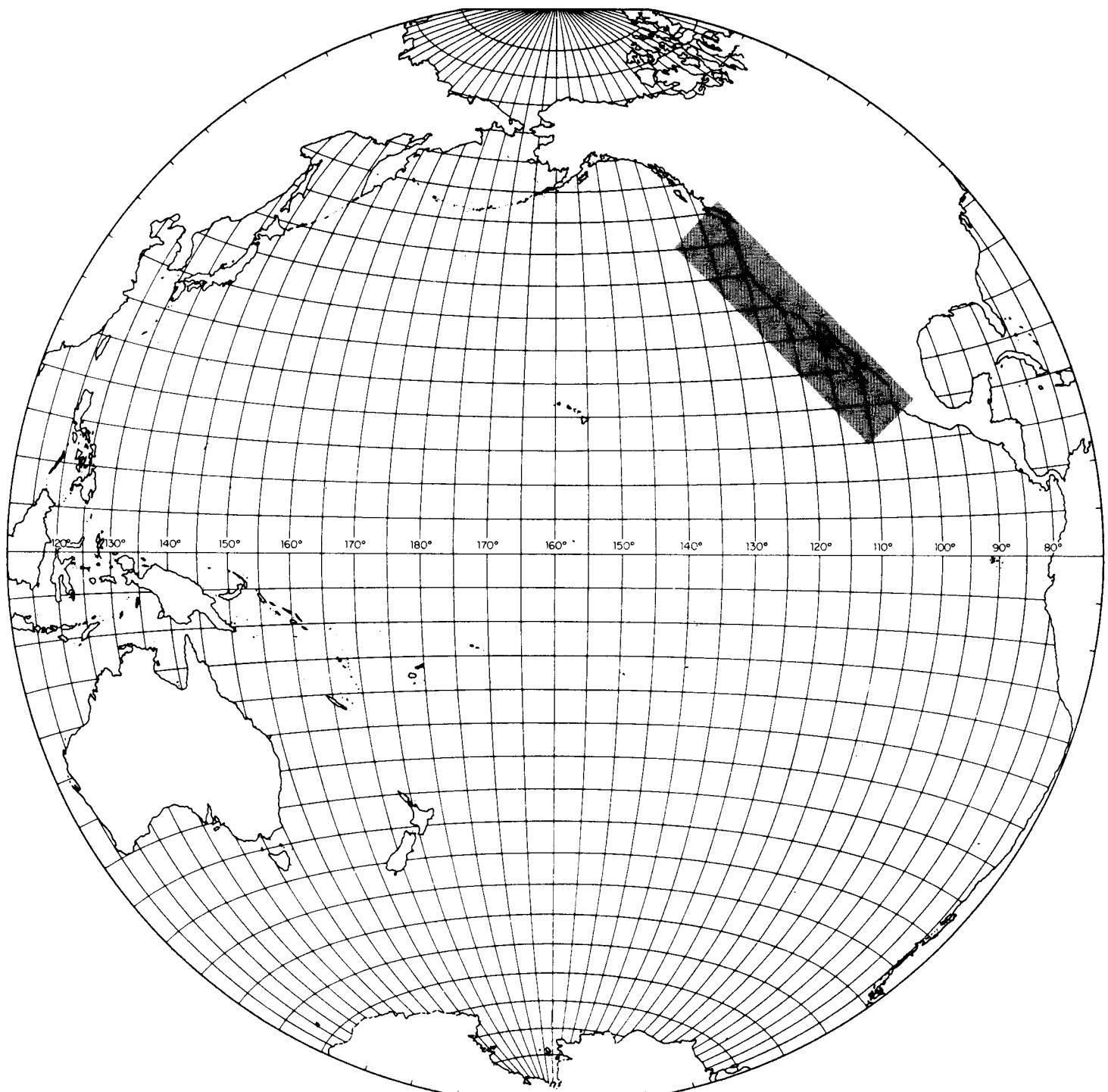
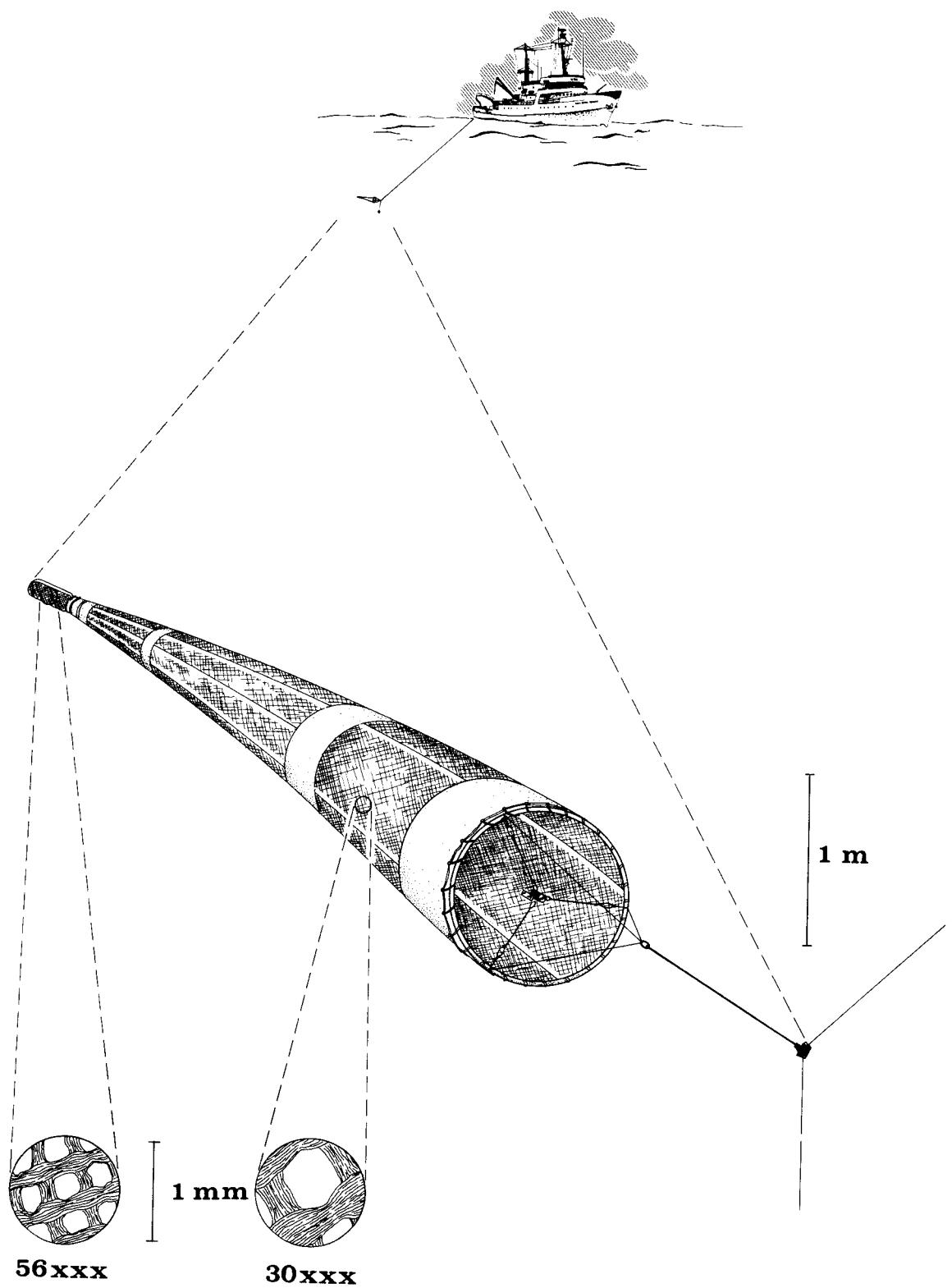


STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE



**CALIFORNIA COOPERATIVE OCEANIC
FISHERIES INVESTIGATIONS**

ATLAS No.13



CALIFORNIA
COOPERATIVE
OCEANIC
FISHERIES
INVESTIGATIONS

Atlas No. 13

STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE

Cooperating Agencies:
CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DEPARTMENT OF FISH AND GAME
STANFORD UNIVERSITY, HOPKINS MARINE STATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, NATIONAL MARINE FISHERIES SERVICE
UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY

June, 1971

THE CALCOFI ATLAS SERIES

This is the thirteenth in a series of atlases containing data on the hydrography and plankton from the region of the California Current. The field work was carried out by the California Cooperative Oceanic Fisheries Investigations,¹ a program sponsored by the State of California under the direction of the State's Marine Research Committee. The cooperating agencies in the program are:

California Academy of Sciences
California Department of Fish and Game
Stanford University, Hopkins Marine Station
National Oceanic and Atmospheric Administration, National Marine Fisheries Service²
University of California, Scripps Institution of Oceanography

CalCOFI atlases³ are issued as individual units as they become available. They provide processed physical, chemical and biological measurements of the California Current region. Each number may contain one or more contributions. A general description of the CalCOFI program with its objectives appears in the preface of Atlas No. 2.

This atlas was prepared by the Data Collection and Processing Group of the Marine Life Research Program, Scripps Institution of Oceanography.

CalCOFI Atlas Editorial Staff:

Abraham Fleminger and Hans T. Klein, Editors
John G. Wyllie, Cartographer

CalCOFI atlases in this series, through June 1971, are:

- No. 1. Anonymous, 1963. CalCOFI atlas of 10-meter temperatures and salinities 1949 through 1959.
- No. 2. Fleminger, A., 1964. Distributional atlas of calanoid copepods in the California Current region, Part I.
- No. 3. Alvariño, A., 1965. Distributional atlas of Chaetognatha in the California Current region.
- No. 4. Wyllie, J. G., 1966. Geostrophic flow of the California Current at the surface and at 200 meters.
- No. 5. Brinton, E., 1957. Distributional atlas of Euphausiacea (Crustacea) in the California Current region, Part I.
- No. 6. McGowan, J. A., 1967. Distributional atlas of pelagic molluscs in the California Current region.
- No. 7. Fleminger, A., 1967. Distributional atlas of calanoid copepods in the California Current region, Part II.
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- No. 9. Kramer, D., and E. H. Ahlstrom, 1968. Distributional atlas of fish larvae in the California Current region: Northern Anchovy, *Engraulis mordax* Girard, 1951 through 1965.
- No. 10. Isaacs, J. D., A. Fleminger and J. K. Miller, 1969. Distributional atlas of zooplankton biomass in the California Current region: Spring and Fall 1955-1959.
- No. 11. Ahlstrom, E. H., 1969. Distributional atlas of fish larvae in the California Current region: jack mackerel, *Trachurus symmetricus*, and Pacific hake, *Merluccius productus*, 1951 through 1966.
- No. 12. Kramer, D., 1970. Distributional atlas of fish eggs and larvae in the California Current region: Pacific sardine, *Sardinops caerulea* (Girard), 1951 through 1966.
- No. 13. Smith, P. E., 1971. Distributional atlas of zooplankton volume in the California Current region, 1951 through 1966.

¹Usually abbreviated CalCOFI, sometimes CALCOFI or CCOFI.

²Formerly called U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries.

³For citation this issue in the series should be referred to as CalCOFI Atlas No. 13.

**DISTRIBUTIONAL ATLAS OF ZOOPLANKTON VOLUME IN THE
CALIFORNIA CURRENT REGION, 1951 THROUGH 1966**

Paul E. Smith

CALCOFI ATLAS NO. 13

Data Collection and Processing Group
Marine Life Research Program
Scripps Institution of Oceanography
La Jolla, California

June, 1971

DISTRIBUTIONAL ATLAS OF ZOOPLANKTON VOLUME IN THE CALIFORNIA CURRENT REGION, 1951 THROUGH 1966

Paul E. Smith¹

Text

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INTRODUCTION

Bigelow and Sears (1939, p. 200) stated, "The most striking feature of volumetric distribution of zooplankton throughout has been the irregularity from station to station, often with volumes differing up to a hundredfold, between localities only a few miles apart . . . comparatively regular gradients nevertheless appear, both secular and regional, when averages are compared, for subdivisions large enough to include several stations each . . ." Small-scale irregularities within spatially and temporally persistent gradients also characterize the volumes of plankton collected in the California Current system.

The basic data for this atlas have been obtained from 11 years of monthly and five years of quarterly cruises generally centered on the United States-Mexican border and extending from Pt. Reyes near San Francisco to Cape San Lazaro in southern Baja California (Staff, South Pacific Fishery Investigations, 1952, 1953, 1954a, 1954b, 1955, 1956; Threlkild, 1956, 1957, 1959, 1961, 1963, 1969, MS.). In general, the same techniques of sampling and the same station grid were used throughout.

To a certain extent, the local variability of plankton volume at adjacent stations obscures regular seasonal, annual and regional changes. As an aid to the interpretation of the individual cruise charts in this atlas, generalizations which

have emerged from the analysis of the volume data will be discussed after the description of the important features of the sampling grid, sampling techniques, sampling gear, and laboratory techniques.

THE BASIC STATION PATTERN

The CalCOFI station grid may be referred to as a centric-systematic-area-sampling scheme (Milne, 1959) with respect to the routine of placing a single sampling station in the center of a rectangle or square which exactly subdivides the entire survey area. Geographic placement of the main axis and the cardinal lines at right angles are shown inside the back cover of each atlas in this series. In the CalCOFI sampling area, particularly near islands, river mouths, and underwater canyons, there remains considerable danger that the systematically placed station represents a far smaller area than that assigned to it in the cruise summary. Even far at sea it is possible for a sample to be taken in a patch of plankton characteristic of only a few tens of meters. For this reason, when scanning charts of this kind, one must be aware that contour intervals based on a single station could represent far less than the 400-1600 square miles usually represented by a station.

To simplify description of the sampling results, stations have been pooled into roughly 4800 square mile areas (Fig. 1). The boundaries of the areas have been aligned to the basic CalCOFI station grid so that each pooled area contains all lines with the same number in the "10's" position, irrespective of the numeral in the "units" position, i.e. 80., 83., 85., 87., and all stations on a line with the same number in the "10's" position, i.e., .50, .53, .55, so that, for example, 80.55, 83.53, 83.55, 87.50, 87.55 all occur in the pooled area "8.5." With the exception of the coastal regions, pooled areas

¹National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fishery - Oceanography Center, La Jolla, California 92037.

are 40 miles perpendicular to the coastline and 120 miles parallel to the coastline. Irregularities of the coastline cause pooled areas to vary between 2,027 and 8,388 square miles ("12.3" and "11.3"). Stations in the Los Angeles Bight ("8.4") and in Vizcaino Bay ("11.3") were arbitrarily pooled regardless of station or line number.

A special closely-spaced grid of stations in an area within the California Current region was occupied on five successive days in April, 1952. It seems clear from Kramer's (1963) study of these grids that major increases in the number of samples per unit area would have been necessary to substantially improve the estimates of mean zooplankton volume. It is equally clear that the same number of stations occupied on a random or stratified random basis would not have resulted in an appreciable improvement in precision, and Milne's (1959) conclusion can be applied to this set of field samples, that "with proper caution, one will not go very far wrong, if wrong at all, in treating the centric-systematic-area sample as if it were random."

SAMPLING TECHNIQUE

The towing method used over the period reported here may be characterized as an "even oblique" tow as contrasted with a stepped oblique tow or vertical tow. The objective of the oblique tow was to encompass the vertical distribution of fish eggs and larvae found largely in the mixed layer.

The tow itself requires the slowing of the ship to about 2 knots, lowering a 100-pound weight (45.5 kg) on a 3/16-inch (5 mm) wire to 10 meters and affixing the cable clamp to the wire. The cable clamp is lowered to the water and the wire meter is set at zero. With the ship's speed at about 2 knots, the net is lowered at about 50 meters per minute. After about one minute of lowering, the ship's forward motion is adjusted until the wire is at an angle of 45 degrees relative to the horizon. This angle is maintained within plus or minus 3 degrees for the remainder of the tow. The wire is retrieved smoothly at 20 meters per

minute with the aid of a stop-watch. It is frequently possible by this technique to carry out a tow to within five seconds of the allotted tow period of 14.5 minutes. Experienced marine technicians can do this regularly.

THE CALCOFI STANDARD NET

The CalCOFI net is preceded through the water by a cable clamp, three or more meters of leadline, the junction of a three-leg bridle one meter ahead of the mouth and the bridle itself. Flow disturbances caused by the structures very likely contribute to underestimates of the numbers of more mobile organisms (Fleminger and Clutter, 1965; Clutter and Anraku, 1968). About 10-15 per cent of the water encountered by the mouth of the net is shunted aside because there is not enough aperture area in the body of the net to accept all the water encountered (Smith, Counts and Clutter, 1968). It appears unlikely that clogging appreciably lowers the filtering efficiency in the oblique tow over much of the extent of the California Current region.

The silk gauze used in the CalCOFI standard net is of two sizes: 30 xxx grit gauze (0.55 mm shrunken mesh), and 56 xxx grit gauze (0.25 mm shrunken mesh) in the proportions described by Ahlstrom (1948, Table 1). The smaller 56 xxx grit gauze was used in the cod end bag and in a 40 cm section immediately in front of it. The remainder of the mesh was 30 xxx comprising a 65-cm cylinder behind the mouth followed by a 270-cm truncate cone that tapers from 1 m to 20 cm in diameter. With canvas sleeves and seams the net is nearly five meters long.

Between July, 1956 and August, 1959, a nylon net was used on 21 cruises. On eight cruises the nylon net was used for every sample. Table 1 is a list of the cruises and ships on which the nylon net was used. Details of construction are essentially the same as the silk standard net except that the mesh was 0.471 mm rather than 0.55 mm typical of silk net after shrinking. The section with 56 xxx grit gauze was replaced by 0.280 mm nylon. This net very likely retained more zooplankton than the standard net but no

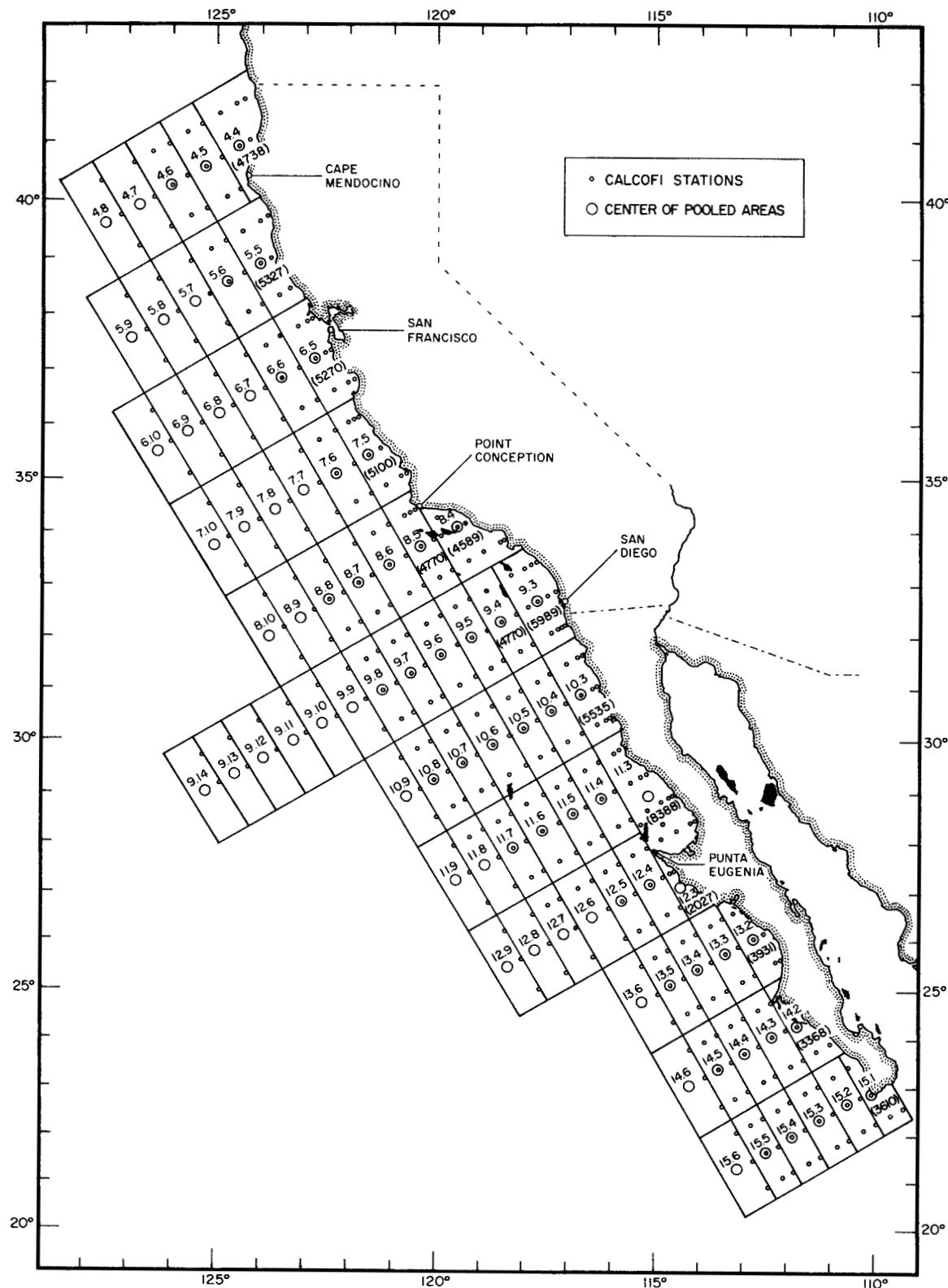


Figure 1. Pooled statistical areas of the CalCOFI pattern. Each rectangle represents 4,800 square miles (40 x 120 nautical miles) unless otherwise indicated as in the nearshore delineations.

estimates of the value of this difference have been made. Comparison with used silk nets at 0.55 mm and nylon nets of 0.505 mm yielded a 20 percent difference in plankton volumes in favor of the smaller mesh (unpublished data). The nylon mesh was abandoned (Ahlstrom, 1959b) when it was noted that filtration efficiency decreased when towing volume was listed in the order in which tows were taken. This clogging between tows was more severe than changes in silk nets with age; thus silk was retained for the surveys through 1966.

Table 1. Cruises conducted in part with 0.471 mm nylon nets.

| BLACK DOUGLAS | ORCA | PAOLINA-T | HORIZON | SPENCER F. BAIRD | STRANGER | HUGH M. SMITH |
|---------------|------|-----------|---------|------------------|----------|---------------|
| 5607* | 5607 | 5607 | 5612 | 5702 | 5707 | 5908* |
| 5608* | 5610 | | 5702 | 5804 | 5710* | |
| 5609 | 5611 | | 5704 | | | |
| 5702 | 5701 | | 5705 | | | |
| 5703* | 5711 | | 5706* | | | |
| 5705 | 5807 | | | | | |
| 5709* | 5901 | | | | | |
| 5805* | | | | | | |

*Nylon net used throughout.

LABORATORY TECHNIQUES

Through 1959, the plankton sample was preserved by adding formalin to make a 3% formalin solution in sea water. After 1959, the strength was increased to a 5% formalin solution. Plankton sample jars were filled to the top with sea water to prevent the damage that accompanies sloshing in partly filled jars and stored for periods of one month to two years before the volume was measured.

Two methods have been used for the determination of plankton volume by displacement. The first method consisted of measuring the total volume of plankton plus preserving liquid in a graduated cylinder. The plankton was poured into a draining sock and the preservative drained into a graduated cylinder; the difference in the volumes was the measure of the plankton (Ahlstrom and Threlkill, 1963). The second, more recent method consists of measuring the total volume of plankton and preservative in a calibrated quart jar in which the plankton is originally preserved at sea. When their total volume is brought to the inscribed volume of the jar the plankton is poured into a drainage cone, the preservative is caught in a graduated cylinder and, as in the first method, the difference in the volumes is the measure of the

plankton (Threlkill, in MS.). Between 20% and 50% of the displacement volume of the wet sample is due to water in the interstices of the plankton and 35% appears to be a representative central value for this error (Ahlstrom and Threlkill, 1963, Table 6). More exhaustive treatment of the plankton sample to remove this error has not been done routinely because excessive handling adversely affects the condition of some of the organisms which must be subsequently sorted, identified, counted and measured.

In time, samples with appreciable quantities of coelenterates and thaliacians may undergo diminution of volume in direct proportion to the shrinking of these specimens. Most of the shrinkage occurs in the first 30 days (Ahlstrom and Threlkill, 1963, Table 4). Shrinkage is slight among the crustacean constituents. For most samples the time between collection and determination has not been measured and is likely to vary between one month and two years.

Technical errors, such as partial spilling of a sample, malfunctioning flow meters, or excessive tow length occurred in a small proportion of the samples. If the error was detected on station, the tow was usually repeated. Estimates

of missing flow meter readings were obtained from the revolutions per second as a function of wire angle that is routinely established for each flow meter in use.

Organisms exceeding 5 cc as well as adult and juvenile fish were removed and their displacement volume redetermined. While total volume and total volume less "large" organisms are both reported in the original data, only the latter volume is presented in this atlas.

LIMITATIONS OF THE DATA

Due to the "patchy" distribution of zooplankton, the interpretation of a series of charts in an atlas must be done with considerable care. It is the purpose of this section to discuss the magnitude of contouring error caused by patchiness and day-night differences in catch and to sort them out from regional and seasonal trends.

Patchiness—Contouring obscures patchiness due to the assumption of continuity of zooplankton standing stock between adjacent stations. The importance of this problem diminishes as one widens the intervals of contour.

The contouring intervals used here are similar to those appearing in CalCOFI Atlas No. 10, on zooplankton biomass (Isaacs, Fleminger and Miller, 1969, p. xiii). The values are in cc/1000 m³ of sea water strained and the series increases by a factor of 4, i.e., 4, 16, 64, 256 . . . Accordingly, the broad range of plankton volumes encountered in the California Current region can usually be represented by about six contours.

In 1940, duplicate plankton hauls were taken on 141 stations off southern California, with gear similar to that used later in the CalCOFI program. Table 2 shows the distribution of plankton volumes from the second tow on each station relative to that of the first tow when the measurements are arranged in the contouring intervals used in the present atlas. Of the 141 pairs, 106 (77%) would have been placed in the same contour intervals. Of the remaining 23% of paired tows none differed by more than one interval. Ahlstrom (in MS.) concluded that one could discriminate differences between stations of less than 0.6 or more than 1.7 times as large at the 95% level.

Table 2. Percent distribution of the plankton volume of a second tow on station compared to the plankton volume of the first tow.

| First tow (cc/1000 m ³) | Second tow (cc/1000 m ³) | | | | N |
|-------------------------------------|--------------------------------------|-------|--------|----------|-----|
| | 5-16 | 17-64 | 65-256 | 257-1024 | |
| 5-16 | 0% | 100% | 0% | 0% | 1 |
| 17-64 | 0 | 67 | 33 | 0 | 39 |
| 65-256 | 0 | 14 | 84 | 2 | 88 |
| 257-1024 | 0 | 0 | 54 | 46 | 13 |
| | | | | | 141 |

Day-night difference—Often there exists a day-night difference in the standing stock of zooplankton. King and Hida (1954) showed a sine wave correction which was suitable for the zooplankton in Hawaiian waters. Isaacs, Fleminger and Miller (1969) illustrated differences among functional groups and due to the resulting complexity chose the relatively simple method of ratio of medians for day and night

to adjust catch size to the higher (night) values. The day-night difference may be ascribed to daily changes in vertical distribution which result in more organisms in the upper 140 m at night, and a marked day-night difference in the ability of mobile organisms to avoid capture by the slow moving (less than 2 knots) CalCOFI standard plankton net. Brinton (1962) described the catches of euphausiids in a rela-

tively long series of tows on the same stations (October 1950, Stations 72.62, 70.90 and 70.130; April 1952, Station 123.40). The zooplankton volumes have also been assembled for the same stations (Ahlstrom, unpublished data; Kramer, 1963). Table 3 illustrates the frequency with which contour values may change day and night. At Station 70.90 in October 1950, and Station 123.40 in April 1952, about half of the tows increased one contour level at night. At 70.130, however, 63 tows showed virtually no effect of

time of day on zooplankton volume. The Kruskal-Wallis test (a non-parametric analogue of the variance-ratio test) of the data from Stations 70.90 and 70.130 supported the null hypothesis of identical sum of ranks for 70.130 (3 degrees of freedom, $H = 0.654$, $0.900 > p > 0.750$) but did not support the null hypothesis for Station 70.90 ($H = 12.012$, $0.017 > p > 0.005$). Brinton (1962) found day-night differences in the numbers of euphausiids from the same tows on both stations.

Table 3. Percent distribution of day and night samples with repetitive tows in the same area.

| Plankton volume (cc/1000 m ³) | 17- 64 | 65- 256 | 257- 1024 | 1025- 4096 | N |
|--|-----------|------------|--------------|---------------|----|
| Cruise 5010 | | | | | |
| Station 70.90 | | | | | |
| Time—Day | 0% | 88% | 13% | 0% | 16 |
| Dusk | 0 | 44 | 56 | 0 | 16 |
| Night | 0 | 38 | 63 | 0 | 16 |
| Dawn | 0 | 50 | 44 | 6 | 16 |
| Station 70.130 | | | | | |
| Time—Day | 60% | 40% | 0% | 0% | 15 |
| Dusk | 63 | 38 | 0 | 0 | 16 |
| Night | 63 | 38 | 0 | 0 | 16 |
| Dawn | 69 | 31 | 0 | 0 | 16 |
| Cruise 5204 | | | | | |
| Station 123.40 | | | | | |
| Drogue — Day | 73% | 27% | 0% | 0% | 15 |
| Night | 7 | 93 | 0 | 0 | 14 |
| Anchor — Day | 93 | 7 | 0 | 0 | 15 |
| Night | 53 | 47 | 0 | 0 | 15 |
| Grid — Day | 81 | 19 | 0 | 0 | 68 |
| Night | 16 | 80 | 2 | 2 | 51 |

Of the three errors noted here, the day-night difference probably imposes an appreciable bias over much of the California Current region, and patchiness can have effects similar in magnitude but produce either over- or under-estimates. Shrinkage due to fixation appears to be a negligible source of variability.

Spatial and Temporal Trends

Figure 2 illustrates the major regional and seasonal trends of median zooplankton volume data for the period 1951-1960. The data for

each pooled statistical area in each adequately sampled month are presented in Table 4. Medians are used here to represent the central value of a suite of samples.

It may be observed in Table 4 that peak values commonly occur from May through July and minimum values occur in October and January. Also, the months of August, September, November and December are not sampled adequately for a decade summary. The best sampling has been during the spawning seasons of the pelagic fish in this region (January to

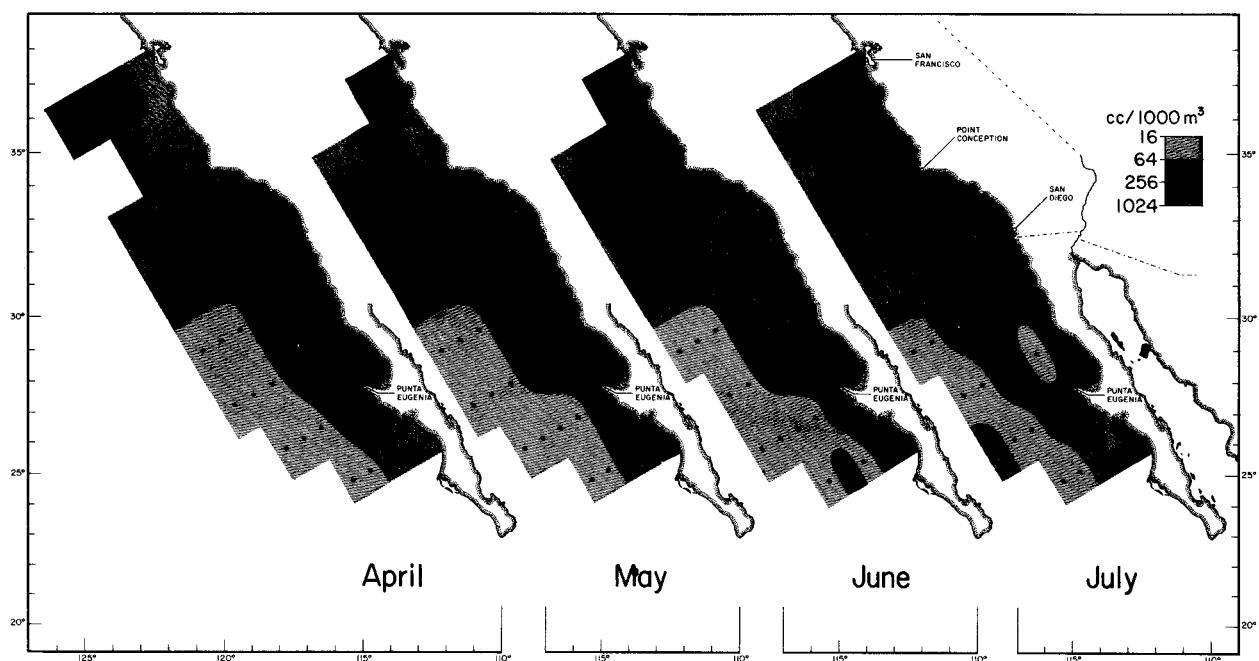
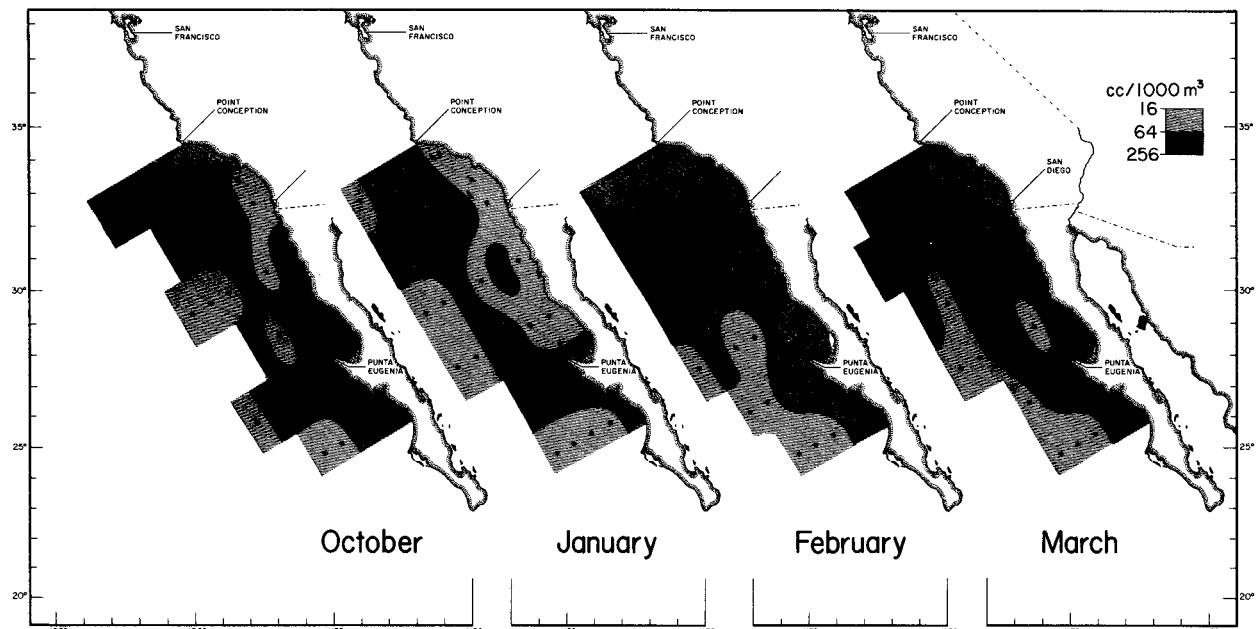


Figure 2. Median zooplankton volumes ($\text{cc}/1000 \text{ m}^3$; large organisms removed) 1951-1960 (based on Table 4).

