response of the fish to the light flash is species-distinctive and allows the trained observer to make an estimation of species. The level of bioluminescent plankton organisms, the schooling configurations, depth of school, and composition of the school (mixed species), are some of the variables in night identification.

School size estimation.—The probability of sighting, identifying, and estimating school size, is affected by the training and ability of the spotter pilot. It was recognized in the beginning of the program that variation in estimating school size probably has more effect on the data than other variables. Some spotter pilots consistently report greater tonnages than do others (Squire 1972). Six of the fish-spotter pilots have continued full-time with the program since 1963 and were the major contributors. Therefore, if biases in reporting of tonnage were present, it may have been relatively consistent throughout the period. MacCall,[3] in an investigation of aerial spotter variation in reported abundance of anchovies, found that differences in spotting power appeared to be consistent for both day and night conditions for two periods of time (1½ yr apart). He also stated that variability in reported tonnages was high even for consecutive flights, giving wide confidence intervals of estimates of spotting power and daily fish abundance. A long-term averaging, however, will reduce the variance in estimates of mean abundance. In evaluating comparative observations between pilots as presented in the flight log, we do not know if they were looking at the same school or school group at the same time. If they were observing the same school or school group, it is possible that some period of time may have elapsed between observations, and the availability level changed. Estimation values between pilots may also change by species, requiring corrective factors by pilot for each species. For example, the anchovy is sometimes one of the more difficult species to evaluate and estimate tonnage because of the large school groups and large tonnages available.

Pilot estimation values for anchovy were calculated using data for the period 15 September to 31 December 1966, 1969, 1974, 1976, and 1977. Flight logs of two or more spotter pilots were compared, using observations thought to be near the same geographical location, for either day or night. One aerial spotter, recognized among his peers as an able and competent observer, was selected as the key observer and his observations were used as a reference base. The results for observations for other spotter pilots indicate that, when compared with the key aerial spotter, two pilots were estimating nearly the same as the key pilot, three were 0.4 times his estimate, two were 0.45 times, and three about 0.08 times. The differences in spotting power appeared to be consistent both day and night, as found by MacCall (footnote 3).

Aerial spotter pilots tended to survey portions of the ocean near their bases of operation: either the greater Los Angeles area or the Santa Barbara coastal area. Pilots operating in the same area tended to estimate the available tonnage in similar amounts, for they frequently communicated via radio and tended to cooperate in the searching and fishing operations in their respective search and fishing areas. As indicated previously, no effort was made during the period of the survey to attempt to influence the individual aerial spotter's tonnage estimation values and the major contributors to the program have participated throughout its 16-yr period.

Comparison of Apparent Abundance Measuring Techniques

A precise measure of a specie's total abundance and its biological composition is most desirable for the management of pelagic marine species. However, at the present time a precise measure of abundance is not possible. Management must therefore rely on sampling techniques to obtain a reasonable estimate of abundance and biological composition. The major coastal pelagic resources are conveniently being measured by methods of sampling which provide a measure or index of apparent abundance (catch or observations per effort). Larval surveys provide an apparent abundance measure, and acoustical surveys are conducted to determine the apparent abundance of fish schools. These apparent abundance indices are then adjusted to yield an estimate of total abundance. For the years since the start of the aerial survey program, some data are available giving estimates for Pacific mackerel and northern anchovy. These data can be compared with the trend of the aerial apparent abundance index. Three types of independent survey data are available for comparison: the larval survey, acoustical or sonar surveys, and the aerial spotter surveys. For the following species, some comparative data are available.

Pacific Mackerel

Smith and Richardson (1977) presented a graph of three independent estimates of the abundance of Pacific mackerel (Fig. 62) using three index values: spawning biomass, larval index, and aerial index. The aerial index can only be compared with values obtained after the start of the aerial survey in 1963. A rank correlation test (Spearman) was used to examine the aerial index vs. spawning biomass (1963-67), giving a significant correlation ($r_s = 1.00$). For the aerial index vs. larval index comparison, the correlation coefficient was $r_s = 0.77$, not significant at the 0.05 level. Although the statistics show promising results, it should be noted that the data are limited by the number of years tested, and that the three indices show a common decrease in value.

Northern Anchovy

Three research programs using different techniques have independently developed apparent abundance data concerning the anchovy resource. Larval catch data have been summarized to produce a larval index and an estimate of spawning biomass. Acoustical surveys to measure school number and size have been used to develop an acoustical index and an estimate of biomass. Aerial survey data have been used to develop an index of apparent abundance. The larval and acoustical techniques sometimes used different indices through the years.

Since all estimates are independent of each other, an analysis was made to determine if these methods were estimating a common source. A description of the data sources for Figure 63 is as follows: larval abundance data for the central subpopulation for 1963 through 1972 was provided by Smith,[4] and data from 1972 through 1978 by Stauffer (1980). Acoustical surveys have been conducted since 1966, but acoustical techniques were changed in 1971. Therefore, acoustical data were compiled from Mais (1974, footnote 5). Aerial survey data taken off the coasts of southern California and northwestern Baja California, Mexico, from published records 1962-69 (Squire 1972), and records through 1978 included in this publication, are in Table 2. Figure 63 shows the larval index from 1963 to 1978, for the central subpopulation, the aerial night index, and acoustical index. The acoustical index is based on $N \times 10^3$ schools for the early years, and the school's surface area (square nautical miles) for the later years. The larval index uses the estimated abundance of larvae $\times 10^{12}$ for the central subpopulation.

[3]MacCall, A. 1975. Investigation of aerial spotter variation in reported abundance of anchovies. Anchovy Workship Meeting, July 21-22, 1975, contrib. 19, 3 p. Southwest Fisheries Center La Jolla Laboratory, NMFS, NOAA, La Jolla, CA 92038.

[4]P. E. Smith, Fishery Research Biologist, Southwest Fisheries Center La Jolla Laboratory, NMFS, NOAA, La Jolla, CA 92038, pers. commun. 1974.

[5]Mais, K. F. 1978. Acoustic survey for the assessment of anchovy resources off California and northern Baja California. Unpubl. manuscr., 21 p. California Department of Fish and Game, Marine Resources Laboratory, 350 Golden Shore, Long Beach, CA 90802.

Significant Spearman rank correlations were not found for comparison of aerial to larval and acoustical survey data for 1963-72. Comparison of aerial and acoustical survey indices for the period 1972-78 gave a significant correlation ($r_s=0.810$, $P=0.05$). During this period, only three larval surveys were conducted, not an adequate sample for calculating a correlation. MacCall et al. (1976) calculated a correlation coefficient of +0.30 for larvae vs. aerial (night) surveys during 1962-66, and for 1968 and 1969. More recently, an anchovy spawning biomass estimate based on egg production has been developed (MacCall et al. 1982). The correlation between the aerial (night) anchovy index with the new biomass estimate is very high (Fig. 64).

The aerial night index appears to be closely correlated with the acoustical index developed during the years since 1971. Larval surveys cover a larger geographical area than either the aerial or acoustical surveys, generally extending further offshore. The aerial survey involves only the nearshore area where the purse seine fishery operates. This area commonly has large concentrations of near-surface schooling fish and suitable sea-state conditions for purse seining, conditions which are not common in the offshore areas.

The anchovy night aerial abundance index was not unusually high during the first years of the surveys compared with levels observed in 1973-76. The aerial surveys were started about the time the anchovy population was reported by Ahlstrom (1968) to have reached a plateau in about 1962. The anchovy larvae index for the central subpopulation declined during 1965-72, increased slightly in 1975, then declined sharply in 1978. The aerial and sonar indices rose two or more times their former levels to high levels in 1973 and 1975, then declined, with the aerial index declining to slightly below pre-1972 levels.

The geographical area covered by the aerial survey program contained the major commercial fishing grounds. High abundance level indices from the aerial spotter data were not evident for this area, which apparently did not benefit from the high larval index levels that started in 1962 and resulted in population estimates of 4.0 to 5.0×10^6 t (Ahlstrom 1968). However, a significant but unexplained change to high aerial and acoustic index trends occurred in the fishery during 1973-75, prior to a rapid decline during 1976-78, in the larval, acoustical, and aerial indices.

Pacific Bonito

Studies have been made using the aerial day index of Pacific bonito observed off southern California, in correlation with recreational partyboat CPUE, using yearly time-lag periods (MacCall et al. 1976). The recreational fleet which fishes nearshore generally catches younger fish than the commercial purse seine fleet. The highest correlation between the recreational fleet CPUE and the aerial apparent abundance index for the commercial fishery was for a 3-yr lag period ($r=0.69$) which is shown in Figure 65. We believe this correlation to be useful in predicting recruitment into the commercial fishery, based on partyboat CPUE.

SUMMARY

The aerial index data is positively correlated with the trend of other measures of apparent abundance, particularly the acoustical survey (post-1971) for anchovy abundance. For the limited amount of comparable data available, the Pacific mackerel aerial index appears to correlate well with the biomass estimates. The index levels of Pacific bonito, a species that is more common to the south, show trends that appear to parallel the trend of the biomass.

Index trends for both the northern anchovy, beginning in 1974, and Pacific bonito, in 1968 and 1973, show a pronounced downward slope one to two years before major declines occurred in these fisheries.

This program has used the available talents of commercial fish spotters who use standard visual techniques to observe pelagic schooling fish. In recent years, airborne electronic surveillance systems specifically designed to measure the extent of the available near-surface schooling resources at night have been developed. These new techniques, if used in close coordination with commercial operations and research studies, could produce for the program a more refined estimate of apparent abundance, not only for the fishing areas commonly surveyed by the commercial spotters but also for areas farther offshore where resources such as the anchovy are commonly observed during the winter-spring spawning season.

All analyses to date have involved only the production of basic apparent abundance indices, and have not been further adjusted to produce a more refined index or estimates of biomass. The aerial apparent abundance data should be further analyzed to provide more refined estimates of abundance for the major pelagic species. Studies are currently in progress to do this.

ACKNOWLEDGMENTS

The cooperation and interest of the commercial aerial fish spotters over a period of 16 yr is sincerely appreciated by the author. Spotter pilots who participated in the program are some of the best talents in the profession: John Bourgois, C. L. Devillier, Ed Durden, Leon Durden, Jim Ferreri, Roger Hillhouse, Frank Iacono, Jack Mardesich, Paul Mardesich, Tony Marinkovich, Joe Miles, John O'Connor, Chuck Rogers, Jack Whalen, and Andy Witmer.

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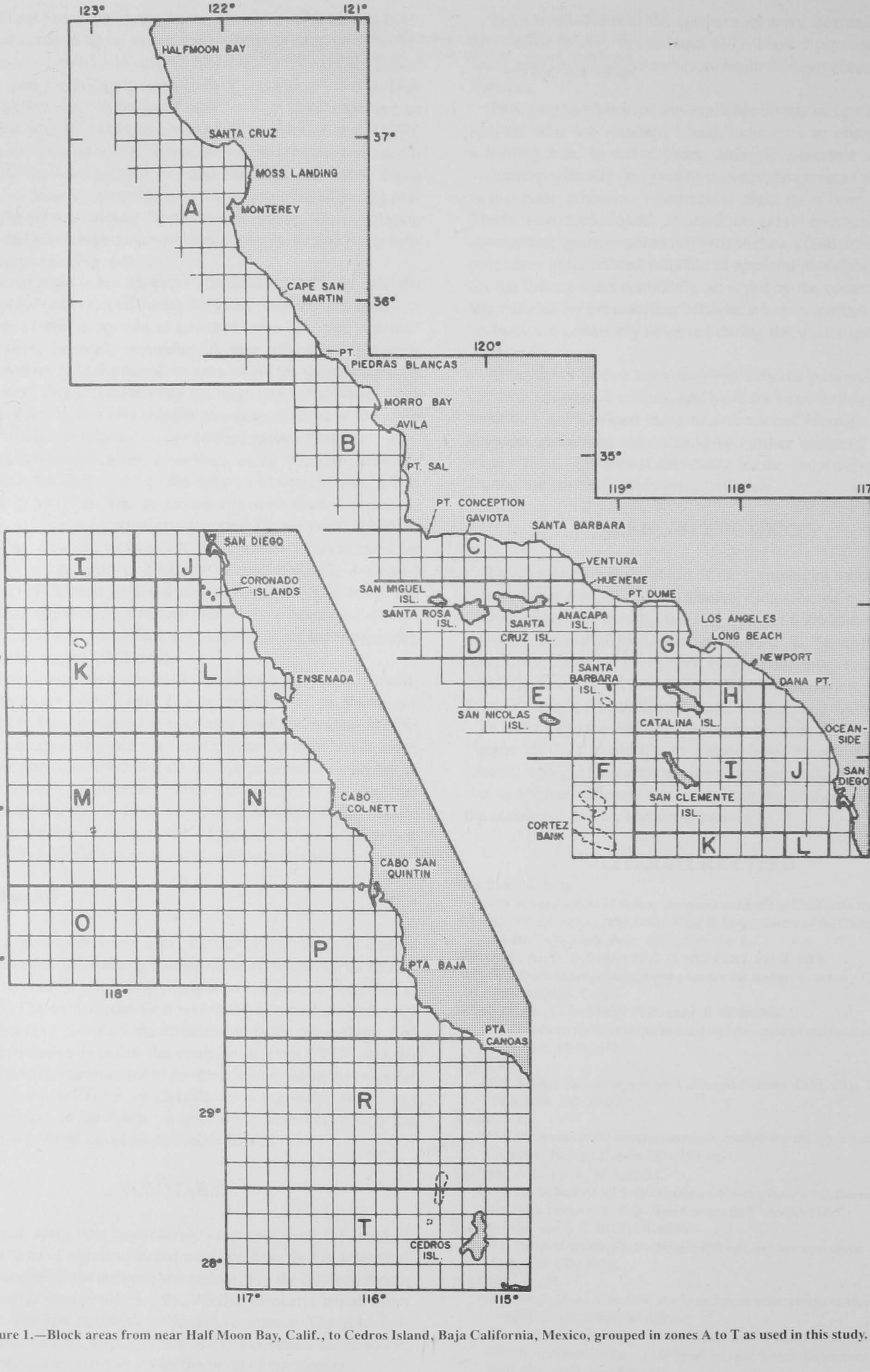

Figure 1.—Block areas from near Half Moon Bay, Calif., to Cedros Island, Baja California, Mexico, grouped in zones A to T as used in this study.

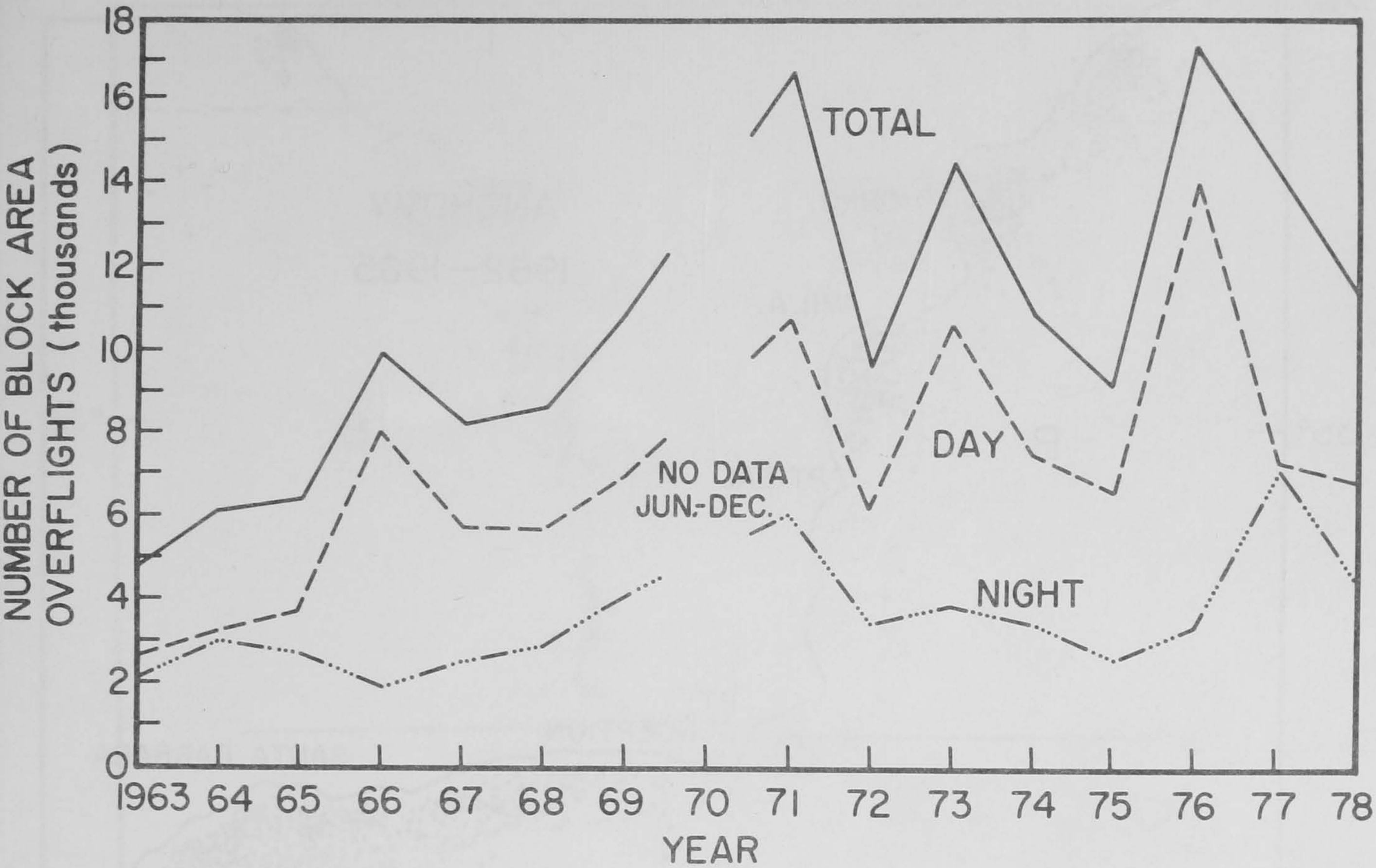

Figure 2.—Summary of observation effort, 1962-78, in terms of total day, night, and total overflights of block areas.

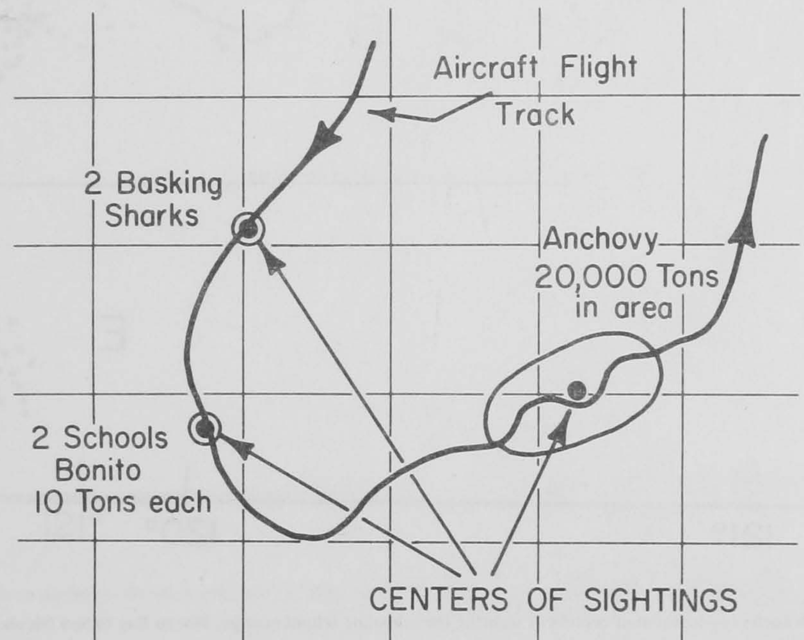

Figure 3.—Graphic description of positioning the center of sighting.

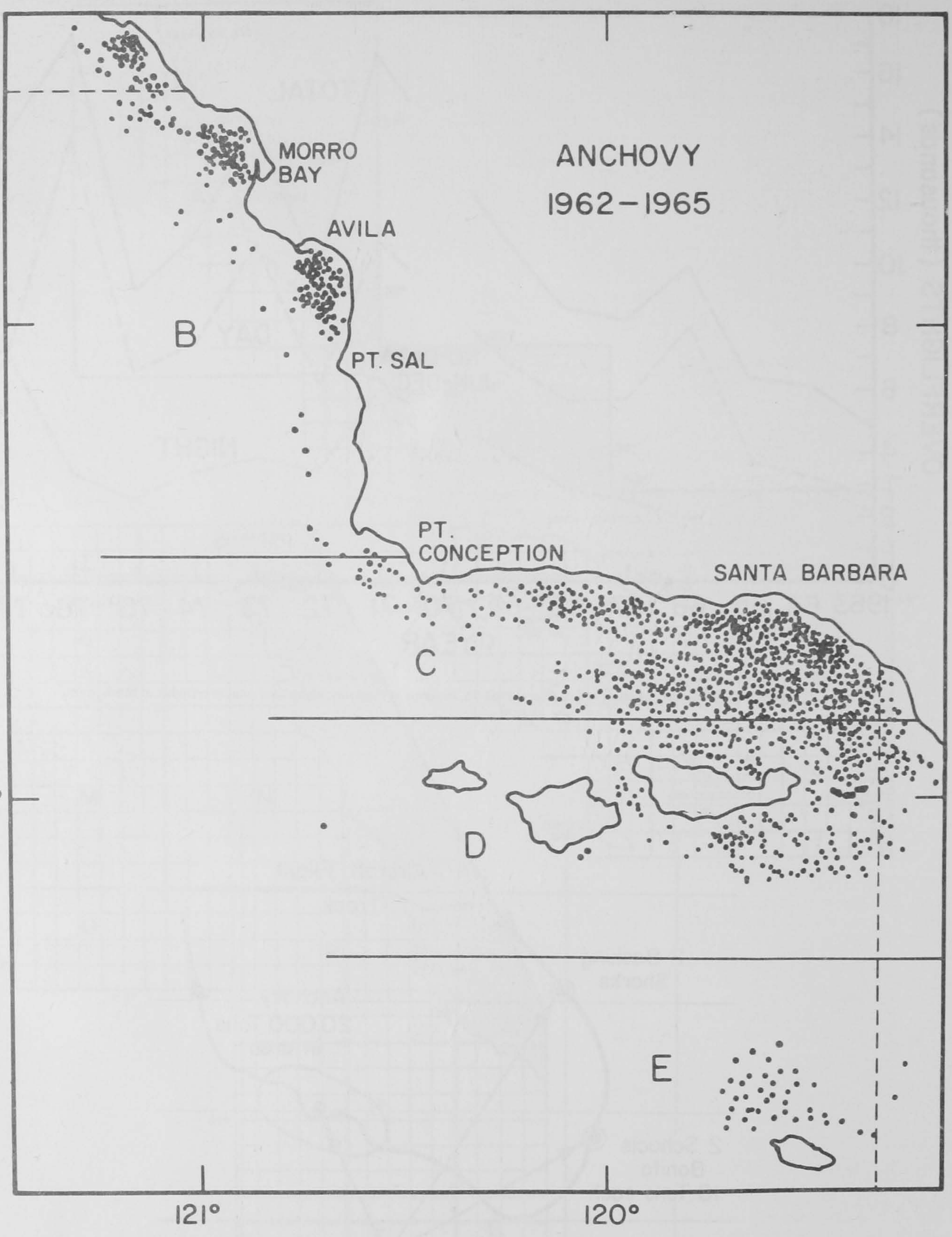

Figure 4.—Northern anchovy—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-65.

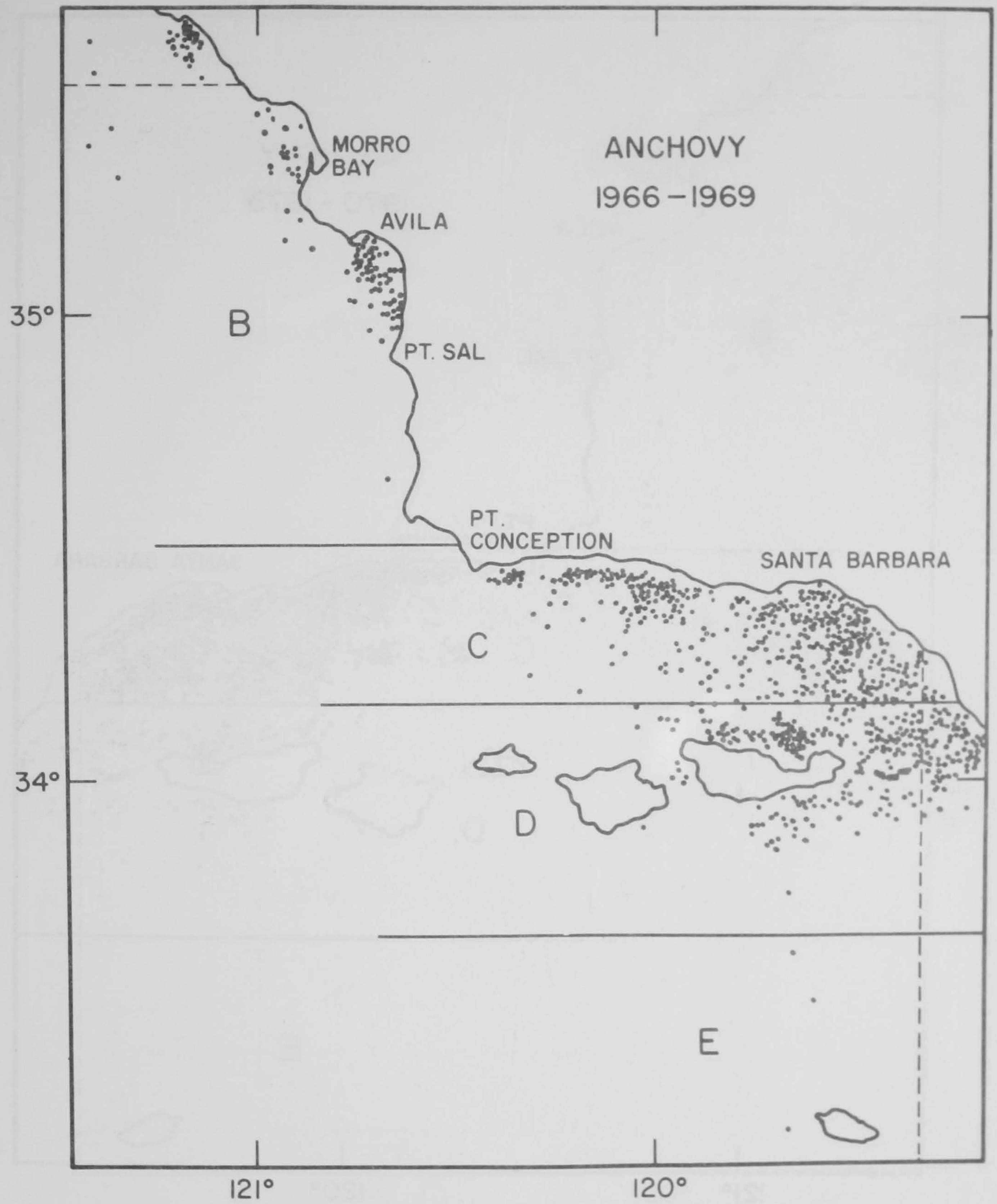

Figure 5.—Northern anchovy—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1966-69.