Table 4. Median zooplankton volumes (cc/1000 m³; large organisms removed) 1951-1960, listed by months and pooled areas.

| Area | January | February | March | April | May | June | July | October |
|------|---------|----------|-------|-------|-----|------|------|---------|
| 6.5 | * | — | — | 238 | 264 | 272 | 376 | — |
| 6.6 | — | — | — | 496 | 455 | 300 | 377 | — |
| 6.7 | — | — | — | 291 | — | — | 400 | — |
| 6.8 | — | — | — | 273 | — | — | 209 | — |
| 6.9 | — | — | — | 565 | — | — | 195 | — |
| 7.5 | — | — | — | 202 | 254 | 347 | 354 | — |
| 7.6 | — | — | — | 232 | 325 | 390 | 305 | — |
| 7.7 | — | — | — | 188 | 388 | 272 | 448 | — |
| 7.8 | — | — | — | — | 135 | 310 | 286 | — |
| 7.9 | — | — | — | — | 160 | 96 | 215 | — |
| 8.4 | 63 | 114 | 121 | 221 | 234 | 210 | 166 | 94 |
| 8.5 | 64 | 143 | 222 | 195 | 209 | 352 | 225 | 110 |
| 8.6 | 167 | 185 | 187 | 189 | 312 | 330 | 300 | 109 |
| 8.7 | 103 | 154 | 181 | 149 | 155 | 291 | 196 | 142 |
| 8.8 | 63 | 92 | 124 | 84 | 95 | 149 | 138 | 86 |
| 8.9 | — | — | — | 170 | 84 | 85 | 115 | 69 |
| 9.3 | 48 | 70 | 97 | 120 | 128 | 147 | 145 | 58 |
| 9.4 | 73 | 82 | 64 | 126 | 154 | 142 | 137 | 89 |
| 9.5 | 97 | 93 | 84 | 127 | 167 | 205 | 204 | 83 |
| 9.6 | 67 | 142 | 91 | 121 | 122 | 176 | 117 | 86 |
| 9.7 | 82 | 135 | 100 | 99 | 84 | 146 | 116 | 82 |
| 9.8 | 65 | 94 | 109 | 67 | 90 | 92 | 89 | — |
| 9.9 | — | — | 93 | 64 | 91 | 84 | 75 | — |
| 10.3 | 41 | 79 | 86 | 114 | 140 | 134 | 122 | 87 |
| 10.4 | 69 | 70 | 66 | 64 | 94 | 93 | 98 | 58 |
| 10.5 | 55 | 93 | 76 | 69 | 85 | 108 | 92 | 66 |
| 10.6 | 65 | 98 | 69 | 67 | 85 | 74 | 73 | 54 |
| 10.7 | 59 | 77 | 58 | 56 | 53 | 61 | 64 | 46 |
| 10.8 | 56 | 65 | 81 | 45 | 55 | 40 | 52 | 43 |
| 10.9 | — | — | — | 43 | 48 | 58 | 60 | — |
| 11.3 | 62 | 84 | 115 | 170 | 200 | 174 | 184 | 78 |
| 11.4 | 63 | 65 | 51 | 65 | 79 | 79 | 60 | 81 |
| 11.5 | 72 | 55 | 64 | 73 | 69 | 92 | 120 | 56 |
| 11.6 | 71 | 47 | 67 | 69 | 67 | 76 | 64 | 77 |
| 11.7 | 44 | 70 | 46 | 50 | 44 | 63 | 44 | — |
| 11.8 | 37 | 49 | 31 | 34 | 36 | 48 | 54 | — |
| 11.9 | — | — | — | 22 | 33 | — | — | — |
| 12.3 | 73 | 135 | 182 | 403 | 192 | 349 | 109 | 81 |
| 12.4 | 76 | 86 | 90 | 102 | 126 | 96 | 122 | 87 |
| 12.5 | 71 | 73 | 70 | 74 | 58 | 59 | 68 | 110 |
| 12.6 | 66 | 45 | 58 | 42 | 51 | 39 | 54 | 99 |
| 12.7 | — | 58 | — | 40 | 40 | 43 | 55 | 100 |
| 12.8 | — | — | — | 34 | 45 | 37 | 70 | 59 |
| 13.2 | 70 | 100 | 178 | 176 | 323 | 811 | 522 | 136 |
| 13.3 | 53 | 80 | 100 | 120 | 113 | 103 | 149 | 76 |
| 13.4 | 37 | 59 | 61 | 64 | 70 | 59 | 67 | 67 |
| 13.5 | 32 | 51 | 44 | 51 | 61 | 64 | 37 | 55 |
| 13.6 | 37 | 55 | 46 | 55 | 52 | 39 | 48 | 56 |

*Undersampled; pooled area sampled in less than 8 of the 10 years or fewer than 10 samples in total.

July) when zooplankton volumes are rising. When zooplankton standing stock is decreasing (August to January), only the months of October and January are available to indicate the decrease.

While the median value for a ten-year period is instructive, it must be remembered that the distribution of zooplankton, and especially individual species, is extremely complex and changeable from year to year. As an example, the

ten-year distribution of zooplankton volumes is shown in Table 5. While this area of 4589 square miles is composed primarily of the waters of the gyre in the Los Angeles Bight, the diversity of zooplankton volumes within its boundaries is great. The seasonal cycle of medians is among the best defined (mean 133 cc/1000 m³, amplitude 84 cc/1000 m³) but nearly a 1000-fold range is possible with individual sample values in any month.

Table 5. Percent occurrence of sample volumes (cc/1000 m³) by month in Los Angeles Bight (pooled area "8.4").

| | 5- 16 | 17- 64 | 65- 256 | 257- 1024 | 1025- 4096 | 4097- 16384 | Md | N |
|----------|----------|-----------|------------|--------------|---------------|----------------|-----|----|
| October | 10% | 31% | 53% | 6% | 0% | 0% | 94 | 51 |
| January | 9 | 41 | 48 | 2 | 0 | 0 | 63 | 46 |
| February | 2 | 20 | 71 | 7 | 0 | 0 | 114 | 55 |
| March | 4 | 13 | 74 | 9 | 0 | 0 | 121 | 54 |
| April | 0 | 3 | 59 | 38 | 0 | 0 | 221 | 61 |
| May | 1 | 10 | 42 | 45 | 1 | 0 | 234 | 69 |
| June | 2 | 9 | 42 | 36 | 8 | 3 | 210 | 64 |
| July | 2 | 16 | 54 | 18 | 9 | 2 | 166 | 56 |

Extreme differences may also be seen over the entire surveyed area of 200,000 square miles. For example, compare the July results for the years 1956 and 1958 (Chart No. 82 and 84).

Onshore-offshore trends—Onshore-offshore trends by percent frequency distribution, median and arithmetic mean are shown for pooled areas "8.4" through "8.9" running from the Los Angeles Bight 240 miles southwest approximately normal to the coast and the California Current (Table 6). In these pooled areas the zooplankton maximum is offshore 80-120 miles, diminishing toward the coast as well as toward the central water mass. This general offshore-onshore trend of higher standing stocks offshore which diminish seaward and inshore is typical of the rest of the coastline but is most pronounced in this transect.

The analysis of onshore-offshore trends is complicated by the incidence of tows in shallow water. Such an oblique tow spends an inordinate amount of time in the upper layers. When a tow from 140 meters deep to the surface is

compared with a tow from 70 meters deep for example, the latter should normally yield more plankton per 1000 m³ strained. In the section used for illustration, advection from the north may bring plankton-rich water into the nearshore and offshore regions (pooled areas "8.4," "8.5") which are derived from the nearshore regions of the coast of Central California (pooled area "7.5") (Fleminger, personal communication).

Upstream-downstream trends

In the northern portion of the California Current surveys, the zone of high plankton standing stock is relatively broad, usually more than 100 miles wide. In the south, the band of high standing stock is often less than 80 miles wide (Table 4). An index of this trend may be derived from the histograms present on each chart of the atlas.

GROUP COMPOSITION

Large sample estimates of the group composition of the zooplankton volumes are now becoming available (Table 7, after Isaacs, Flem-

inger and Miller, 1969). The April and October samples from 1955-1959, show the extent of changes in group composition. In all years except 1957, the rank of components changed very little from spring to fall. The year 1957 has previously been noted as a year of tran-

sition over the entire California Current area (Thrailkill, 1959) with regard to zooplankton volumes. Thaliaceans and larvaceans were second to crustaceans in 1955 and became first for the April cruises of 1956, 1957 and the intervening October. In October 1957, the thali-

Table 6. Percent distribution of zooplankton volumes (cc/1000 m³) along onshore-offshore transect at Los Angeles Bight, 1951-1960.

| | <16 | 17-64 | 65-256 | 257-1024 | 1025-4096 | ≥4096 | Md | \bar{x} | N |
|----------------|-----|-------|--------|----------|-----------|-------|-----|-----------|----|
| October | | | | | | | | | |
| 8.4 | 10% | 31% | 53% | 6% | 0% | 0% | 99 | 117 | 51 |
| 8.5 | 4 | 28 | 48 | 20 | 0 | 0 | 110 | 148 | 50 |
| 8.6 | 4 | 21 | 64 | 14 | 0 | 0 | 109 | 144 | 28 |
| 8.7 | 0 | 13 | 73 | 13 | 0 | 0 | 142 | 149 | 15 |
| 8.8 | 0 | 36 | 57 | 7 | 0 | 0 | 86 | 111 | 14 |
| 8.9 | 7 | 33 | 60 | 0 | 0 | 0 | 69 | 68 | 15 |
| January | | | | | | | | | |
| 8.4 | 9% | 41% | 48% | 2% | 0% | 0% | 63 | 80 | 46 |
| 8.5 | 2 | 51 | 33 | 13 | 0 | 0 | 64 | 126 | 45 |
| 8.6 | 0 | 11 | 57 | 32 | 0 | 0 | 167 | 224 | 28 |
| 8.7 | 0 | 17 | 72 | 11 | 0 | 0 | 103 | 142 | 18 |
| 8.8 | 0 | 50 | 38 | 13 | 0 | 0 | 63 | 159 | 16 |
| 8.9 | 8 | 38 | 38 | 8 | 8 | 0 | 87 | 185 | 13 |
| April | | | | | | | | | |
| 8.4 | 0% | 3% | 59% | 38% | 0% | 0% | 221 | 246 | 61 |
| 8.5 | 2 | 9 | 54 | 33 | 2 | 0 | 195 | 333 | 57 |
| 8.6 | 0 | 5 | 61 | 27 | 7 | 0 | 189 | 289 | 41 |
| 8.7 | 0 | 8 | 67 | 18 | 8 | 0 | 149 | 344 | 39 |
| 8.8 | 0 | 32 | 54 | 14 | 0 | 0 | 84 | 141 | 37 |
| 8.9 | 0 | 21 | 39 | 32 | 7 | 0 | 170 | 286 | 28 |
| July | | | | | | | | | |
| 8.4 | 2% | 16% | 54% | 18% | 9% | 2% | 166 | 406 | 56 |
| 8.5 | 2 | 5 | 50 | 32 | 11 | 0 | 225 | 464 | 56 |
| 8.6 | 0 | 2 | 42 | 44 | 9 | 2 | 300 | 576 | 43 |
| 8.7 | 0 | 10 | 52 | 39 | 0 | 0 | 196 | 232 | 31 |
| 8.8 | 0 | 21 | 55 | 24 | 0 | 0 | 138 | 209 | 29 |
| 8.9 | 0 | 22 | 39 | 28 | 11 | 0 | 115 | 334 | 18 |

aceans and larvaceans were ranked fourth and remained there through April and October of 1958.

It is important to know the group composition, for differences in the proportions of the crustaceans and thaliaceans bear on the carbon

content of the sample. The thaliaceans differ from the crustaceans in dry weight per unit wet weight and in carbon per unit dry weight (Curl, 1962; Ahlstrom and Threlkill, 1963).

Plankton volume data have been used (Lasker, 1970) to describe the use of zooplankton

energy by the Pacific sardine. The location and timing of zooplankton increases coincide with the migration, fat deposition and spawning of

that species. It is apparent that the usefulness of plankton volume data would increase if we

Table 7. Group composition of zooplankton samples (in percent) representing five spring and fall surveys: data from Isaacs, Fleminger and Miller, 1969.

| Cruise | 5504 | 5510 | 5604 | 5610 | 5704 | 5710 | 5804 | 5810 | 5904 | 5910 |
|------------------------|------|------|------|------|------|------|------|------|------|------|
| Crustacea | 55% | 49% | 39% | 17% | 24% | 35% | 60% | 51% | 47% | 37% |
| Thaliacea and Larvacea | 34 | 21 | 45 | 75 | 65 | 17 | 7 | 10 | 34 | 23 |
| Coelenterata | 7 | 14 | 11 | 3 | 6 | 18 | 15 | 17 | 9 | 25 |
| Chaetognatha | 4 | 10 | 4 | 4 | 4 | 27 | 17 | 17 | 7 | 11 |
| Radiolaria | 0.3 | 5 | 0.6 | 1 | 0.4 | 0.8 | 1 | 2 | 0.4 | 0.8 |
| Mollusca | 0.2 | 2 | 0.2 | 2 | 0.3 | 4 | 2 | 4 | 2 | 3 |

knew more about 1) estimates of the transport of plankton from one area to another, 2) the species composition of the individual samples,

3) the population dynamics of the major crustacean and thaliacean species and 4) the abundance of zooplankton of smaller sizes.

Table 8. Page numbers of charts. Charts arranged by month and year. (-) No cruise.
(*) Distribution for early and late monthly cruises are shown on the same chart. (**) Special cruises, no distribution charts included.

| | 1951 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 |
|------------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|-----|
| Jan. (01) | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Feb. (02) | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | — | — | — | — | — | 28 |
| Mar. (03) | 29 | 30* | 31* | 32 | 33 | 34 | 35 | 36 | 37 | 38 | — | — | — | — | — | — |
| Apr. (04) | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 |
| May (05) | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | — | — | — | — | — | 65 |
| June (06) | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | — | — | — | — | — | 76 |
| July (07) | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 |
| Aug. (08) | 93 | 94 | 95 | 96 | ** | 97 | 98 | 99 | 100 | 101 | — | — | — | — | — | 102 |
| Sept. (09) | 103 | 104* | 105 | ** | ** | 106 | 107 | 108 | 109 | 110 | — | — | — | — | — | 111 |
| Oct. (10) | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 125 | — | 127 |
| Nov. (11) | 128 | 129 | 130 | ** | ** | 131 | 132 | 133 | 134 | — | — | — | — | — | — | 135 |
| Dec. (12) | 136 | — | 137 | 138 | 139 | 140 | 141 | 142 | 143 | — | — | — | — | — | — | 144 |

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JANUARY



FEBRUARY



MARCH



APRIL



MAY



JUNE



JULY



AUGUST



SEPTEMBER



OCTOBER

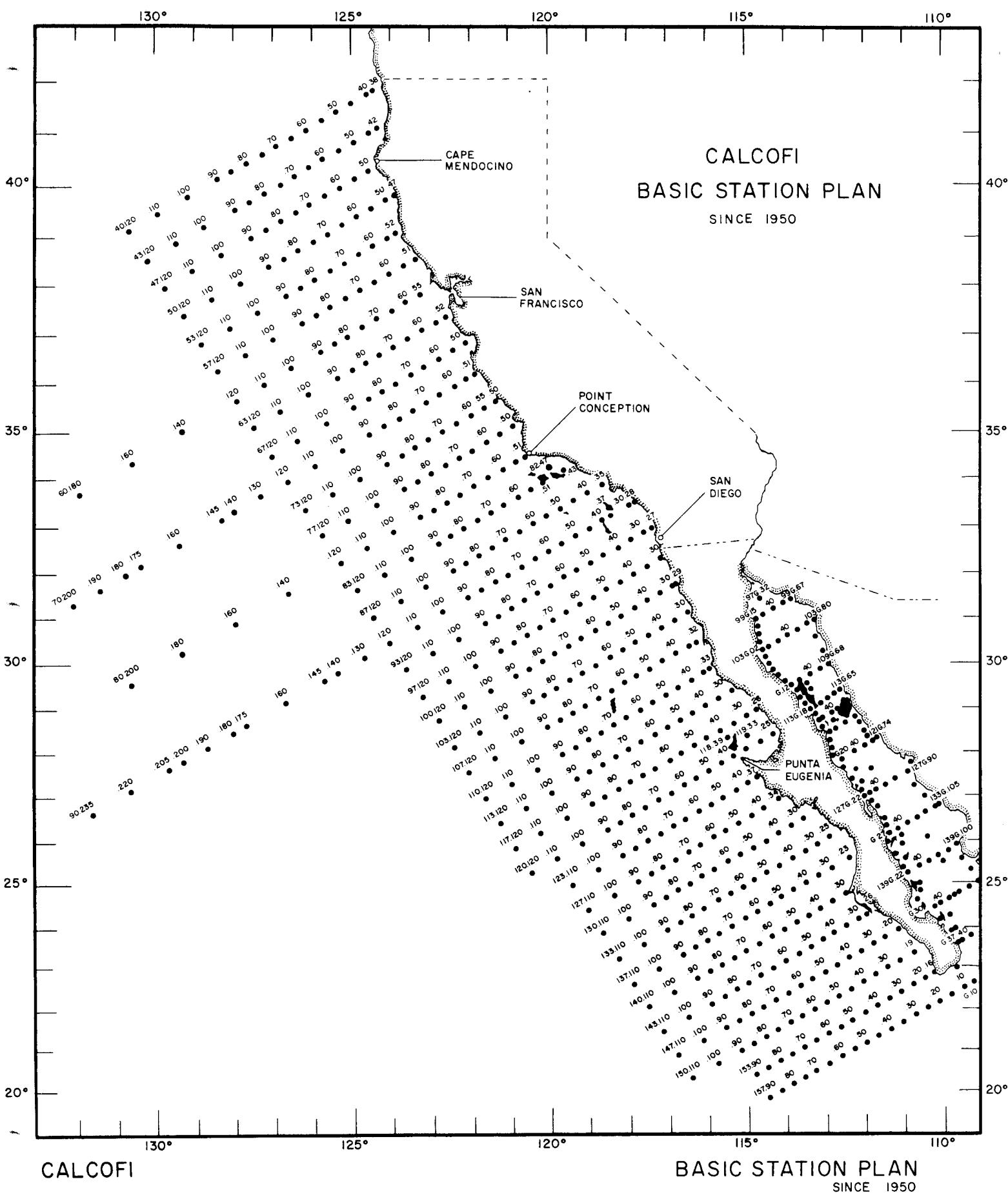


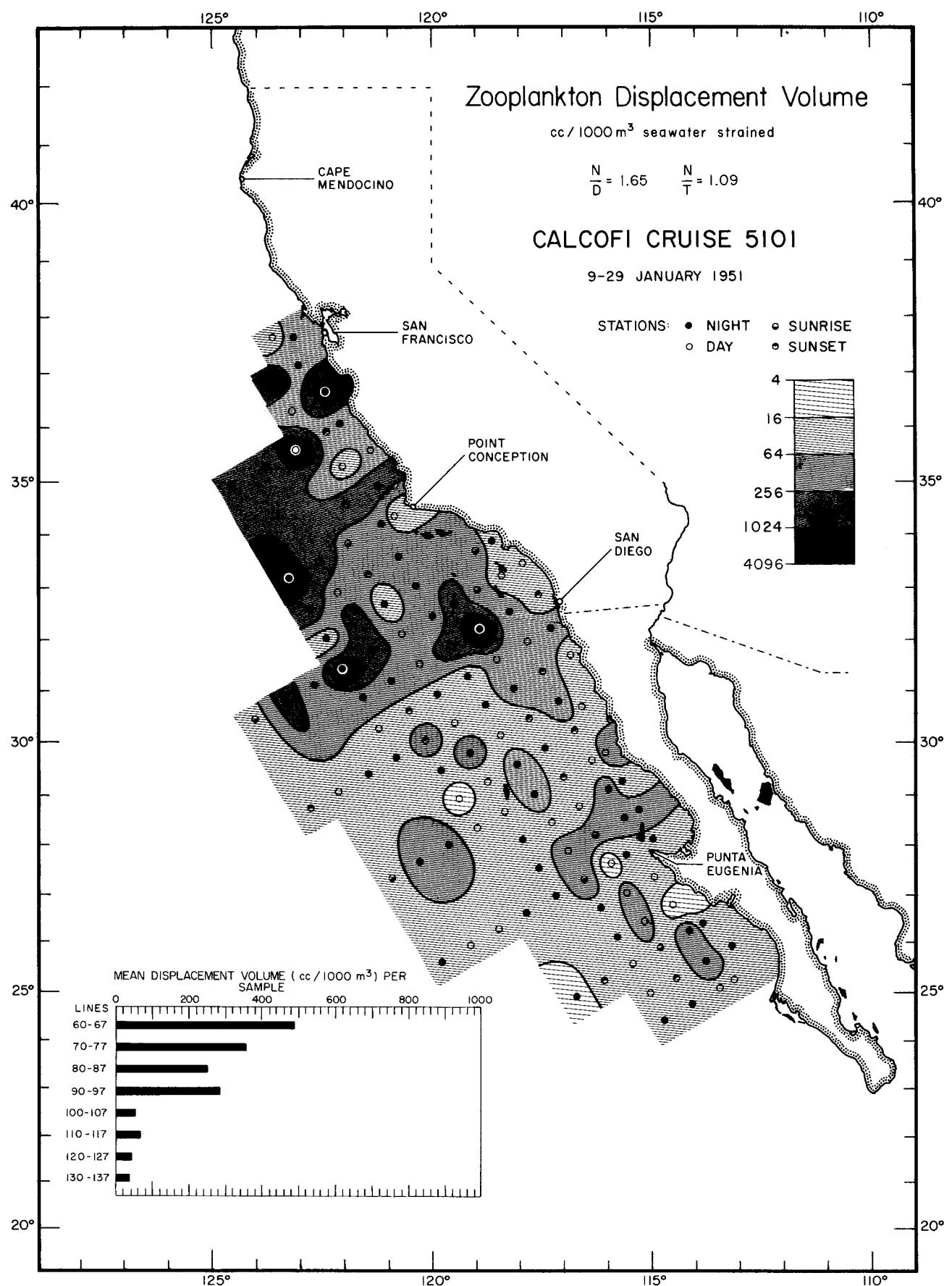
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DECEMBER