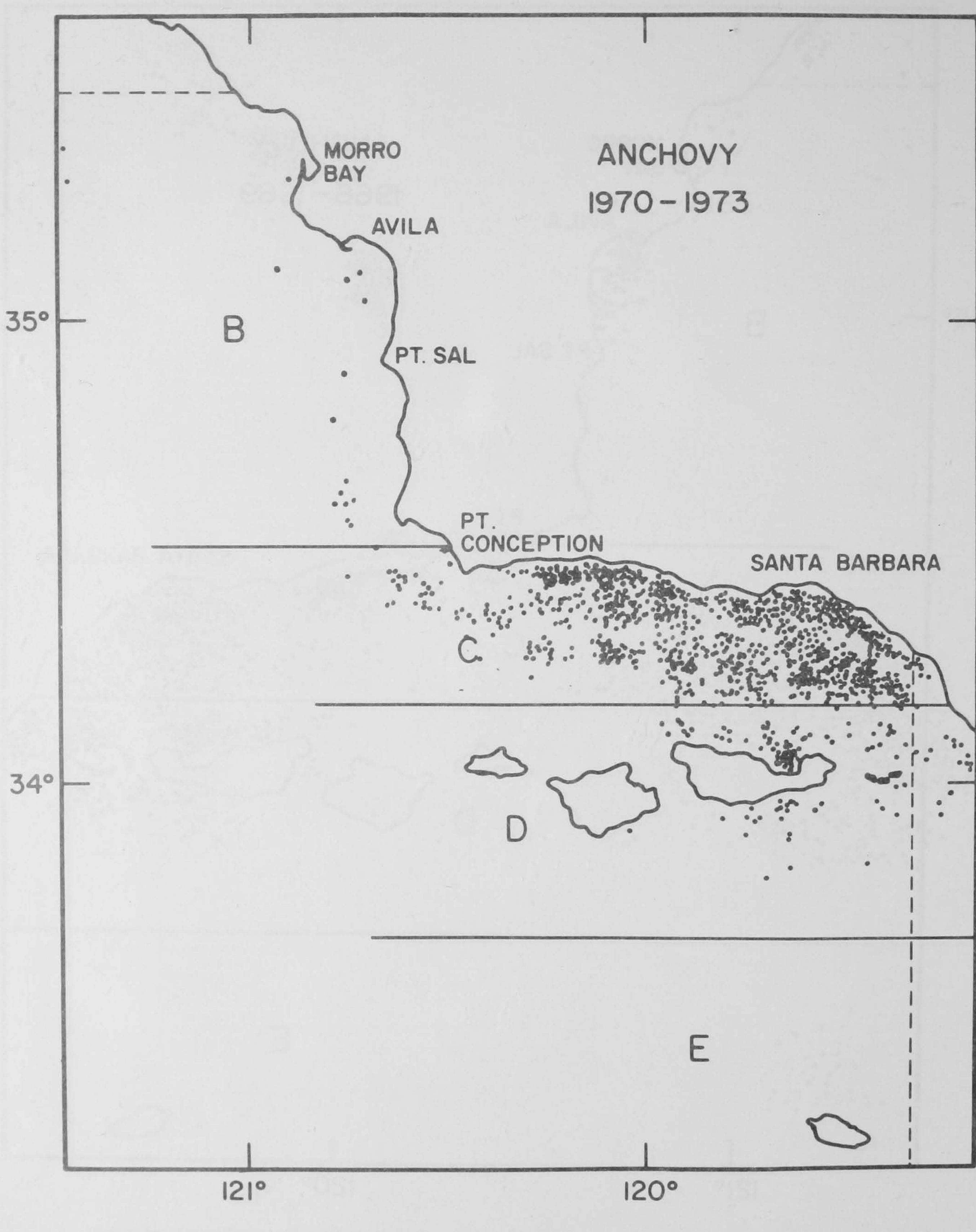

Figure 6.—Northern anchovy—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1970-73.

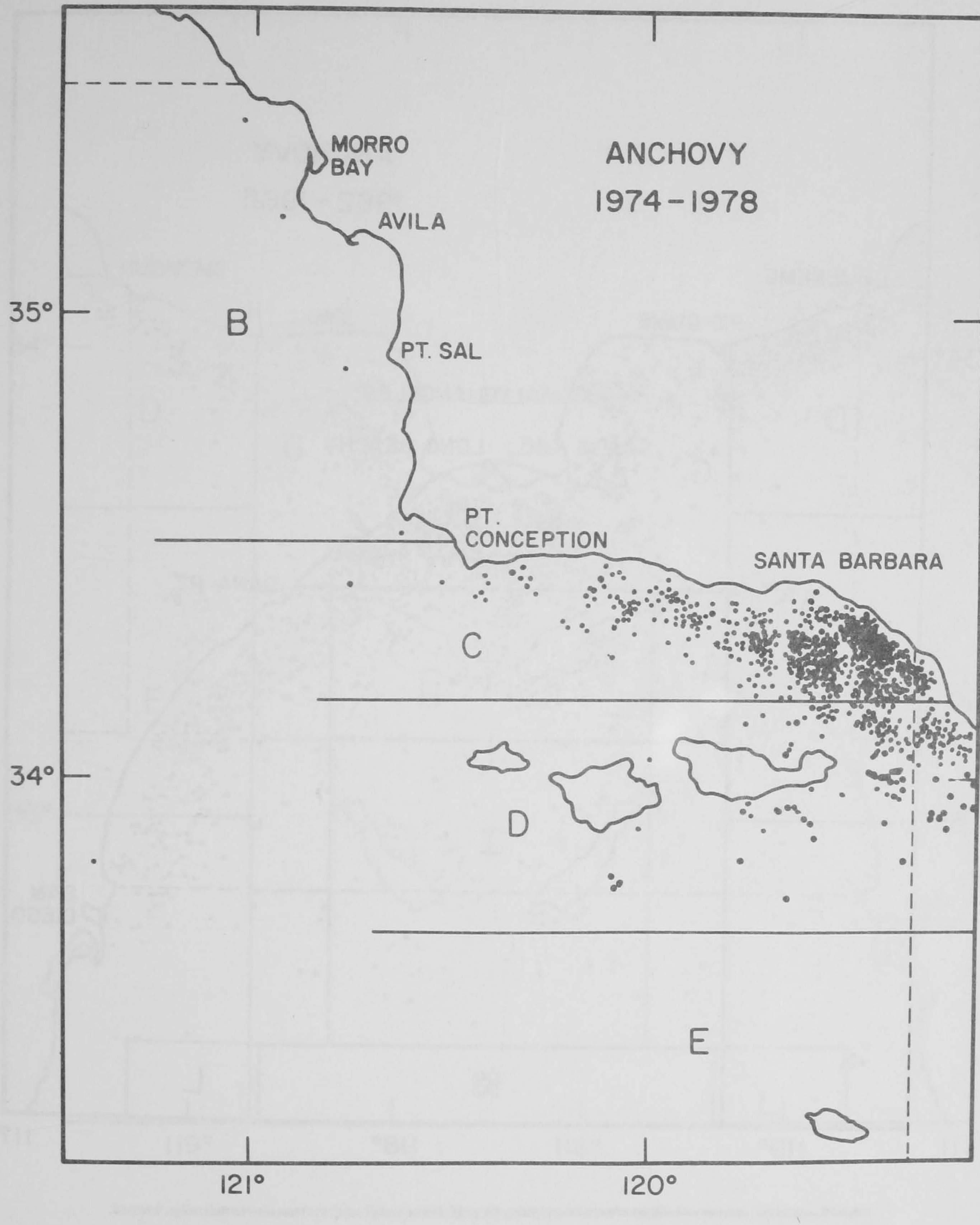

Figure 7.—Northern anchovy—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1974-78.

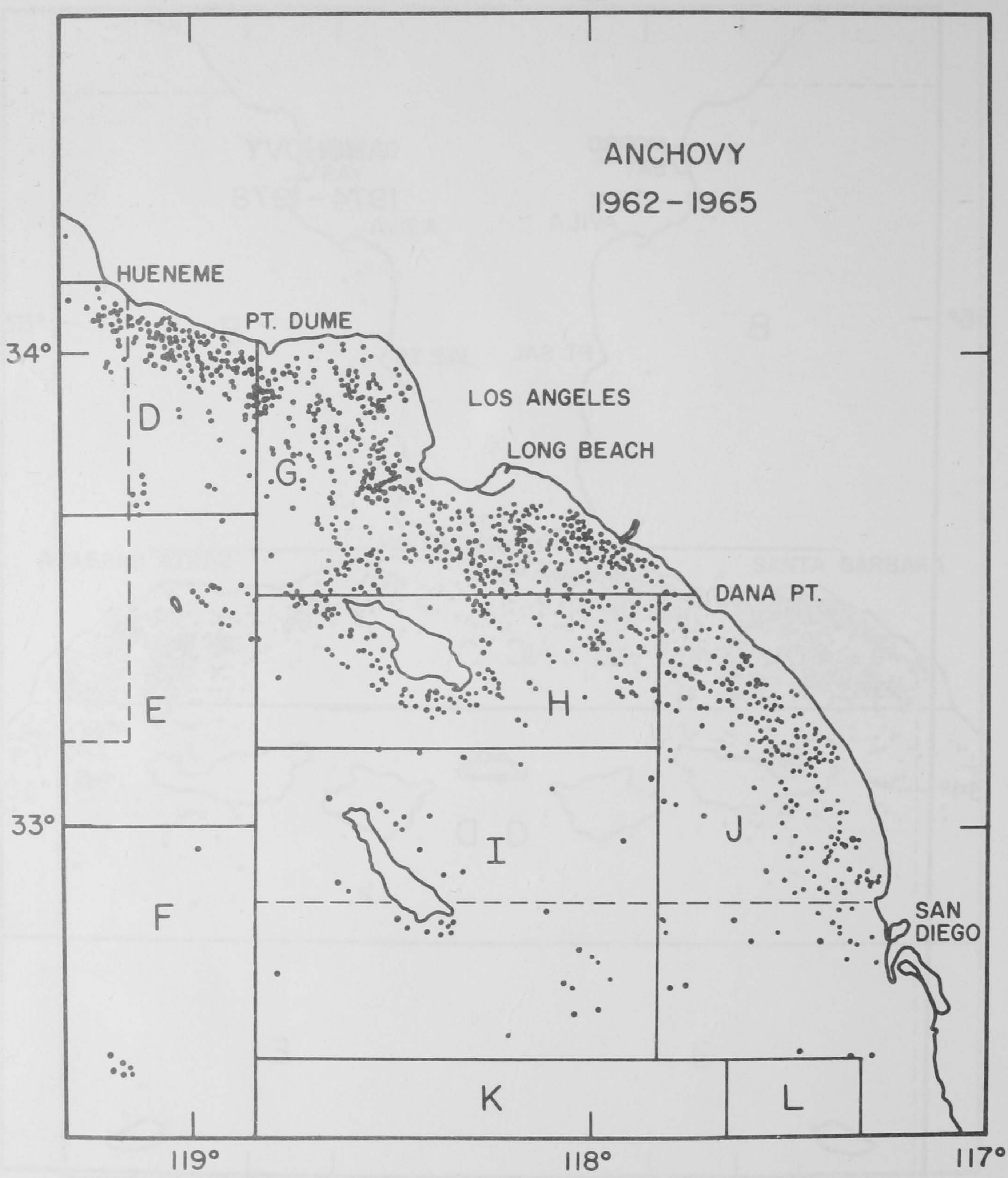

Figure 8.—Northern anchovy—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-65.

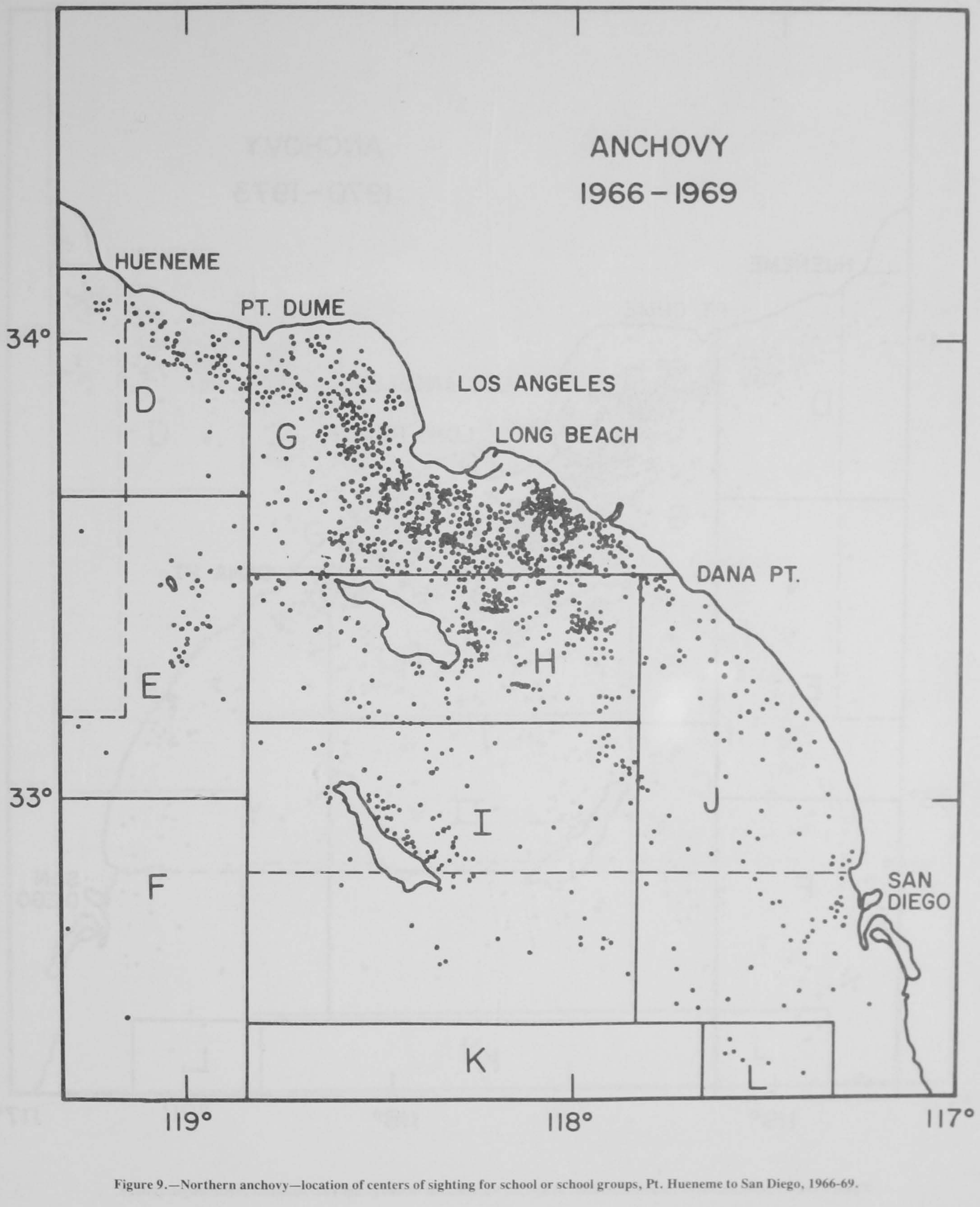

Figure 9.—Northern anchovy—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1966-69.

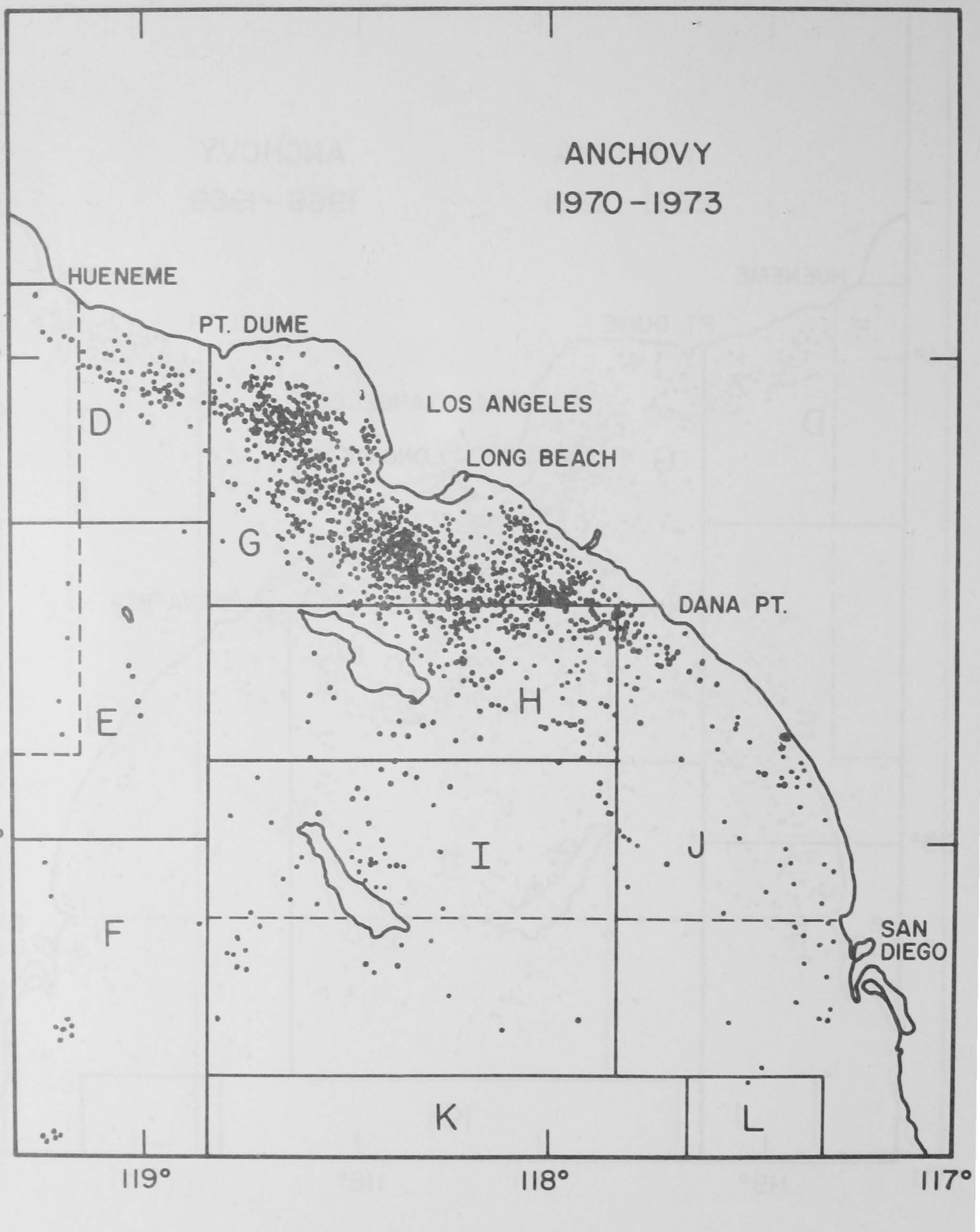

Figure 10.—Northern anchovy—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1970-73.

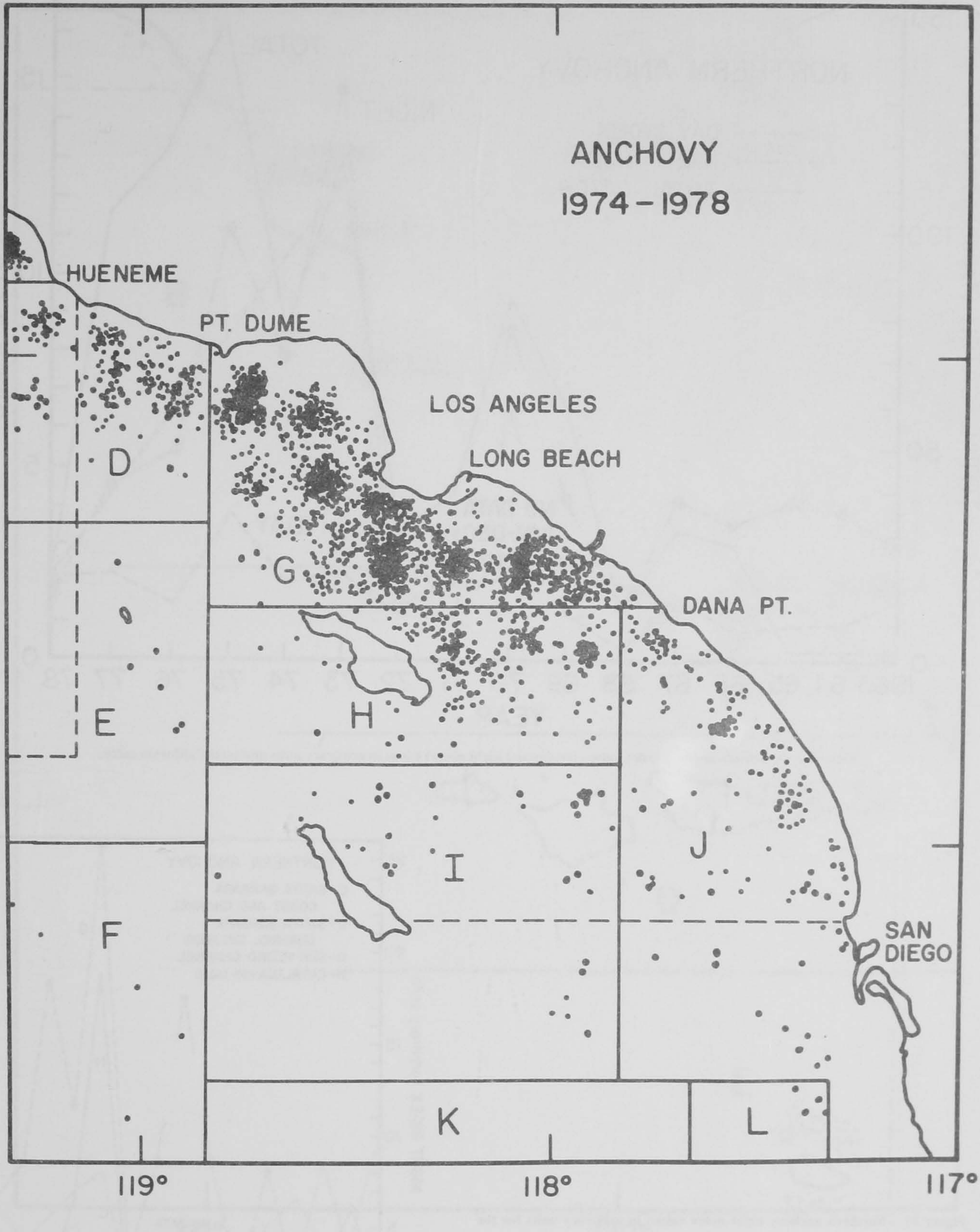

Figure 11.—Northern anchovy—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1974-78.