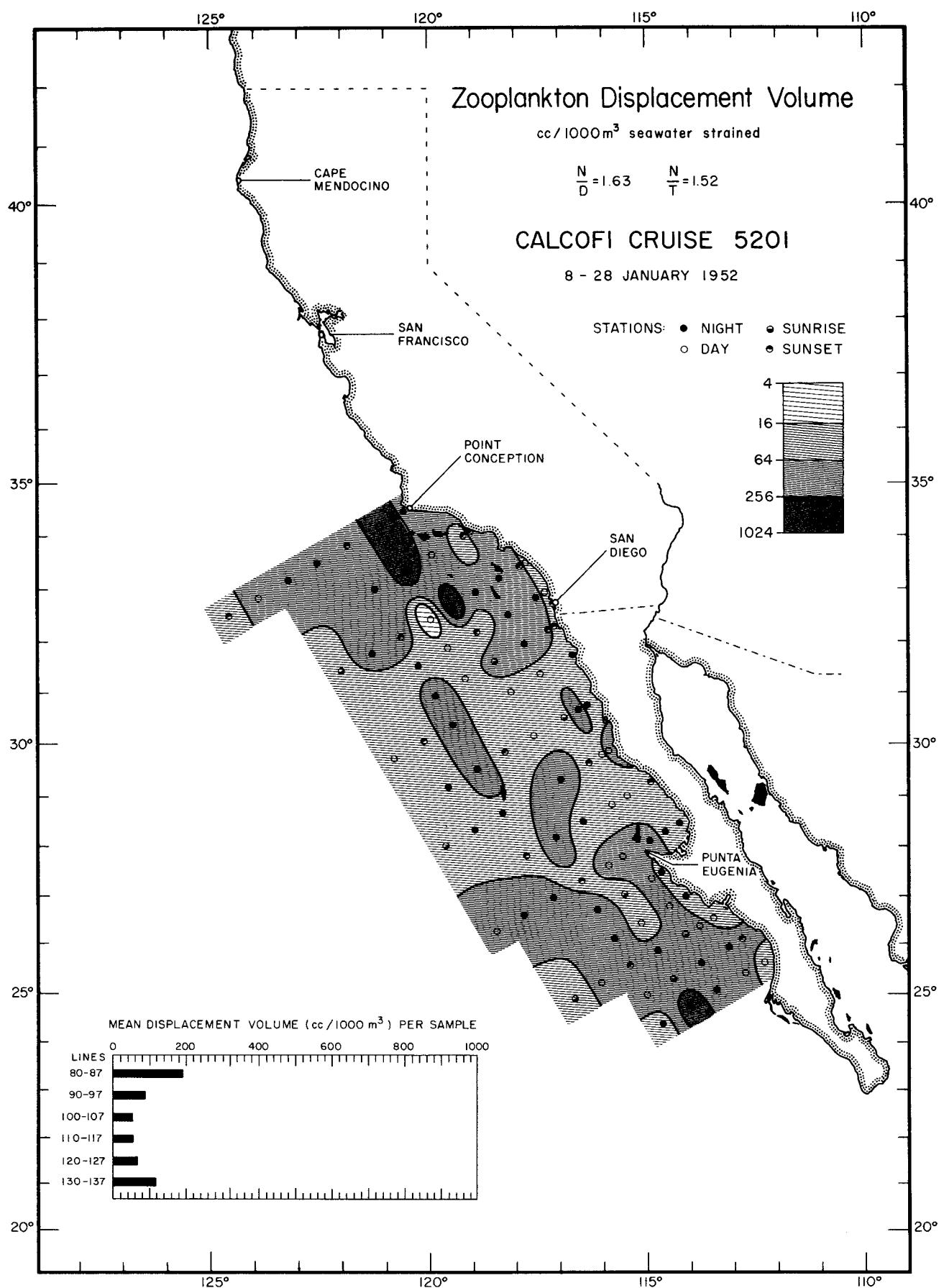






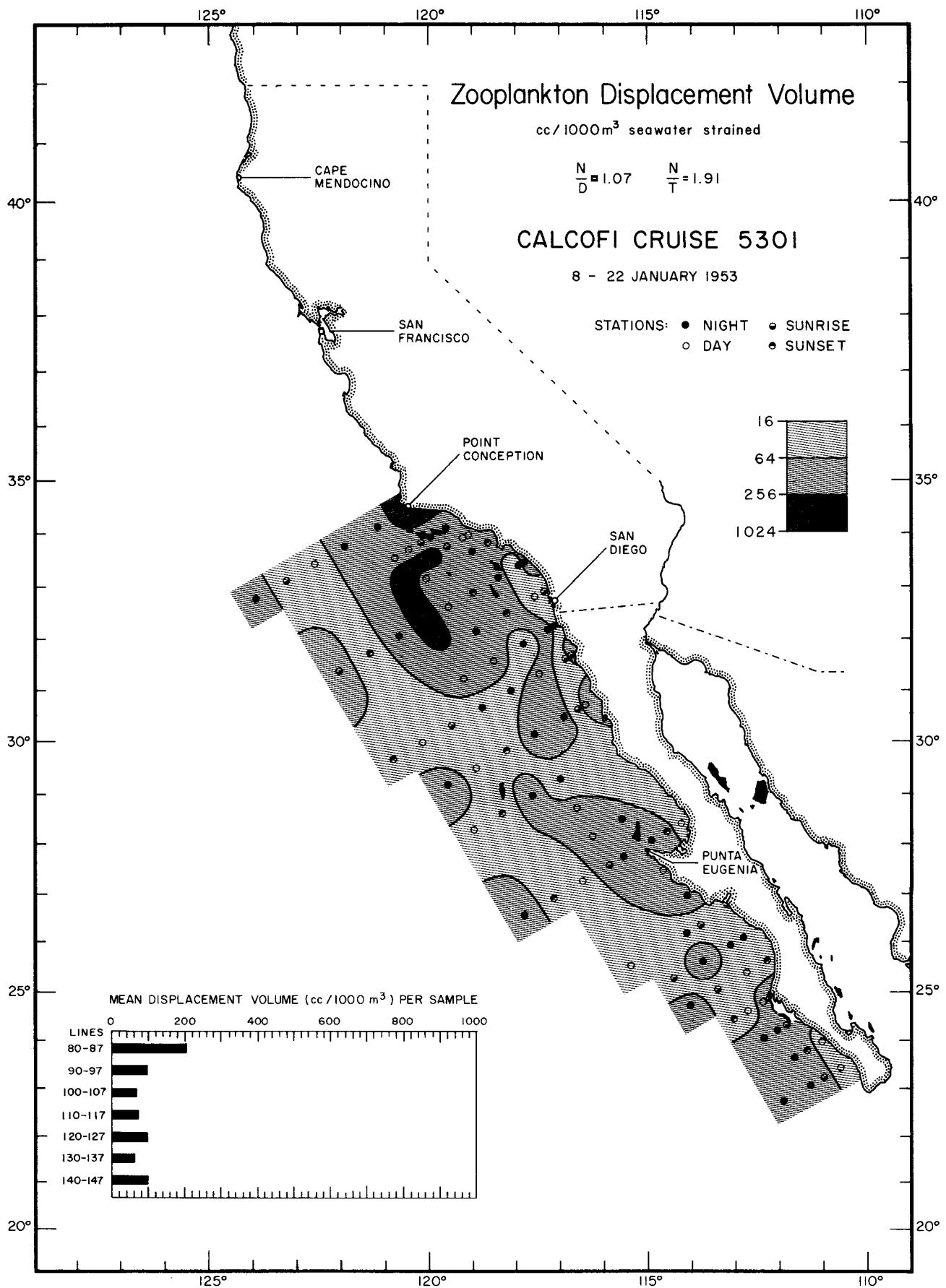
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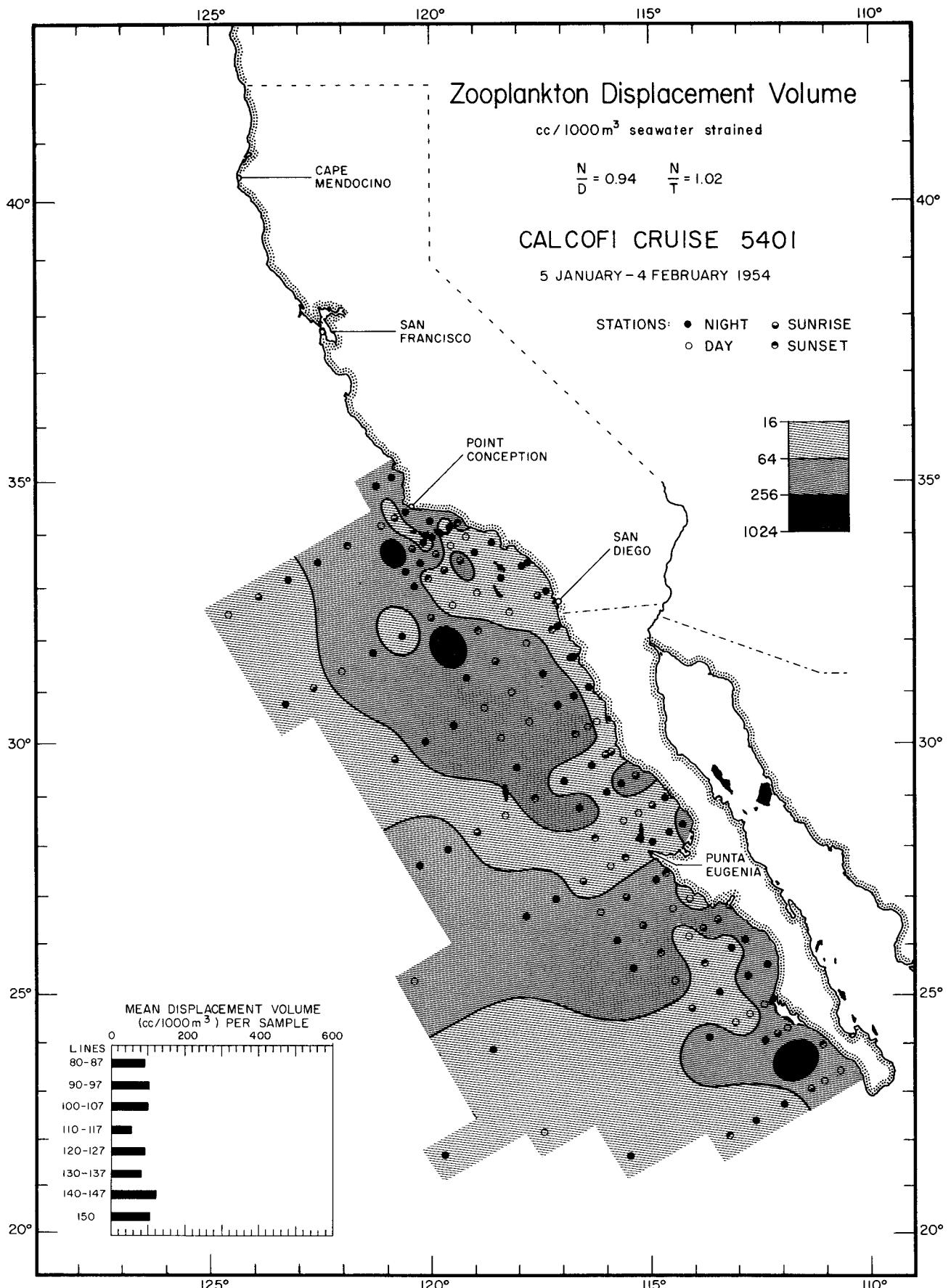
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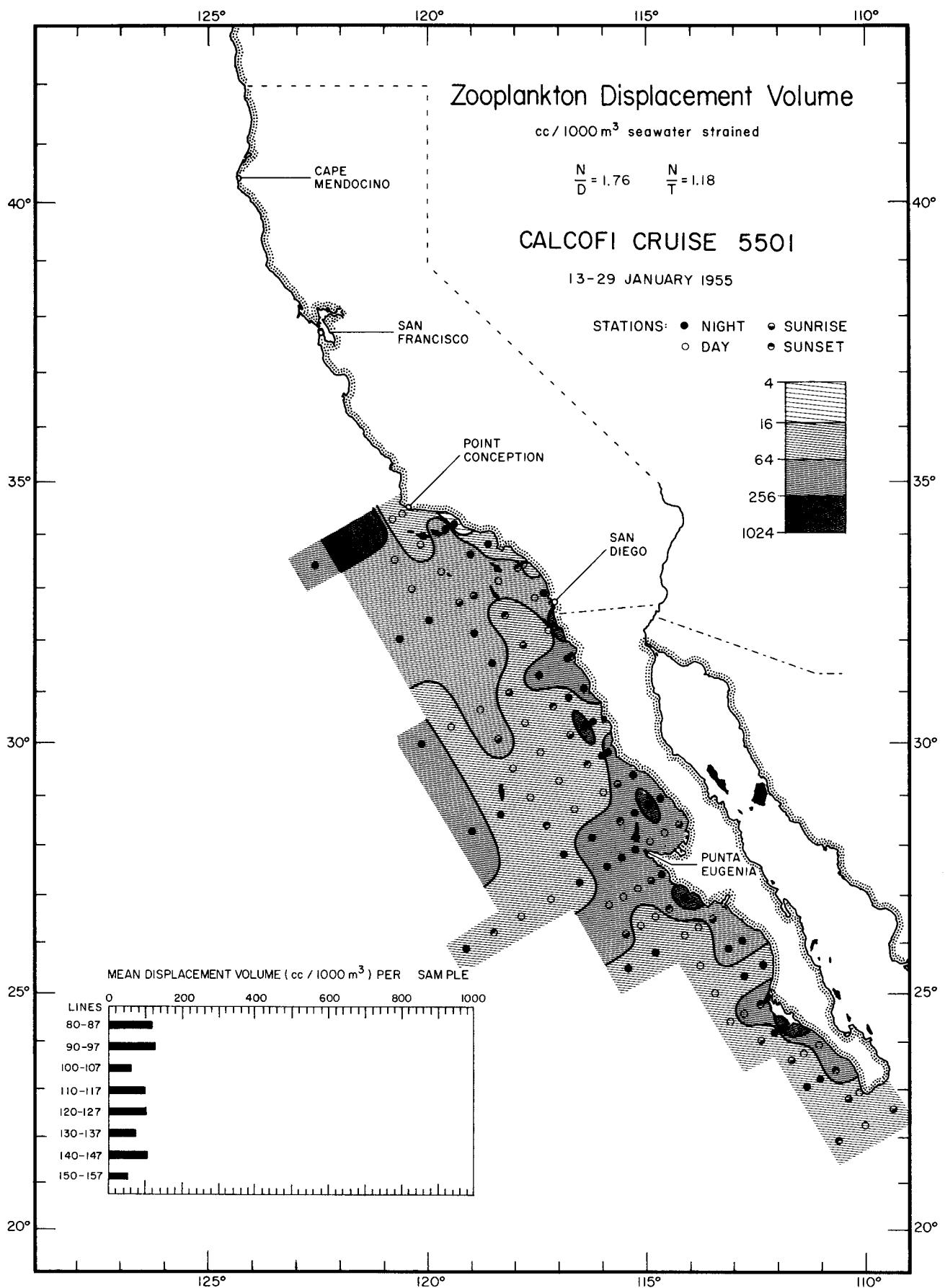
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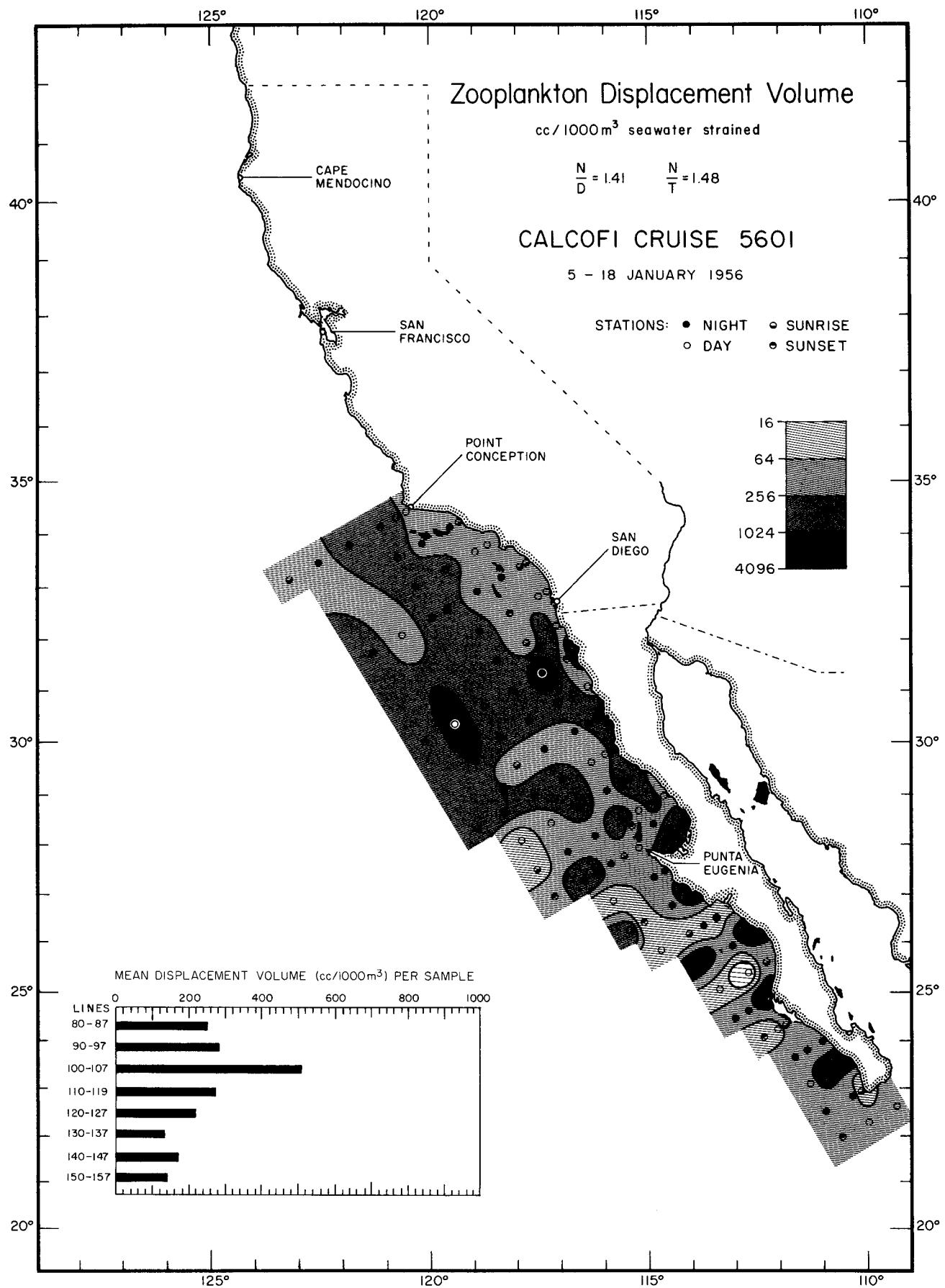
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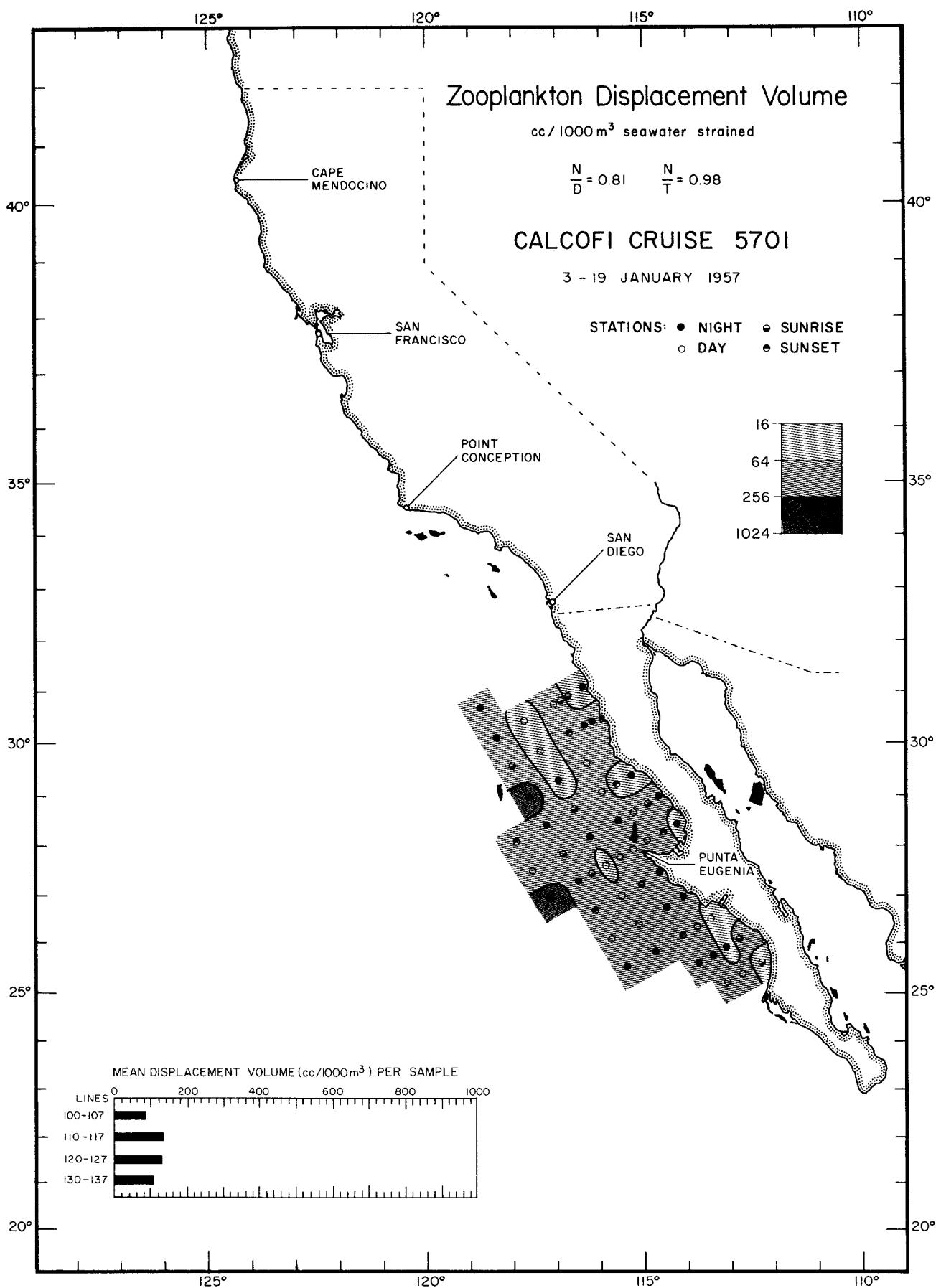
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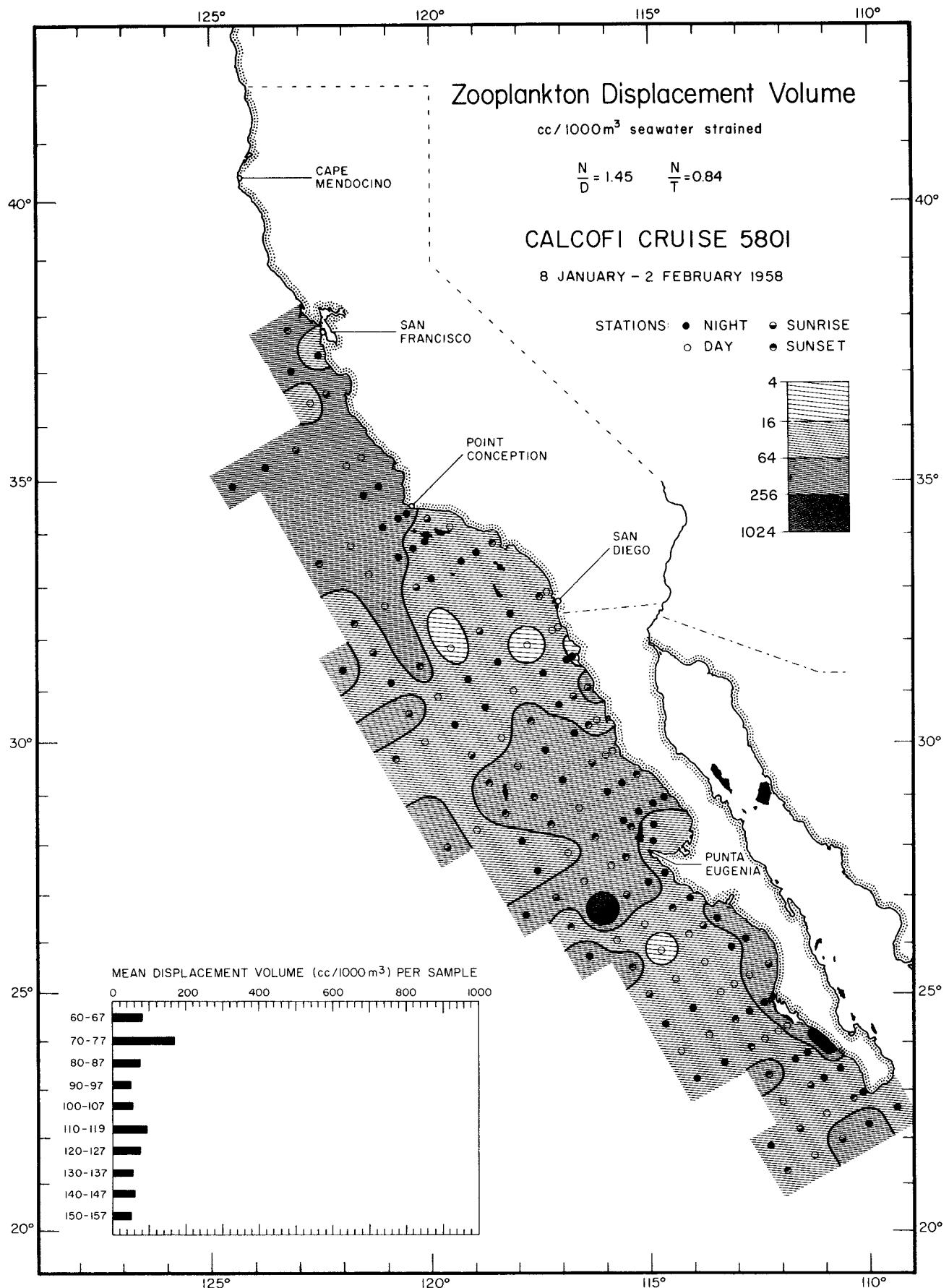
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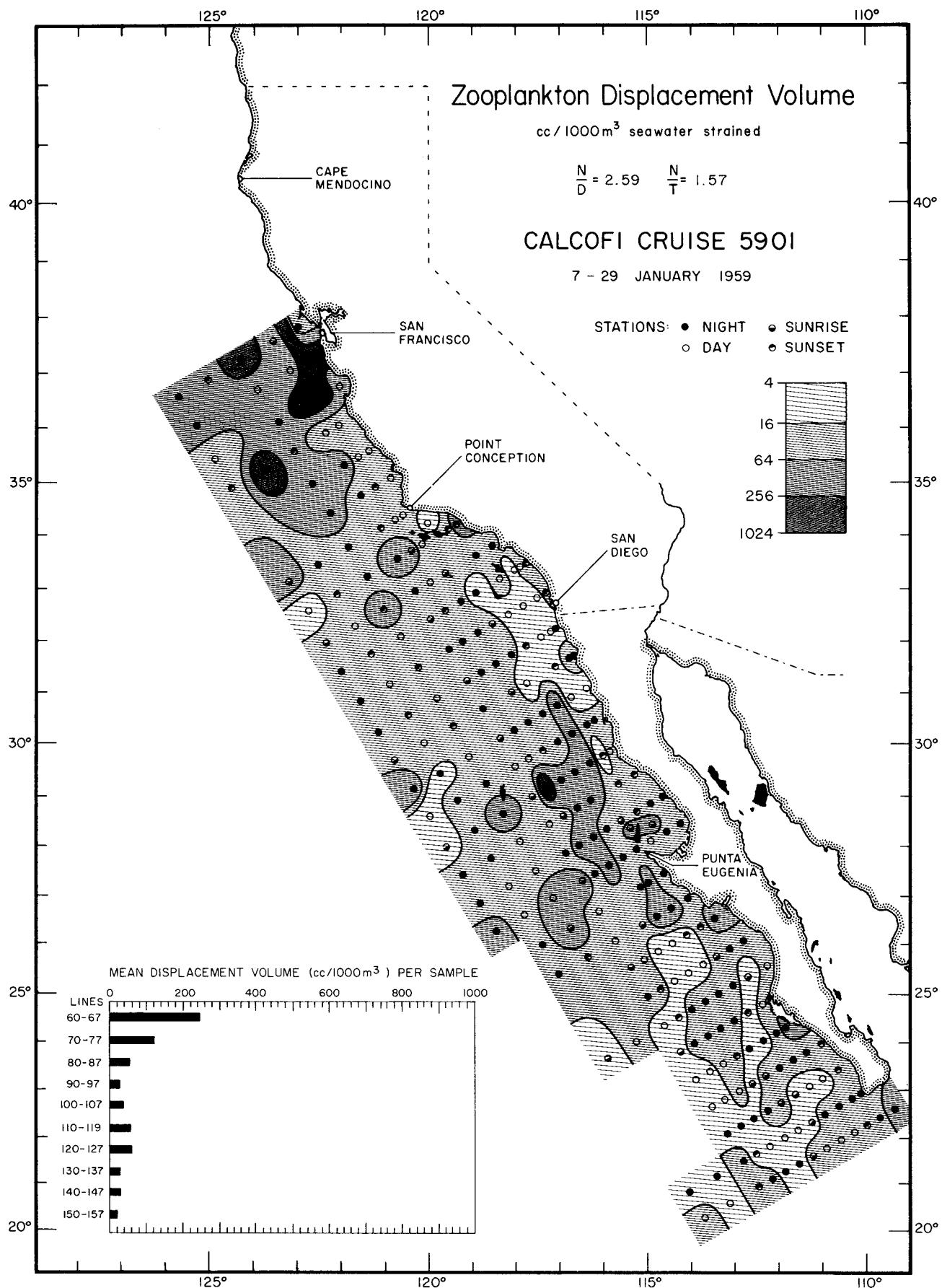
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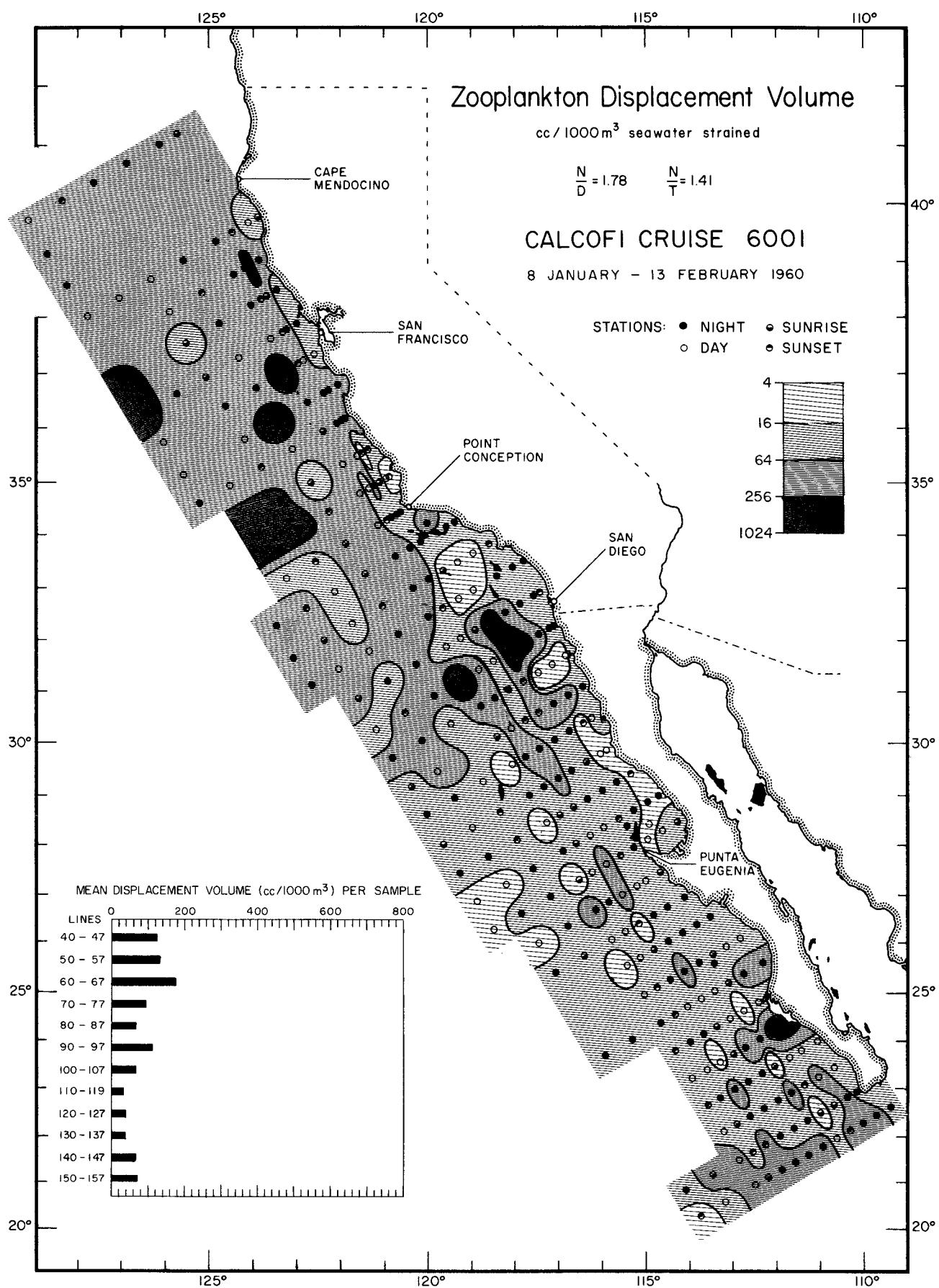
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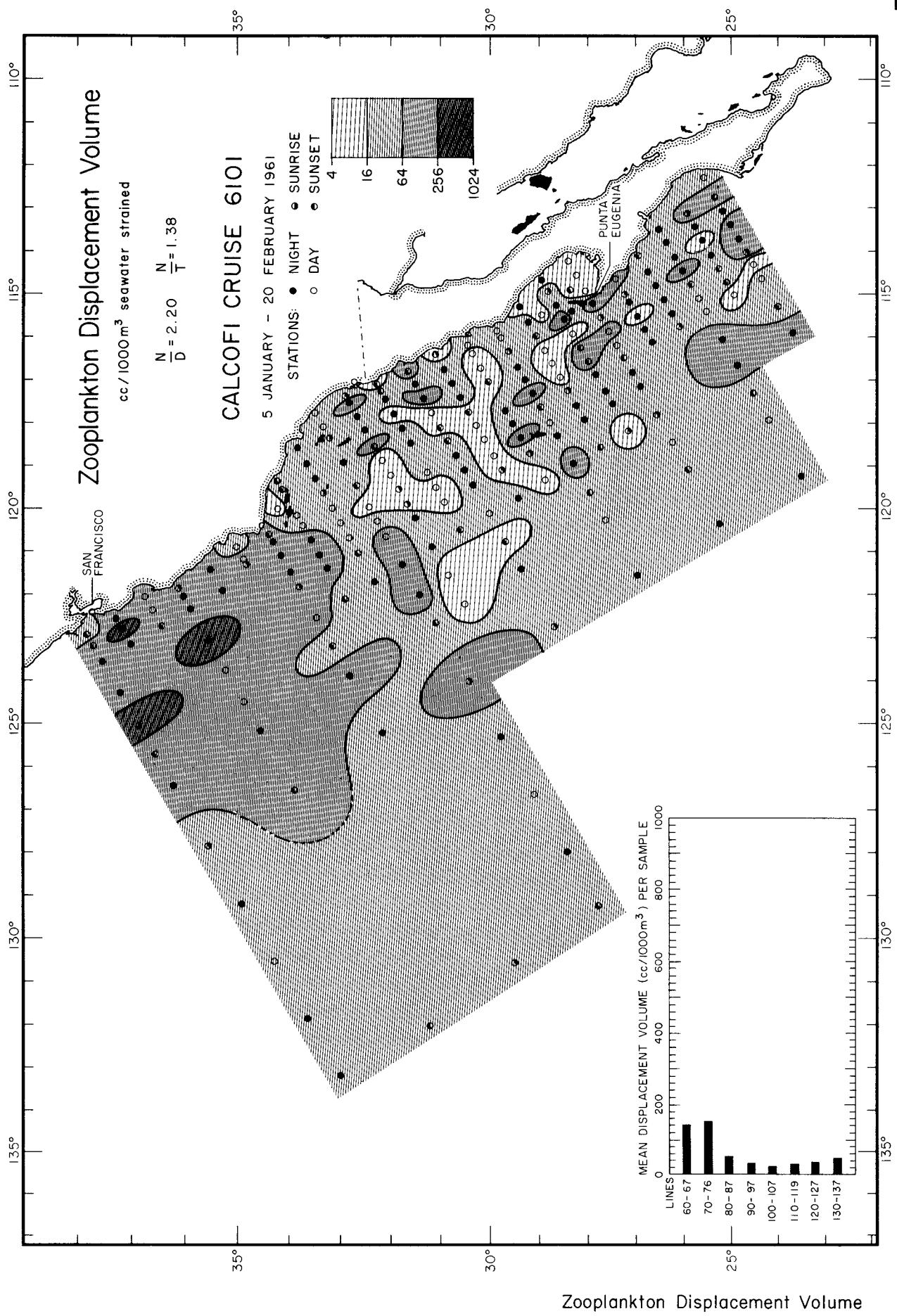
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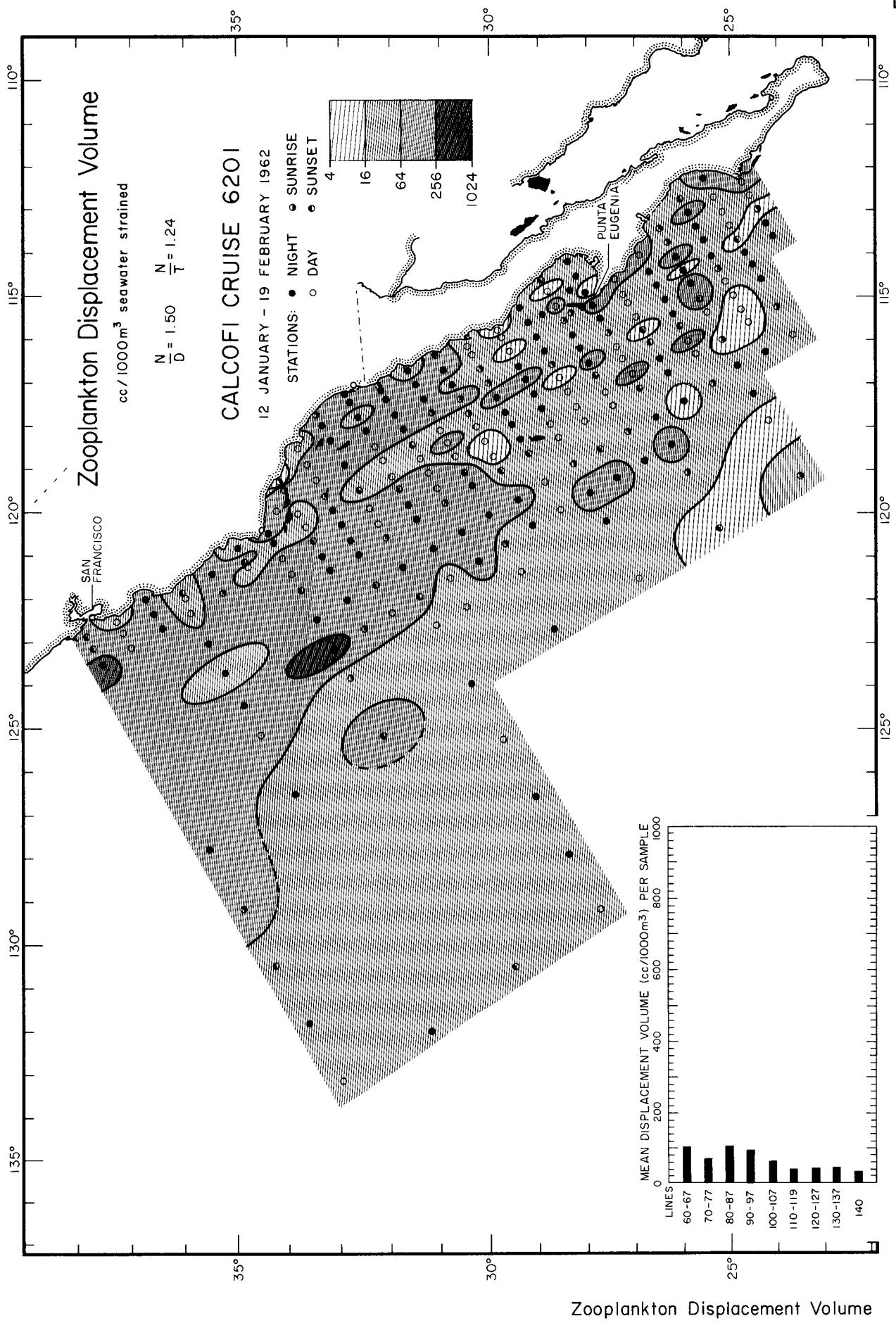
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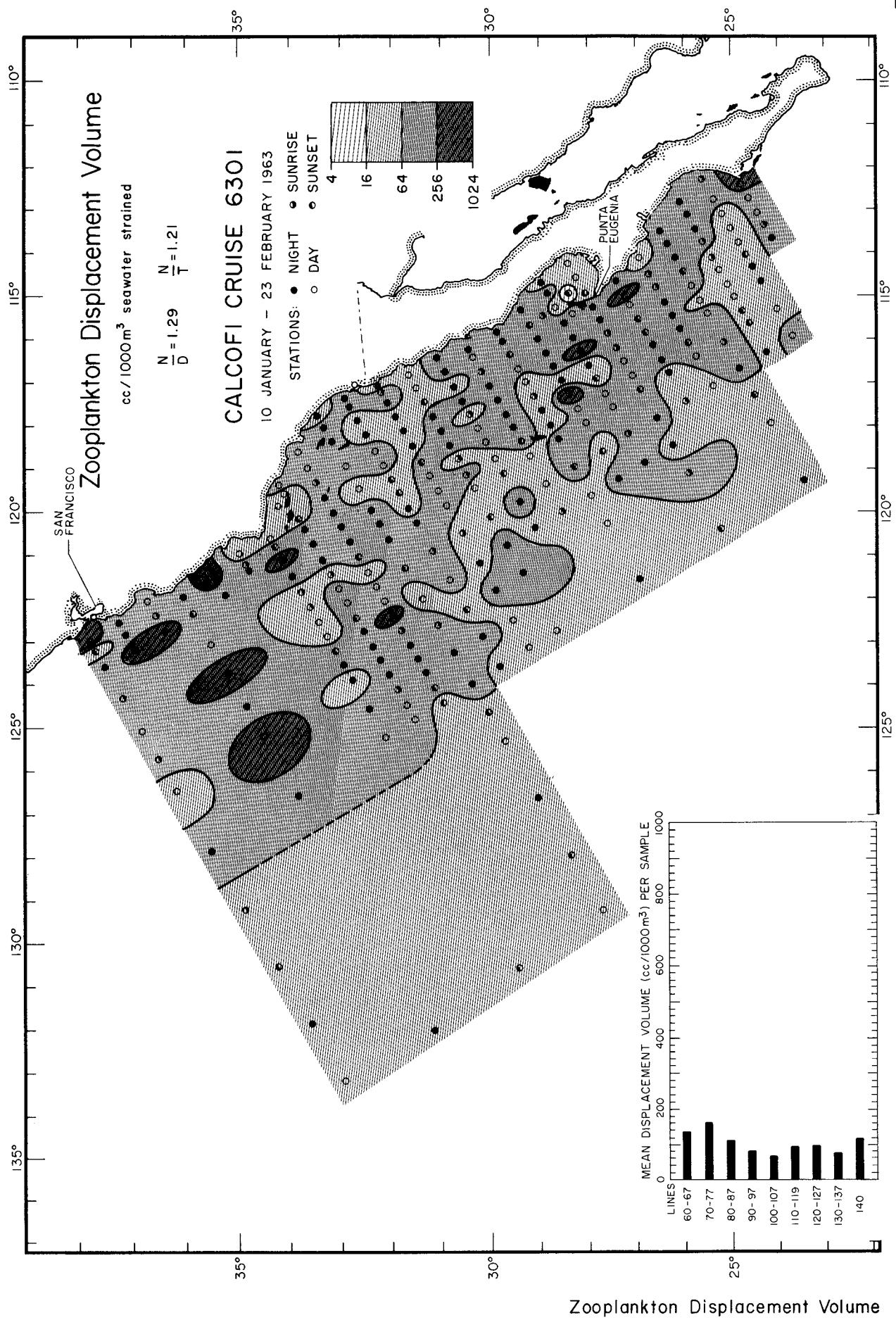
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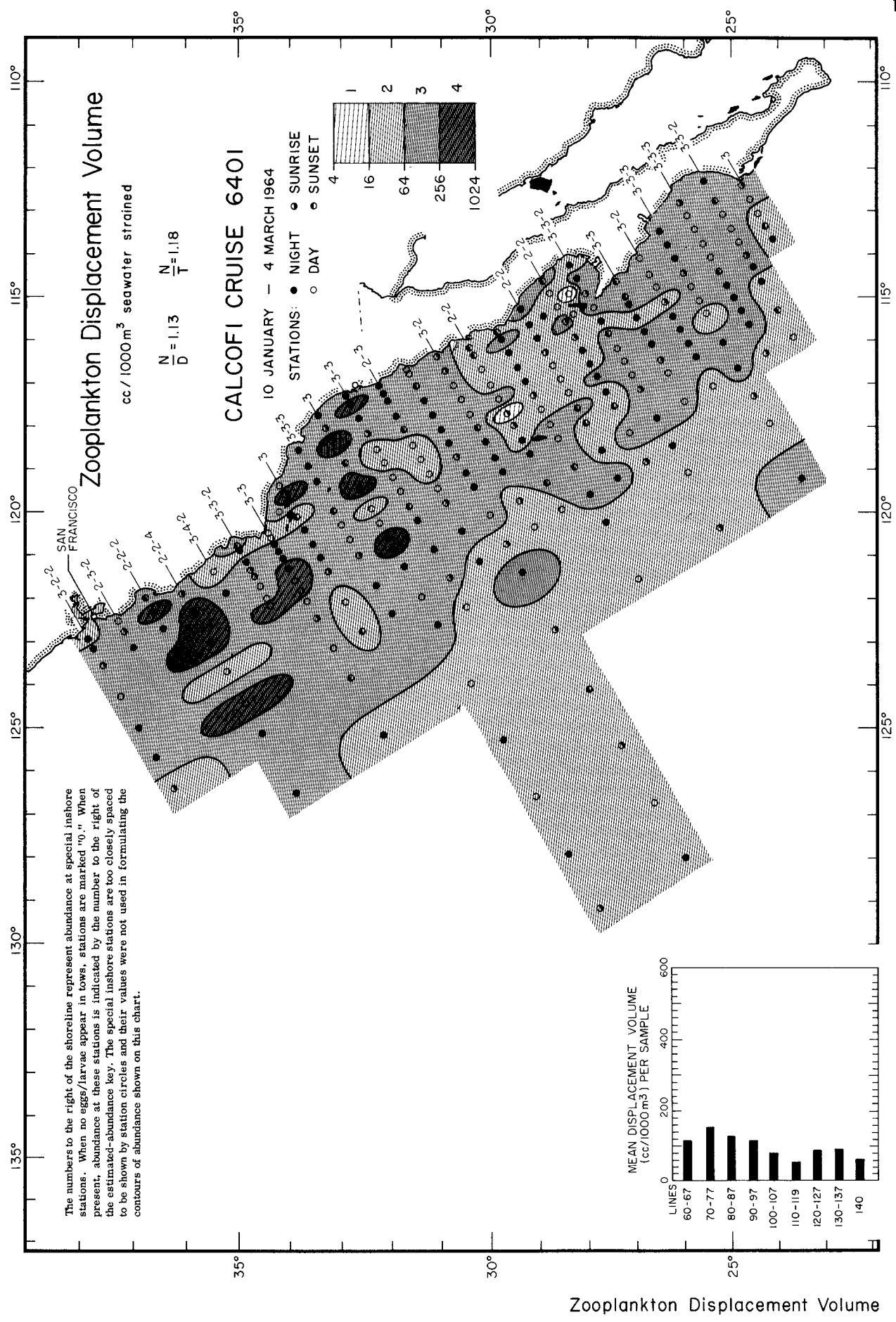
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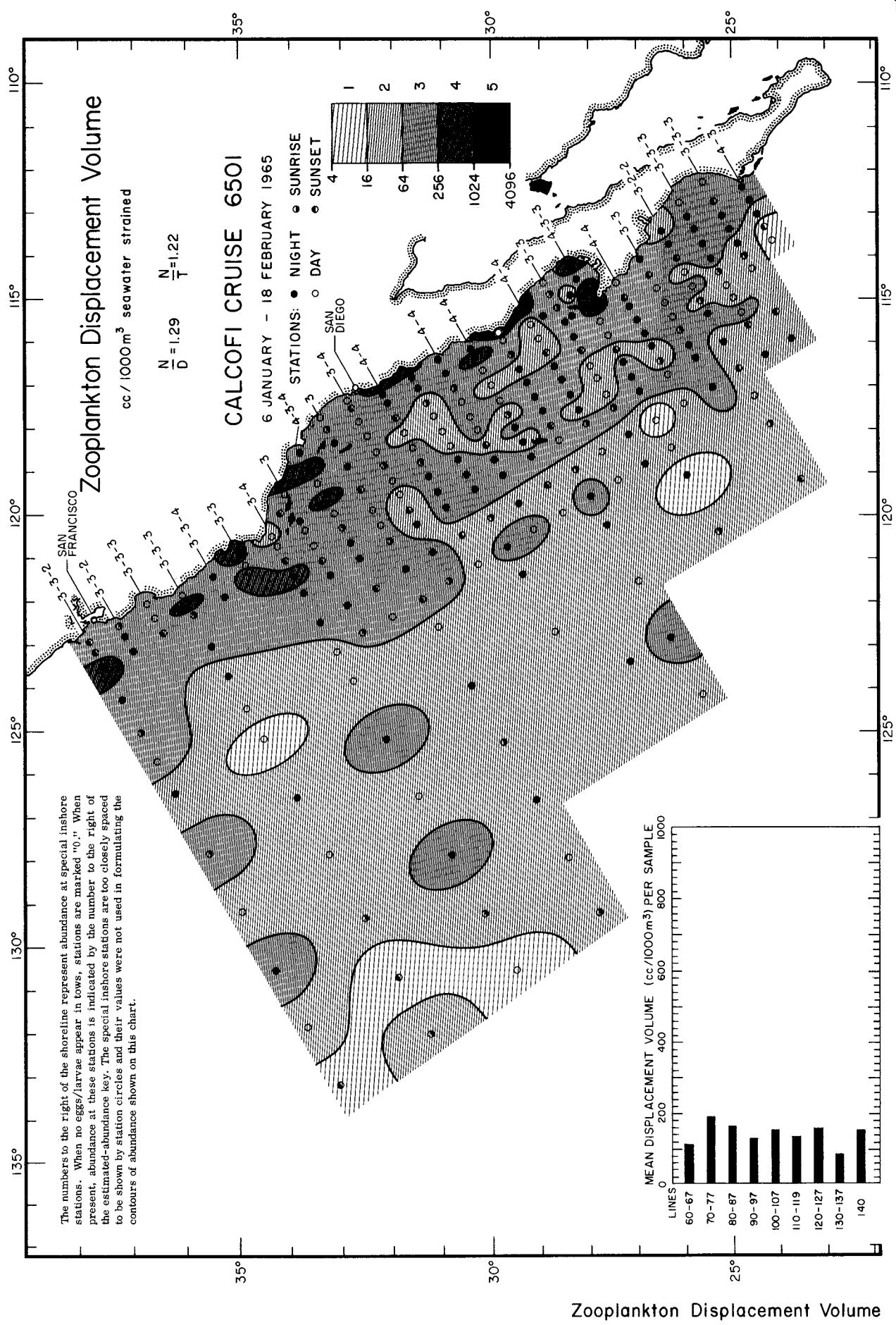