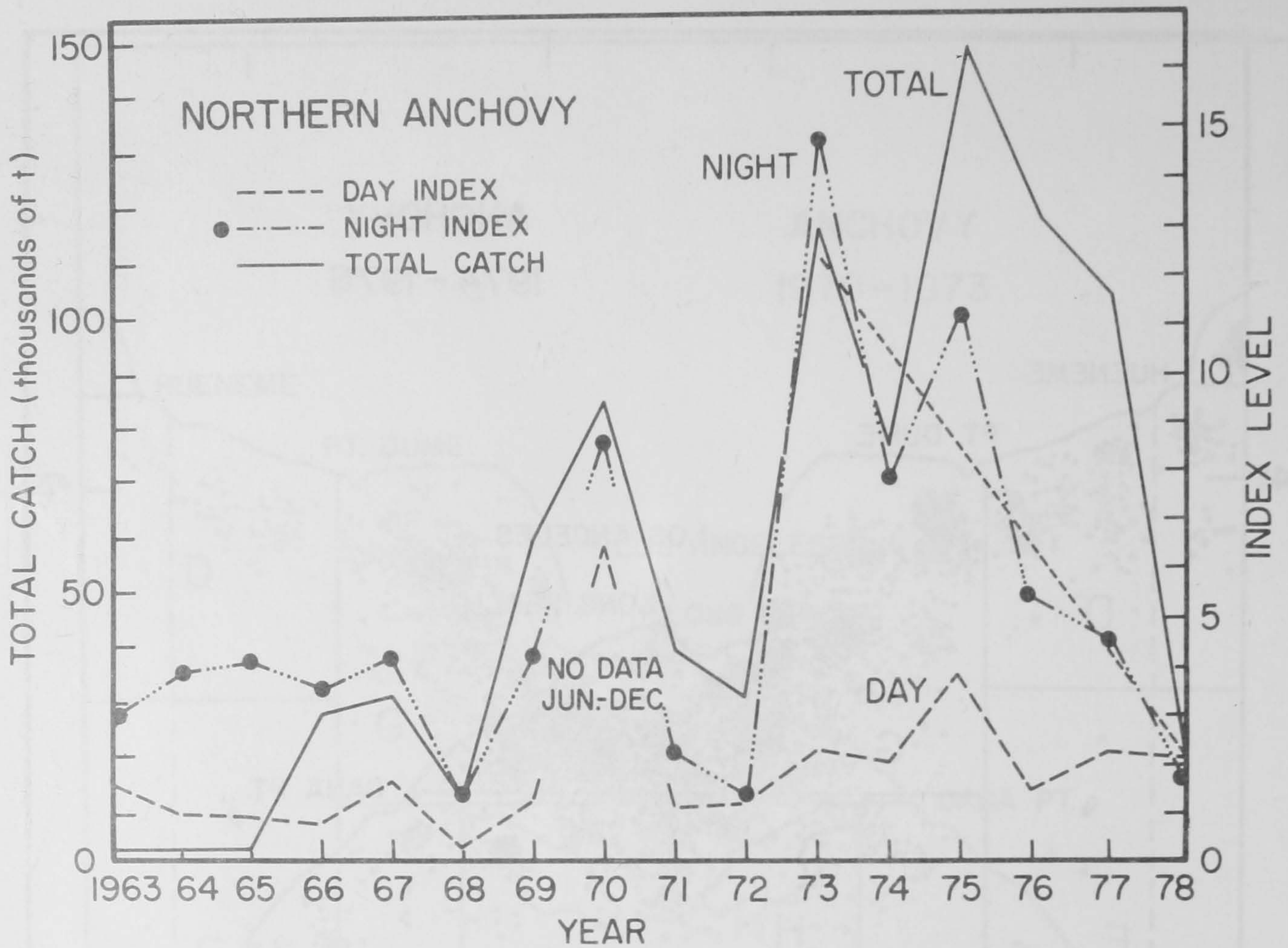

Figure 12.—Northern anchovy index values for day and night observations in arbitrary units and total California catch.

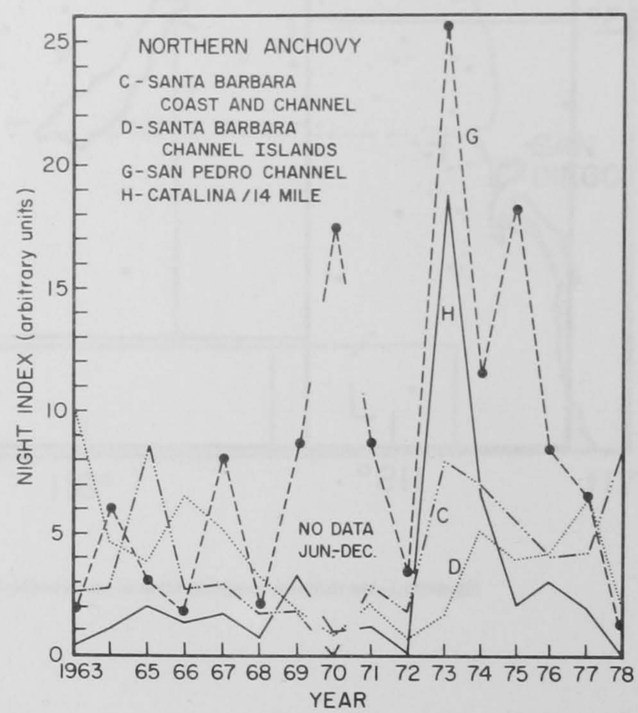

Figure 13.—Northern anchovy night index values in arbitrary units for the major fishing areas.

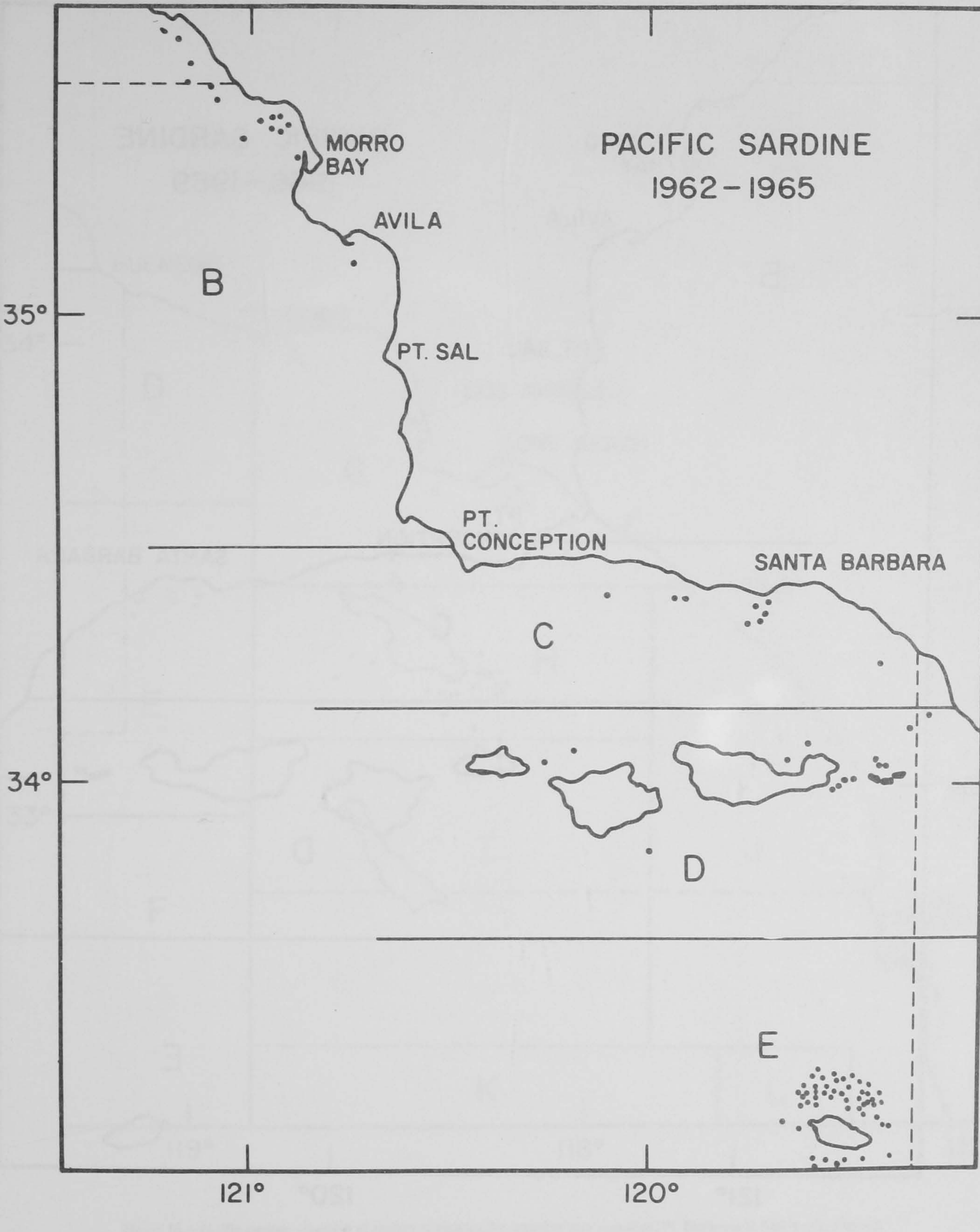

Figure 14.—Pacific sardine—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-65.

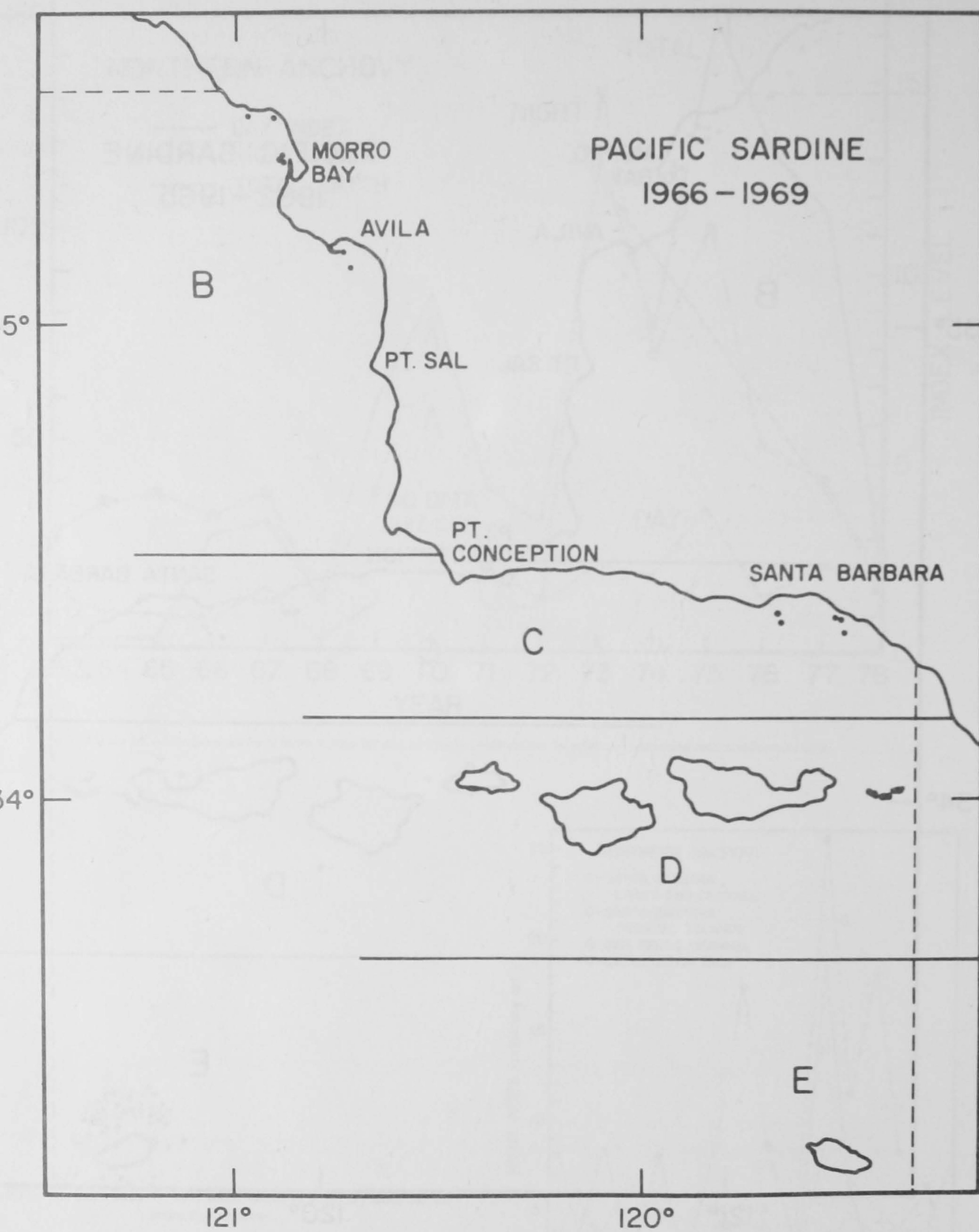

Figure 15.—Pacific sardine—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1966-69.

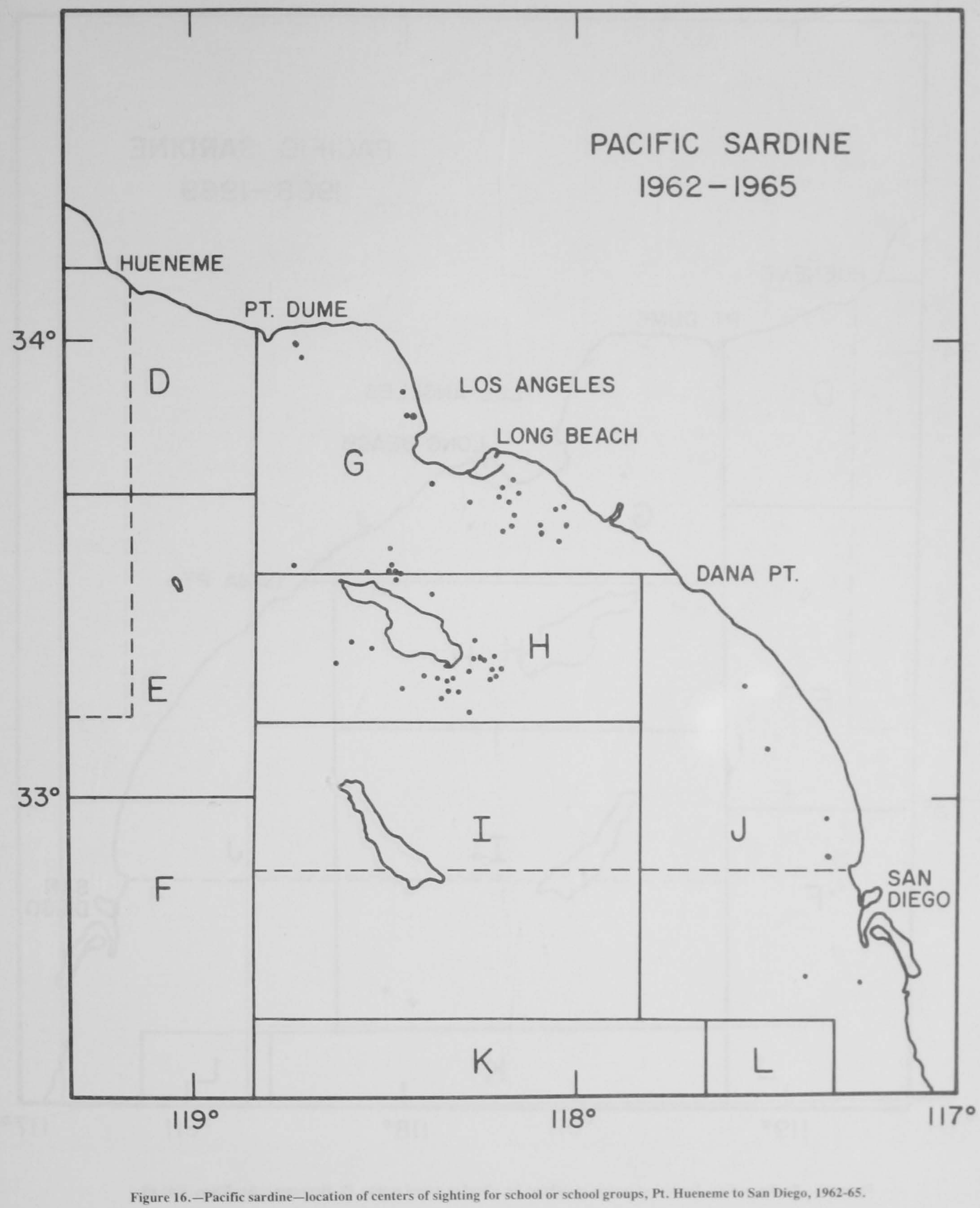

Figure 16.—Pacific sardine—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-65.

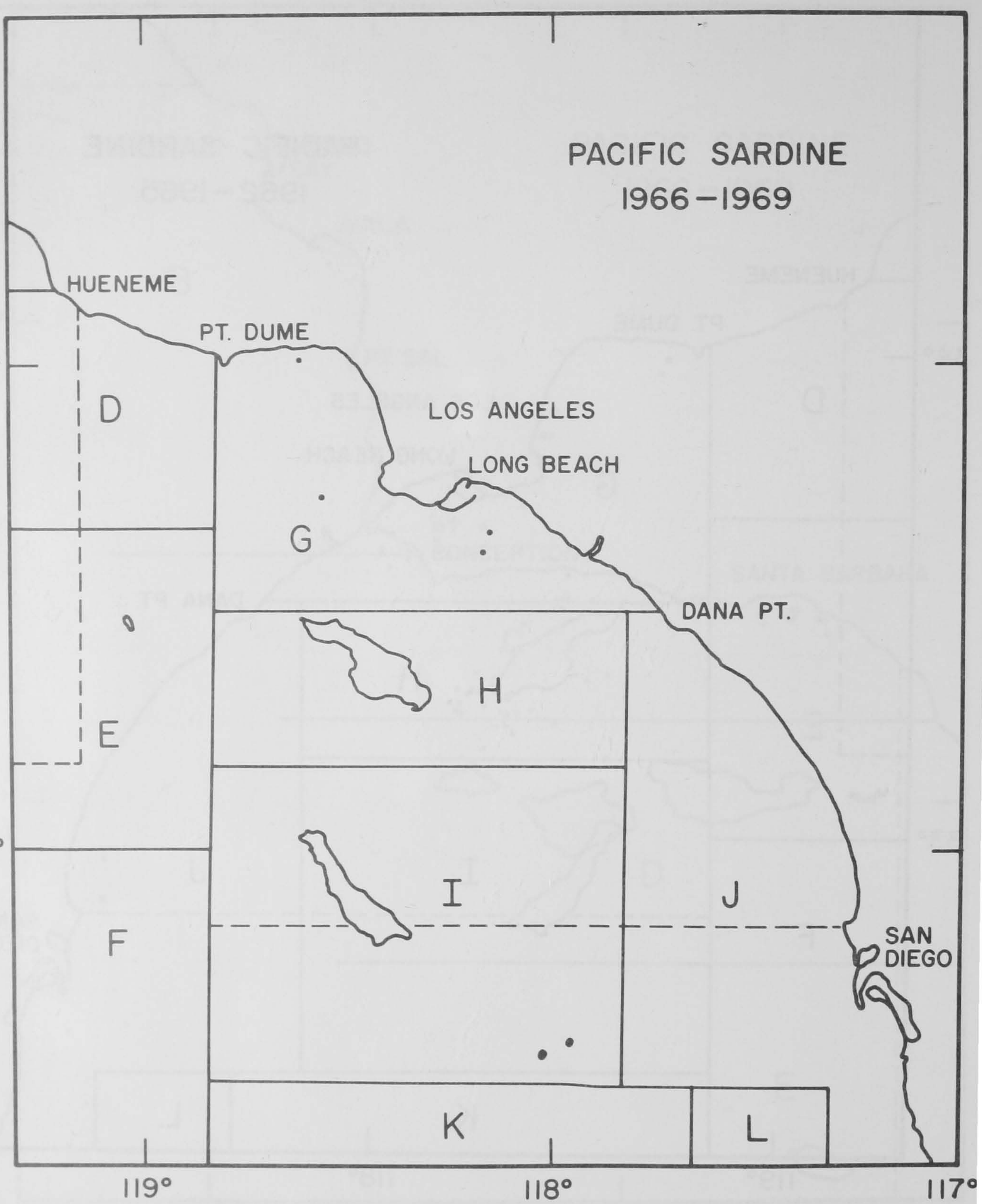

Figure 17.—Pacific sardine—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1966-69.

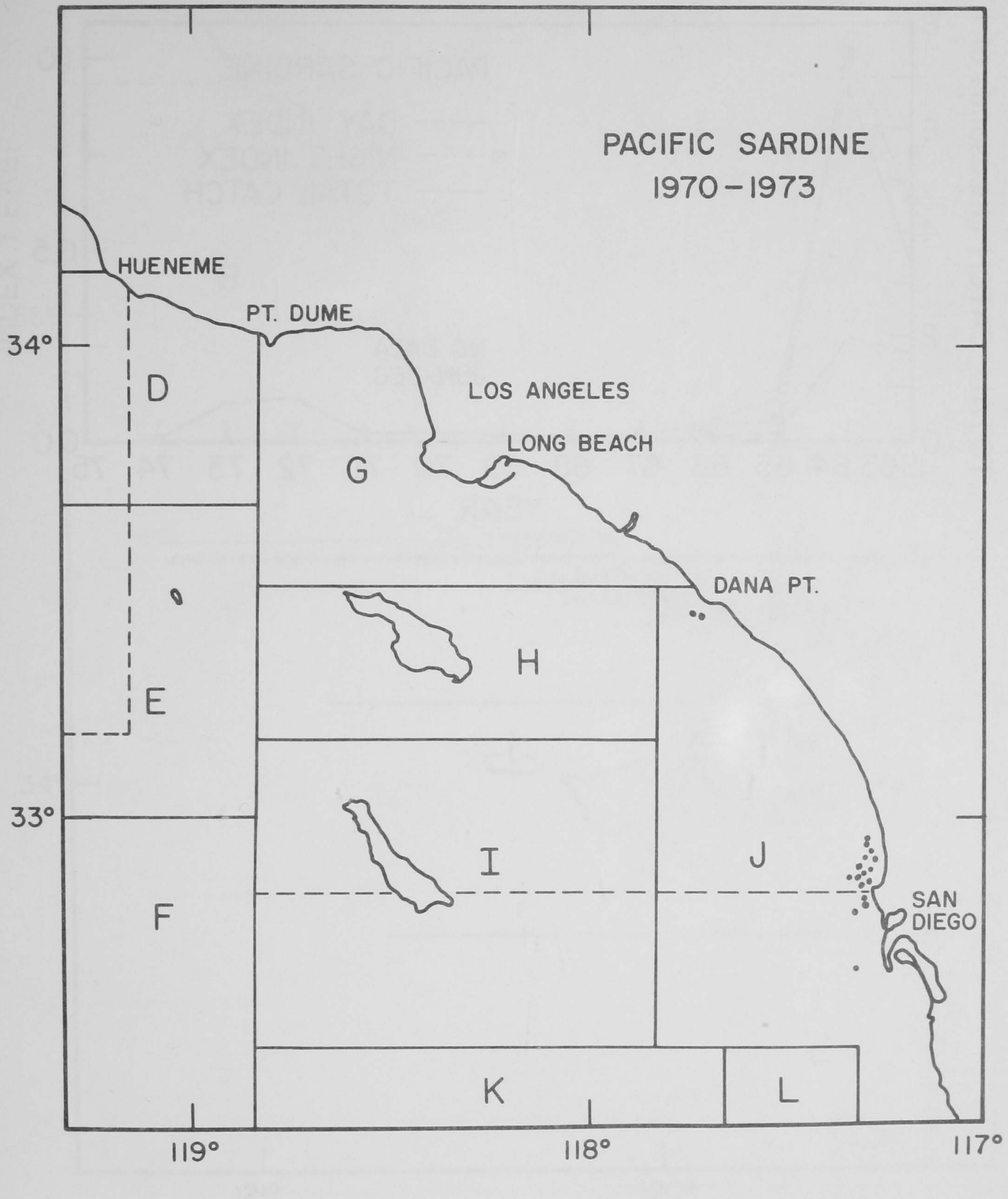

Figure 18.—Pacific sardine—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1970-73.

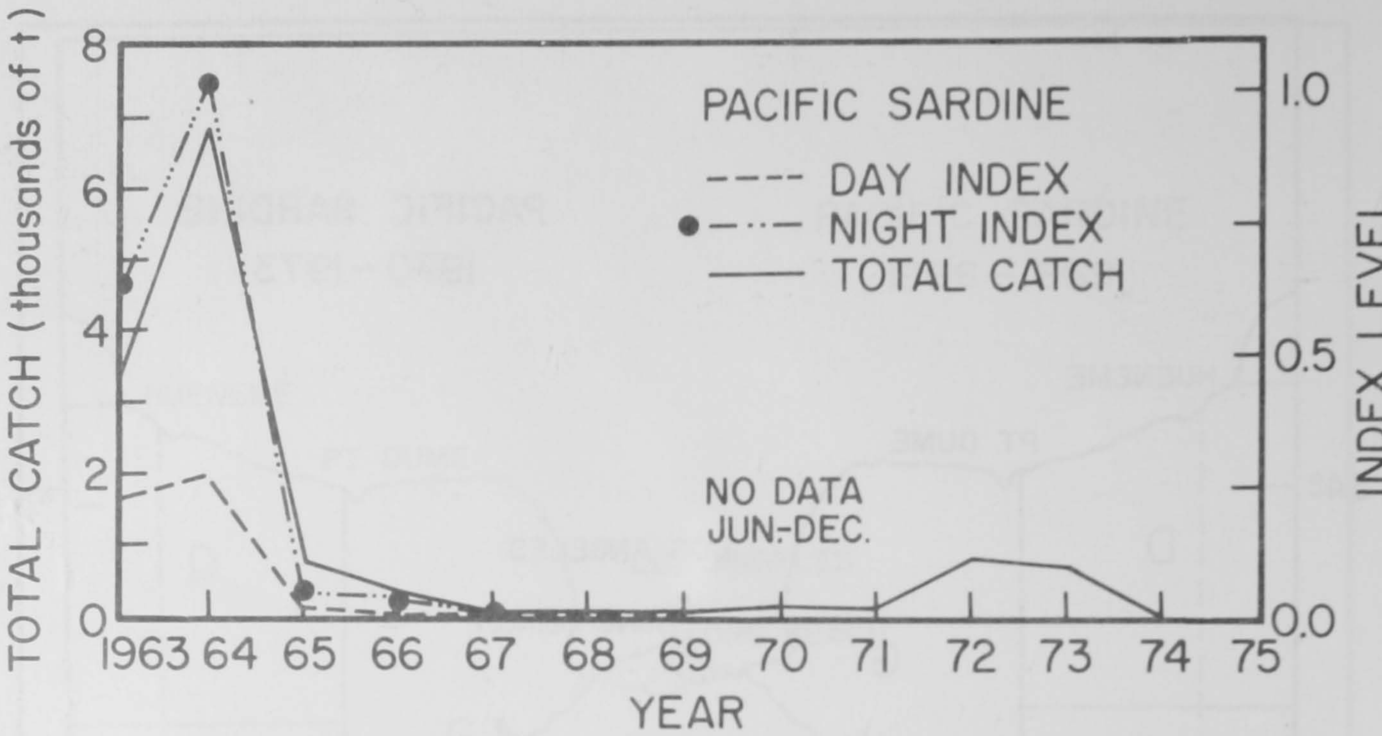

Figure 19.—Pacific sardine index values in arbitrary units for day and night observations and total California catch.