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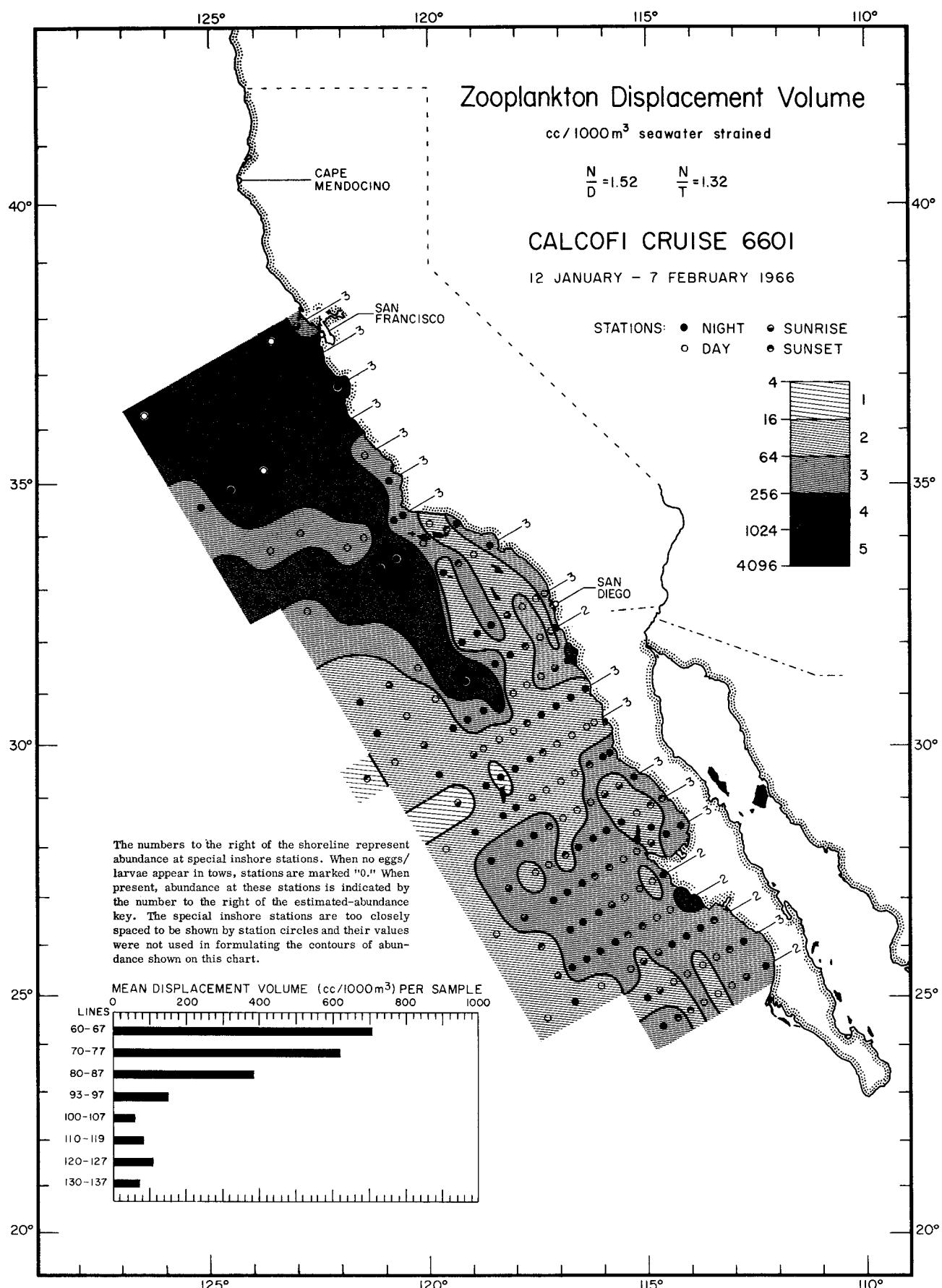




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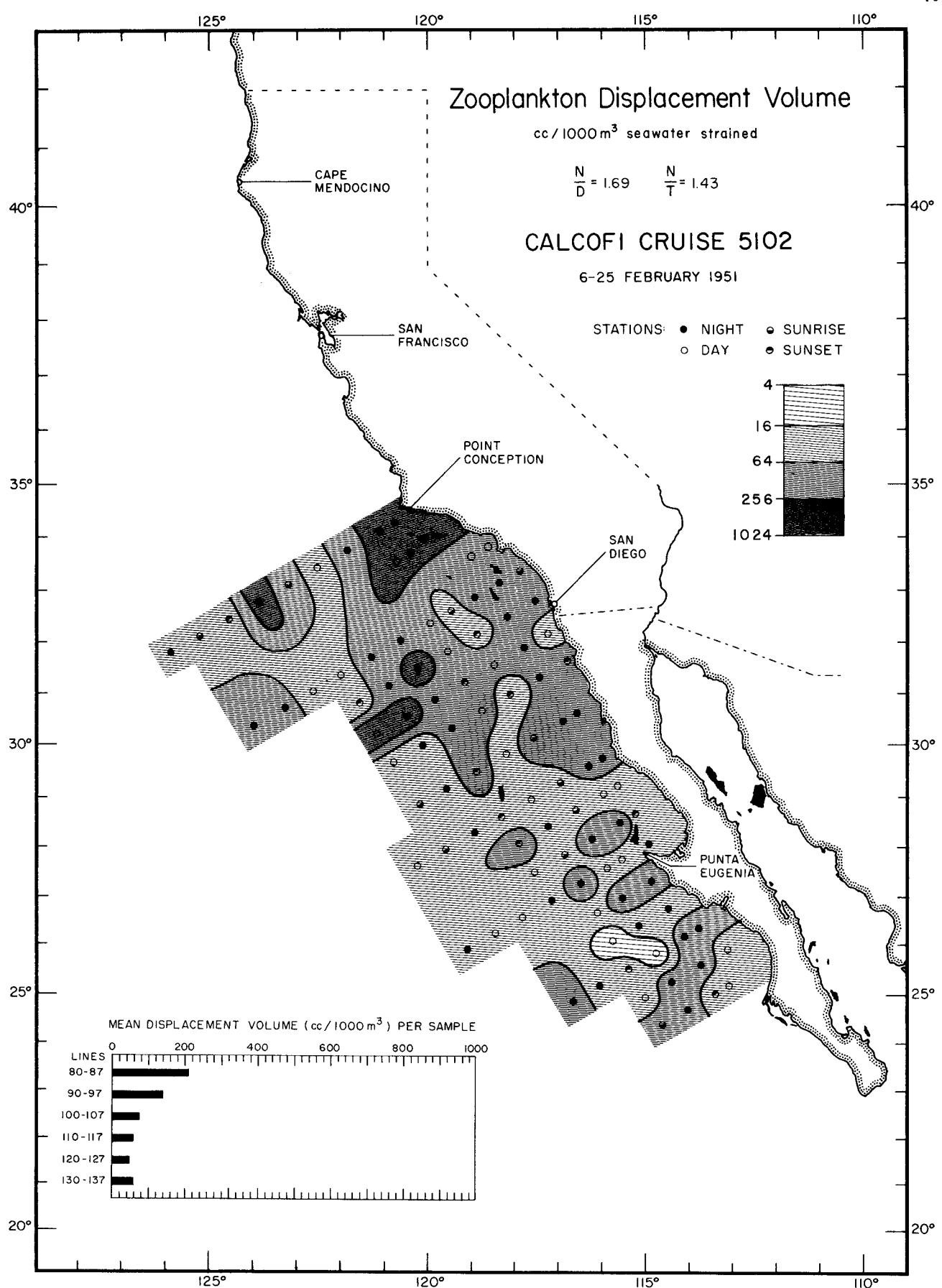


The numbers to the right of the shoreline represent abundance at special inshore stations. When no eggs/larvae appear in tows, stations are marked "0." When present, abundance at these stations is indicated by the number to the right of the estimated-abundance key. The special inshore stations are too closely spaced to be shown by station circles and their values were not used in formulating the contours of abundance shown on this chart.



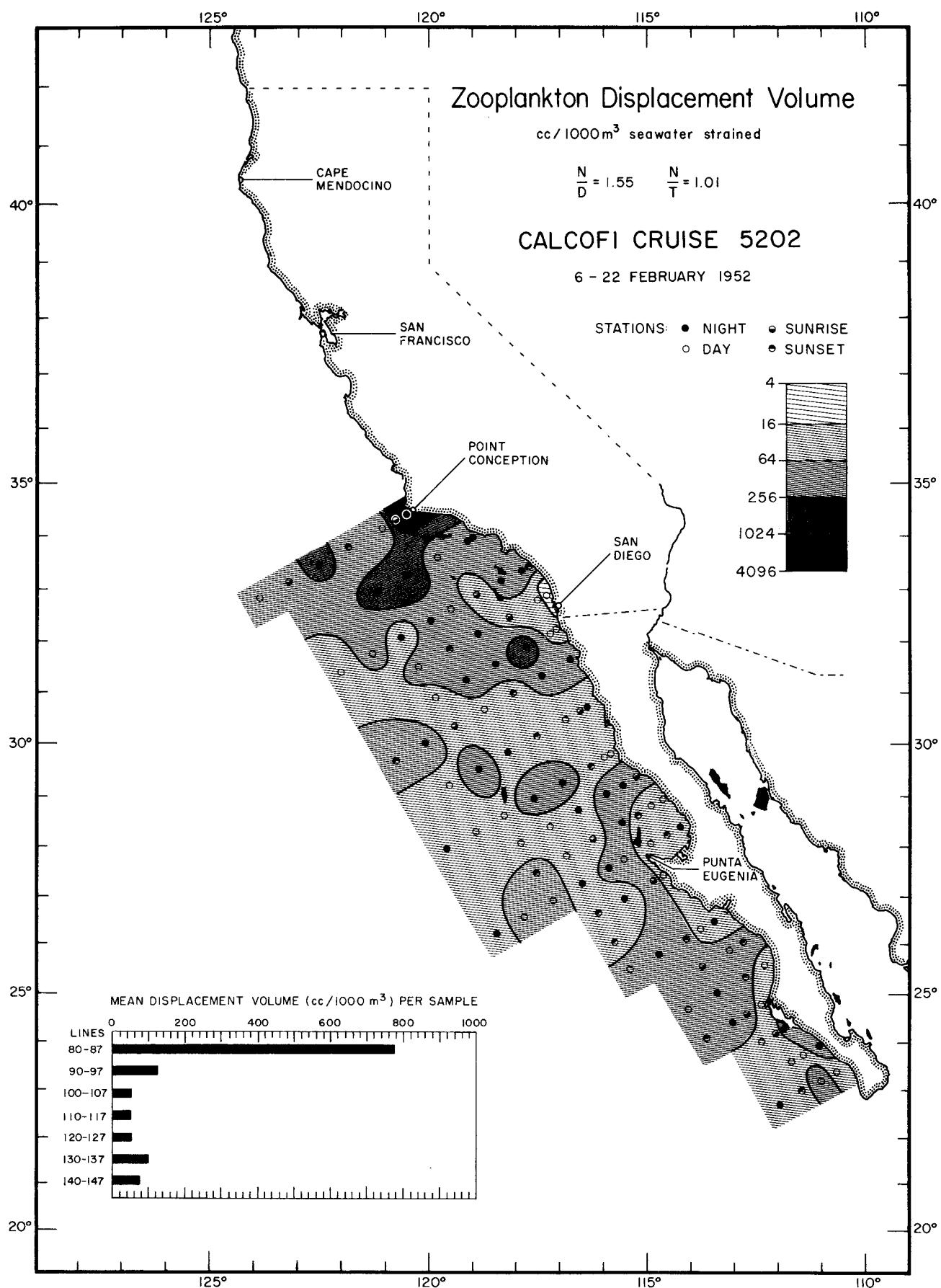
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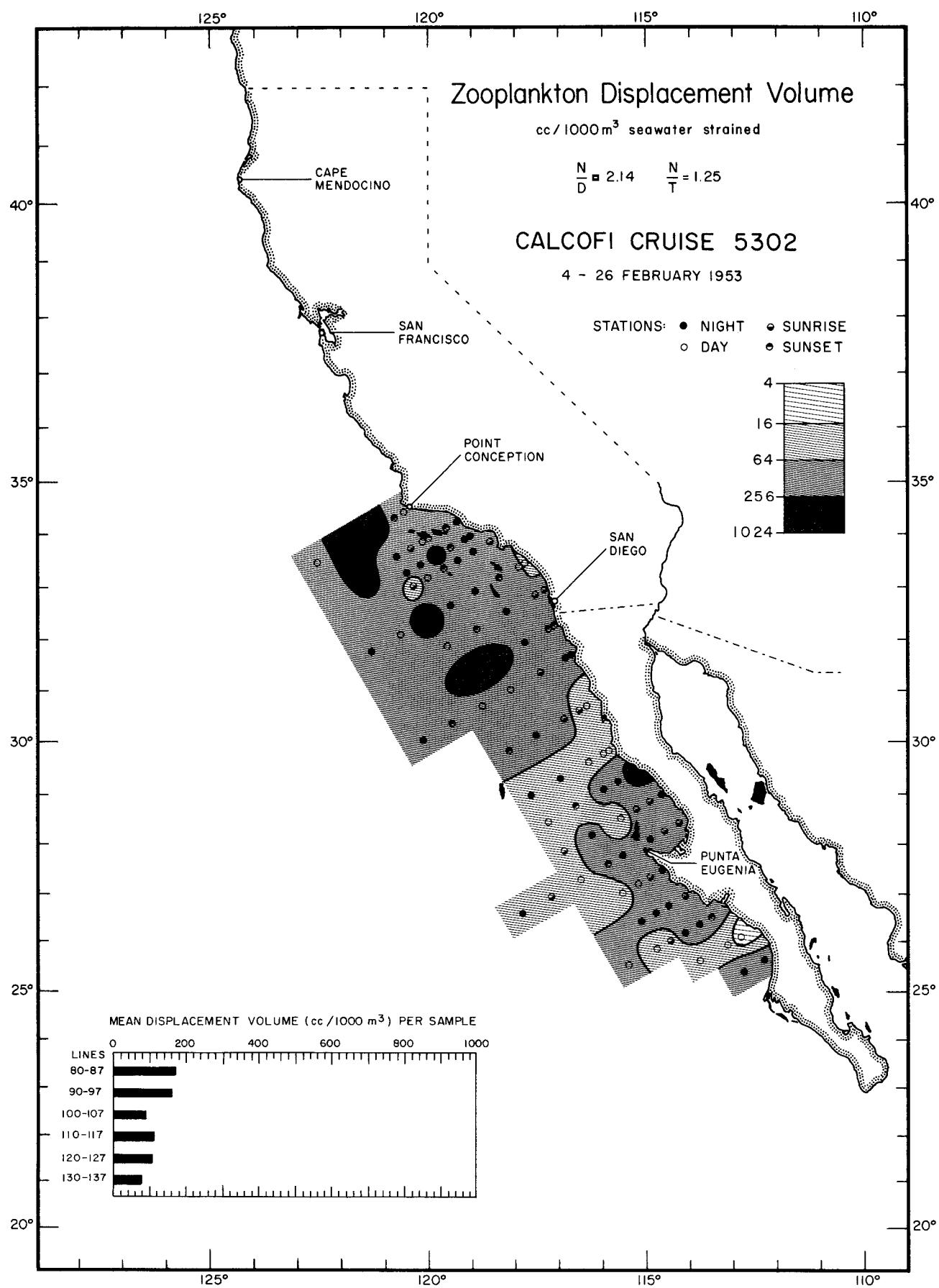
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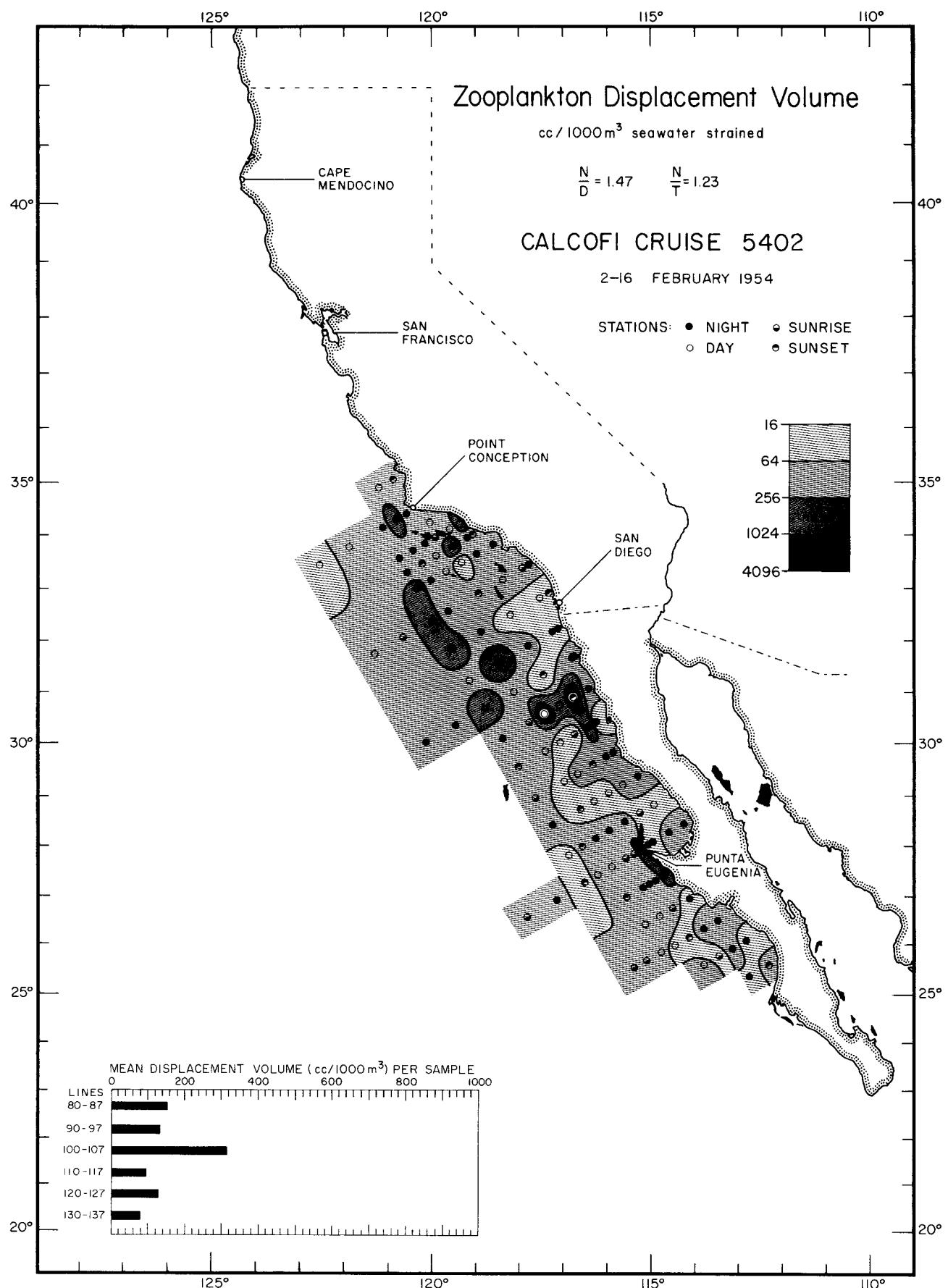
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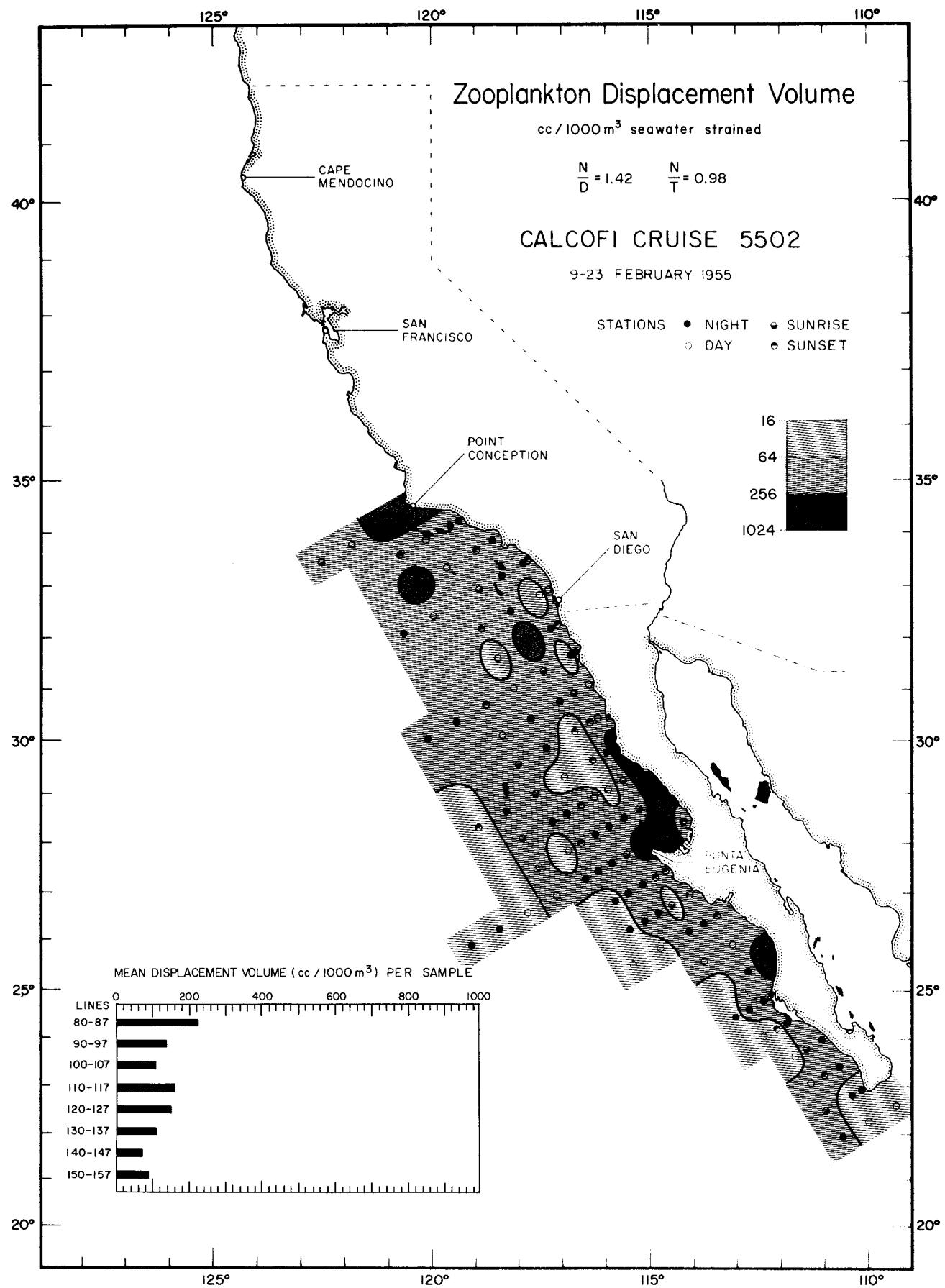
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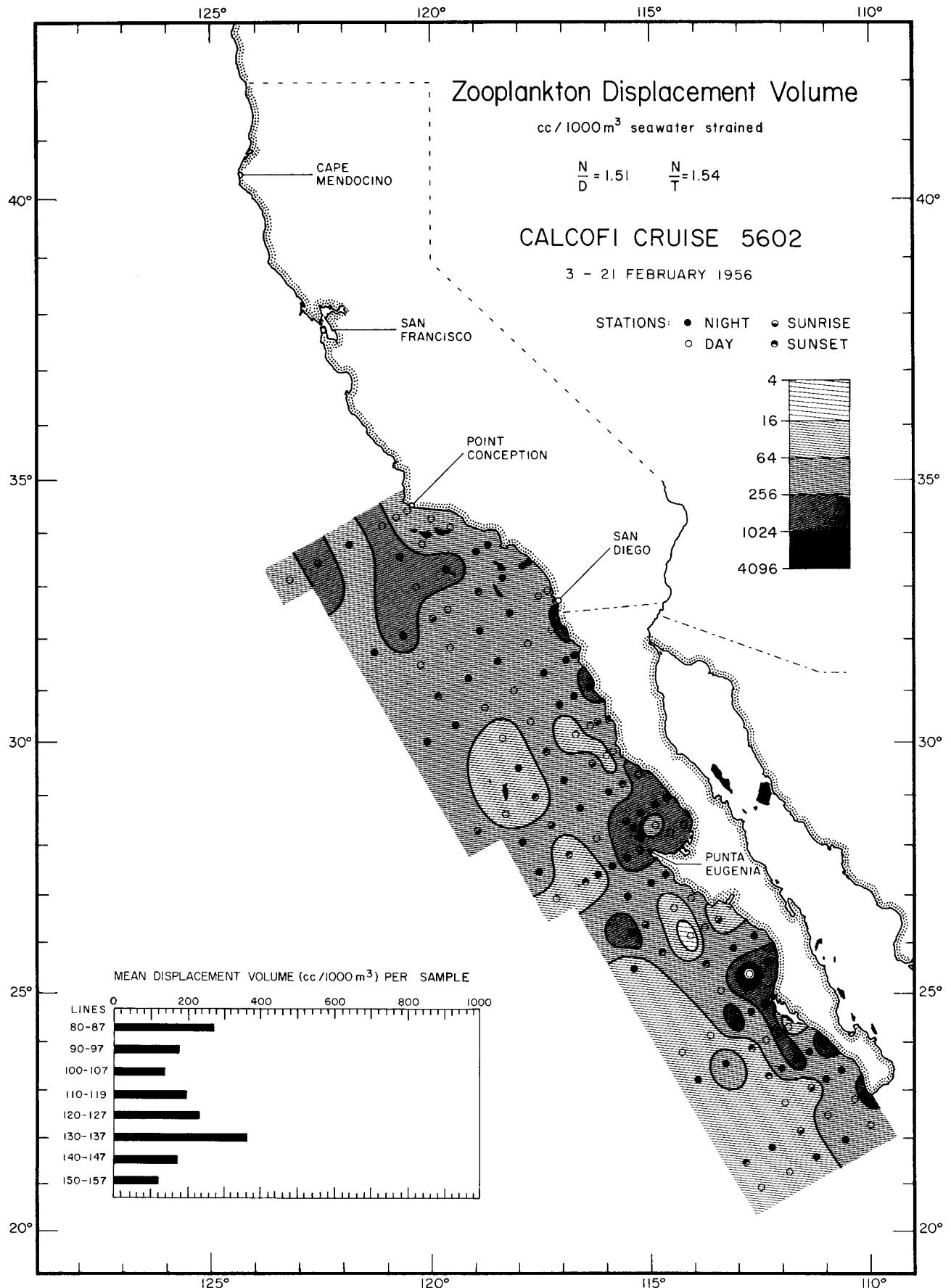
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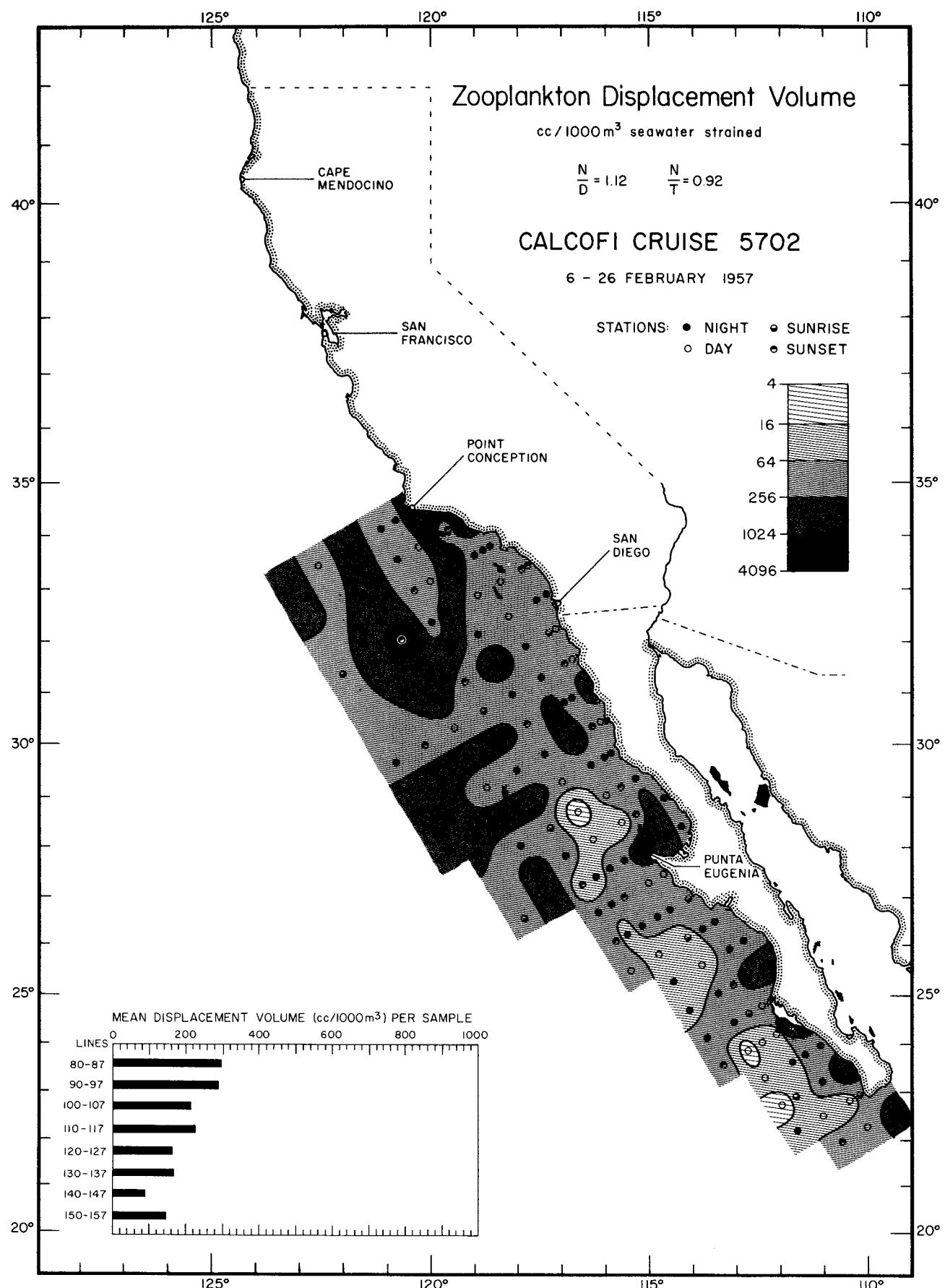
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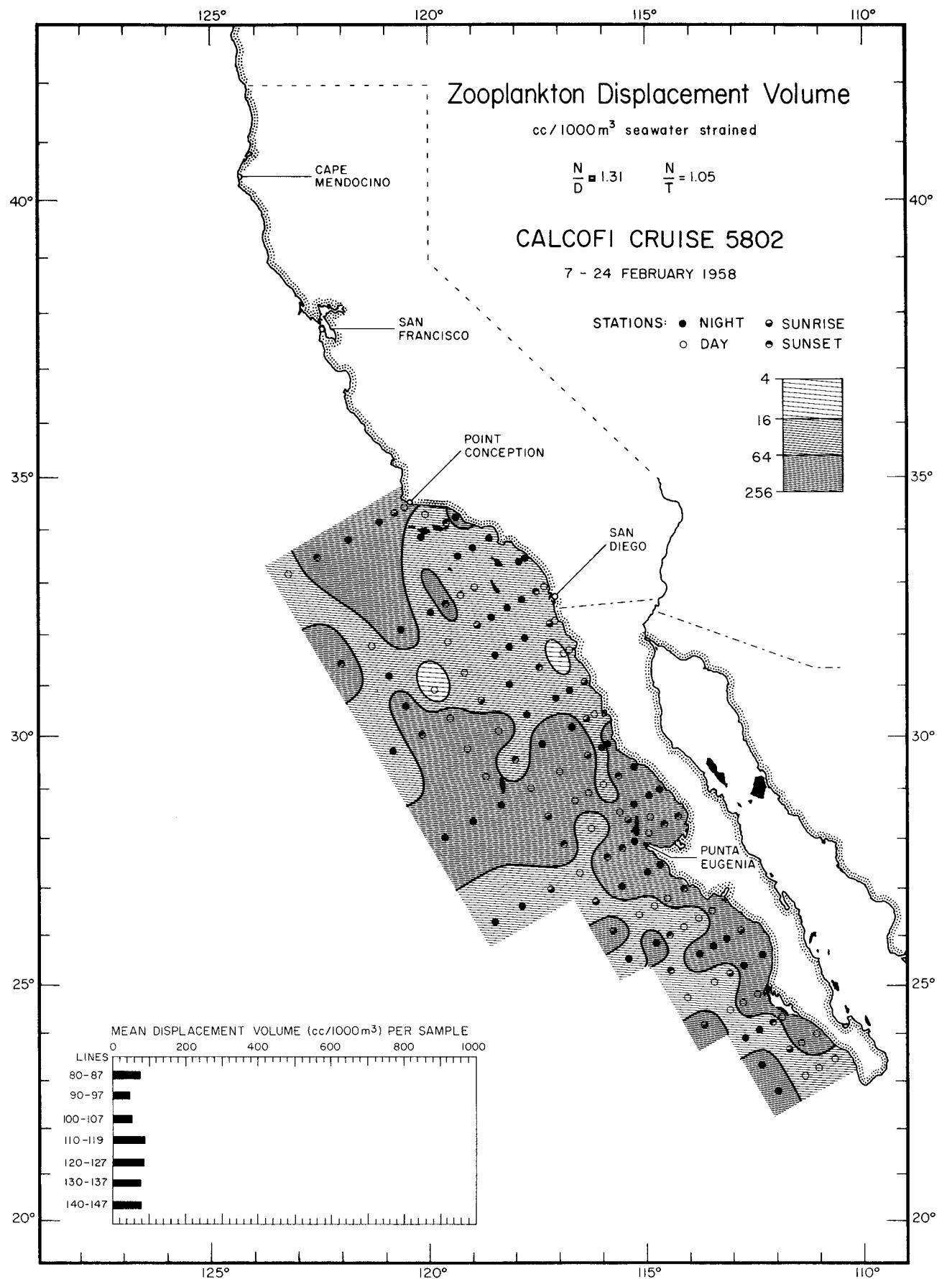
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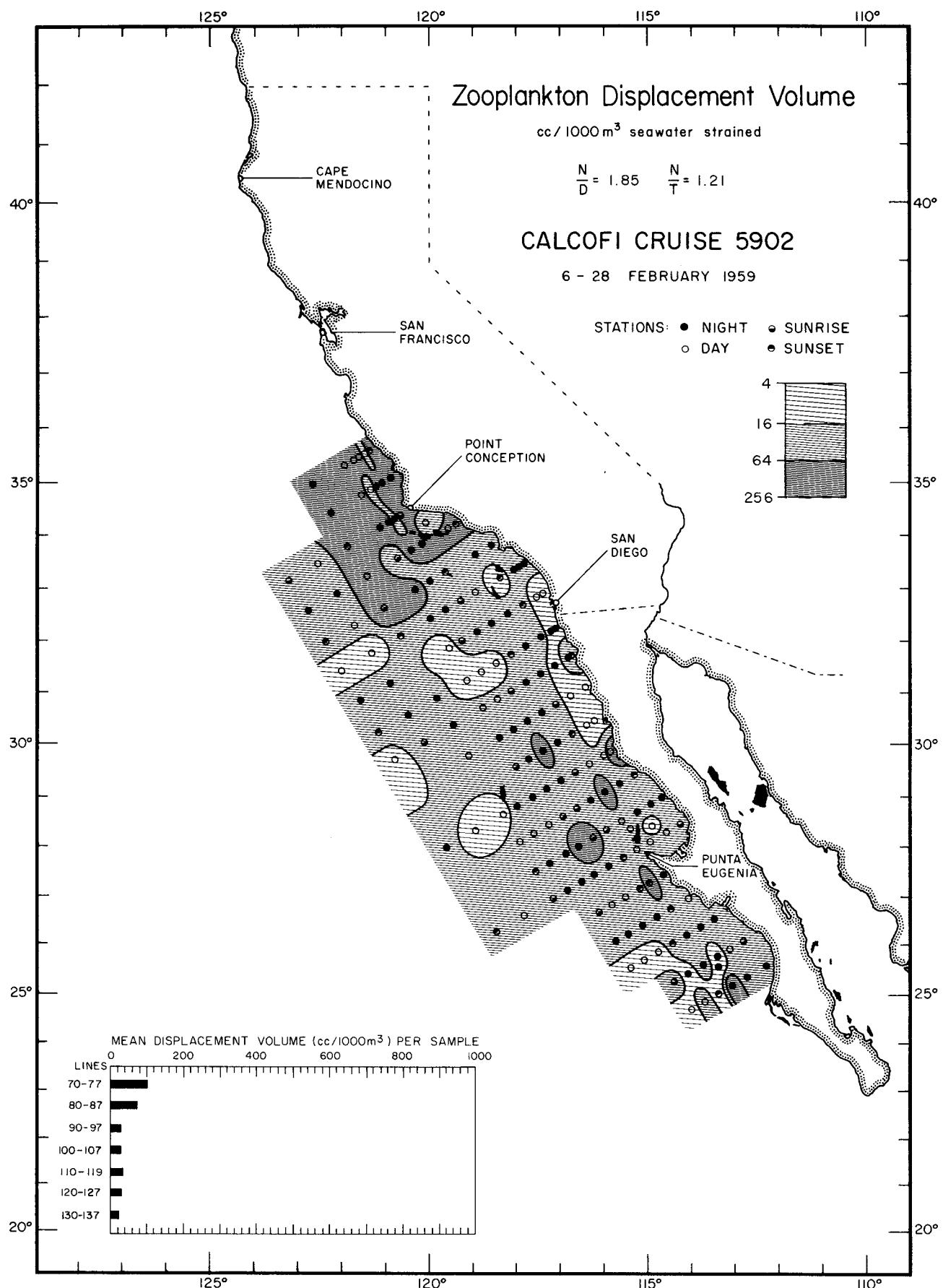
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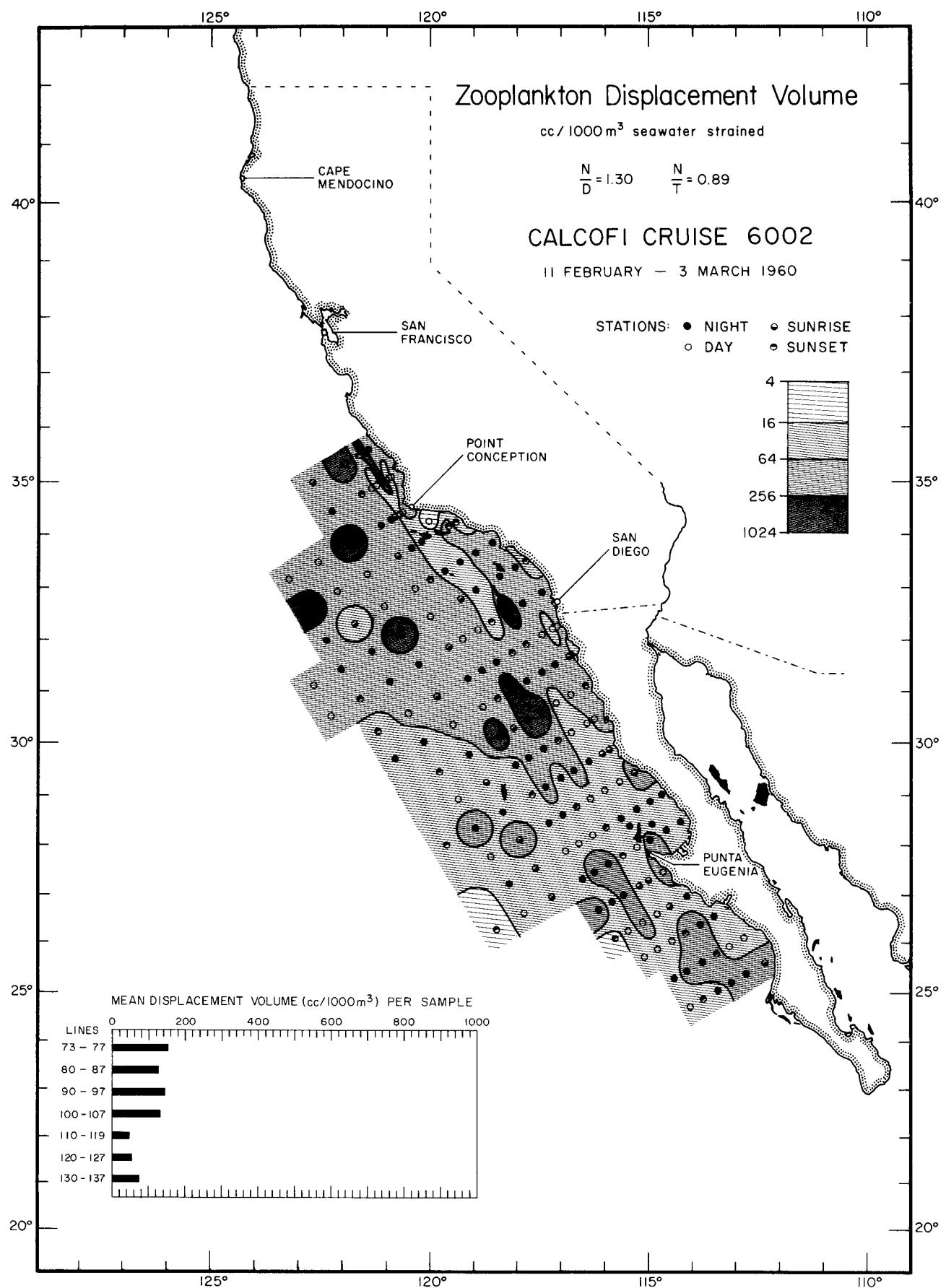
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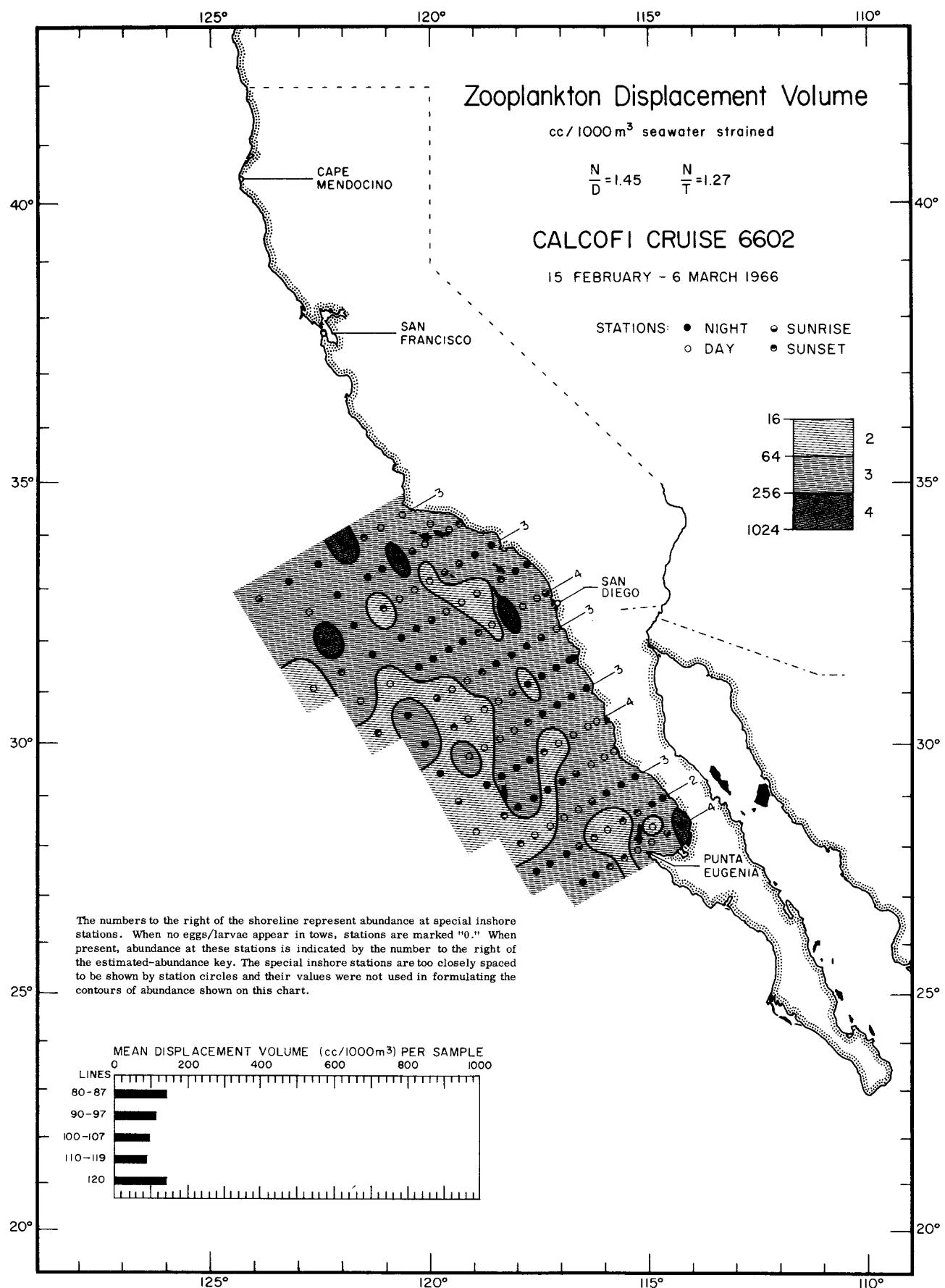
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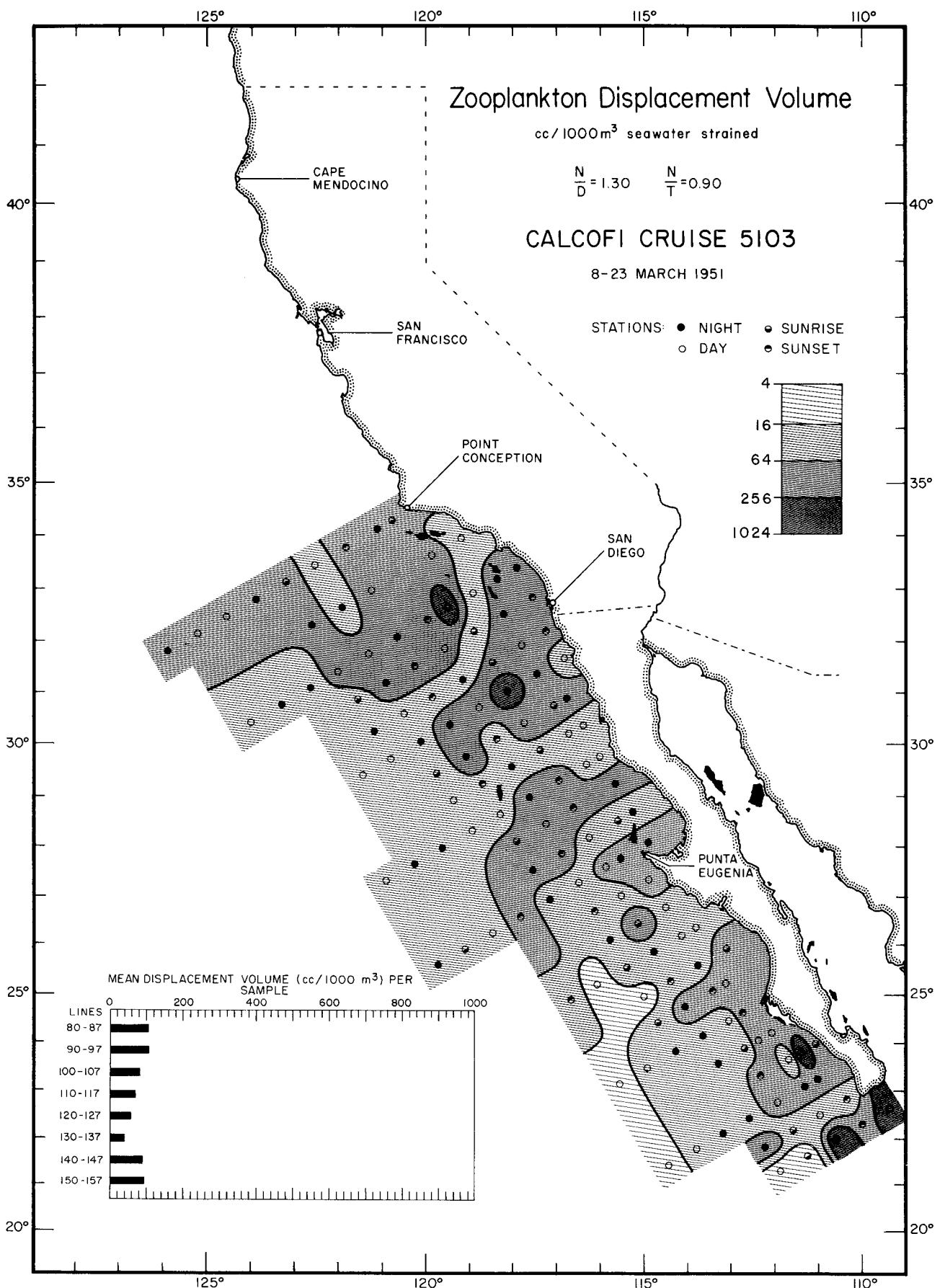
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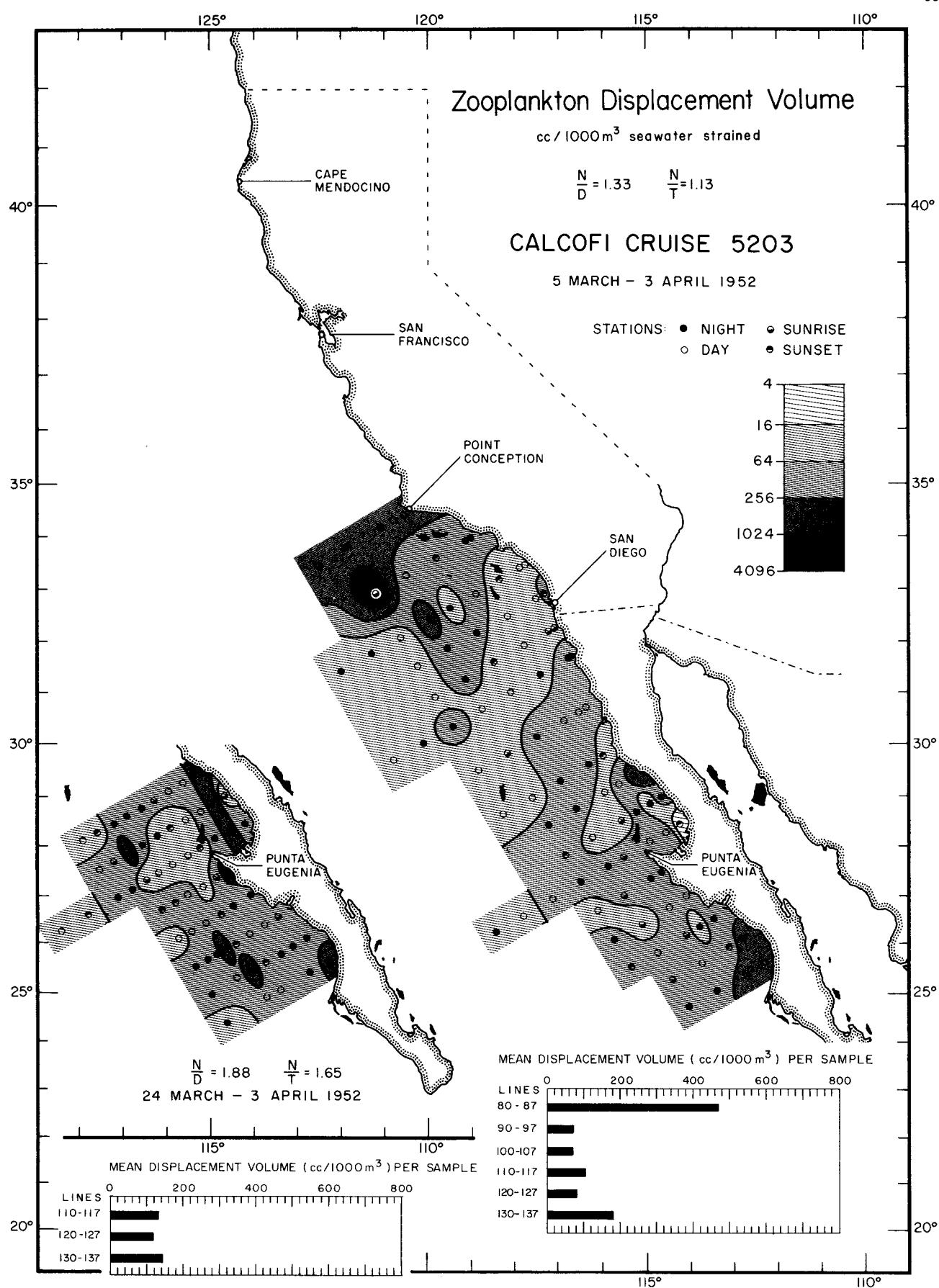


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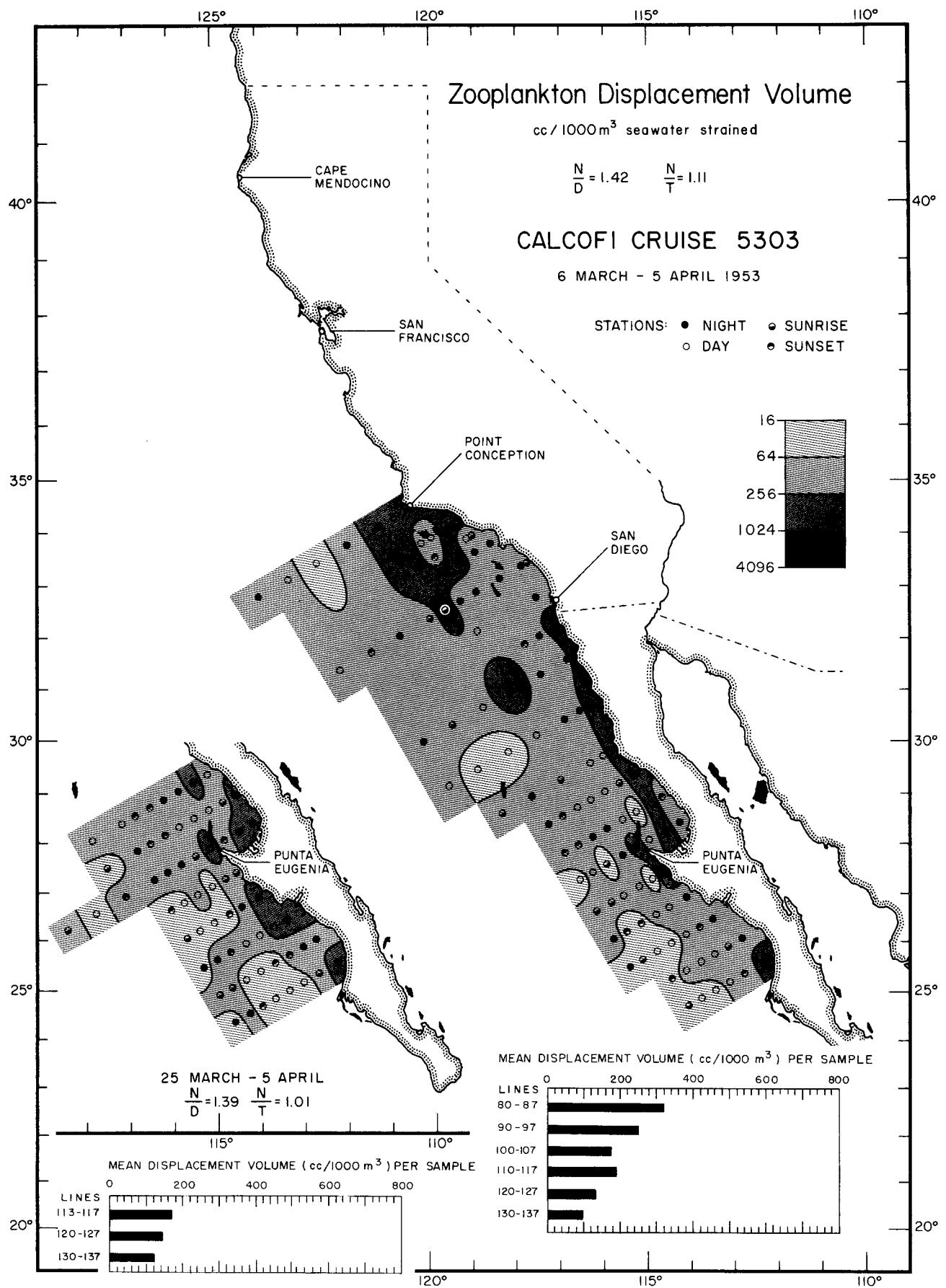