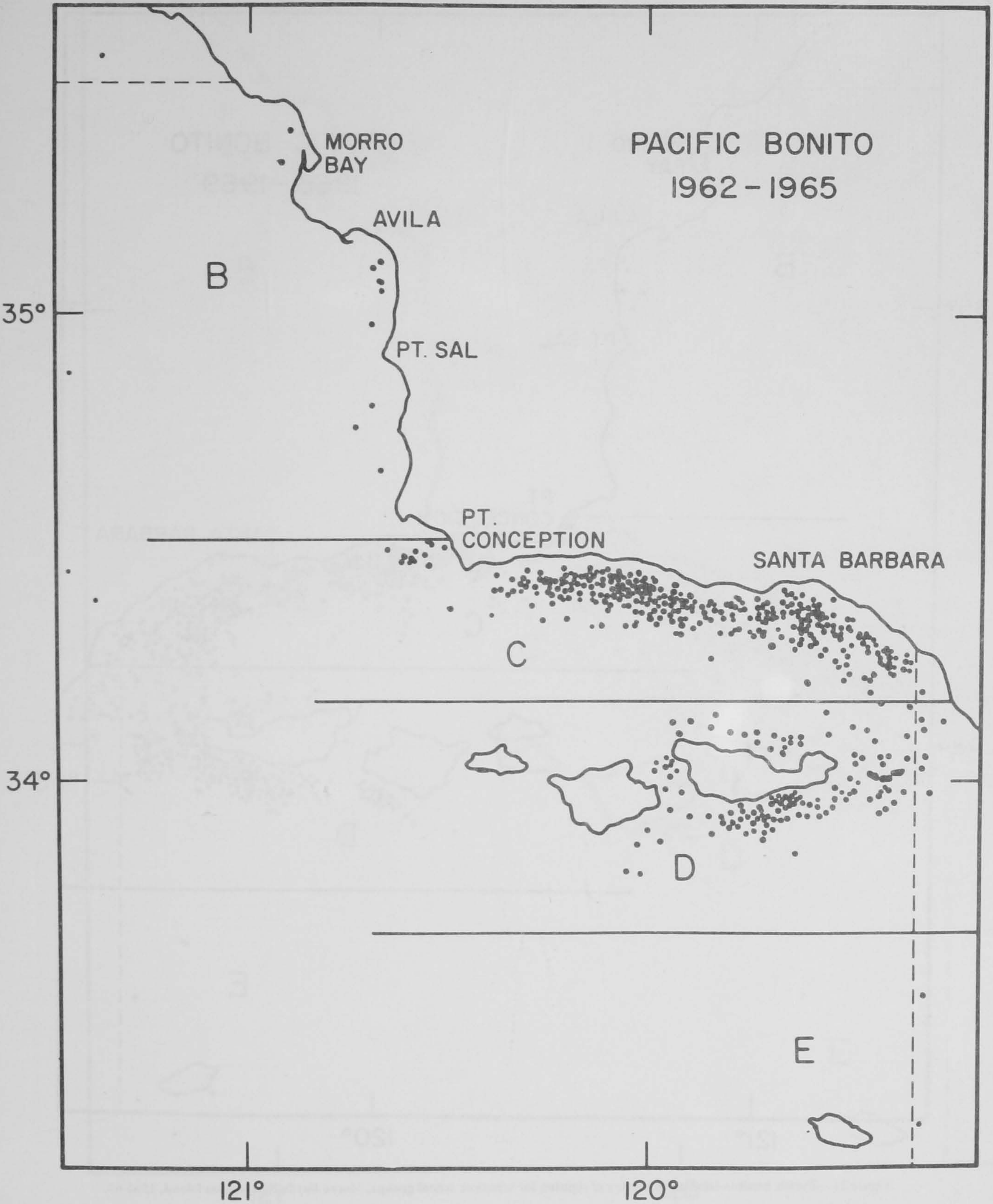

Figure 20.—Pacific bonito—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-65.

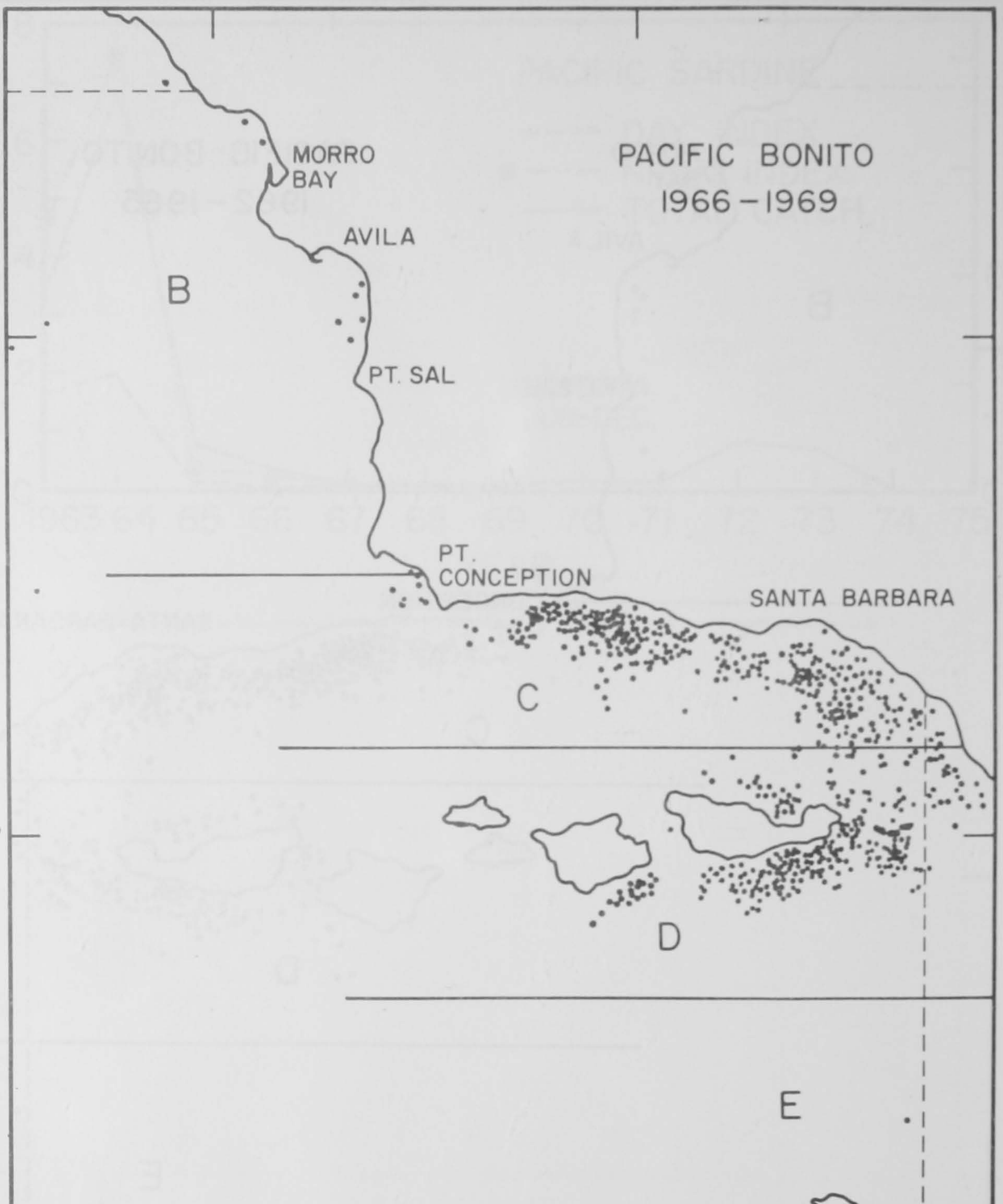

Figure 21.—Pacific bonito—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1966-69.

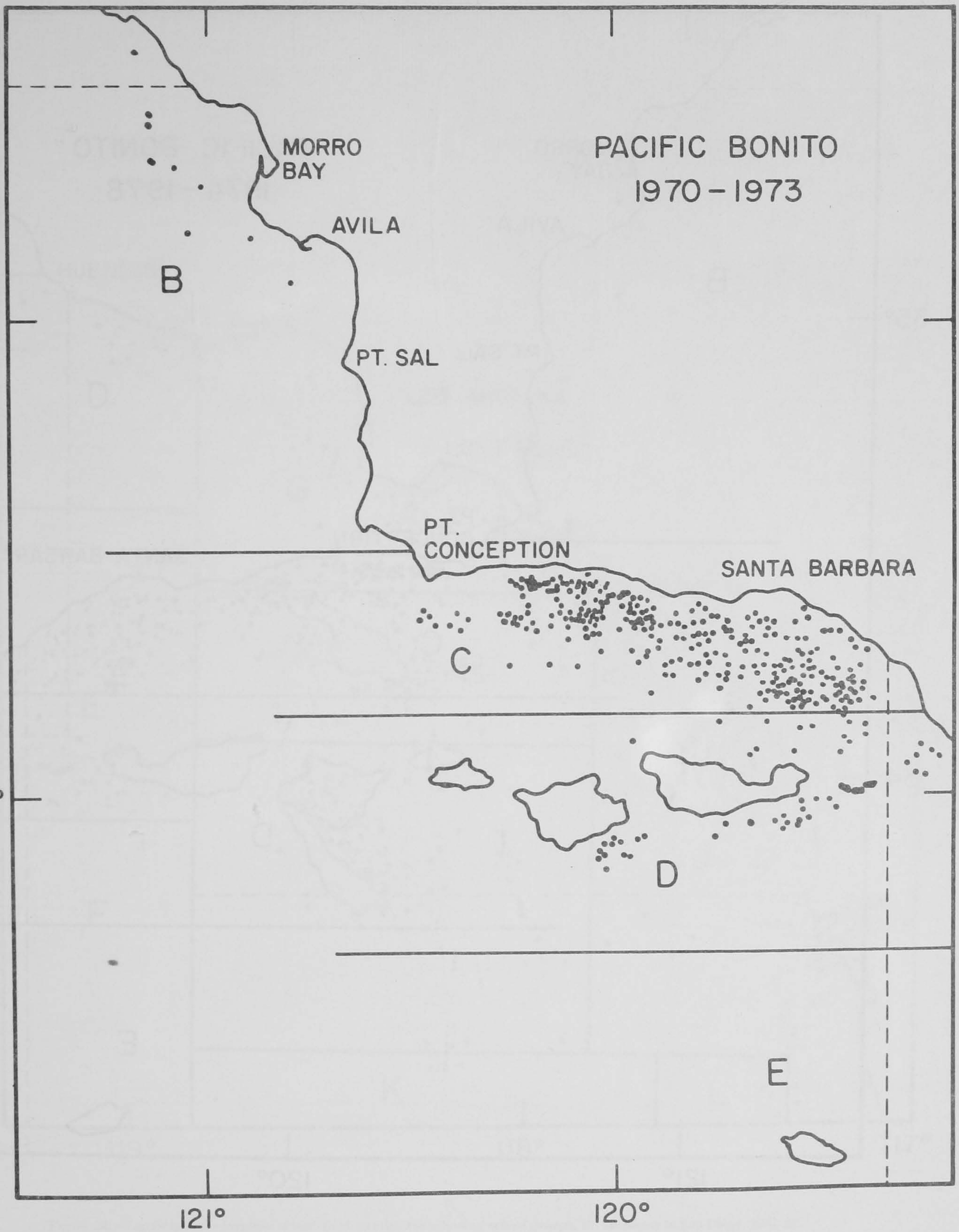

Figure 22.—Pacific bonito—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1970-73.

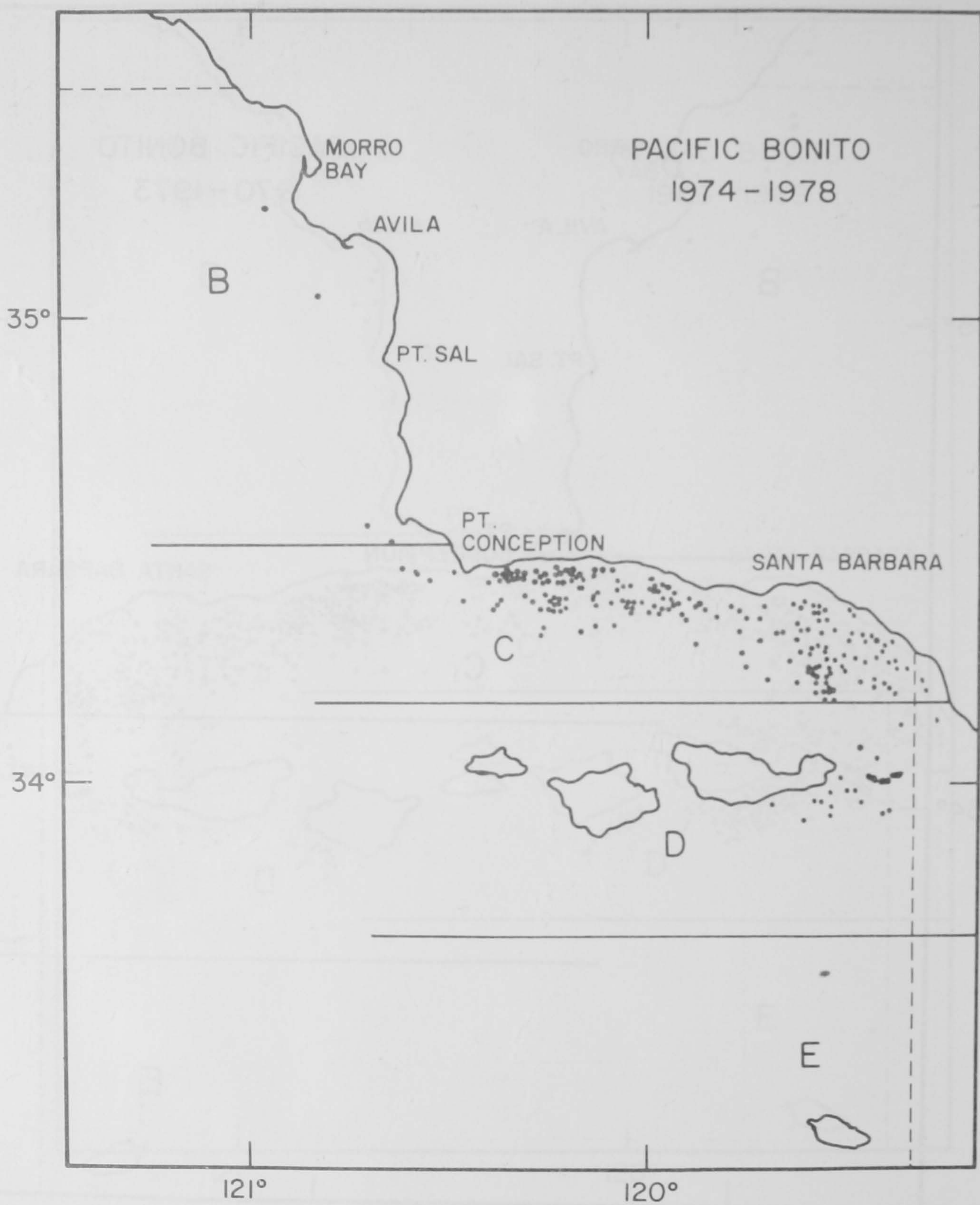

Figure 23.—Pacific bonito—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1974-78.

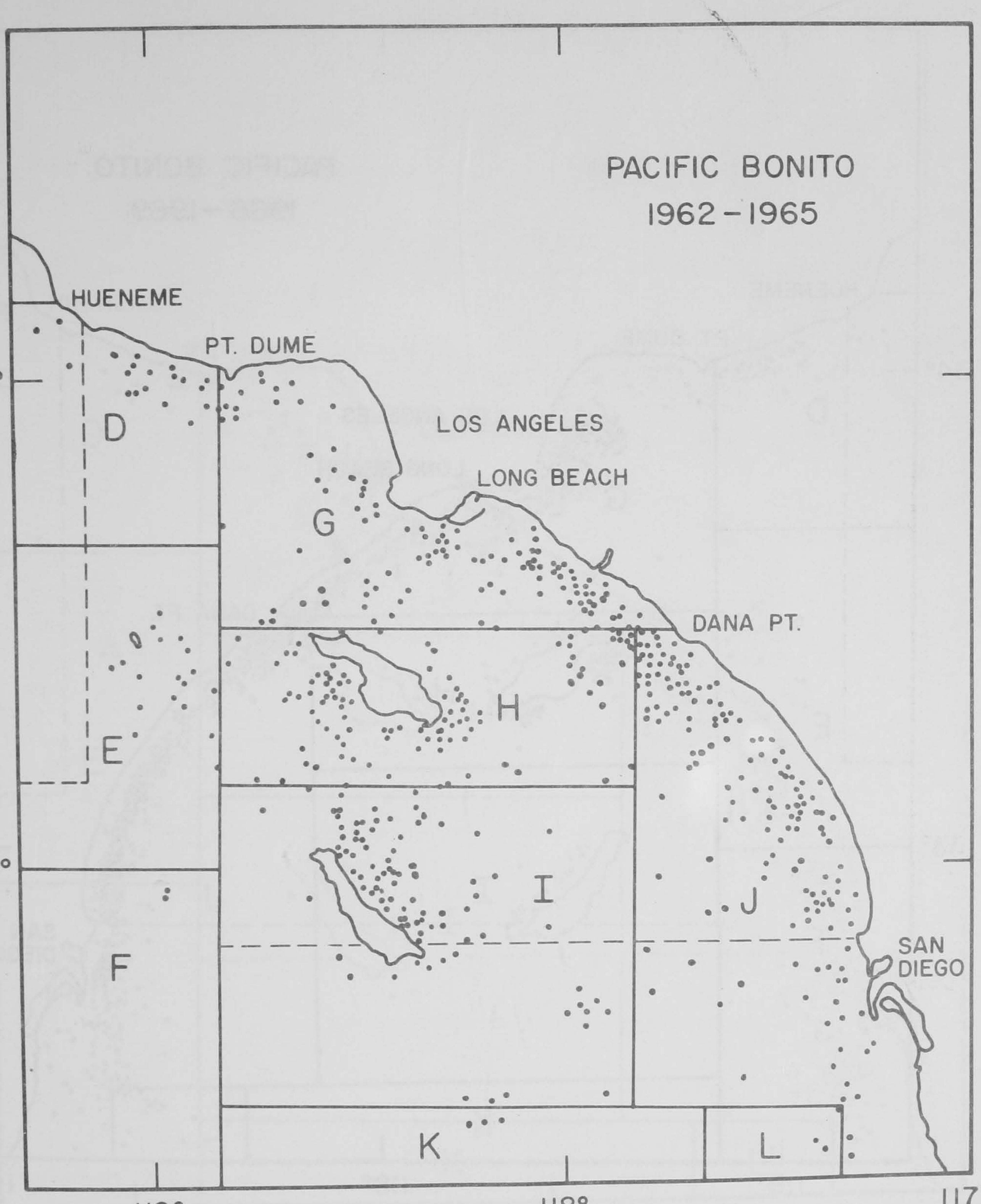

Figure 24.—Pacific bonito—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-65.

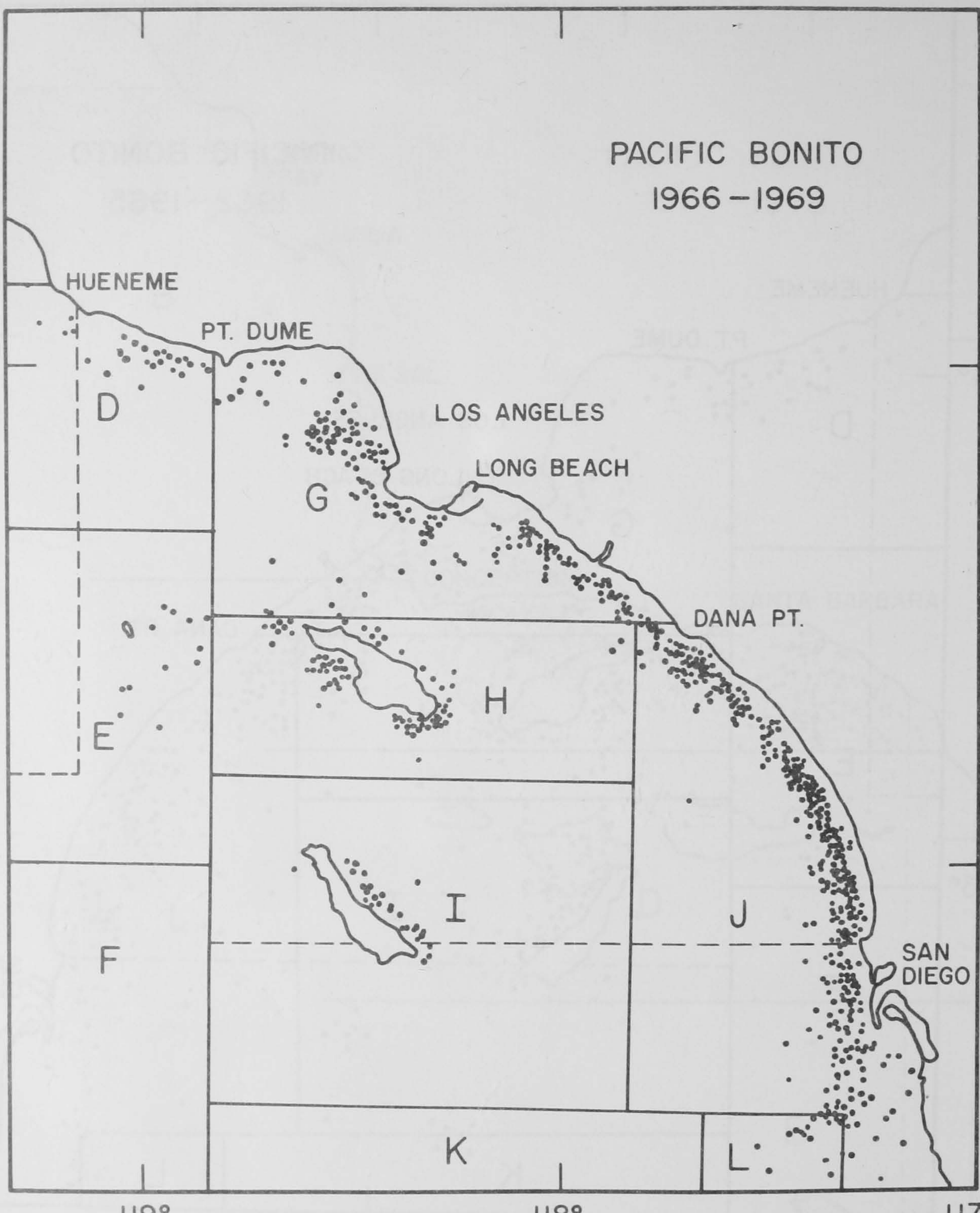

Figure 25.—Pacific bonito—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1966-69.

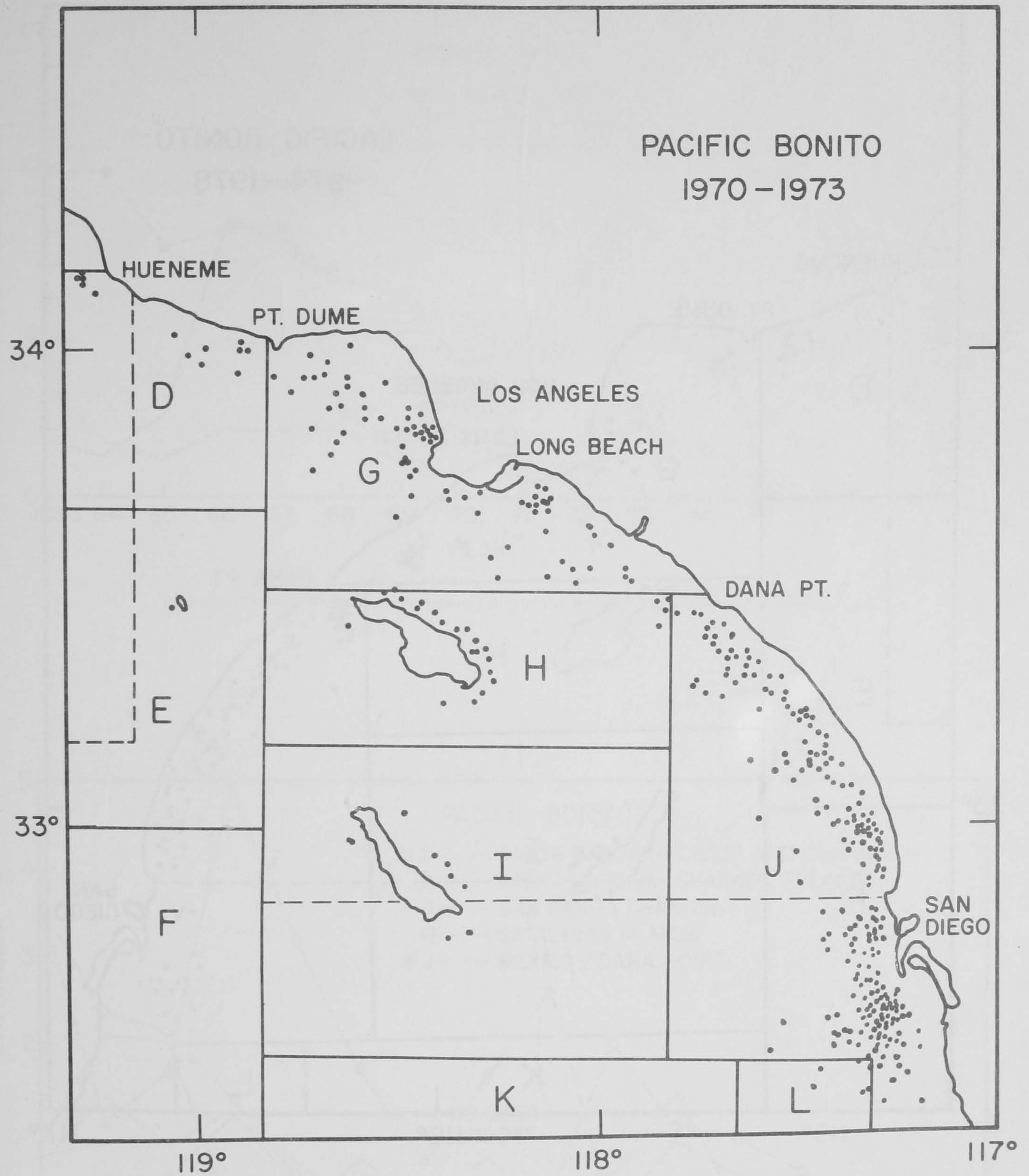

Figure 26.—Pacific bonito—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1970-73.

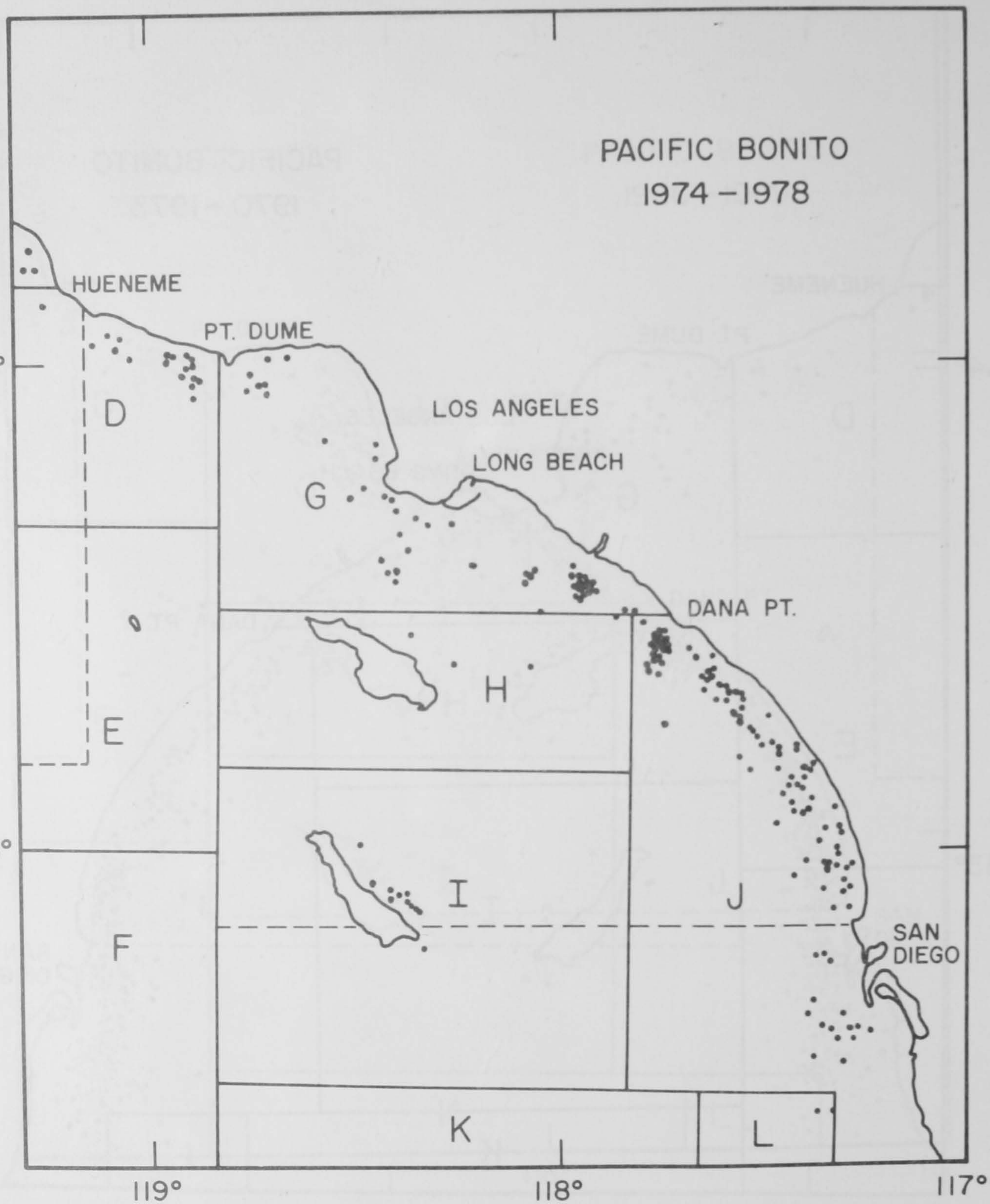

Figure 27.—Pacific bonito—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1974-78.

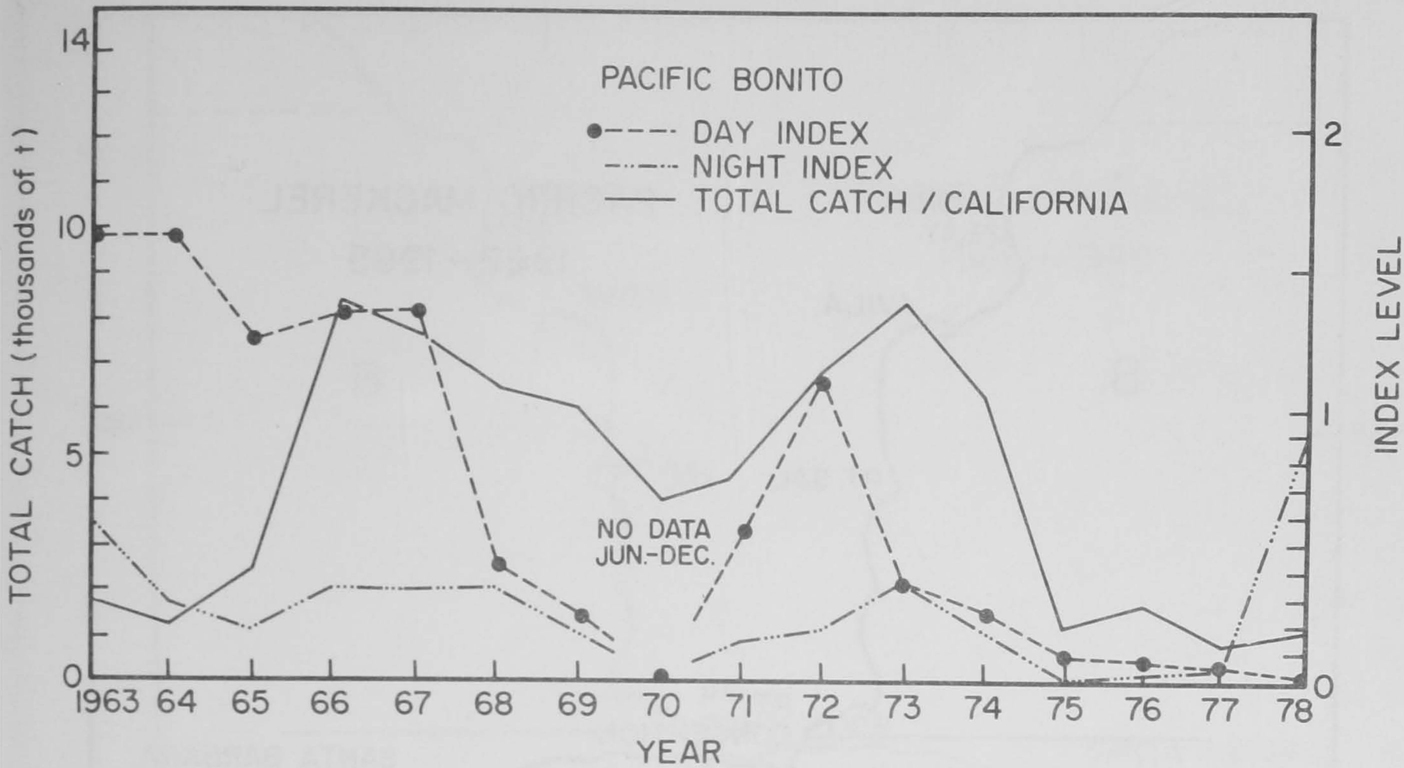

Figure 28.—Pacific bonito index values in arbitrary units for day and night observations and total California catch.

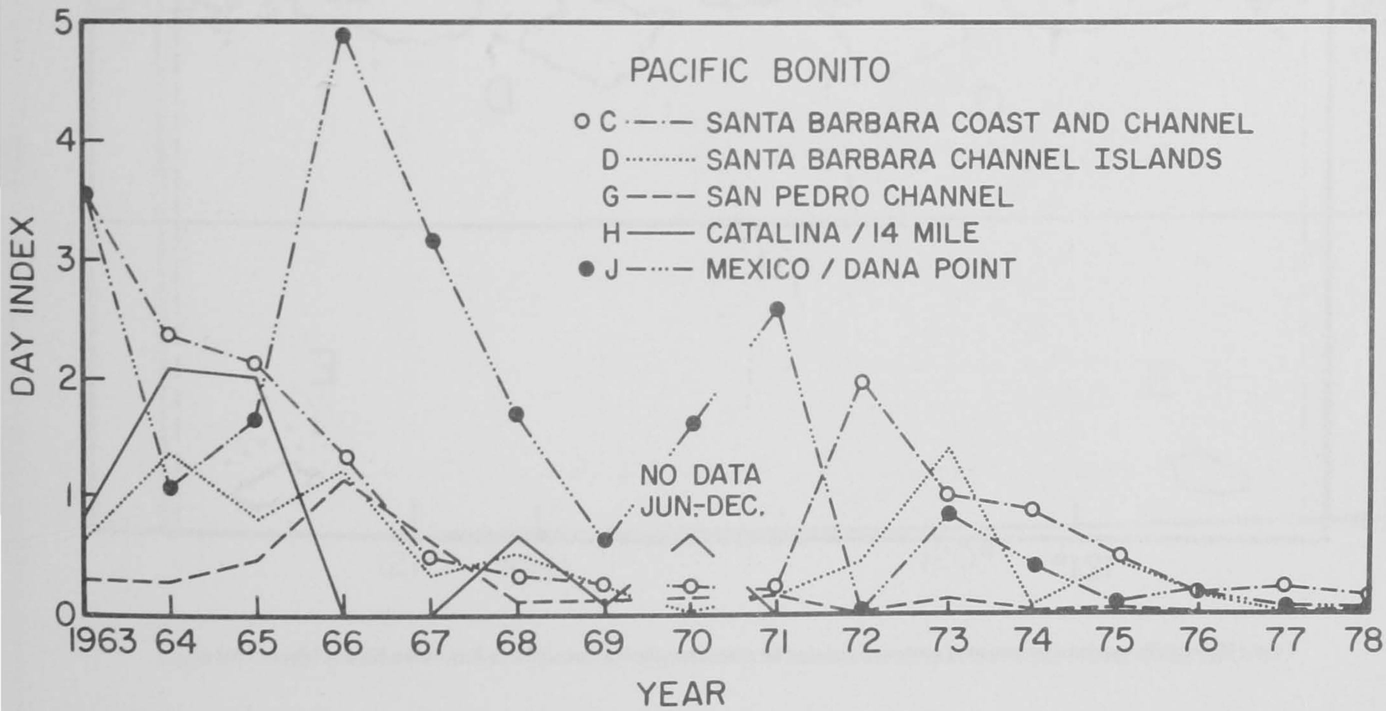

Figure 29.—Pacific bonito day index values in arbitrary units for the major fishing areas.

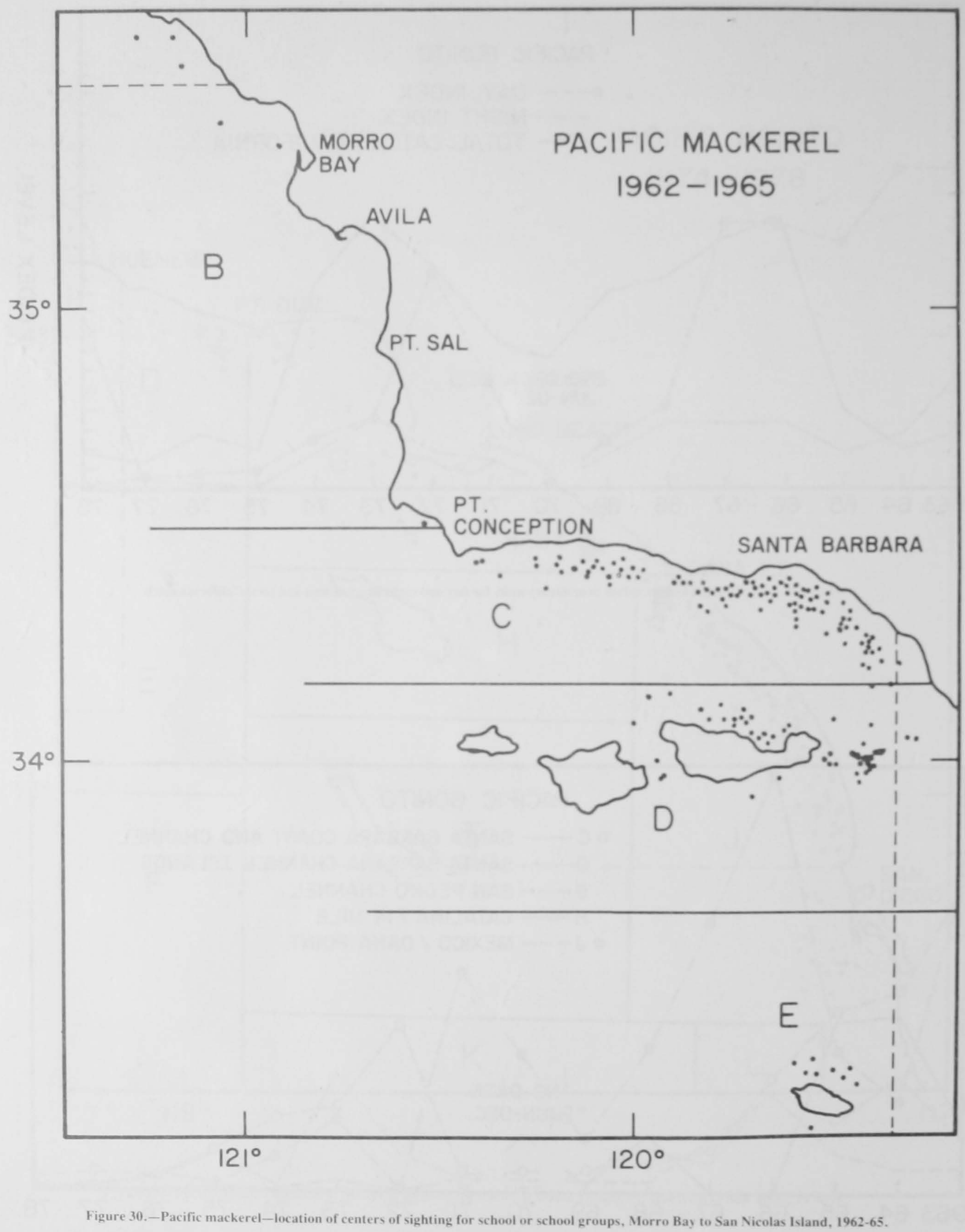

Figure 30.—Pacific mackerel—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-65.

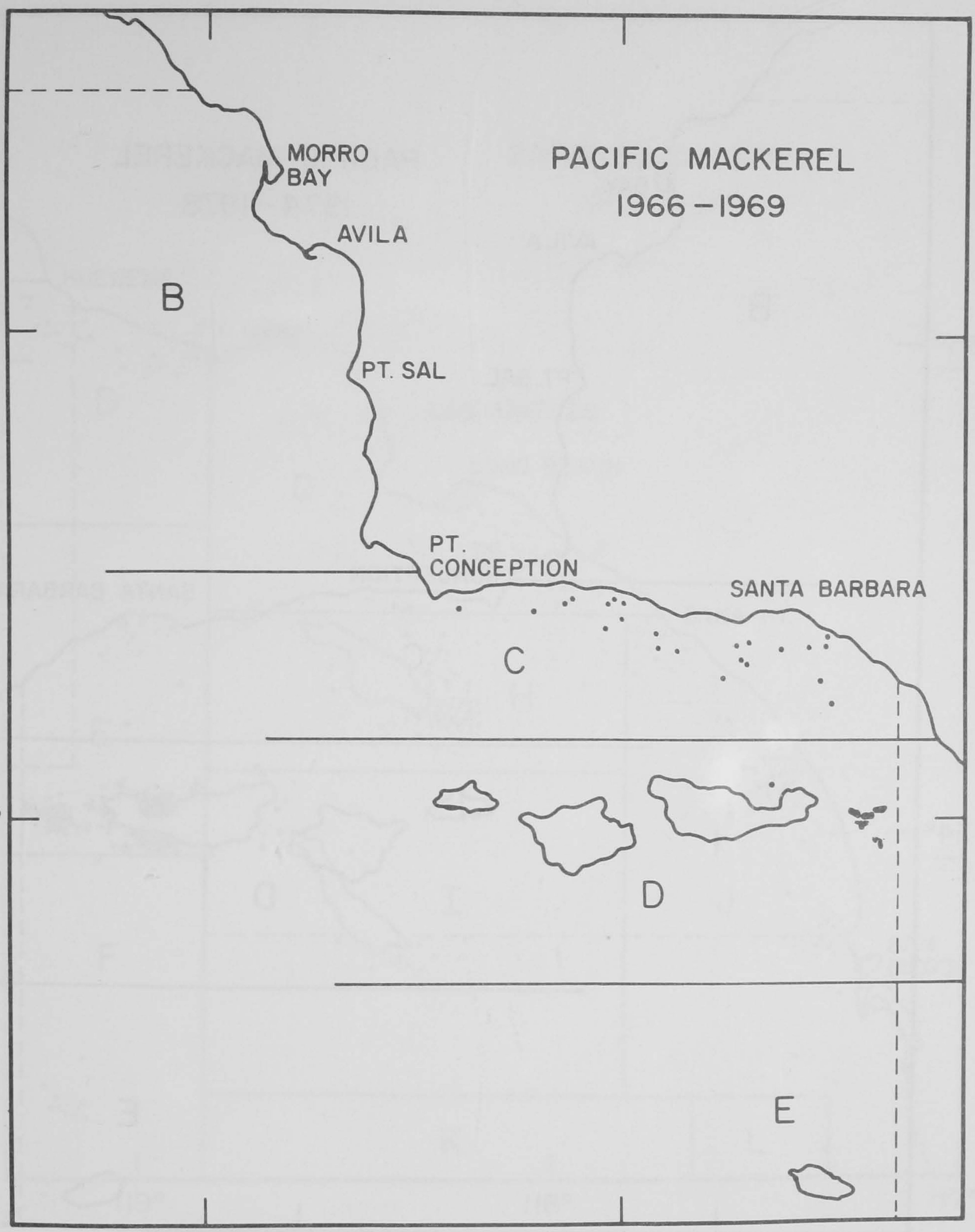

Figure 31.—Pacific mackerel—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1966-69.

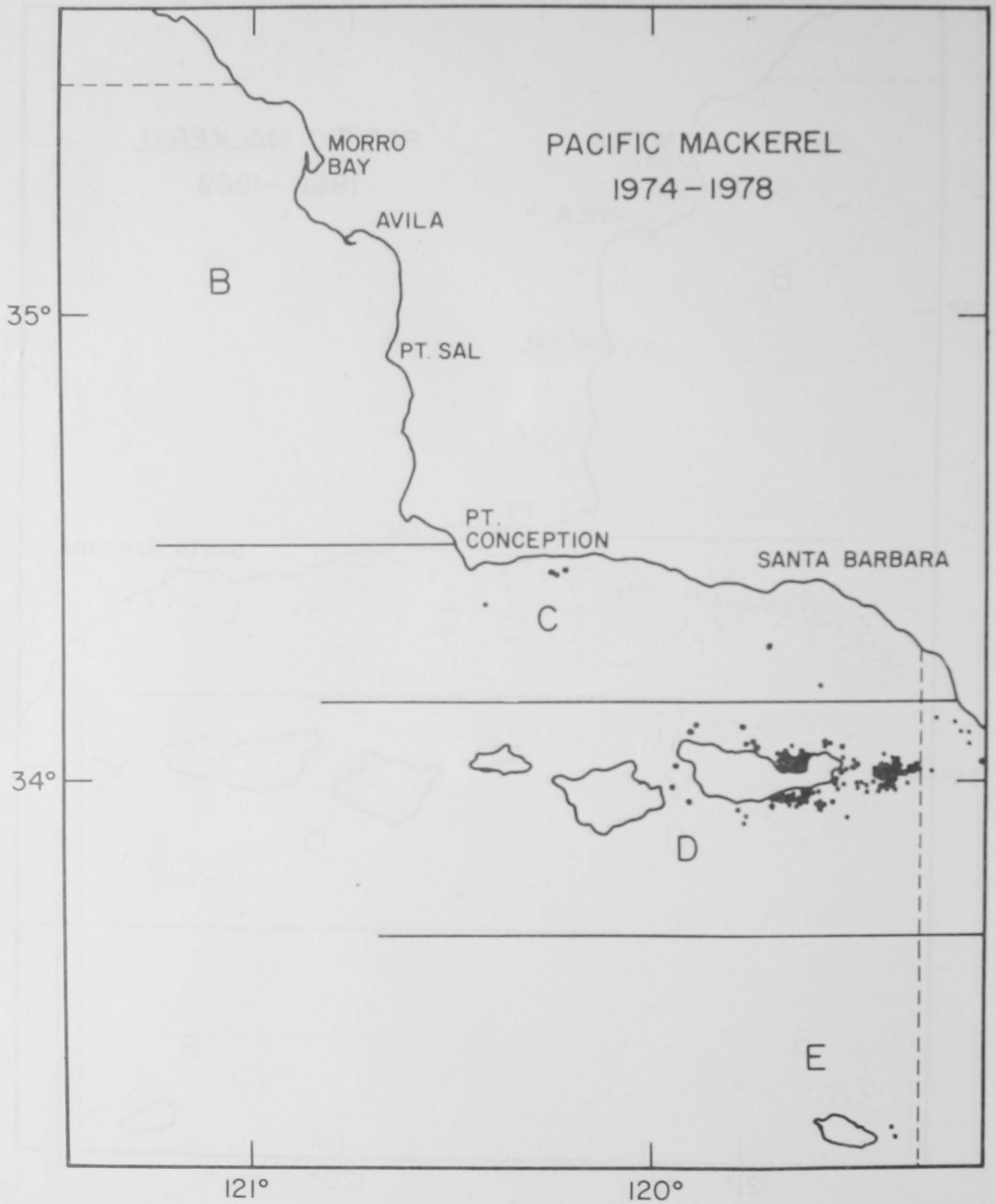

Figure 32.—Pacific mackerel—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1974-78.

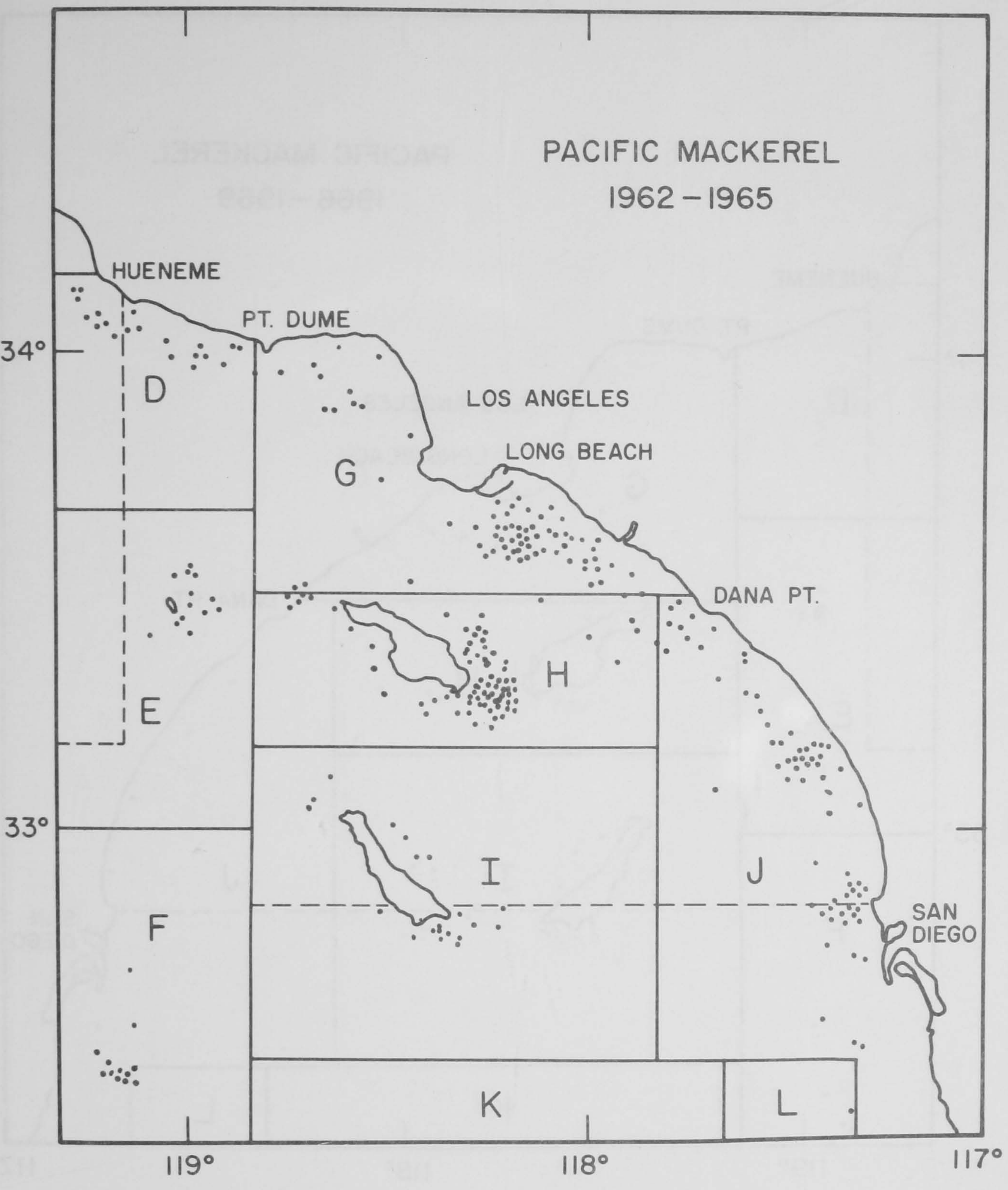

Figure 33.—Pacific mackerel—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-65.