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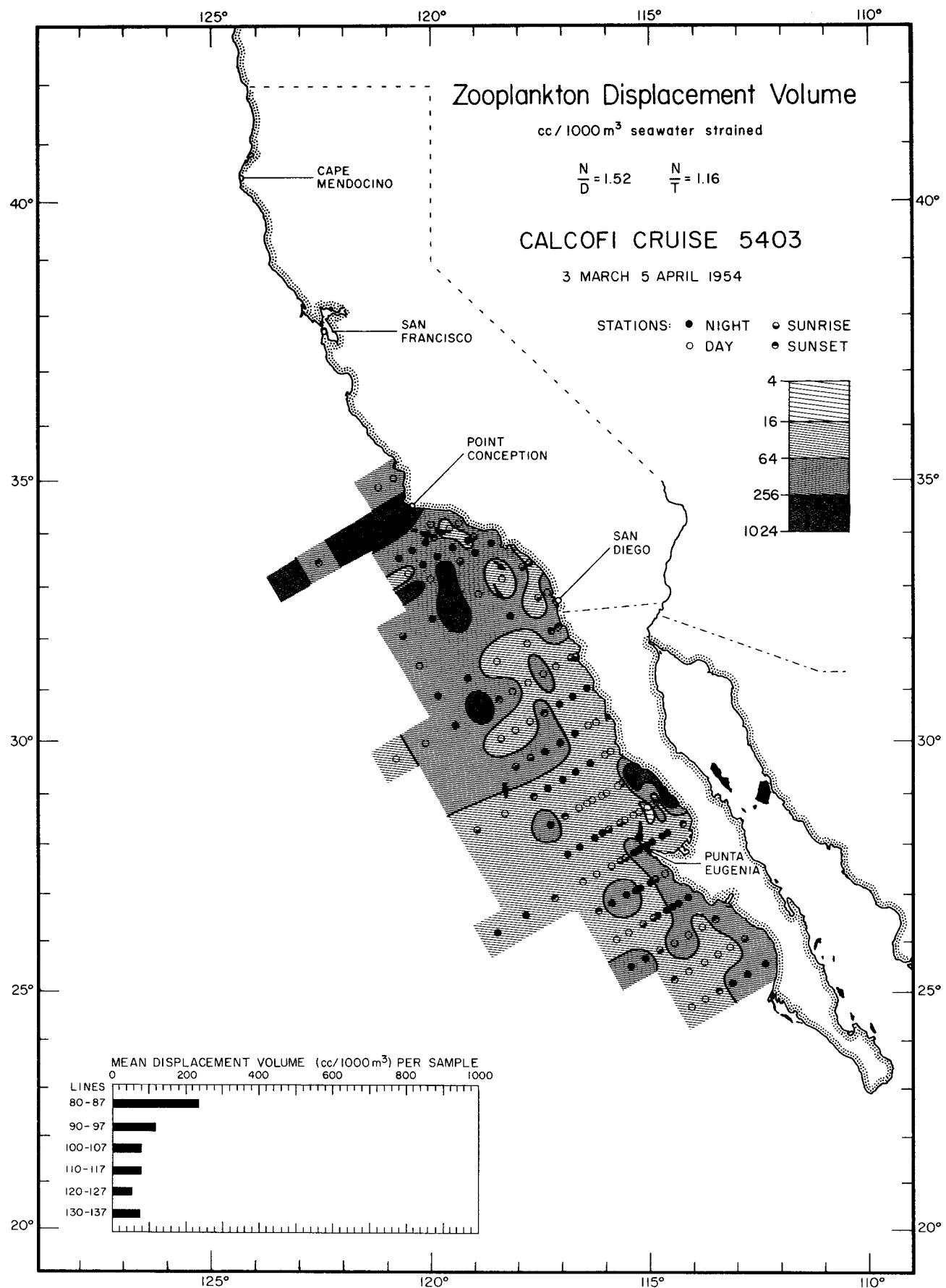
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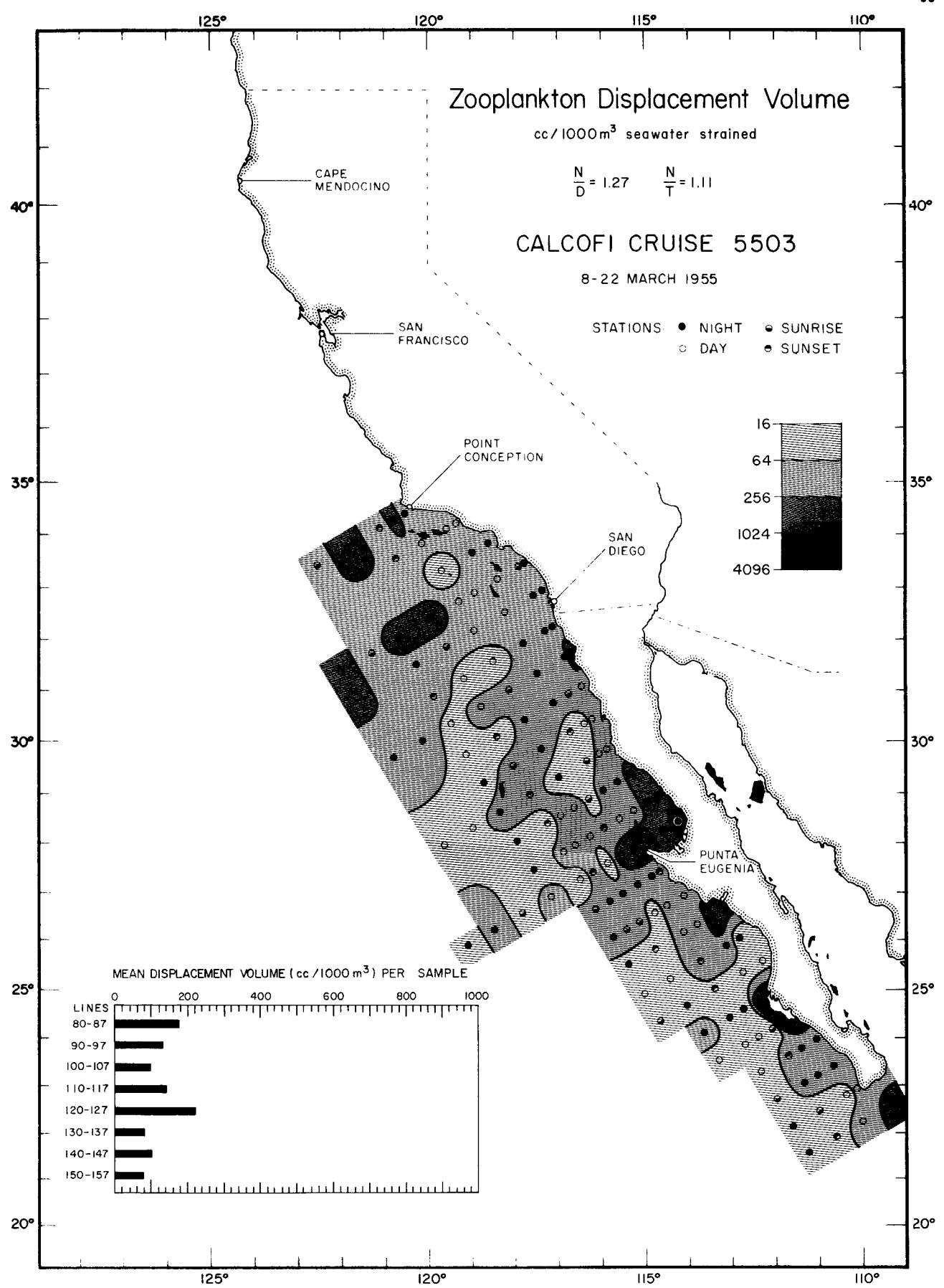
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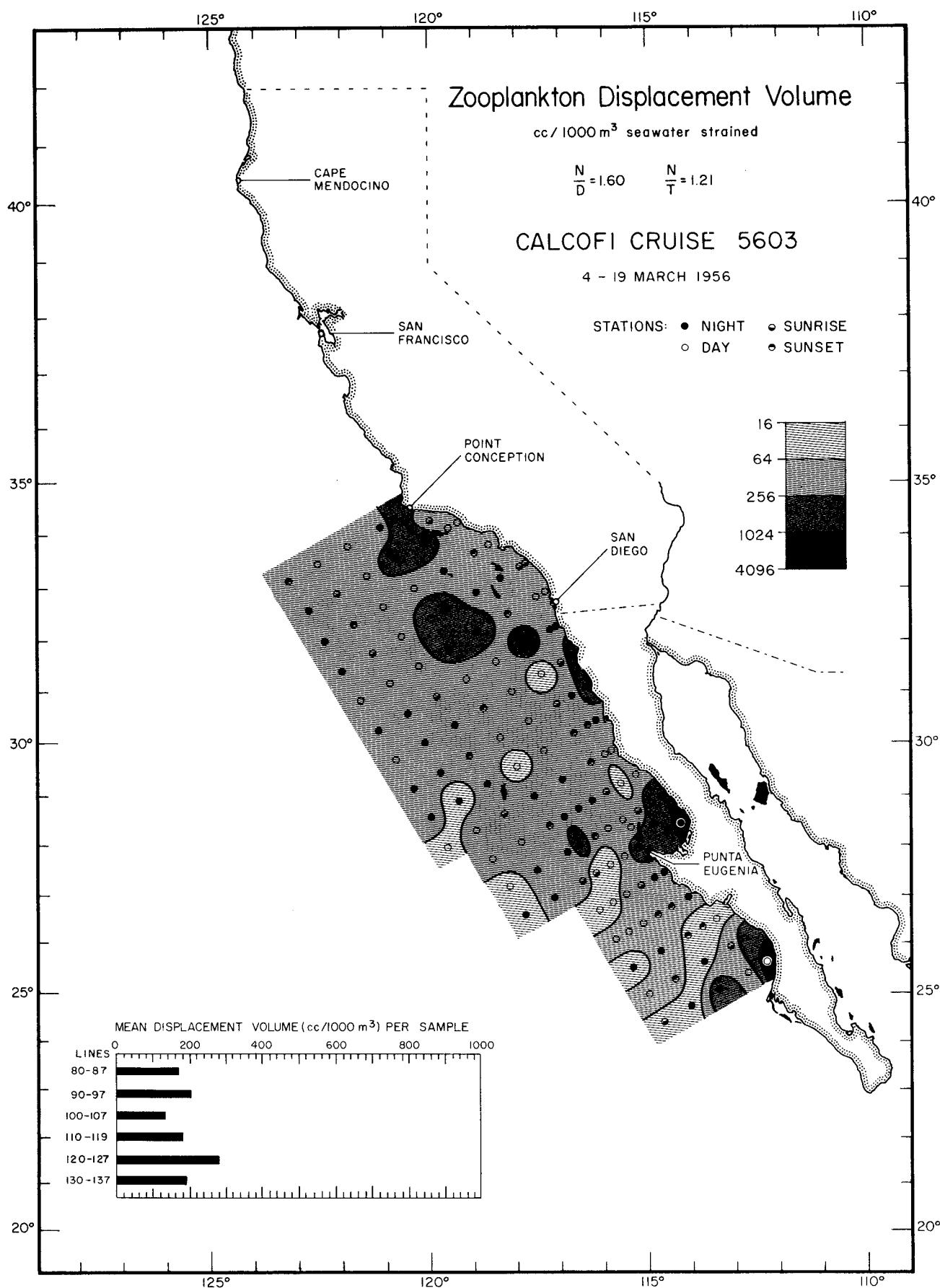
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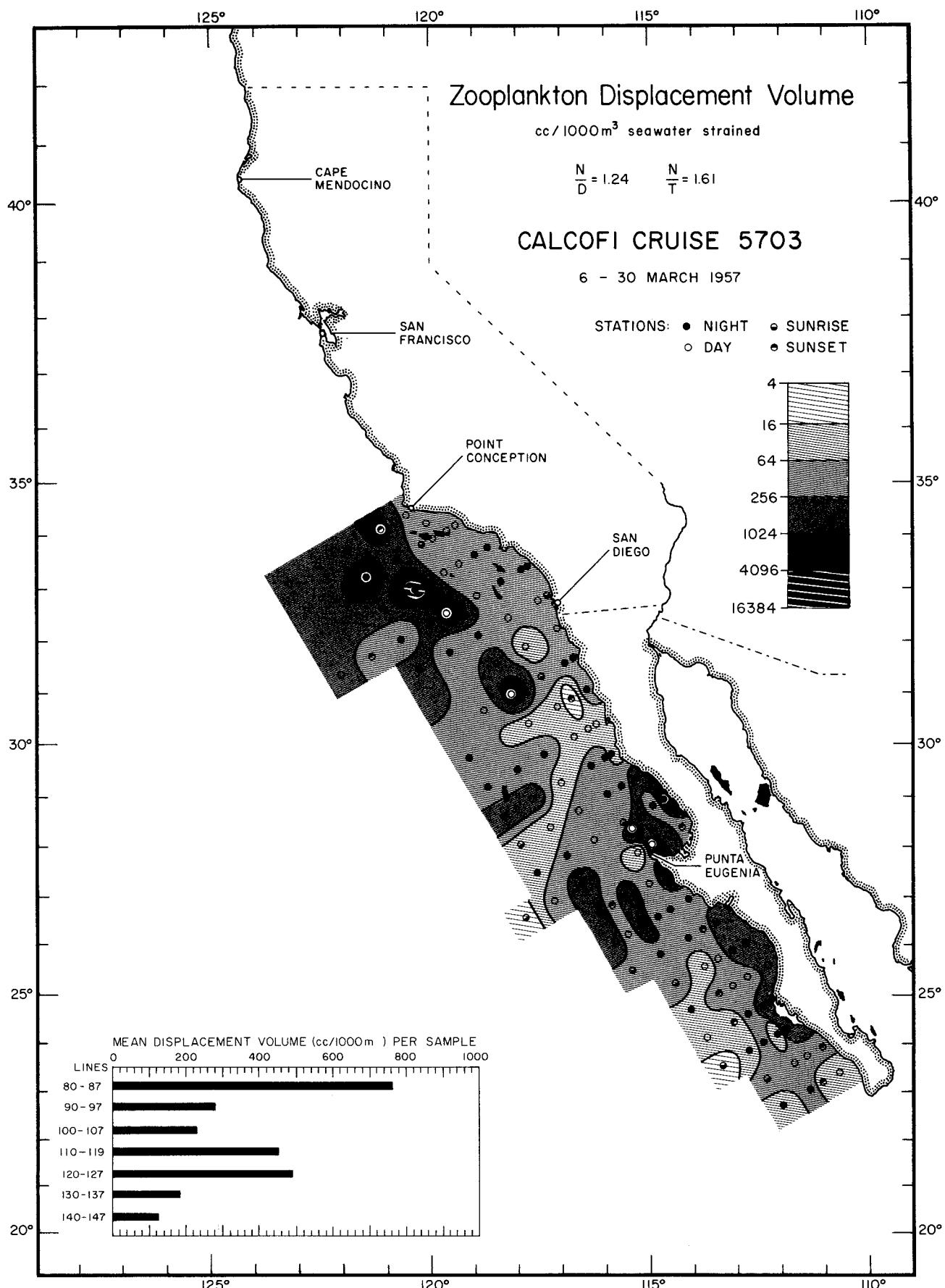
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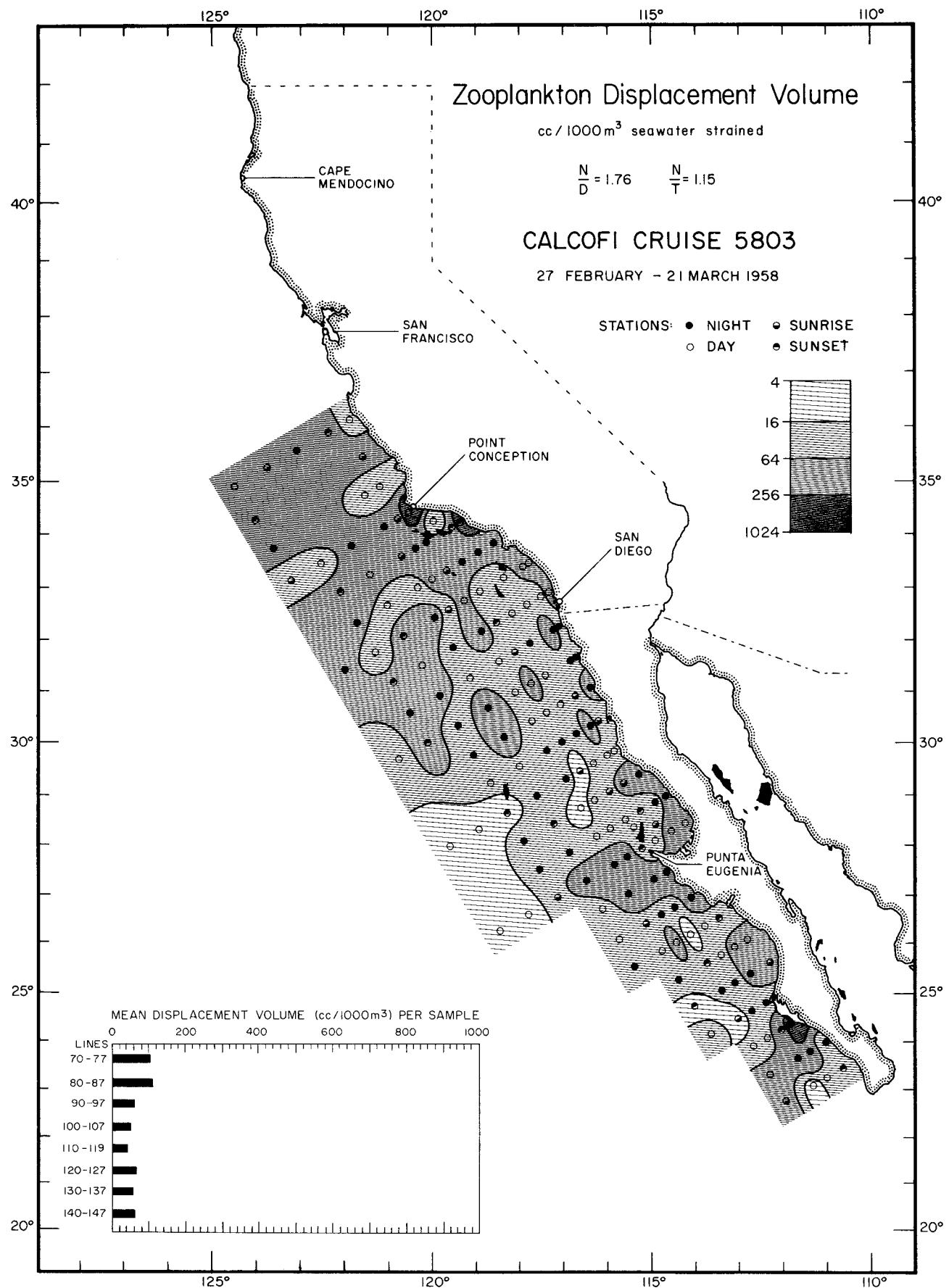
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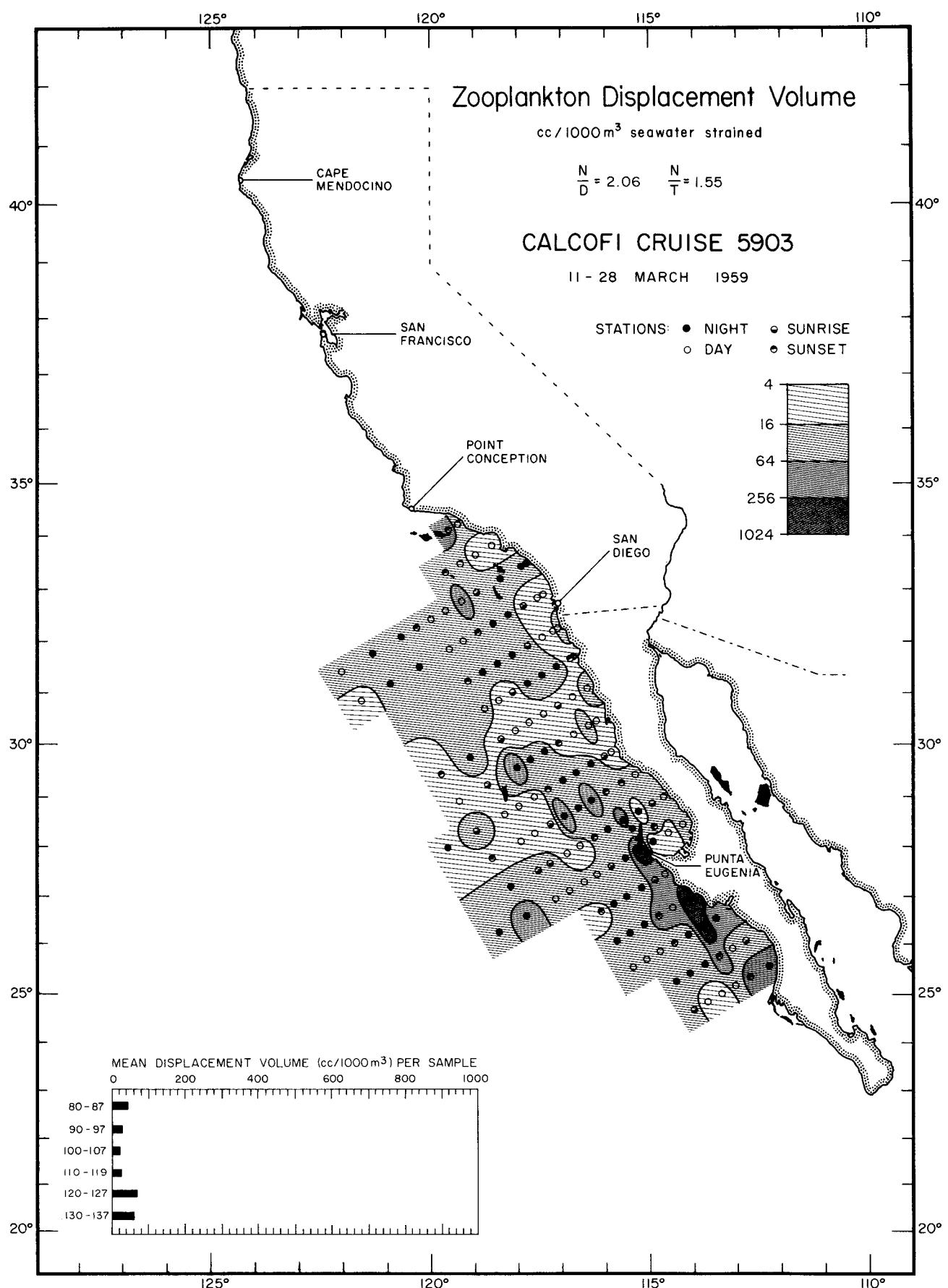
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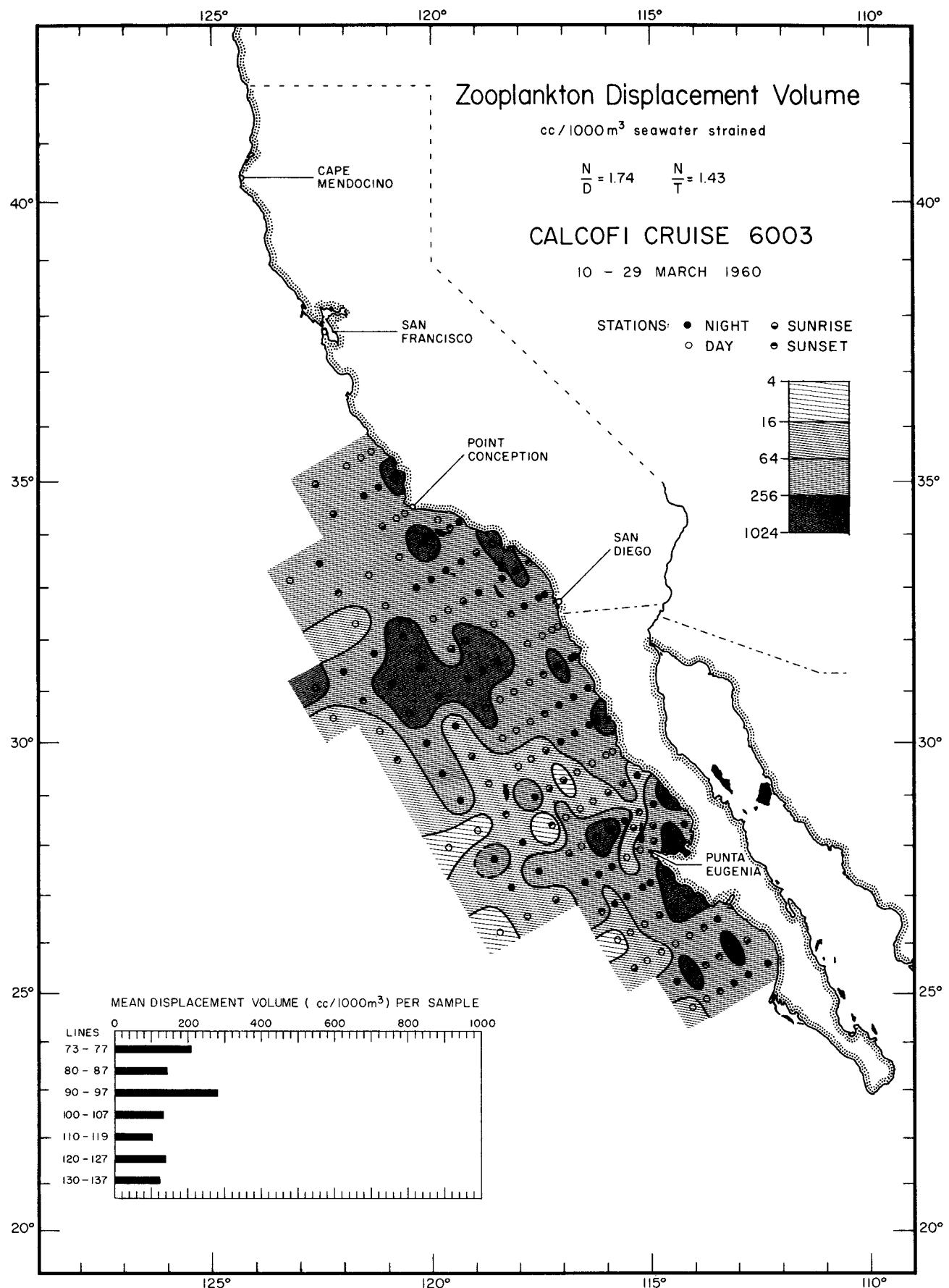
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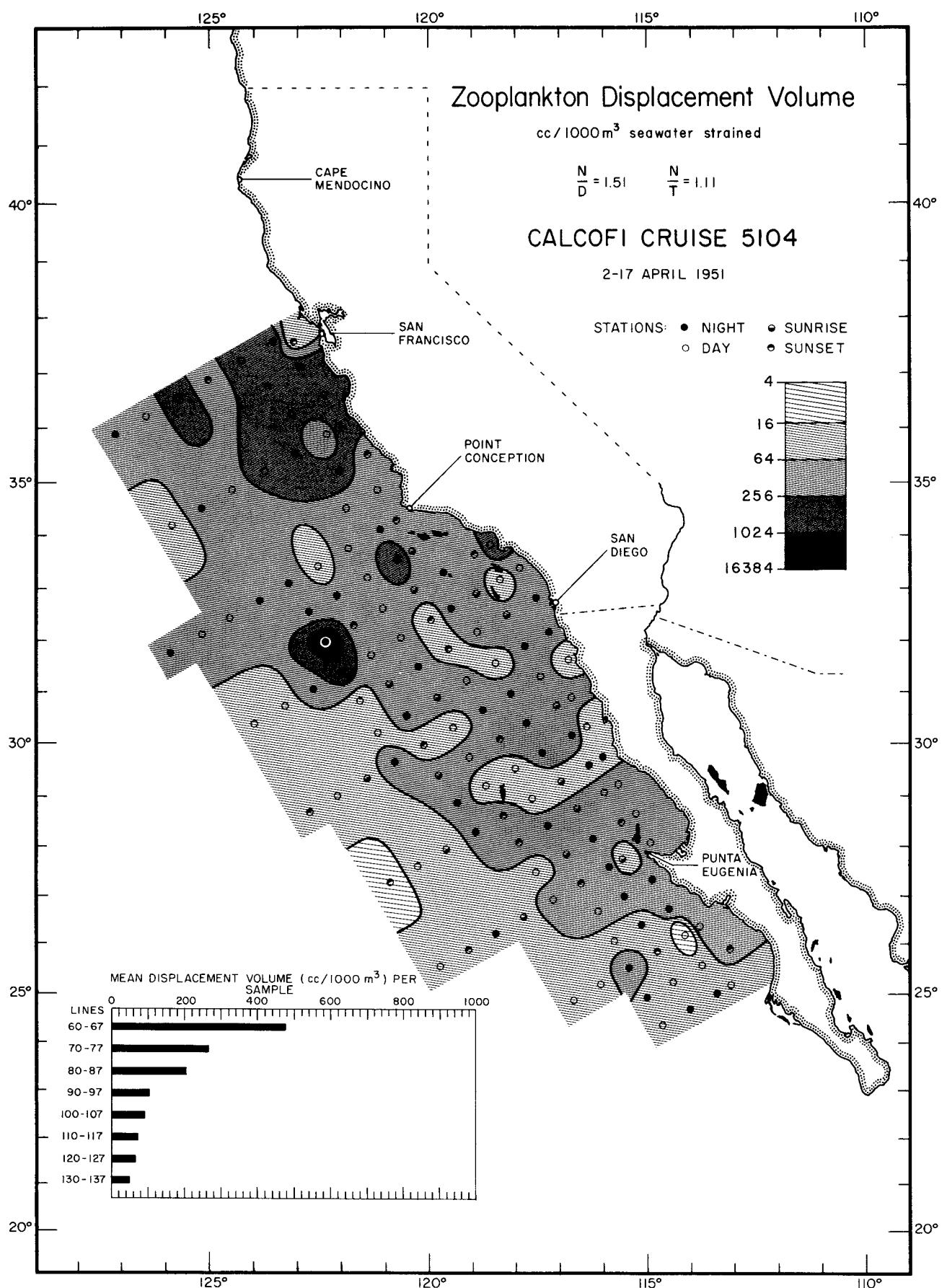
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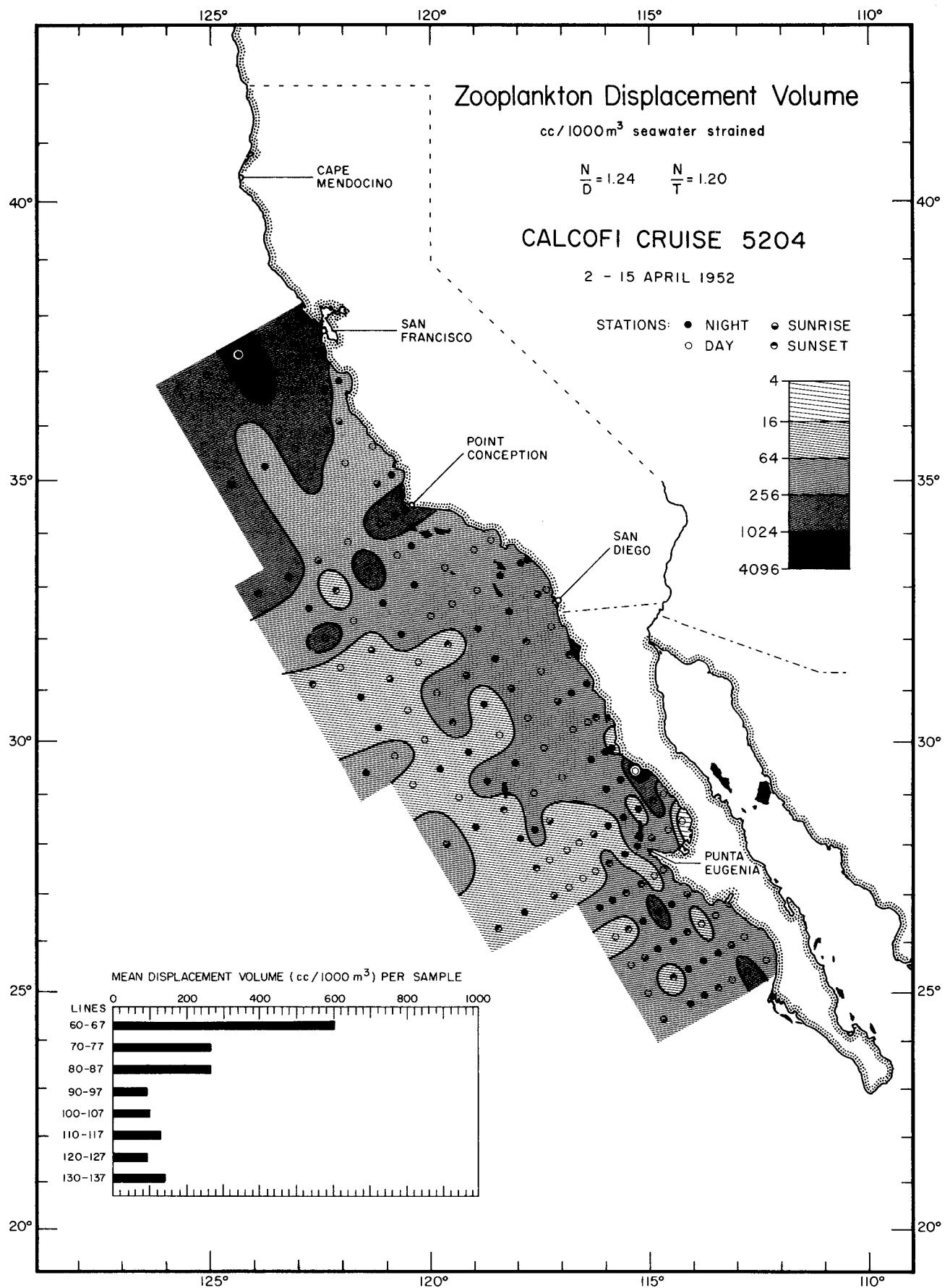