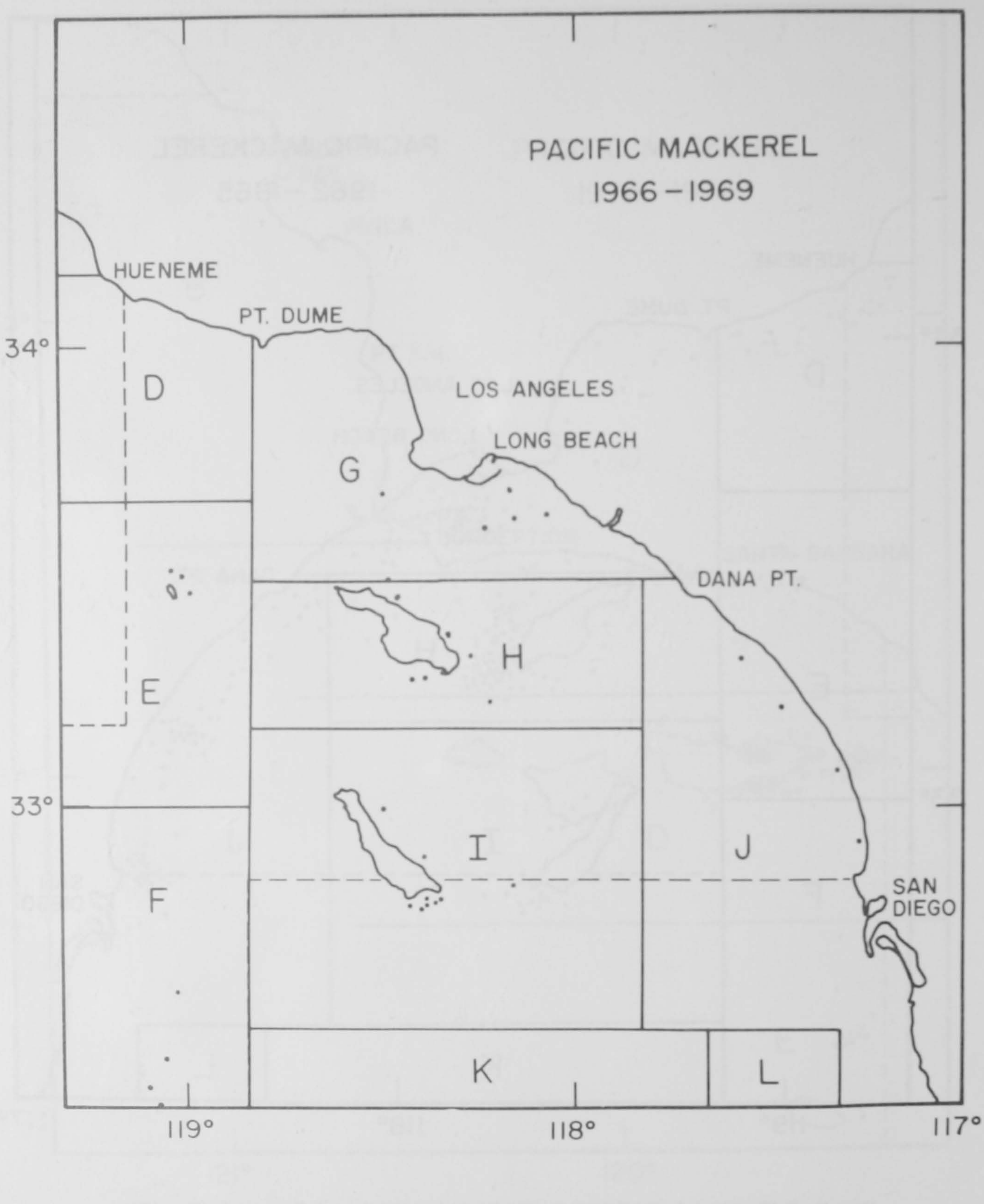

Figure 34.—Pacific mackerel—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1966-69.

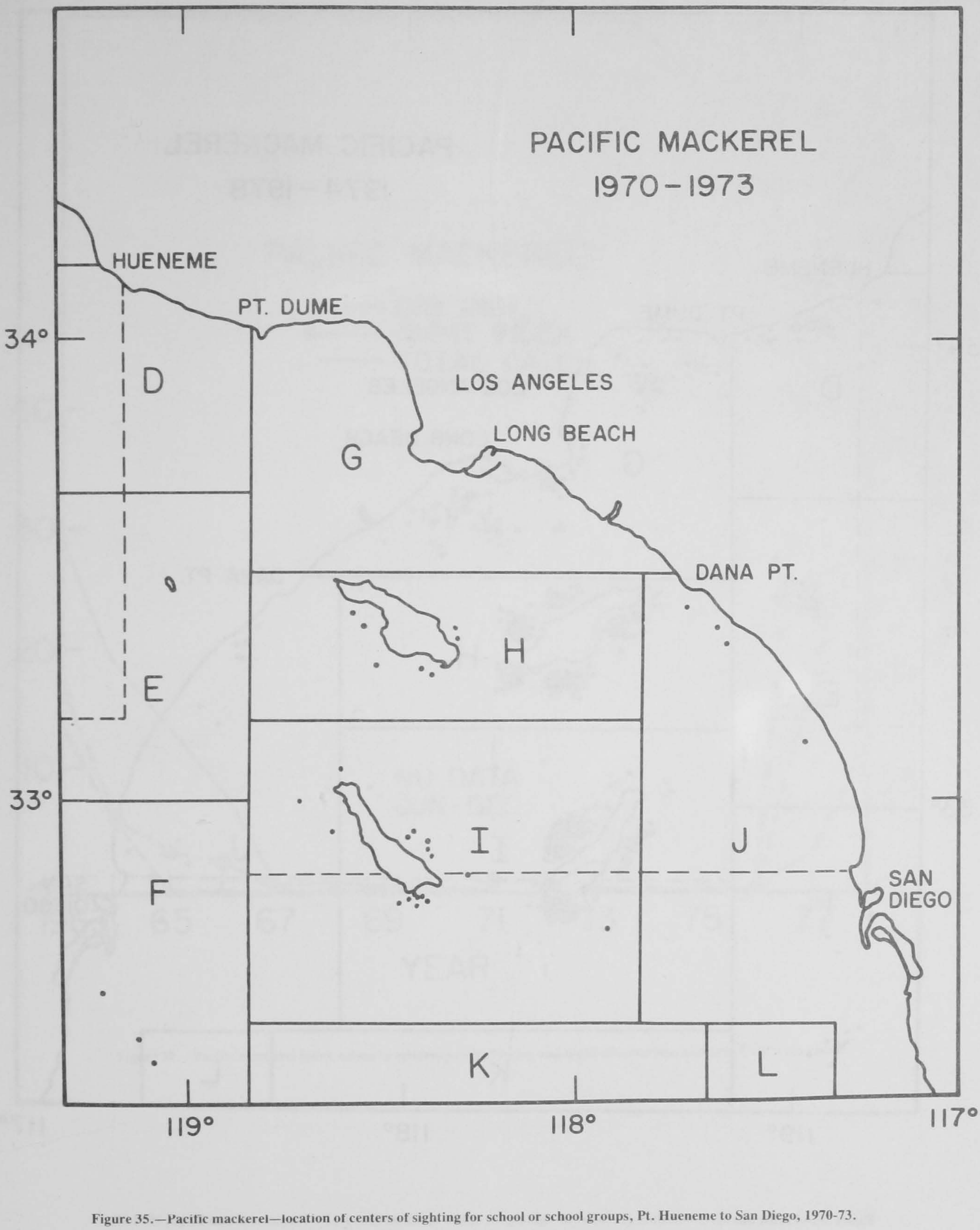

Figure 35.—Pacific mackerel—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1970-73.

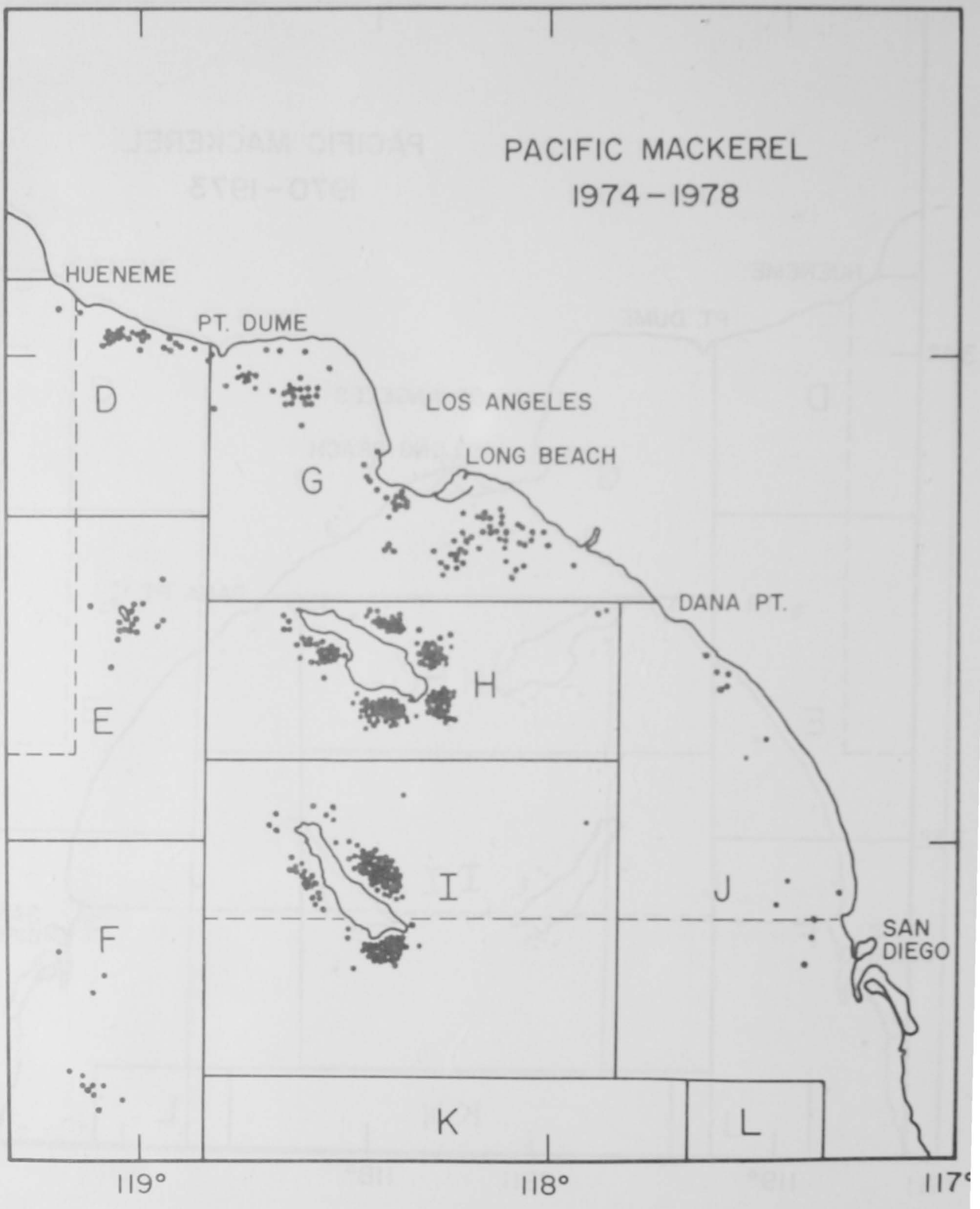

Figure 36.—Pacific mackerel—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1974-78.

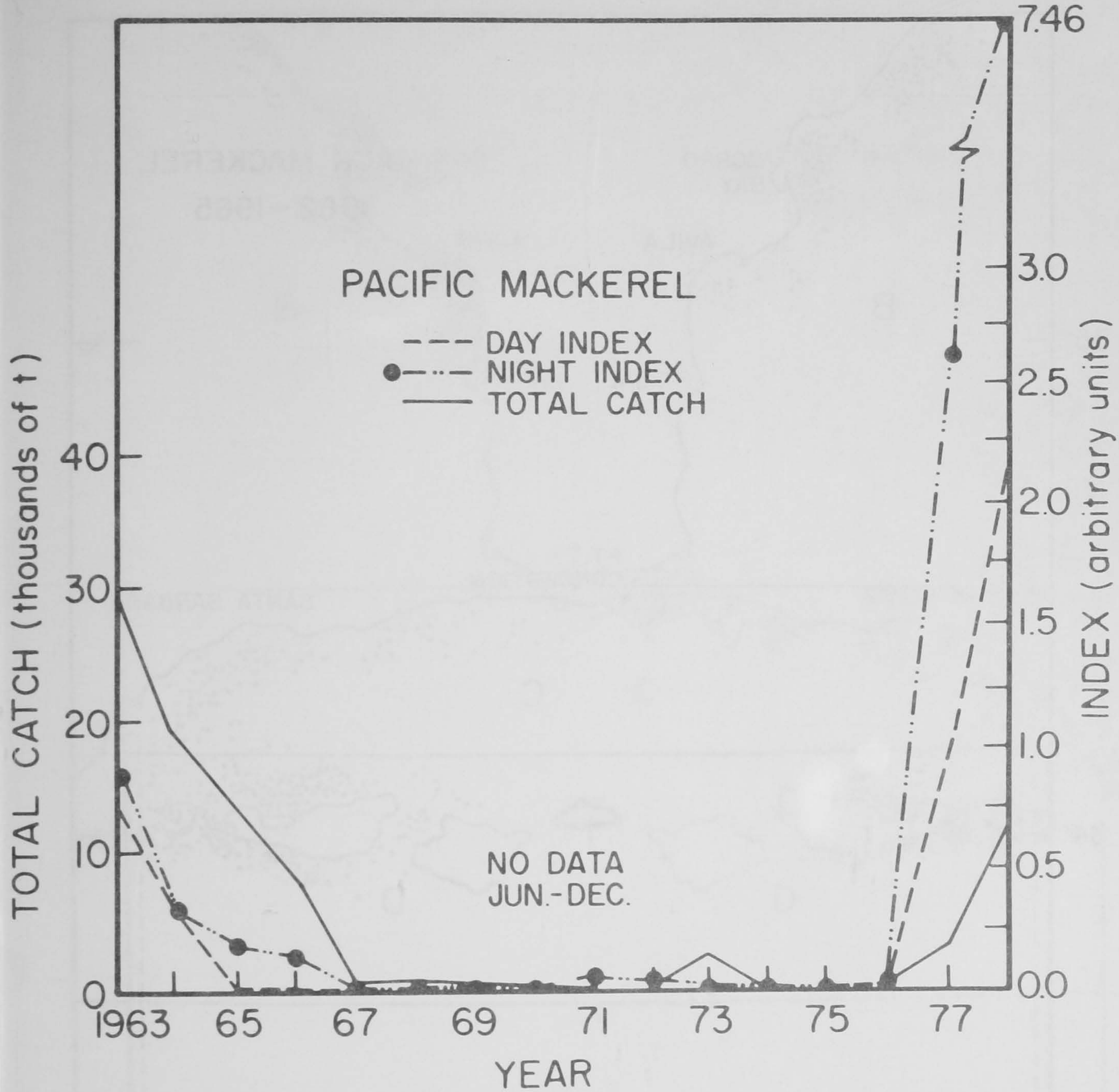

Figure 37.—Pacific mackerel index values in arbitrary units for day and night observations and total California catch.

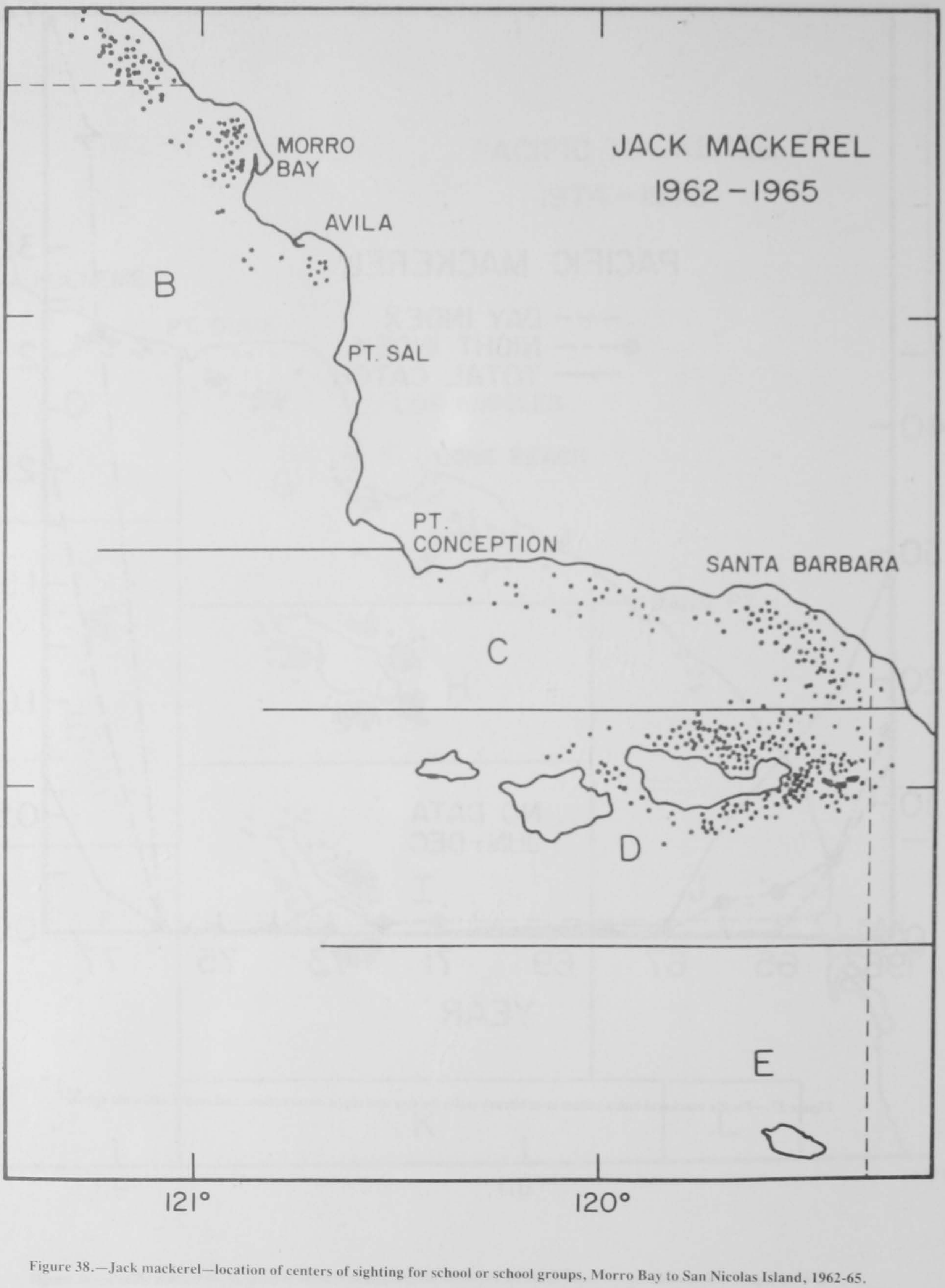

Figure 38.—Jack mackerel—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-65.

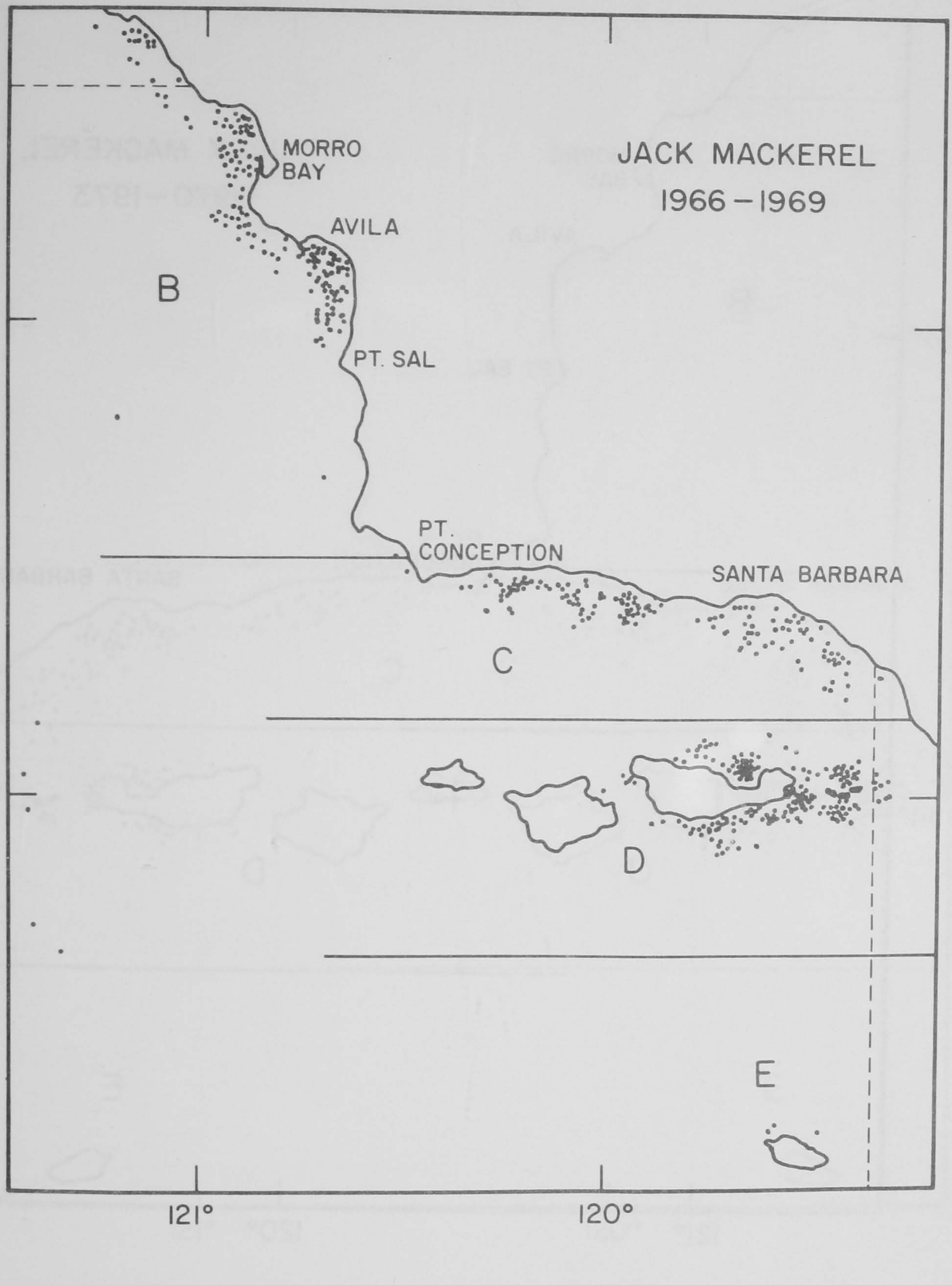

Figure 39.—Jack mackerel—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1966-69.

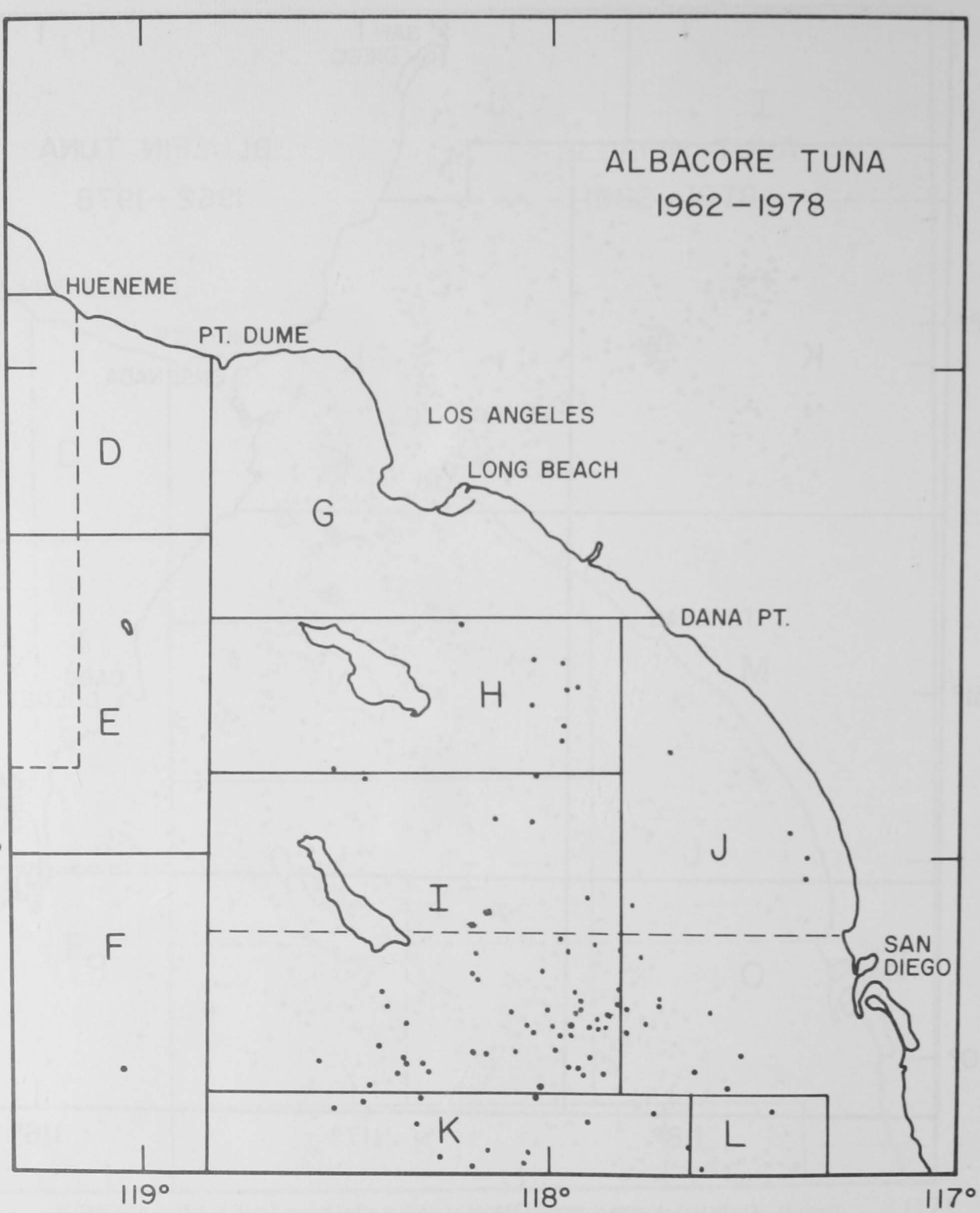

Figure 50.—Albacore tuna—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-78.

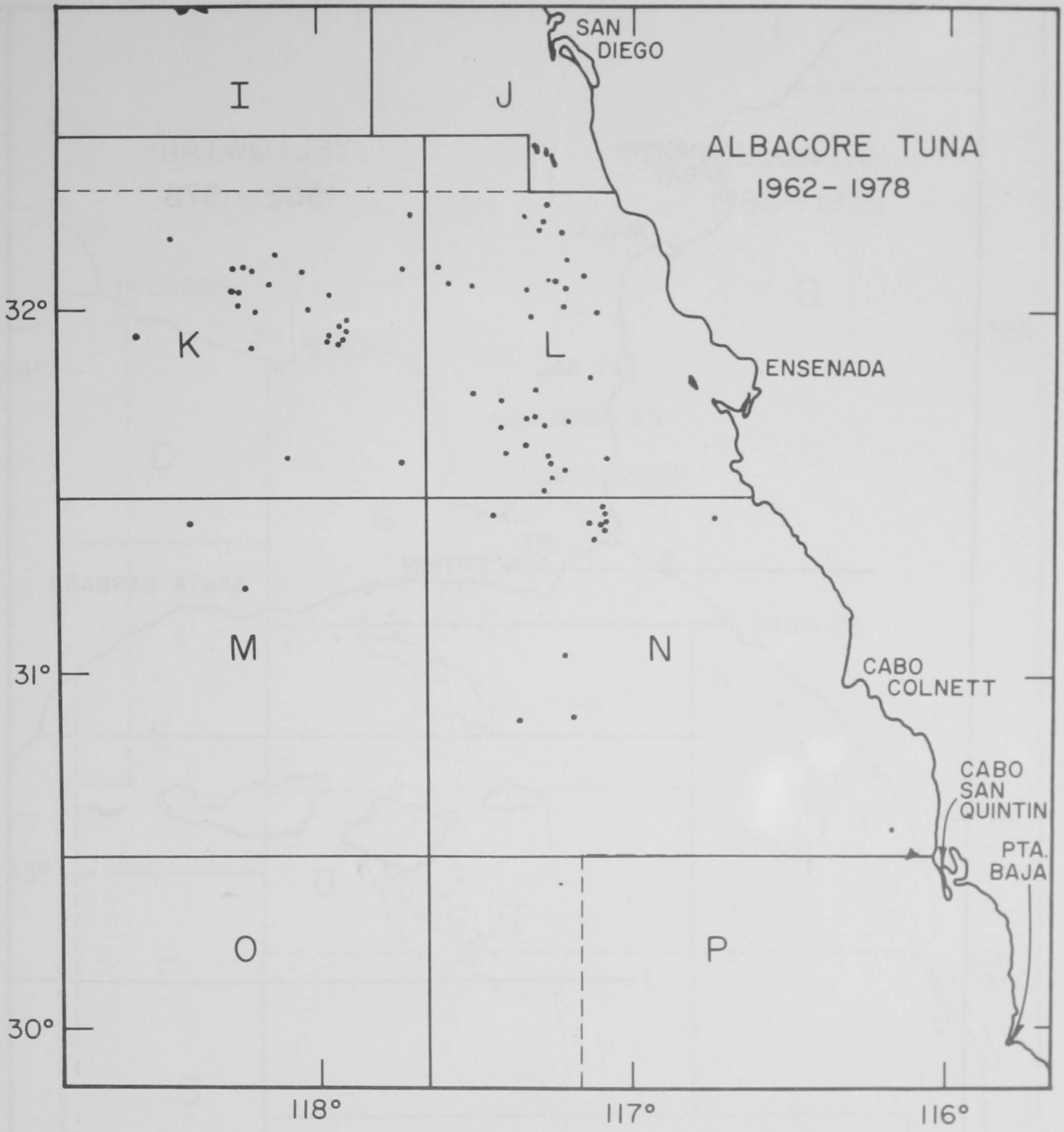

Figure 51.—Albacore tuna—location of centers of sighting for school or school groups, San Diego to Punta Baja, 1962-78.

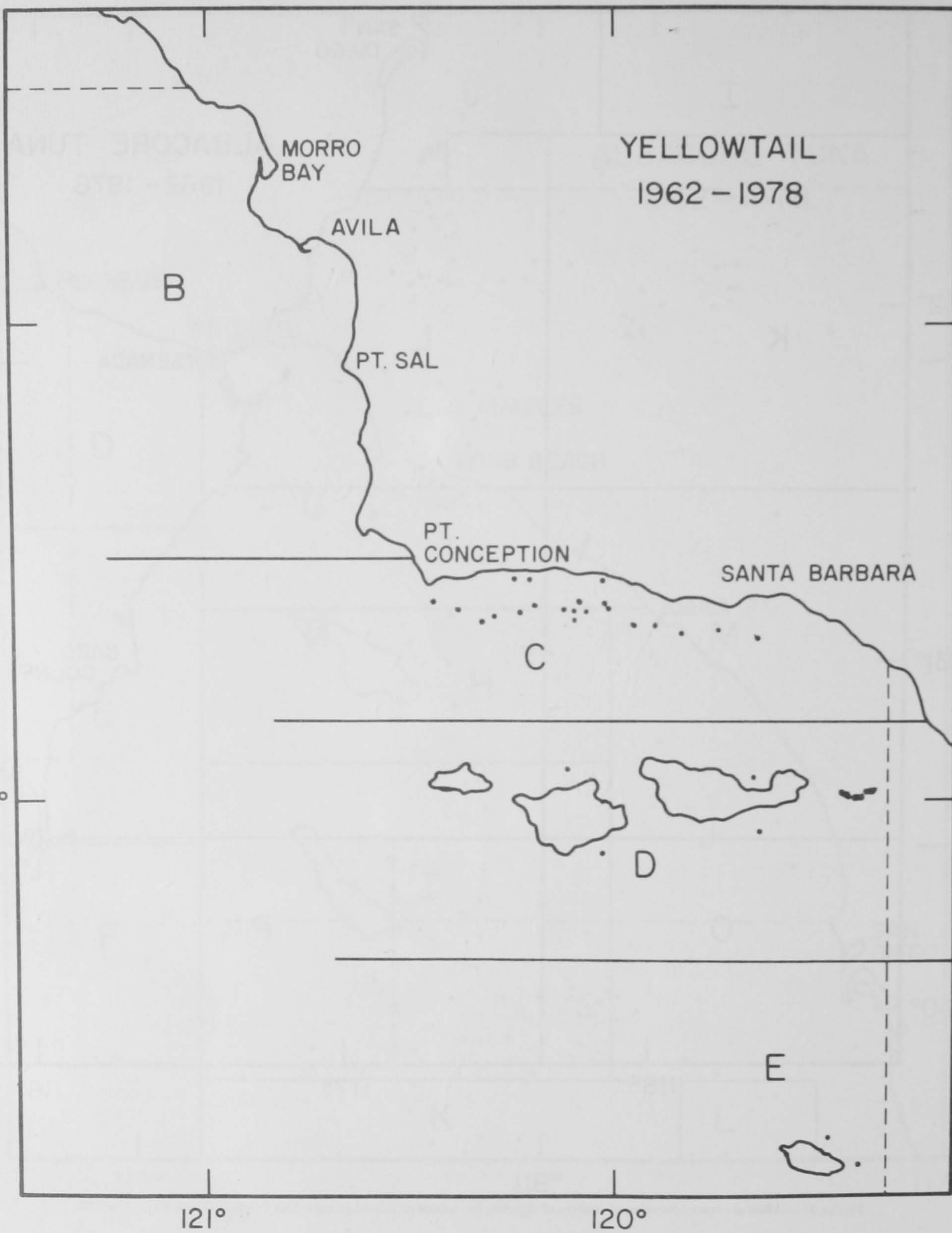

Figure 52.—Yellowtail—locations of school or school group sightings, Morro Bay to San Nicolas Island, 1962-78.

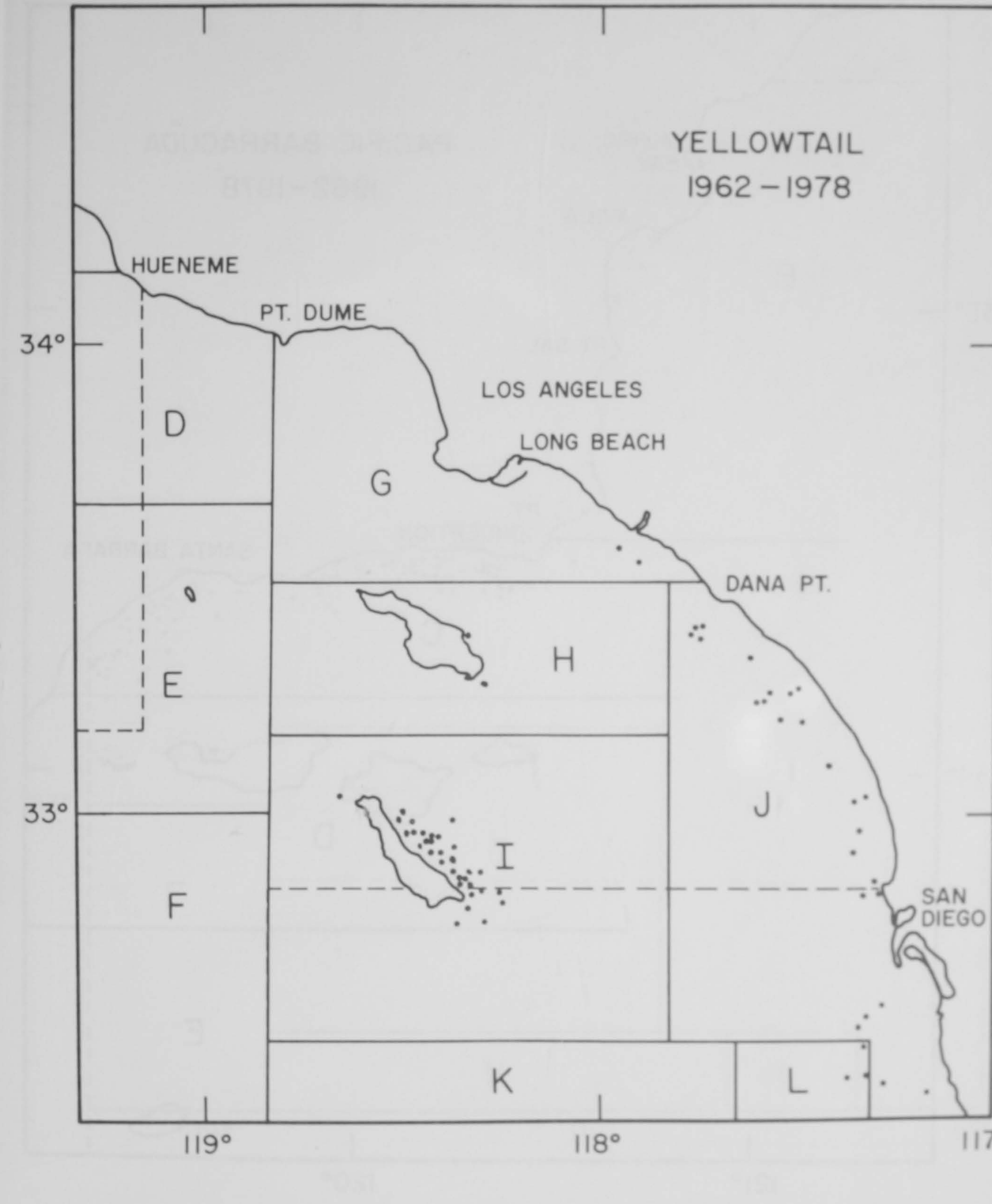

Figure 53.—Yellowtail—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-78.

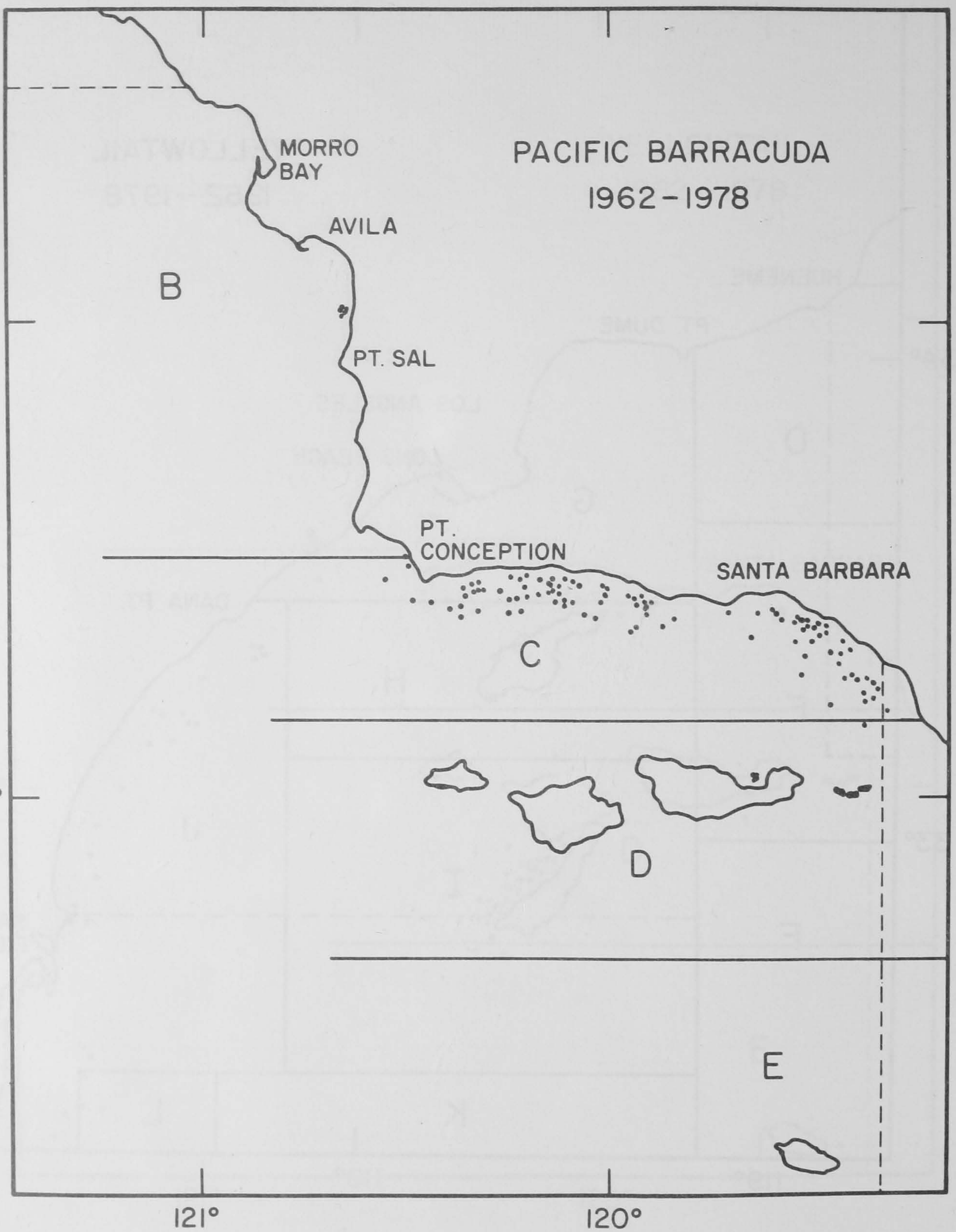

Figure 54.—Pacific barracuda—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-78.

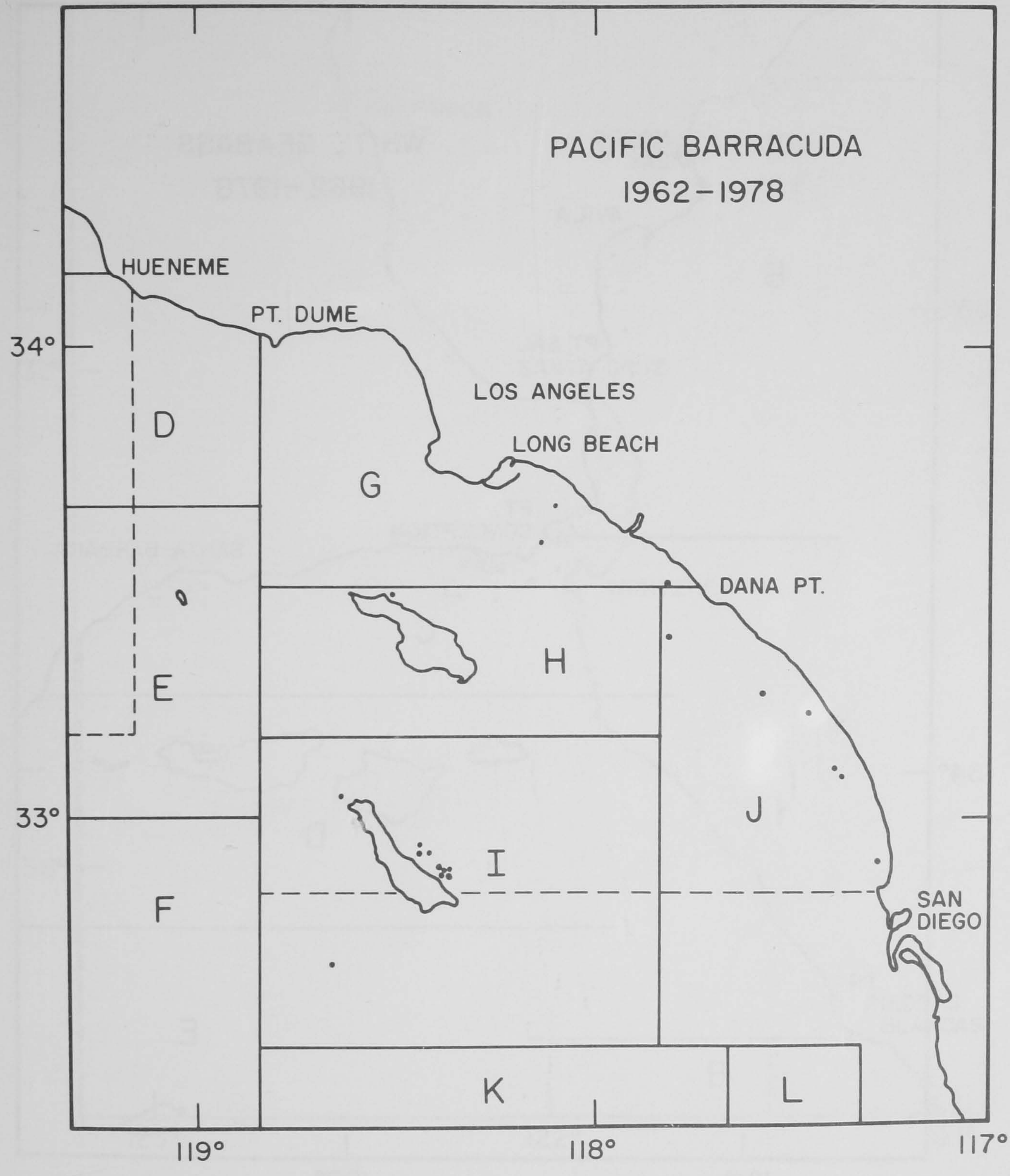

Figure 55.—Pacific barracuda—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-78.

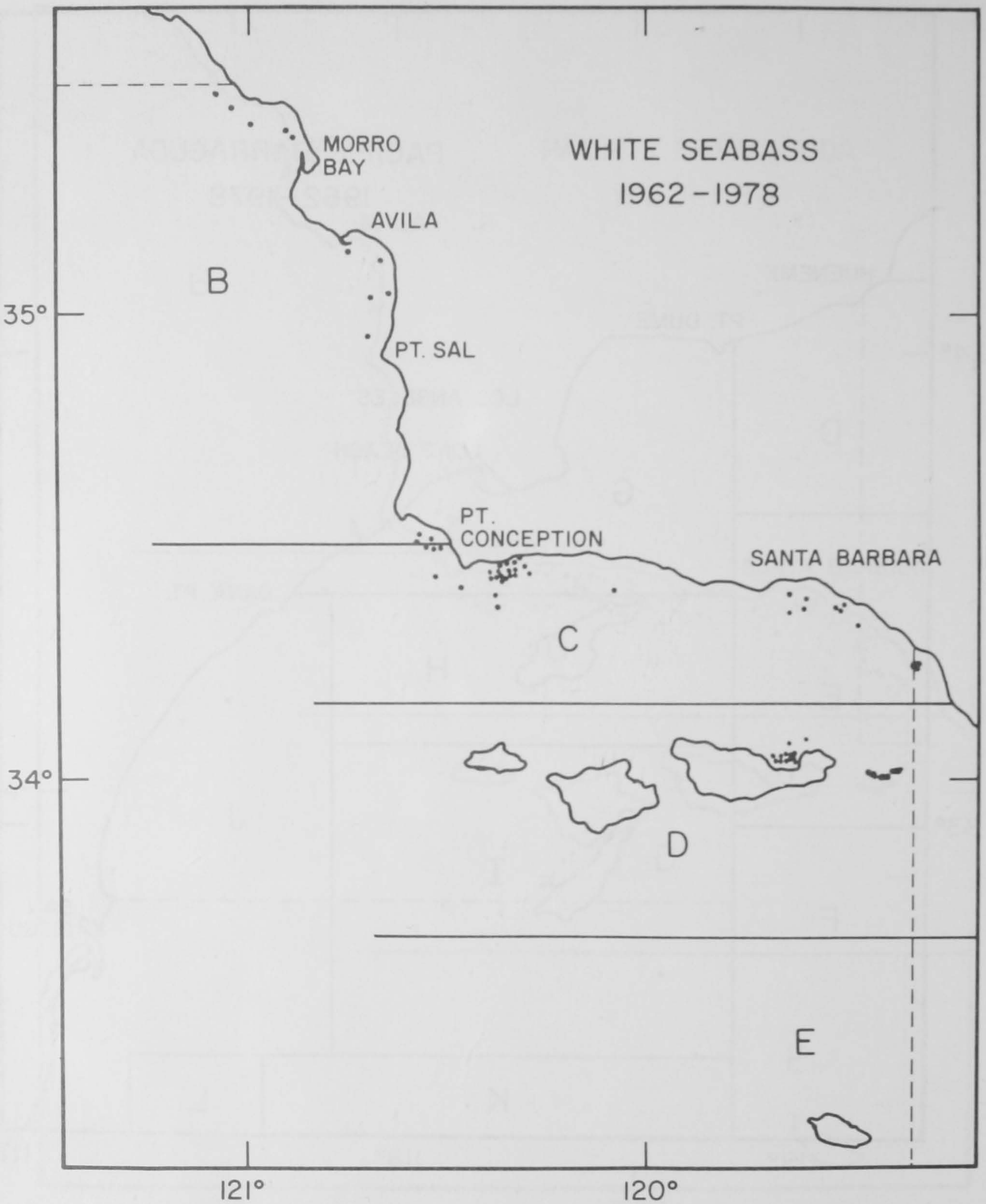

Figure 56.—White seabass—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-78.