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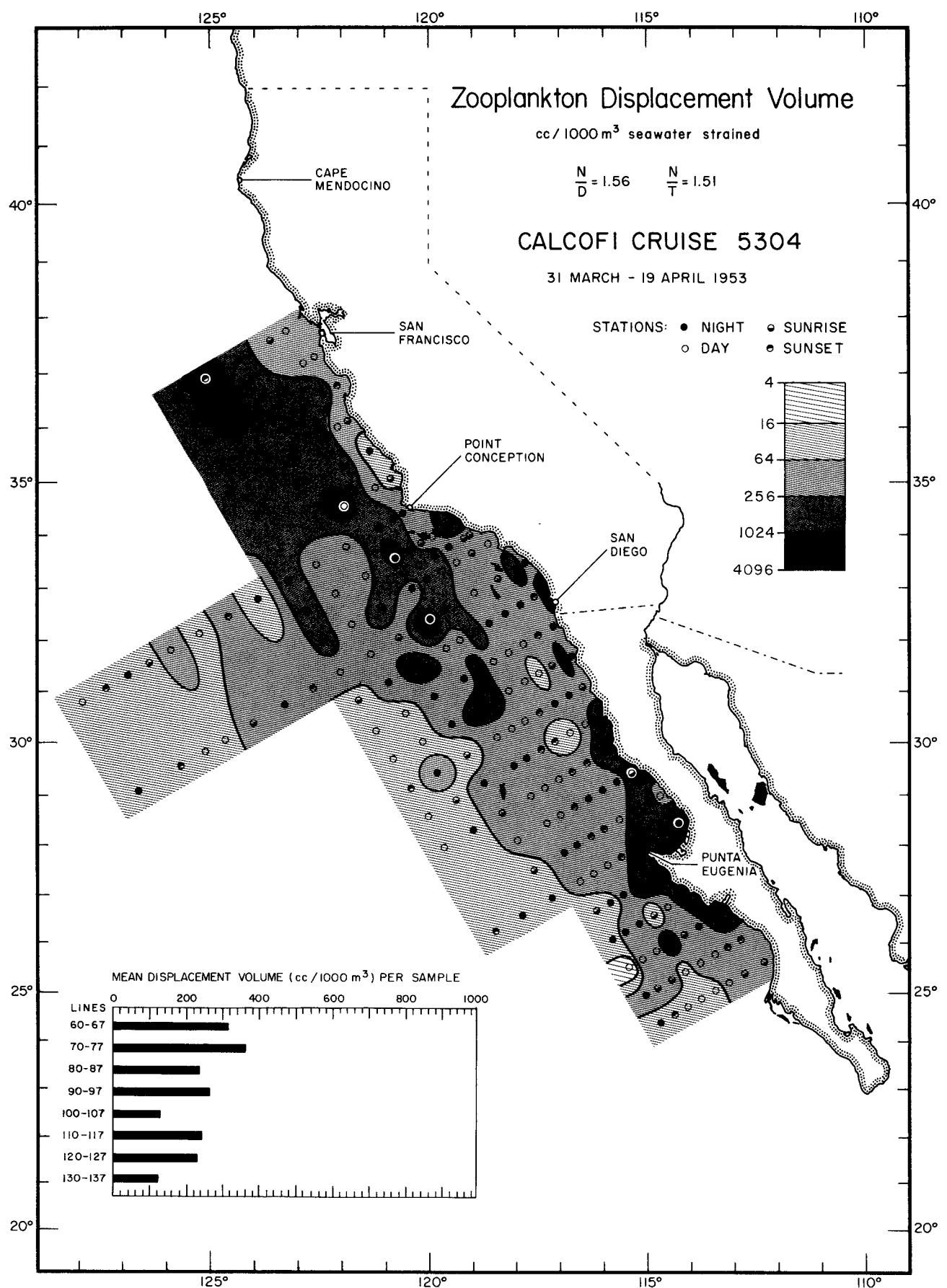
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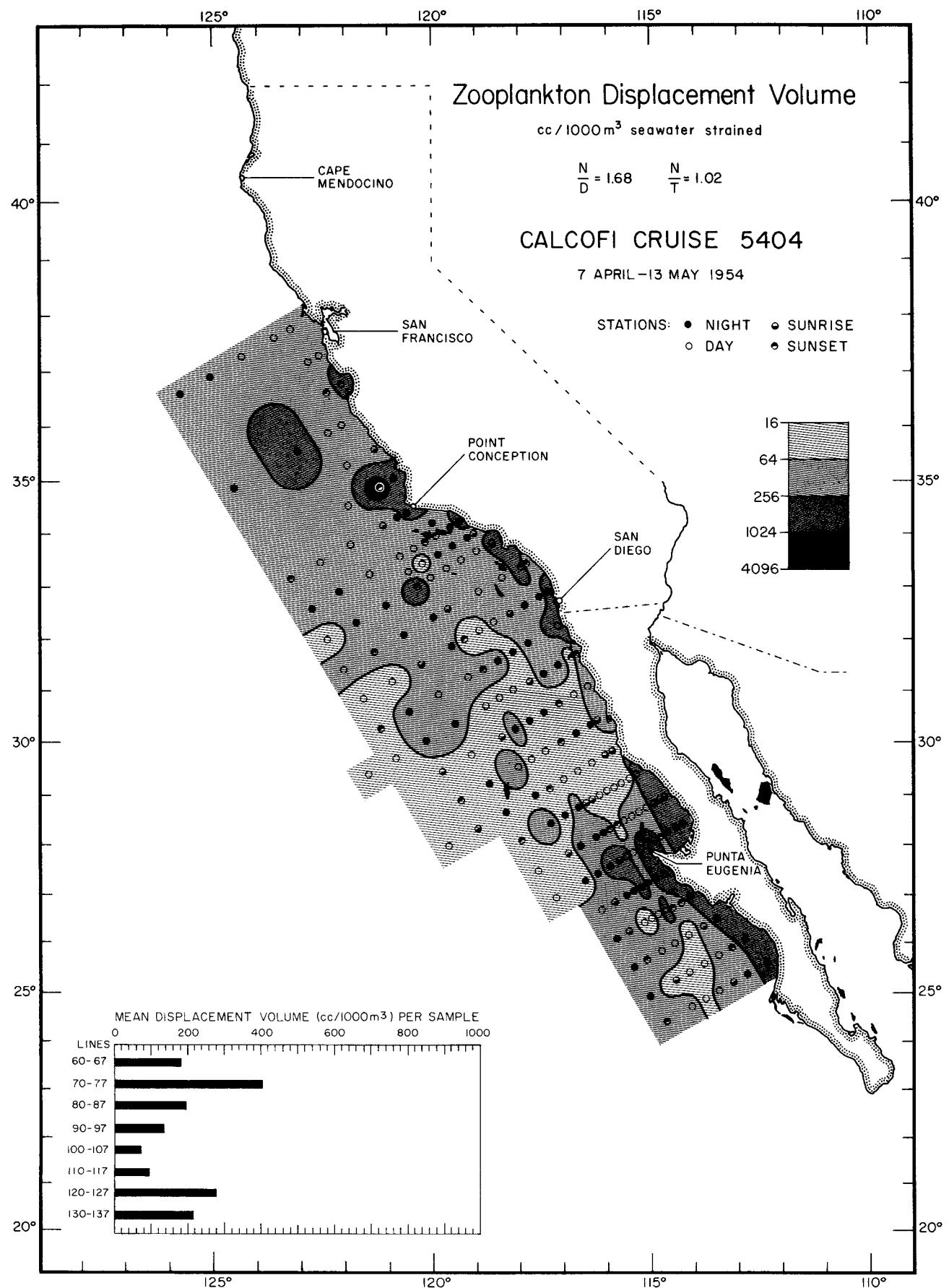
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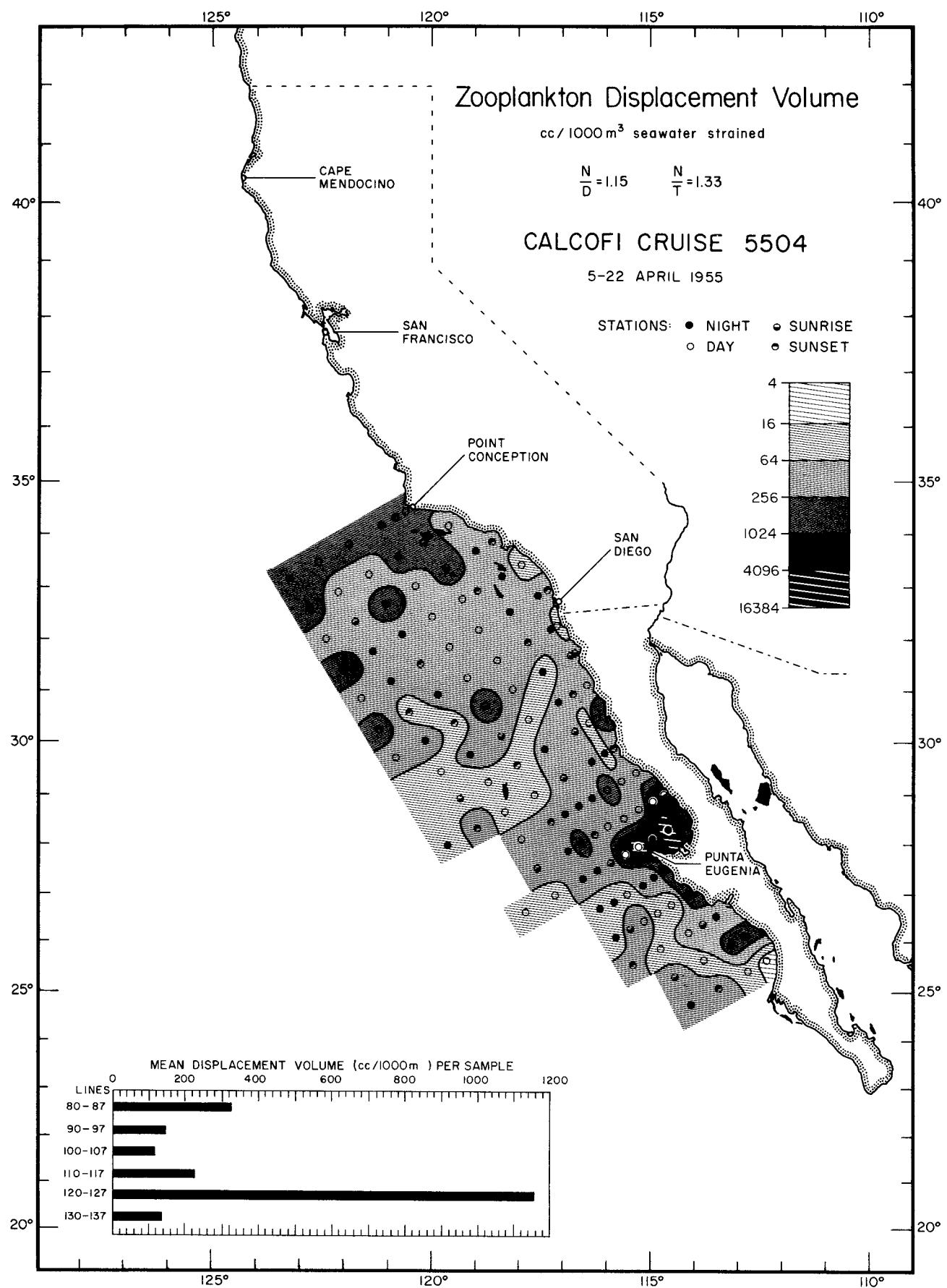
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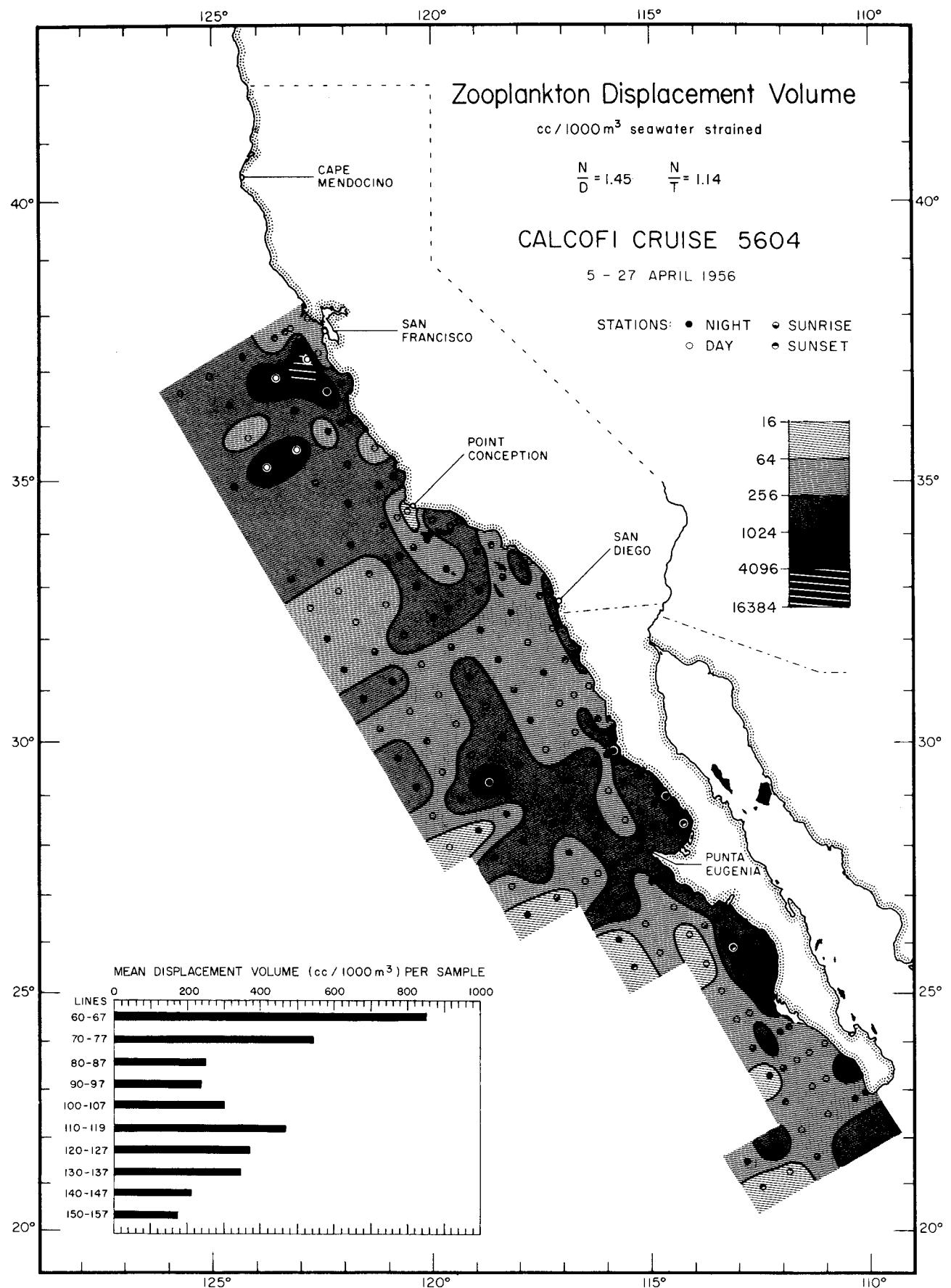
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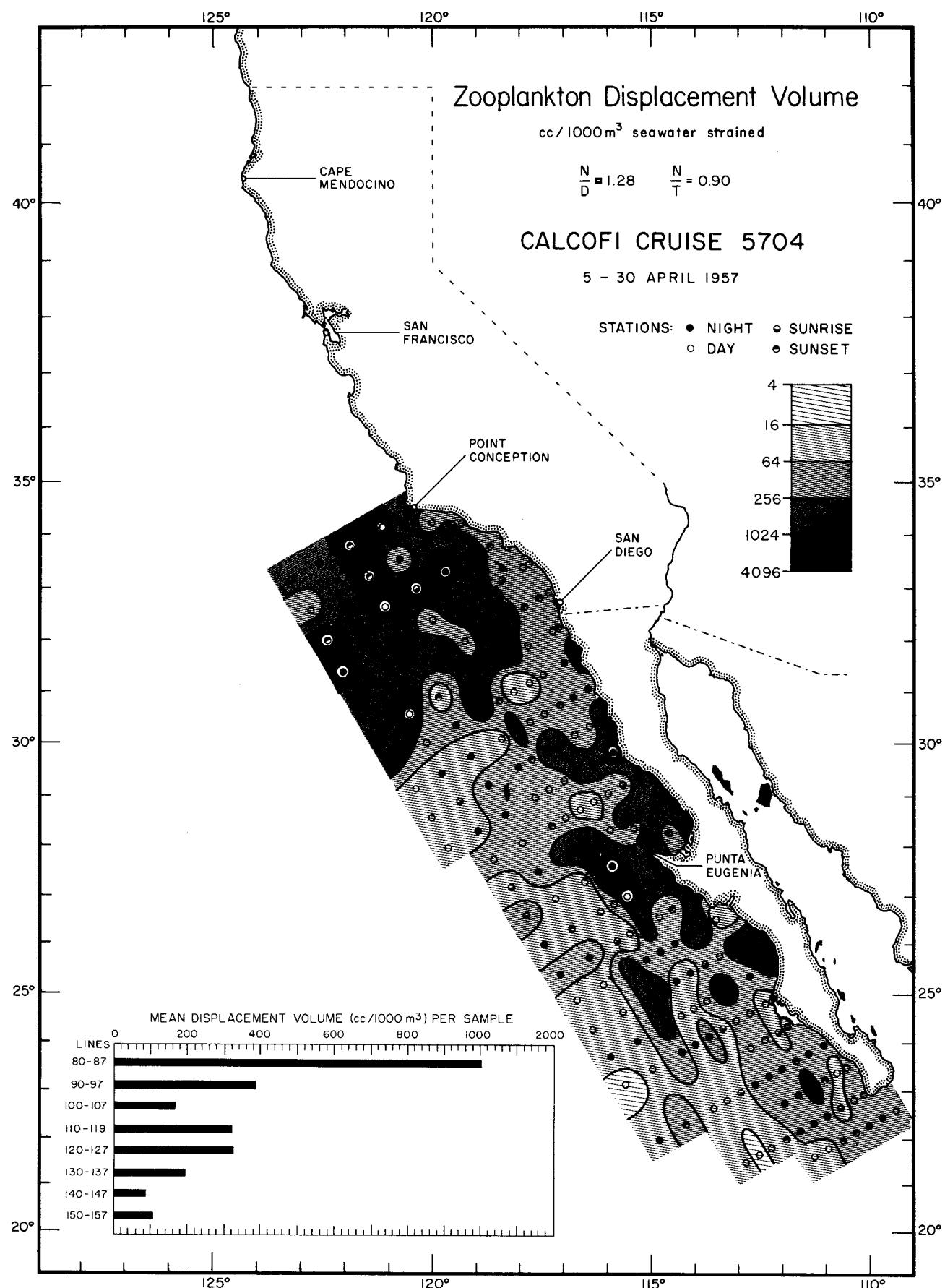
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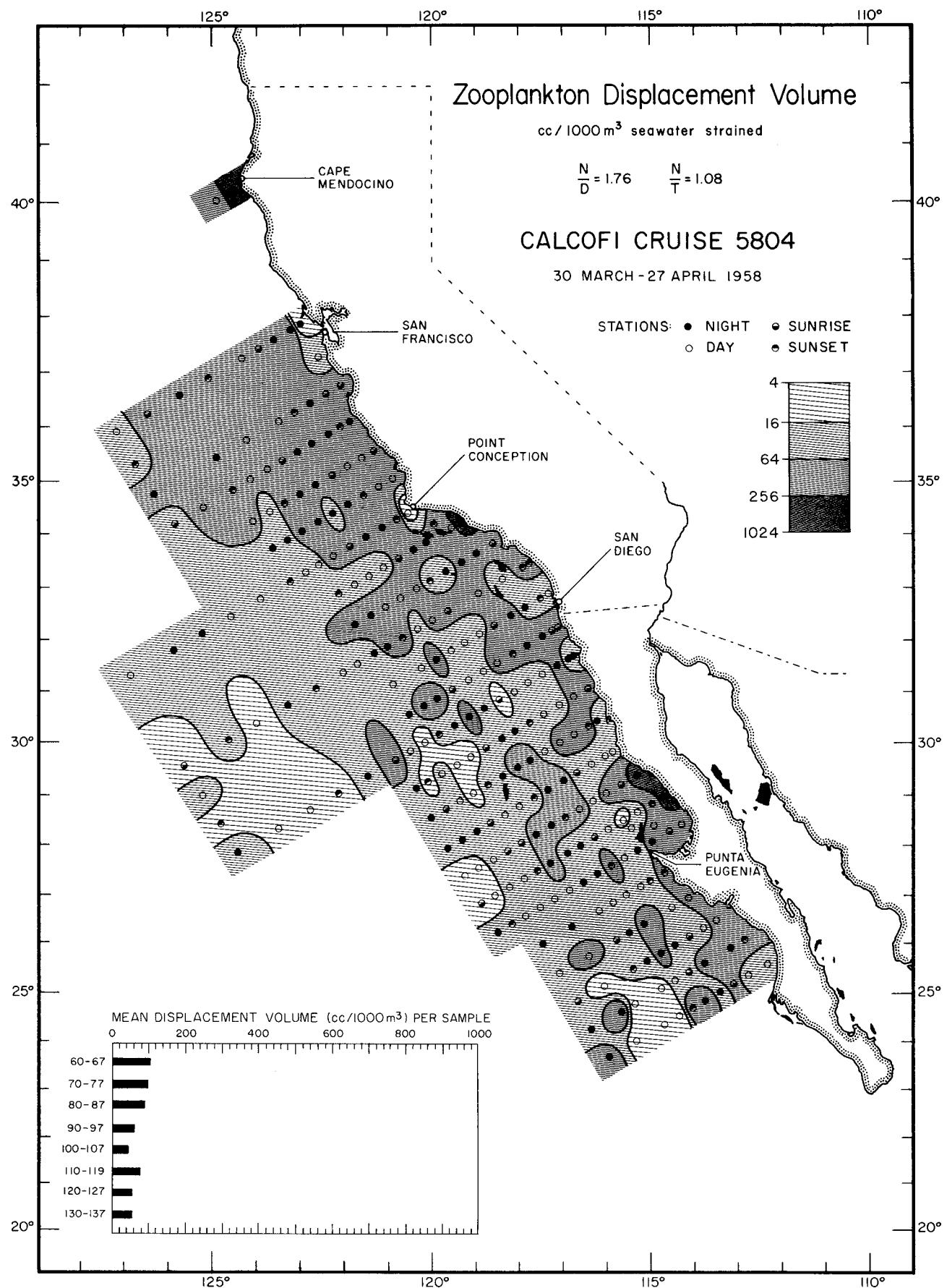
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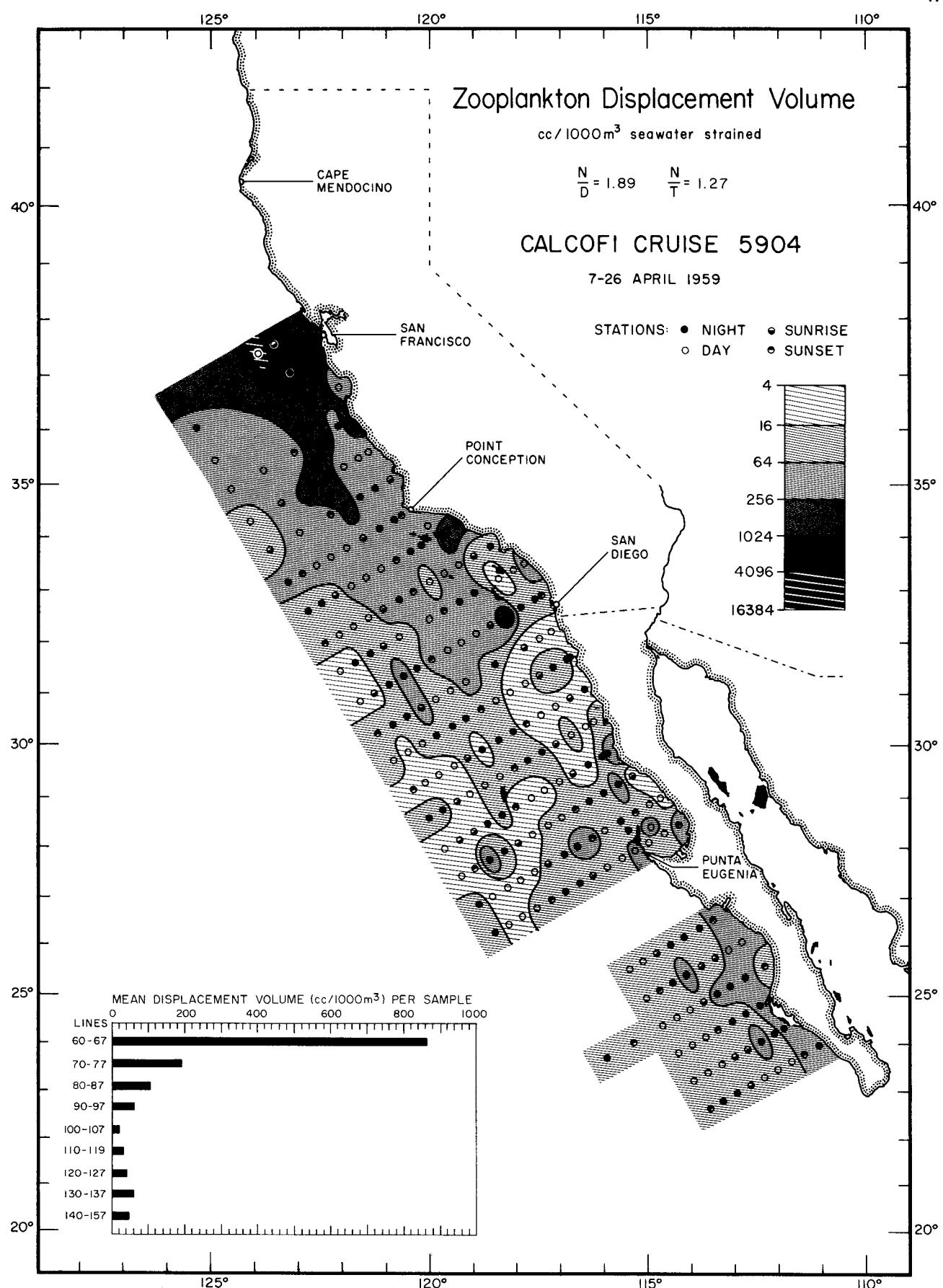
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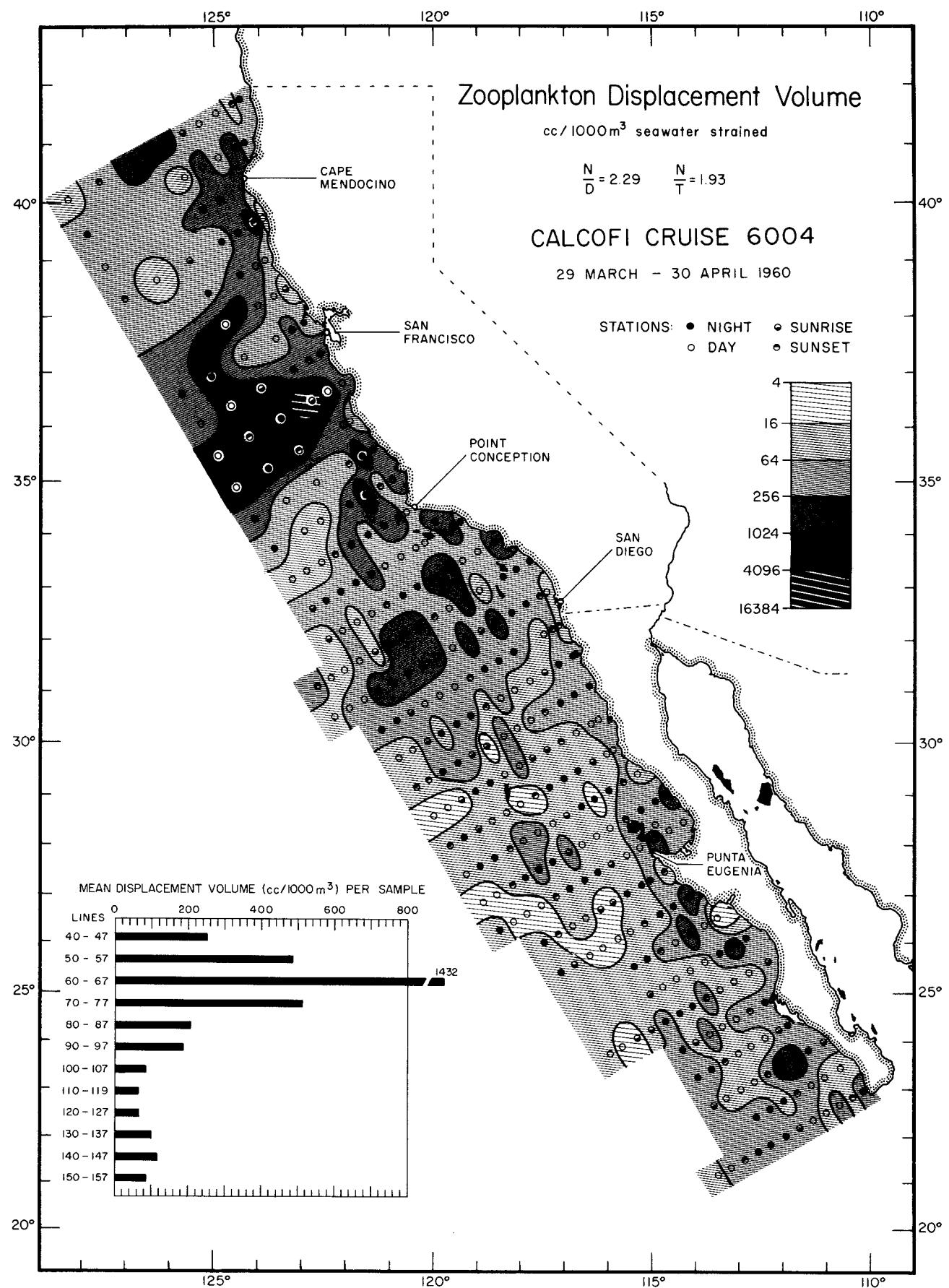
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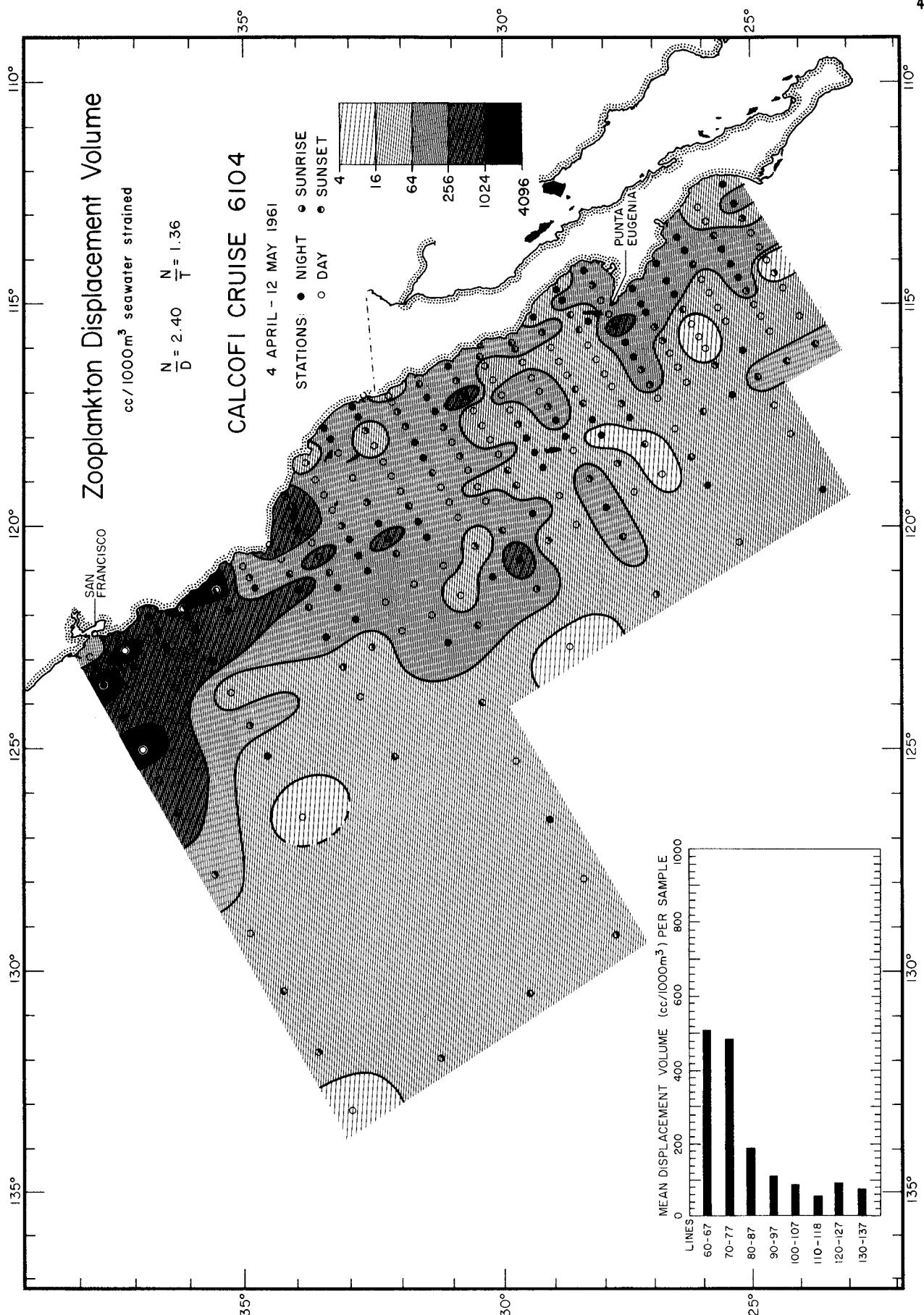
Zooplankton Displacement Volume