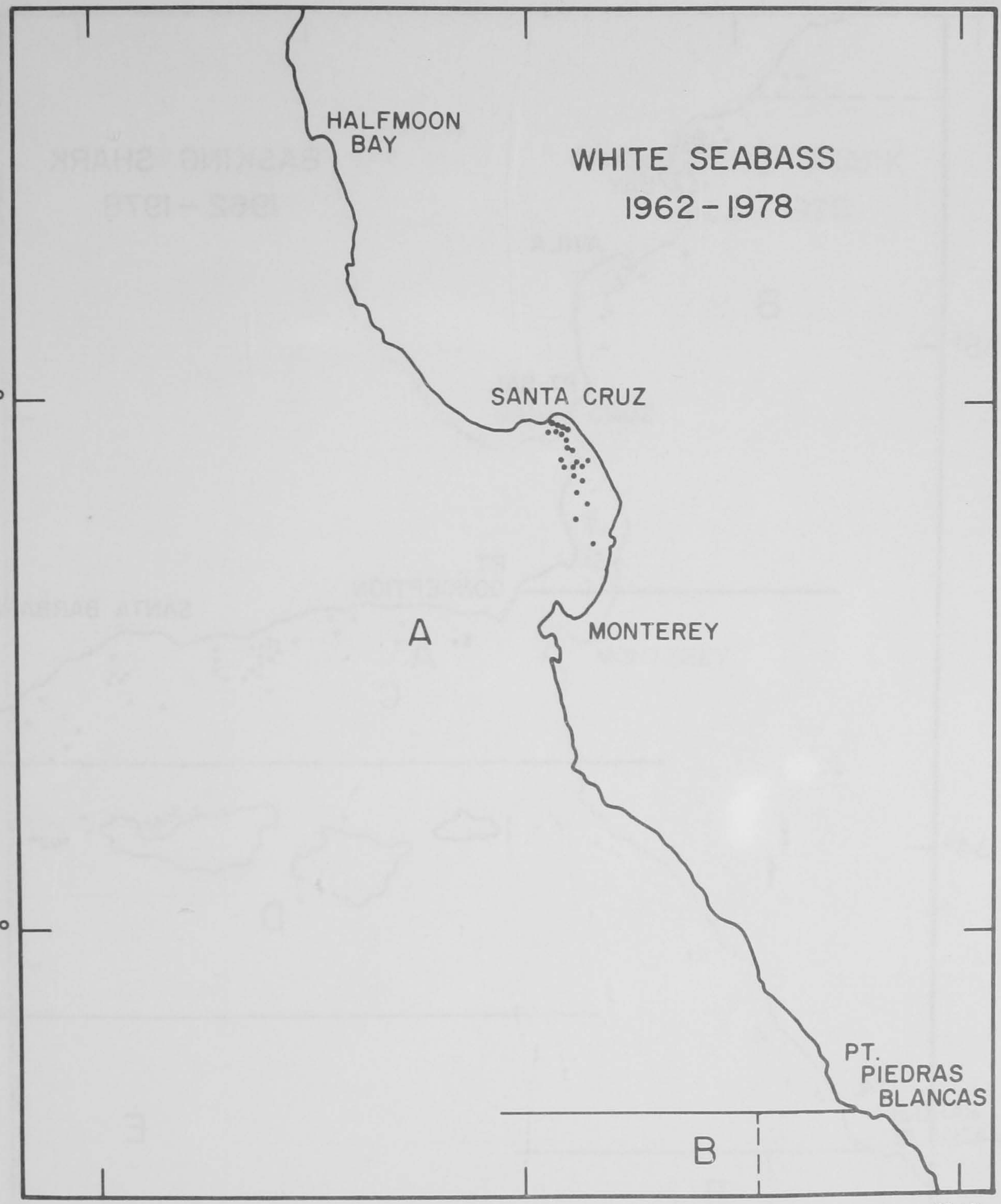

Figure 57.—White seabass—location of centers of sighting for school or school groups, Half Moon Bay to Pt. Piedras Blancas, 1962-78.

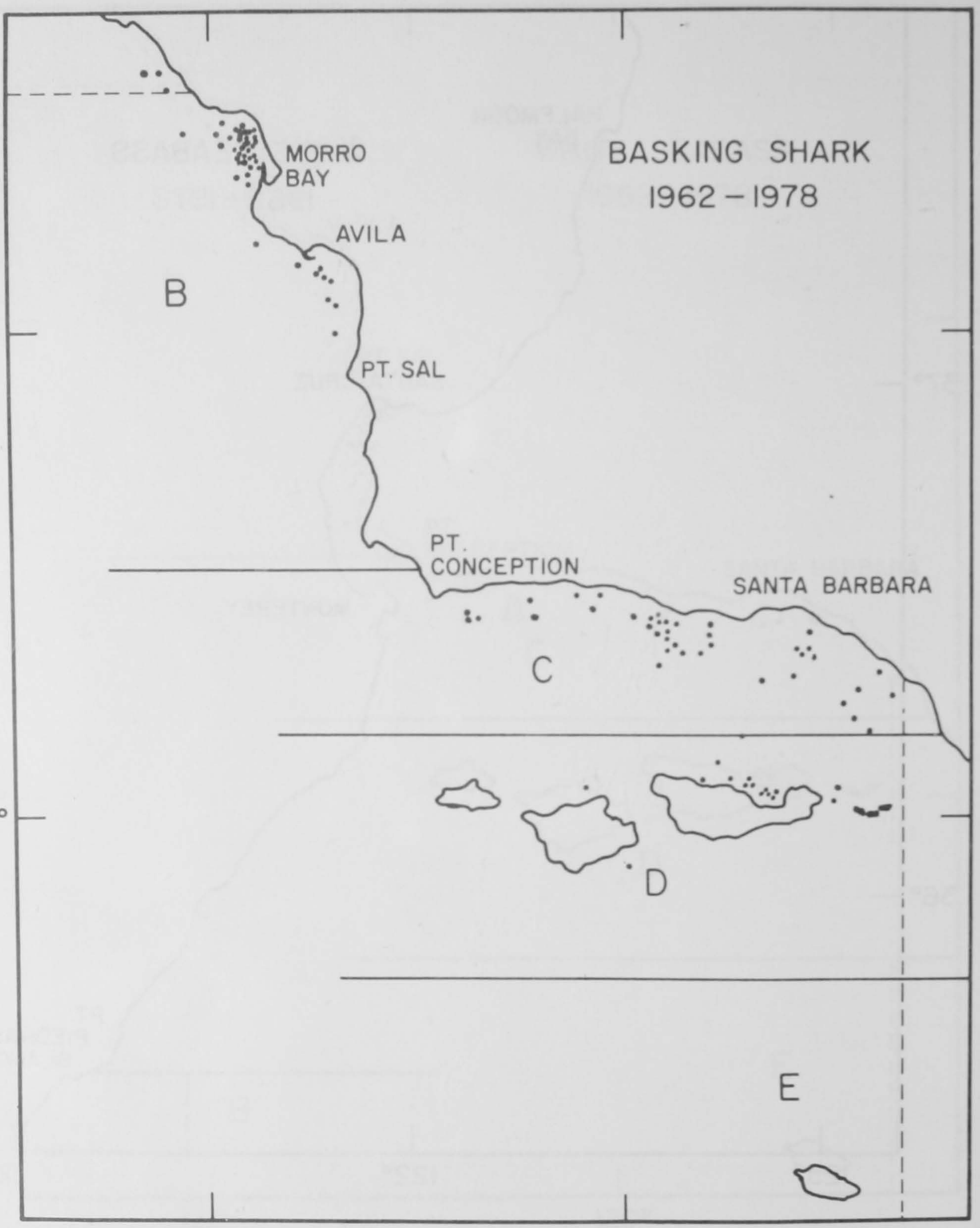

Figure 58.—Basking shark—locations of sighting one or more animals, Morro Bay to San Nicolas Island, 1962-78.

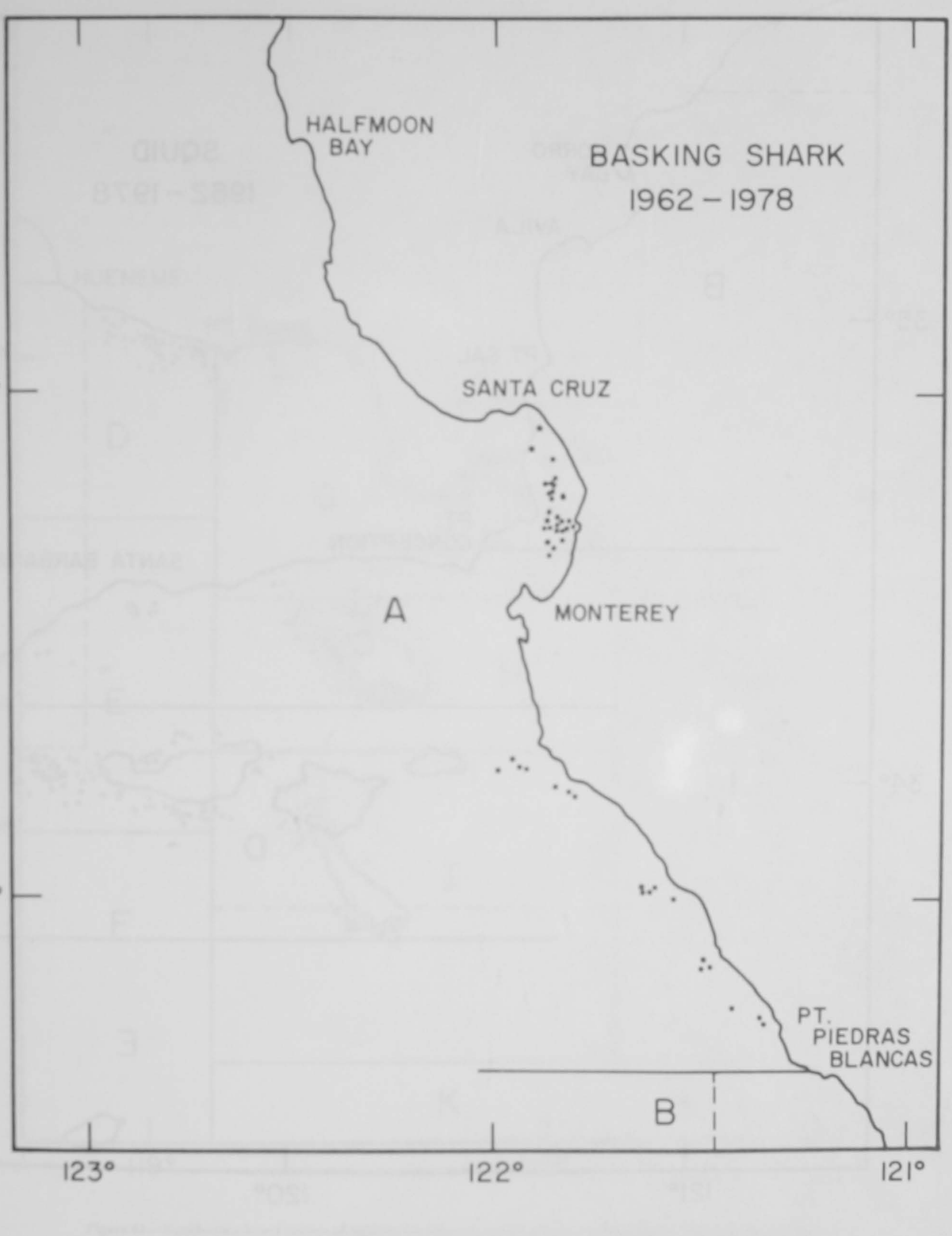

Figure 59.—Basking shark—locations of sighting one or more animals, Half Moon Bay to Pt. Piedras Blancas, 1962-78.

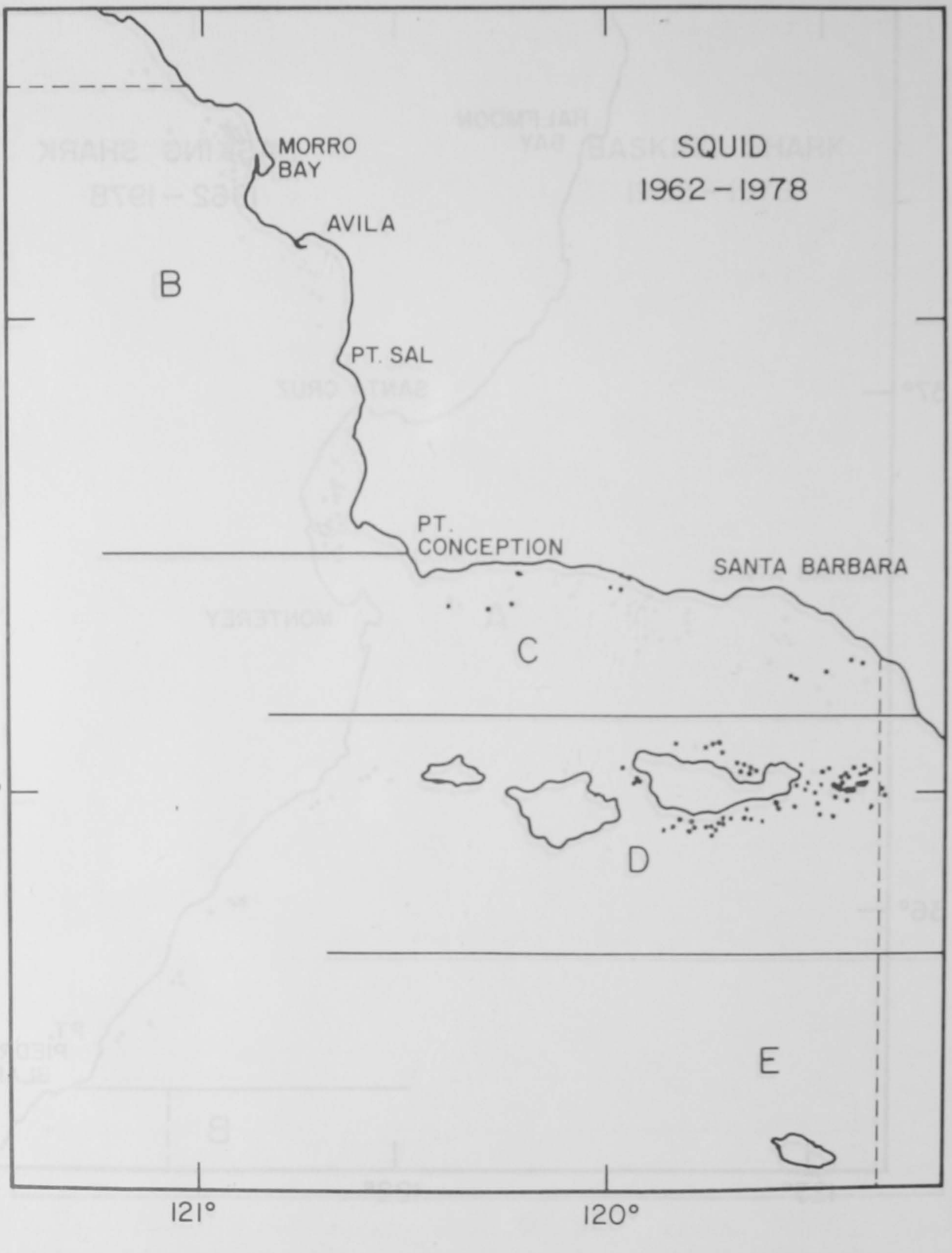

Figure 60.—Squid—location of centers of sighting for school or school groups, Morro Bay to San Nicolas Island, 1962-78.

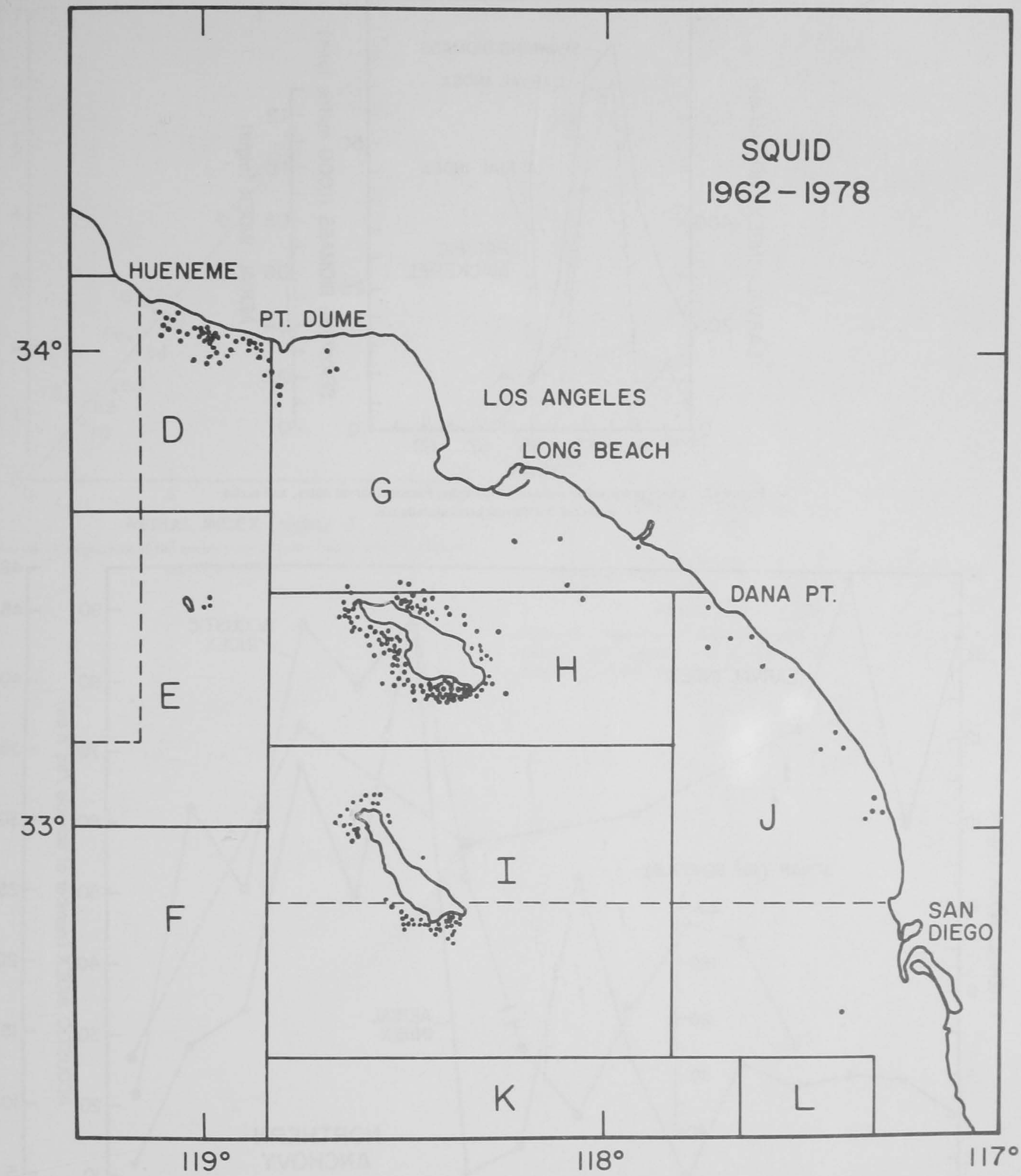

Figure 61.—Squid—location of centers of sighting for school or school groups, Pt. Hueneme to San Diego, 1962-78.

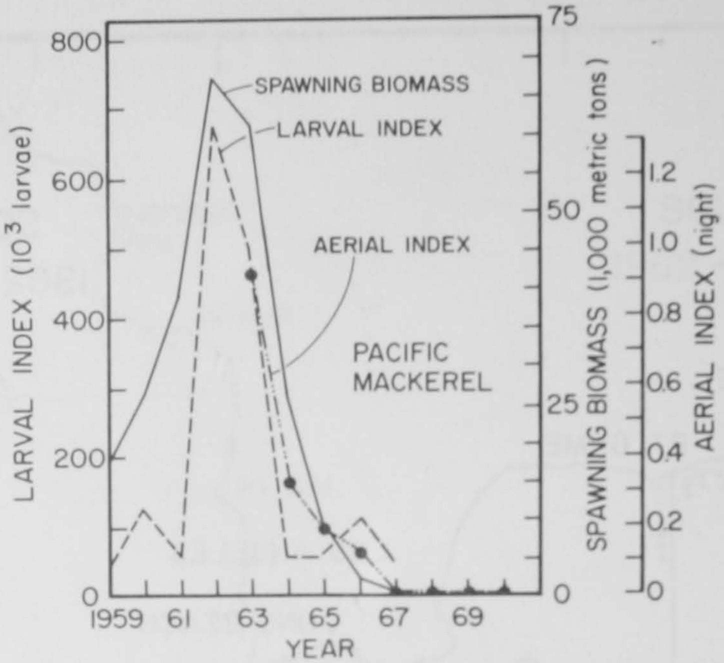

Figure 62.—Three independent estimates (spawning biomass, larval index, and aerial index) of Pacific mackerel abundance.

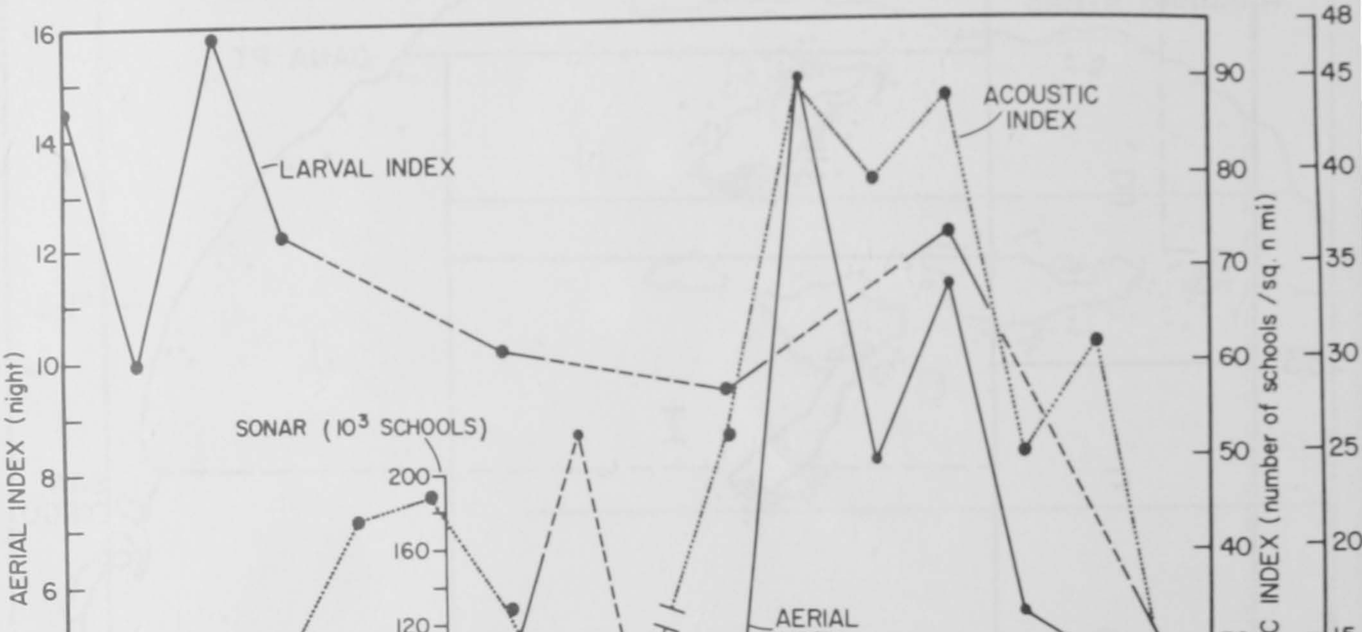

Figure 63.—Aerial, larval, and acoustic indices for the northern anchovy. Aerial night index in arbitrary units, acoustic index in schools per square nautical mile, a larval index in 10^{12} larvae.

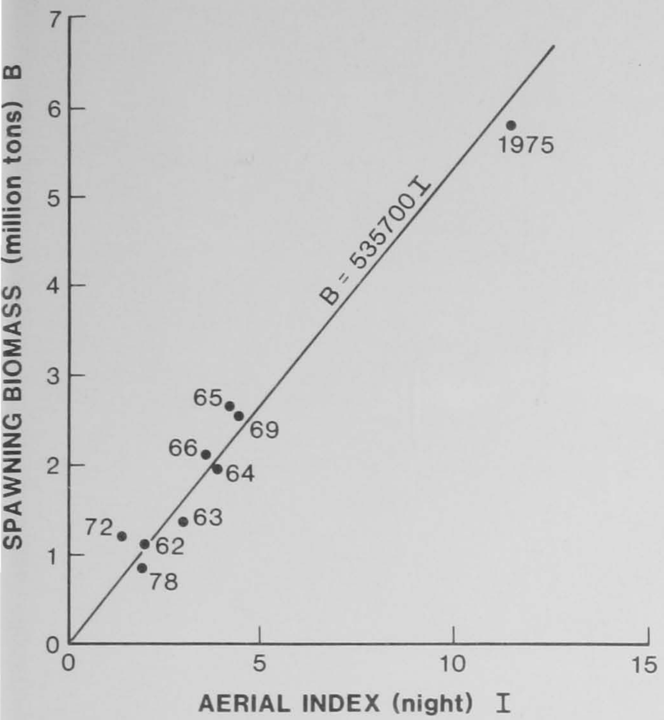

Figure 64.—Comparison of the anchovy aerial index (night) and the anchovy spawning biomass.

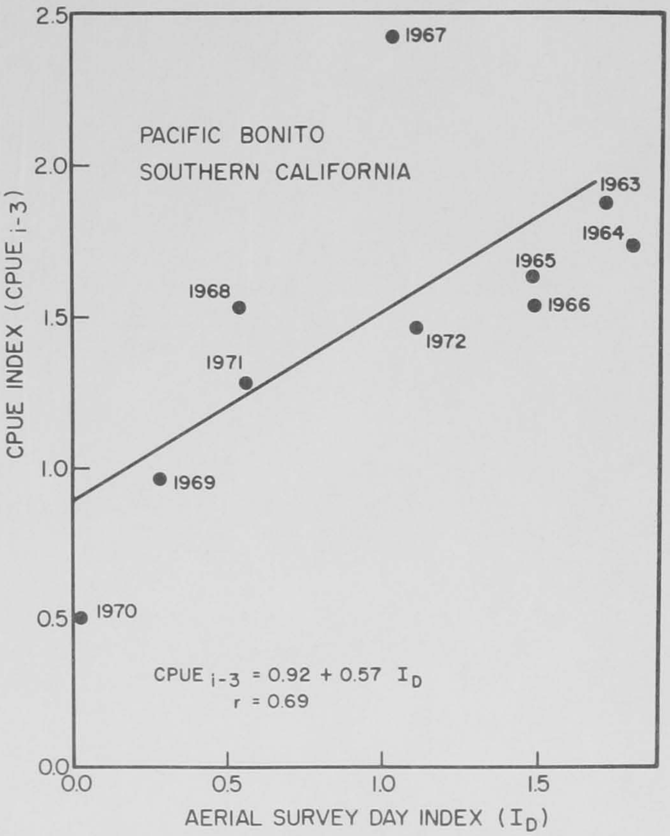

Figure 65.—Regression of aerial survey day index for Pacific bonito against partyboat CPUE index 3 yr earlier. Comparison data is for observations off southern California only.