5904



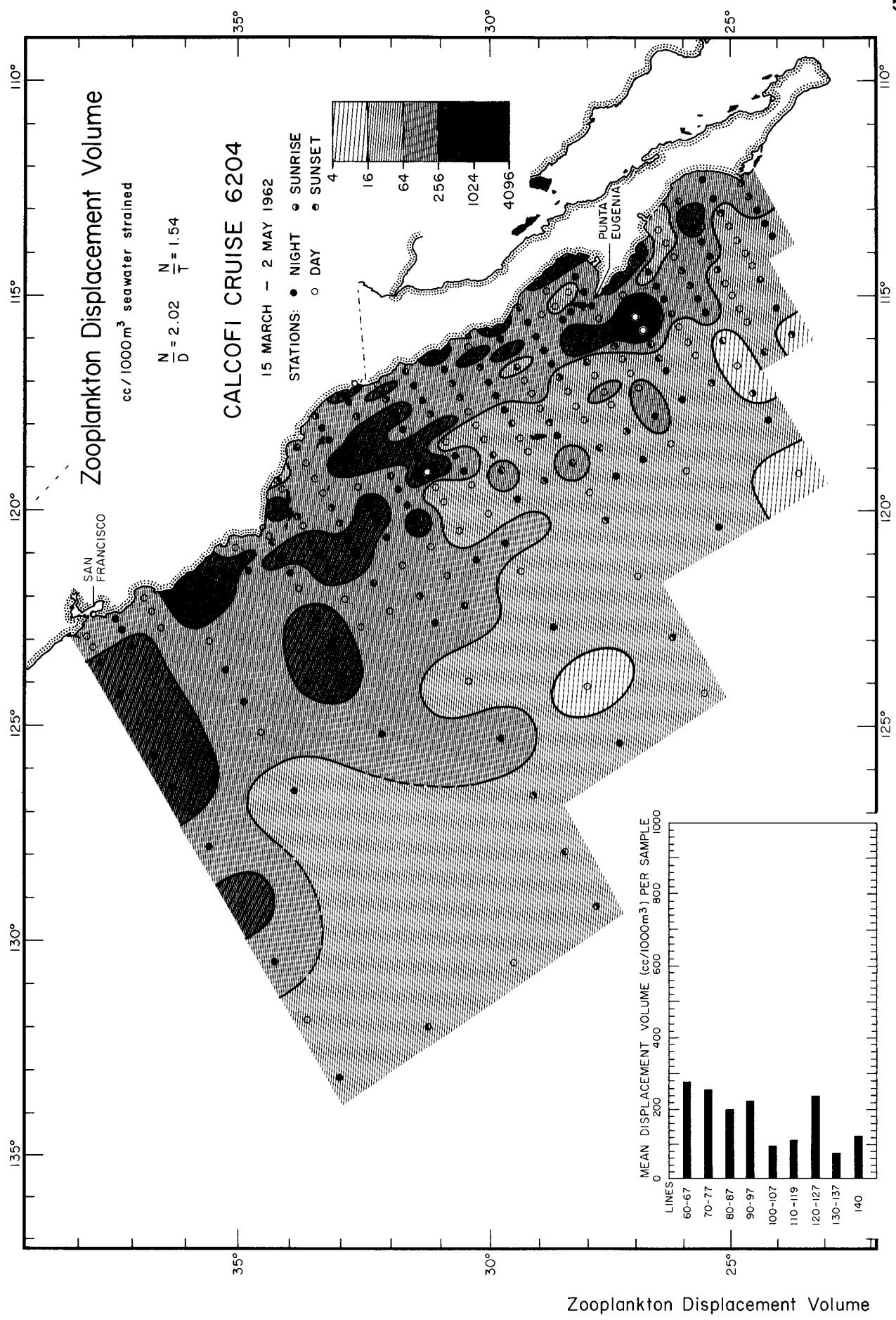
Zooplankton Displacement Volume

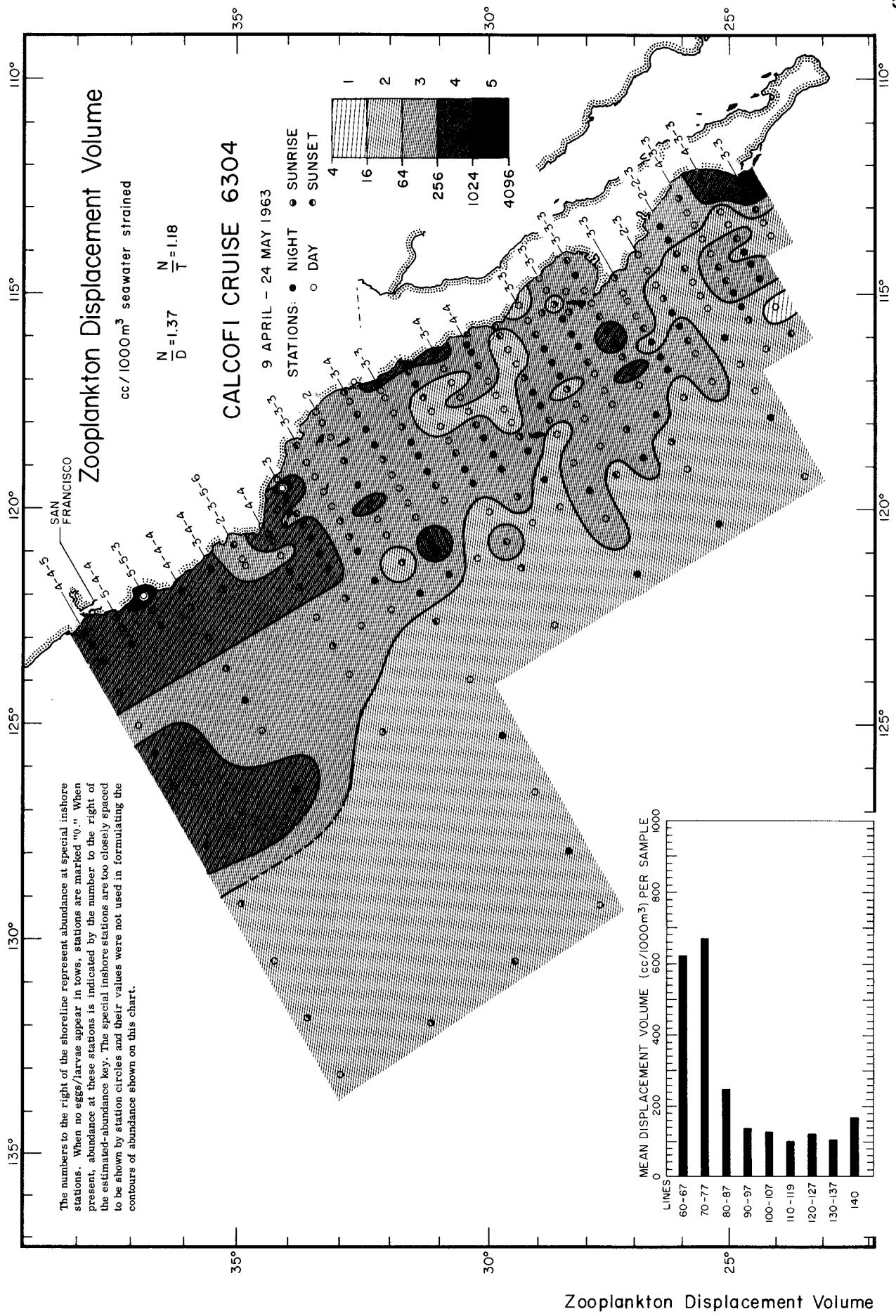
6004

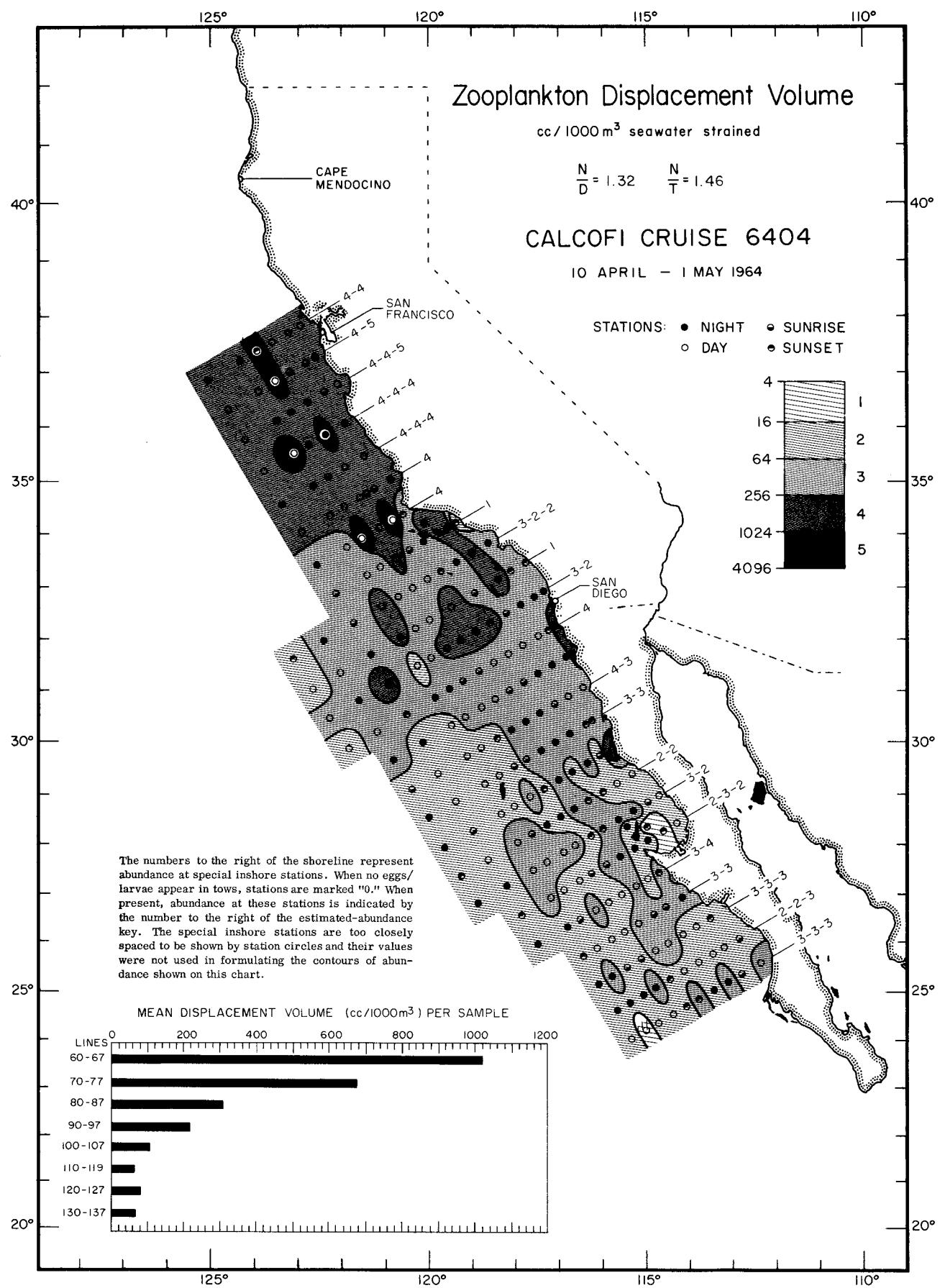


Zooplankton Displacement Volume

6104

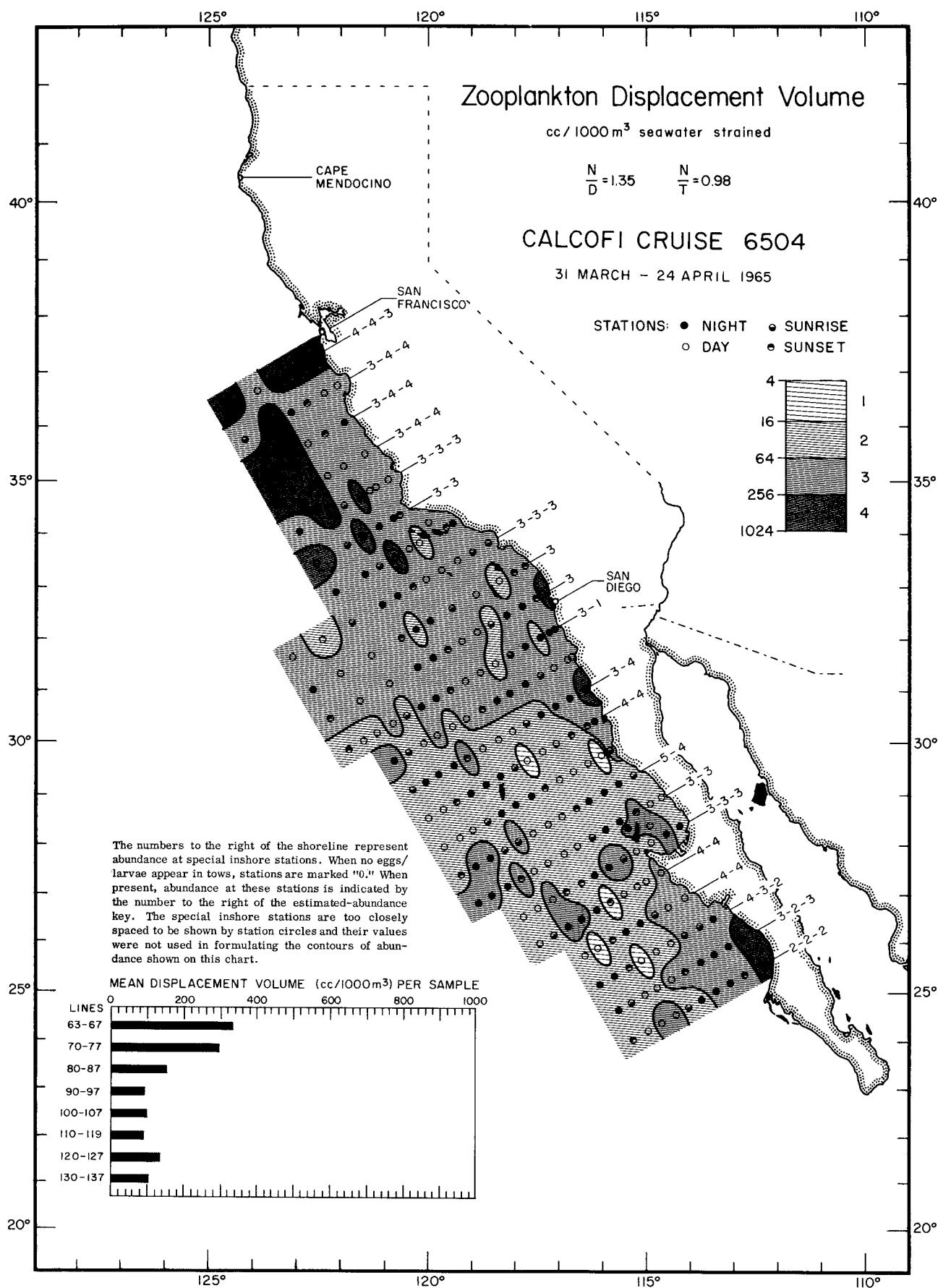




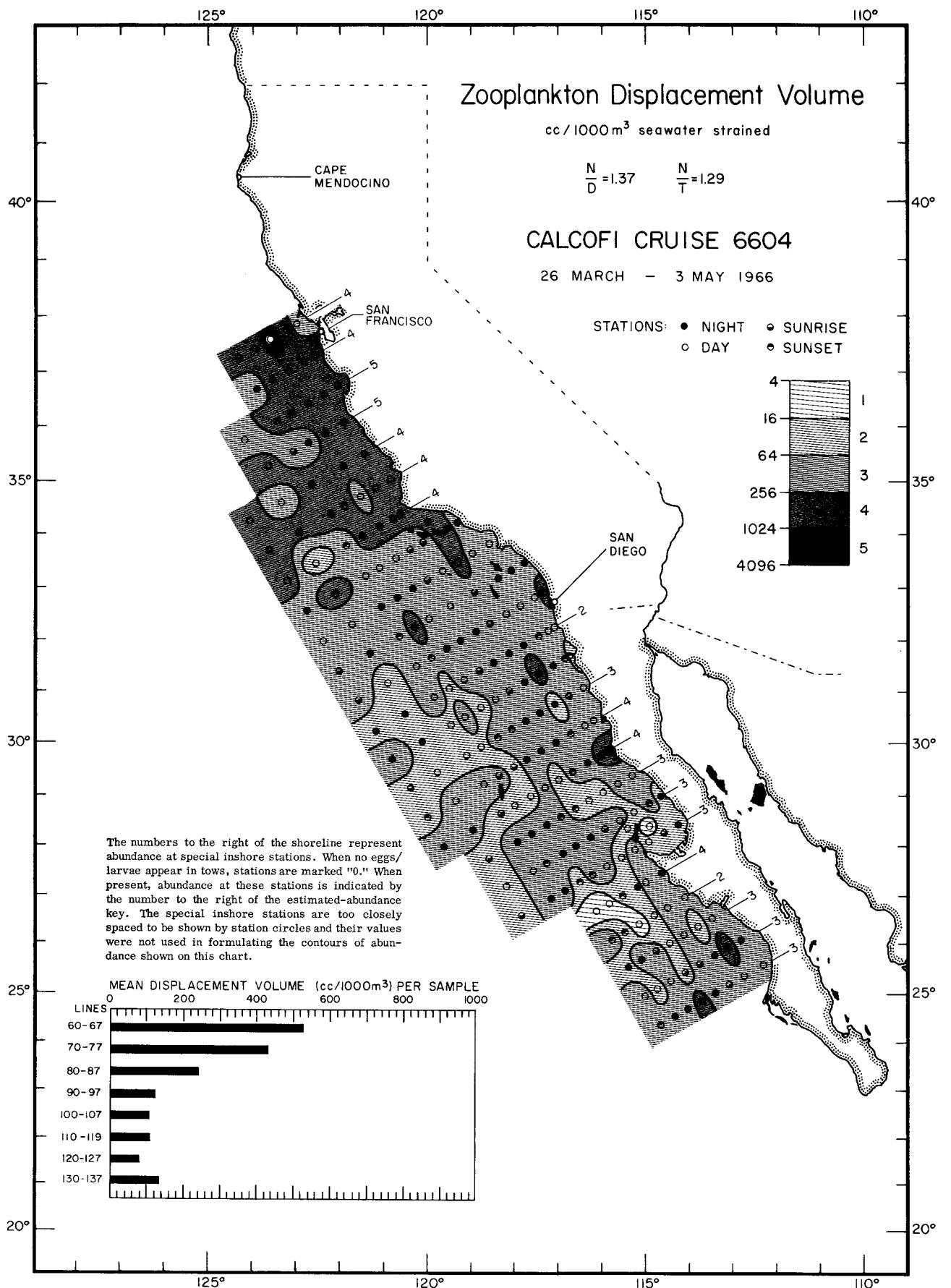


Zooplankton Displacement Volume

6404

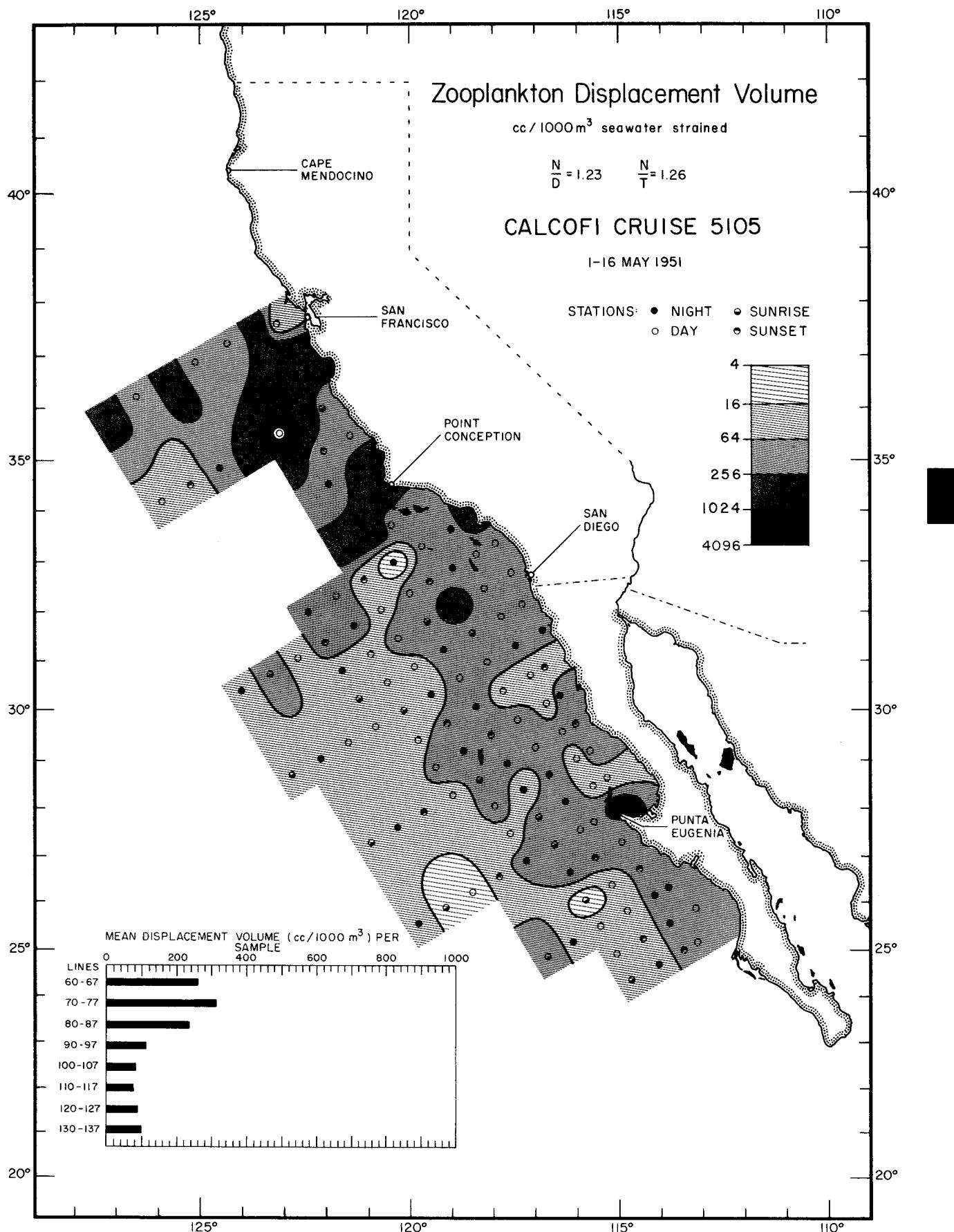


Zooplankton Displacement Volume



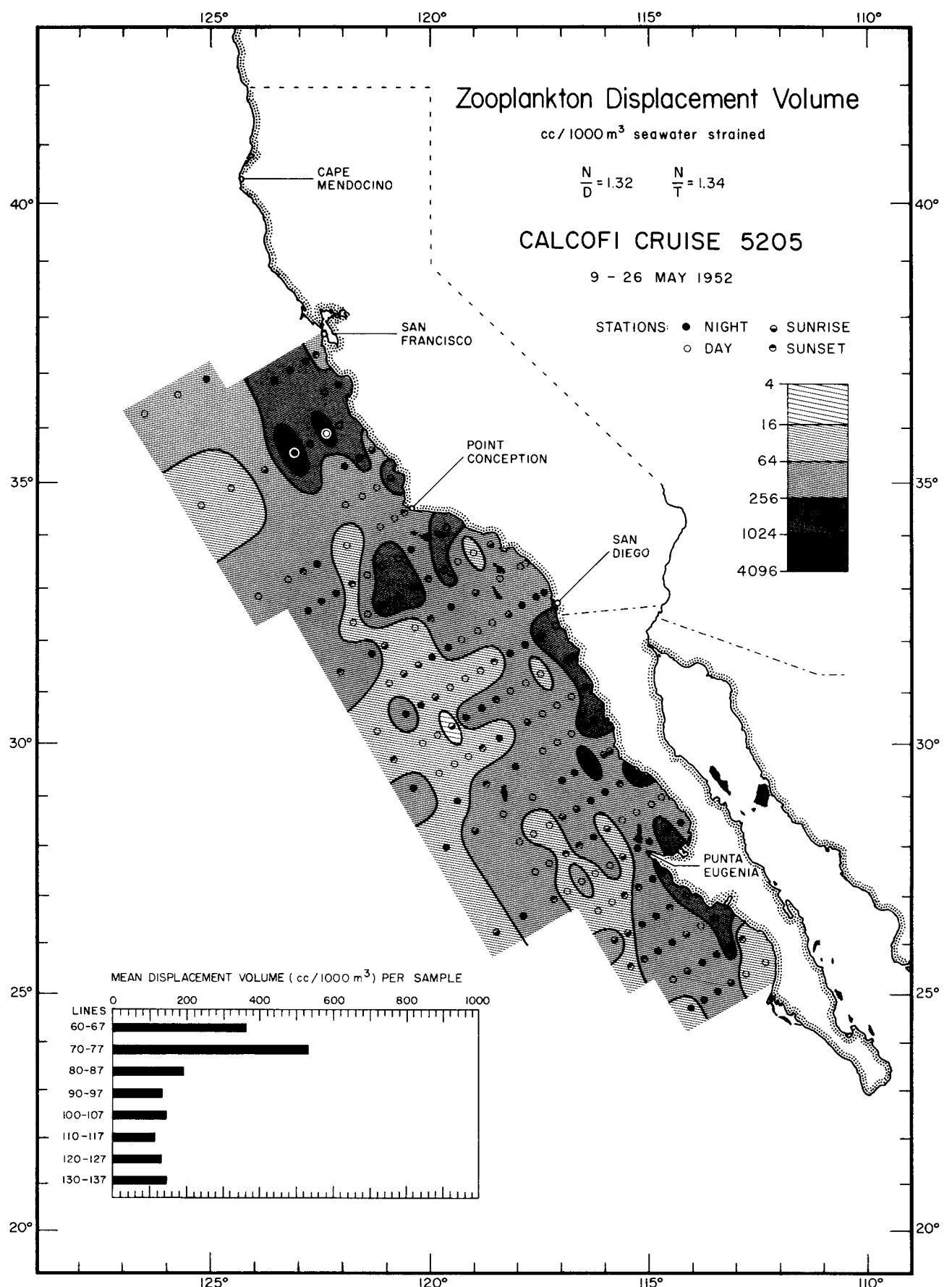
Zooplankton Displacement Volume

6604



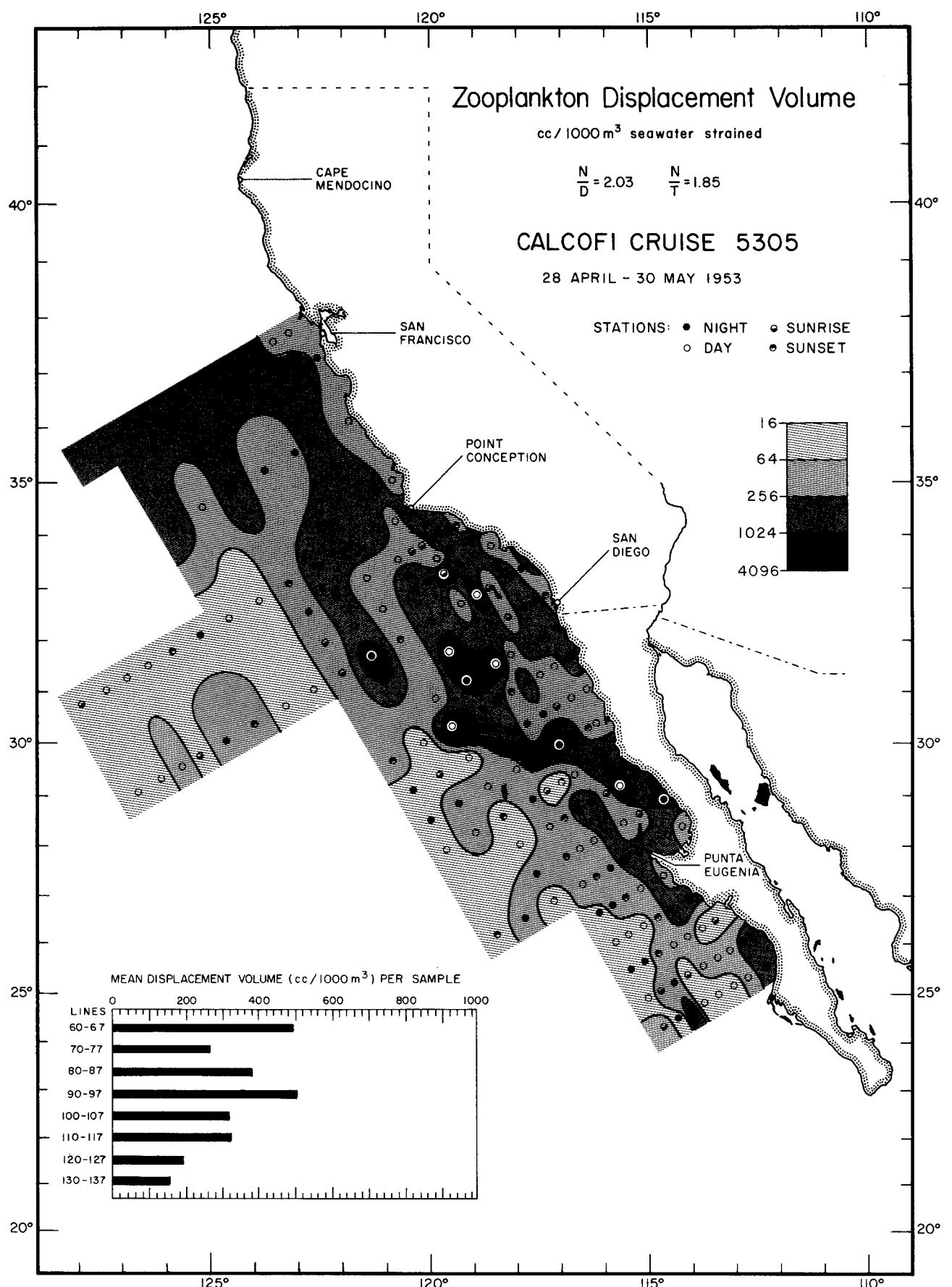
Zooplankton Displacement Volume

5105



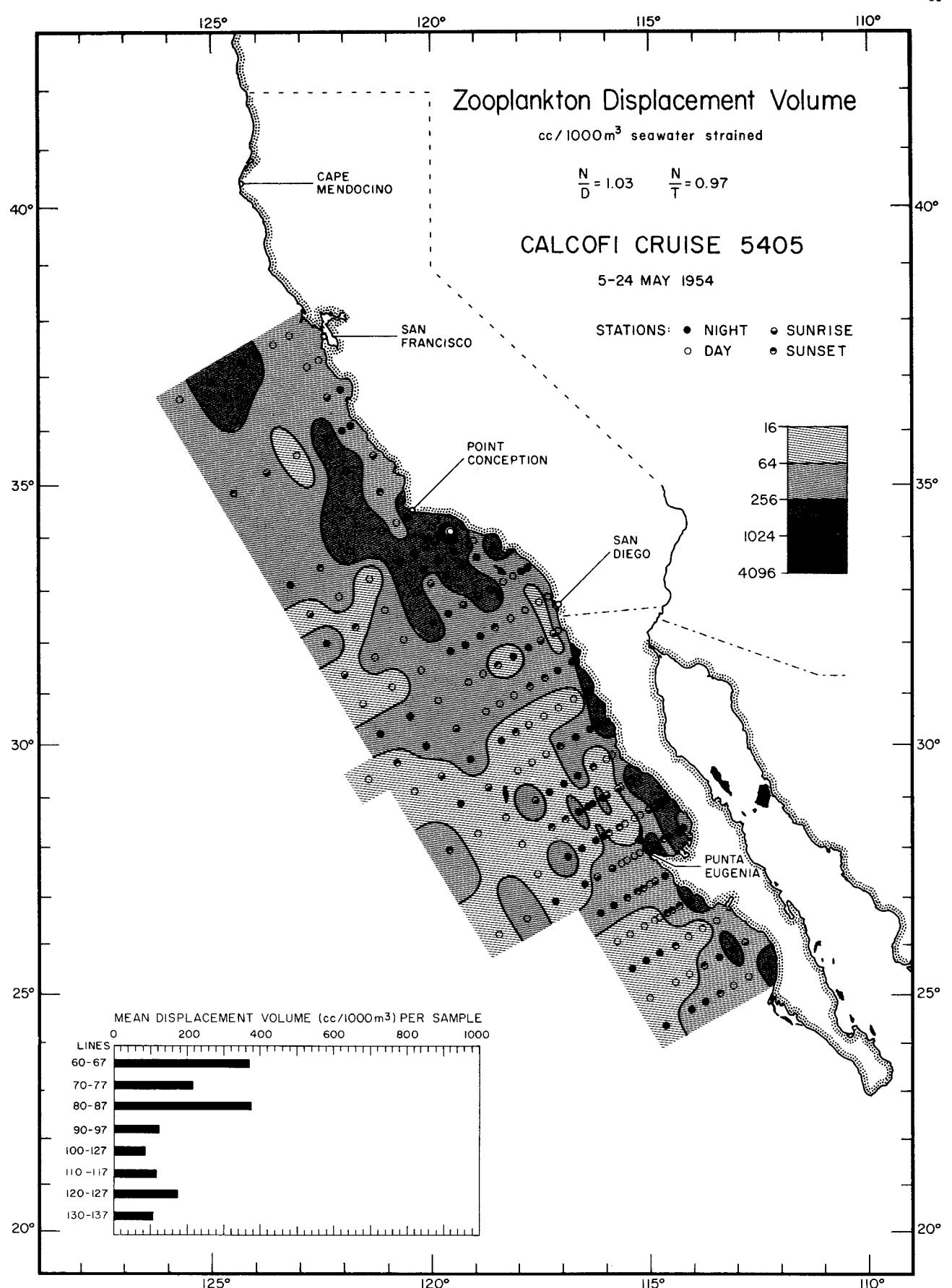
Zooplankton Displacement Volume

5205



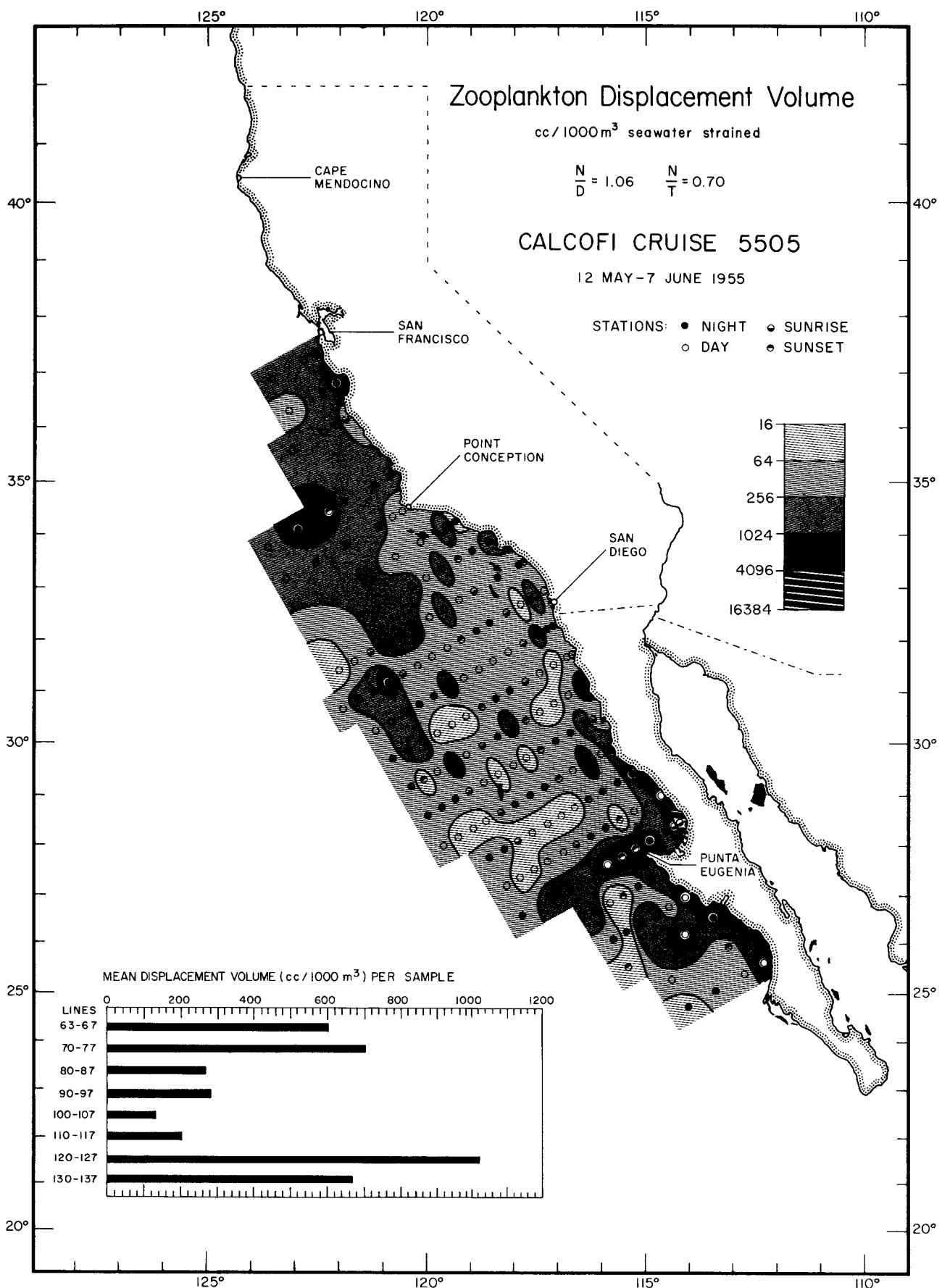
Zooplankton Displacement Volume

5305



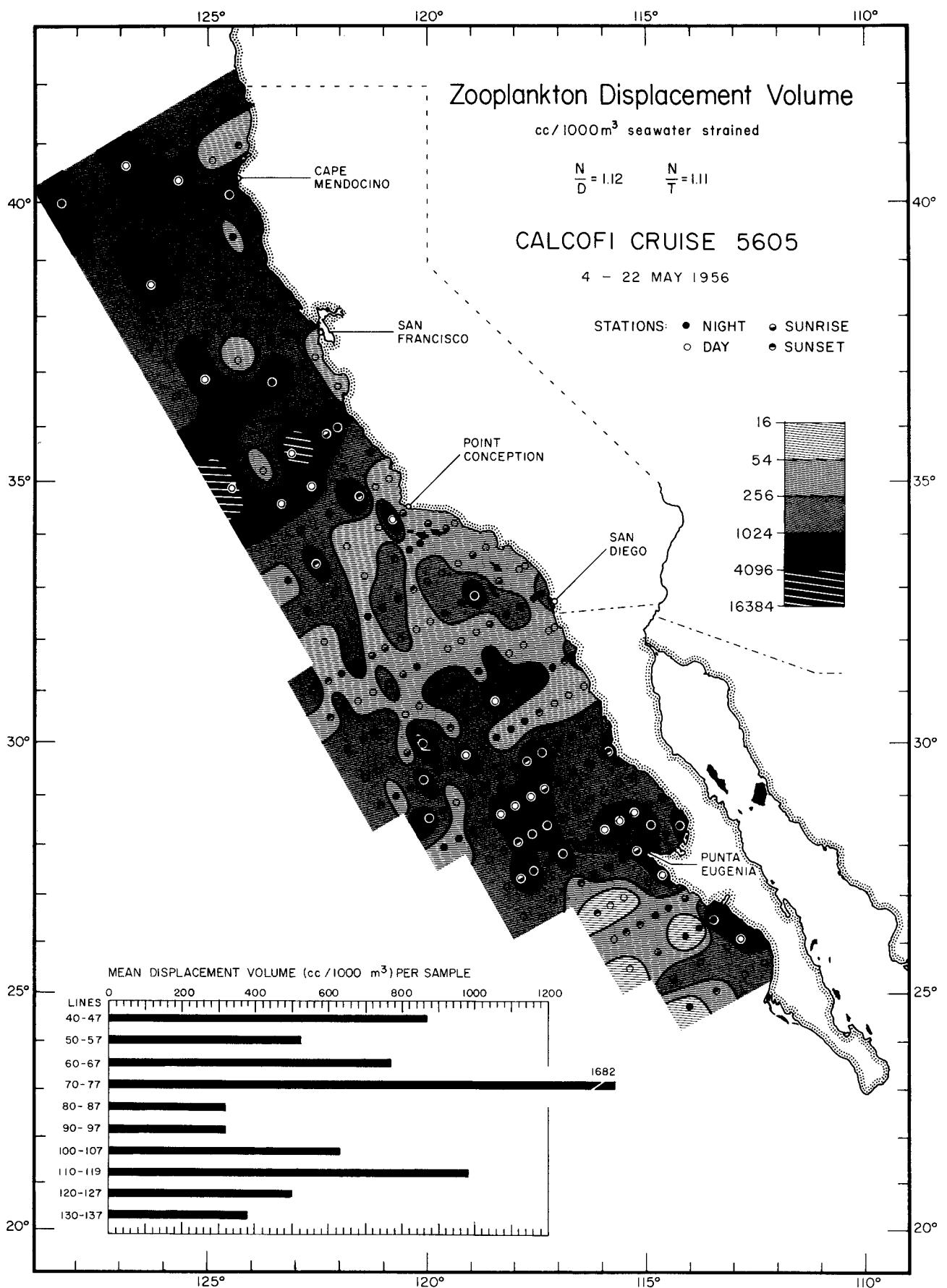
Zooplankton Displacement Volume

5405



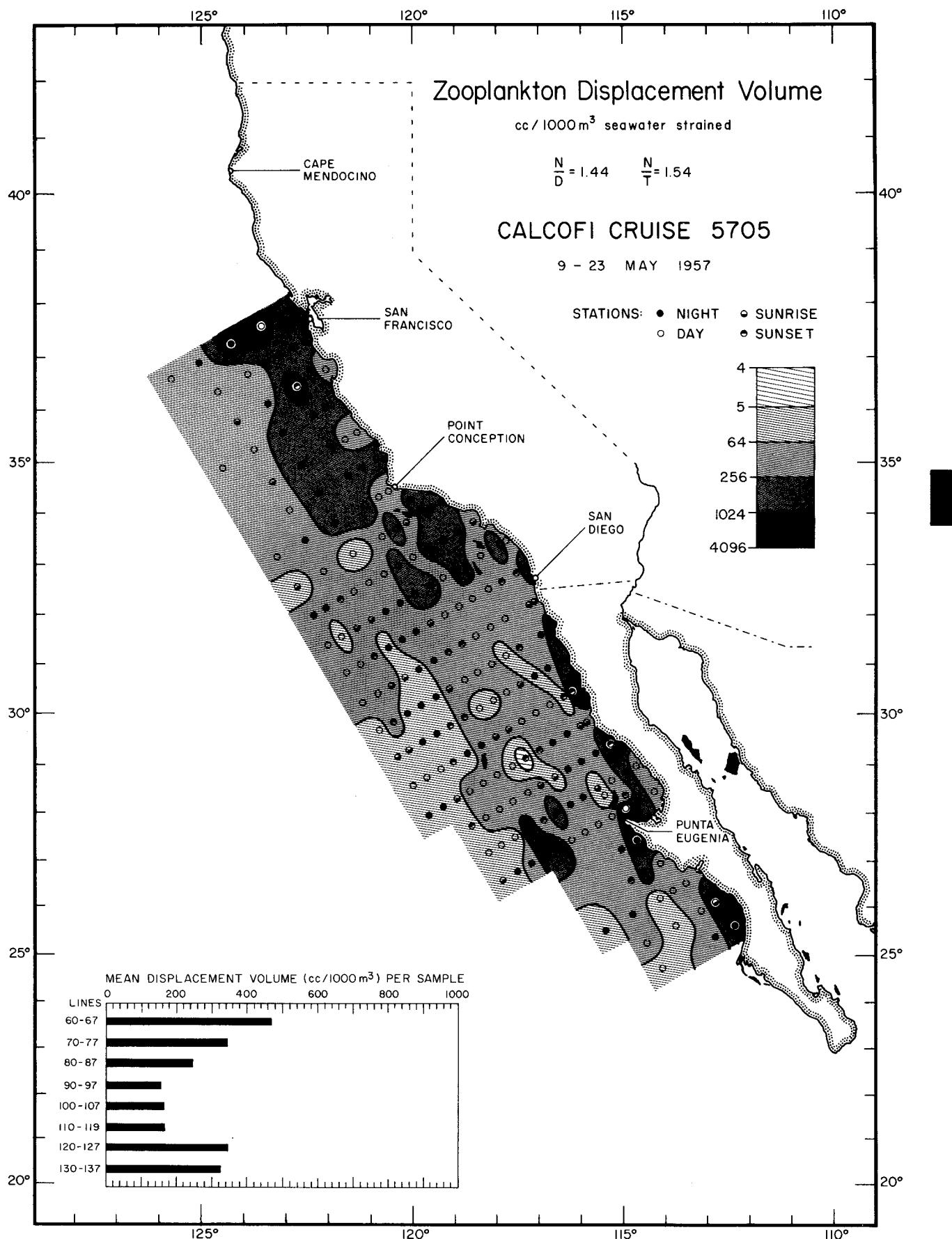
Zooplankton Displacement Volume

5505



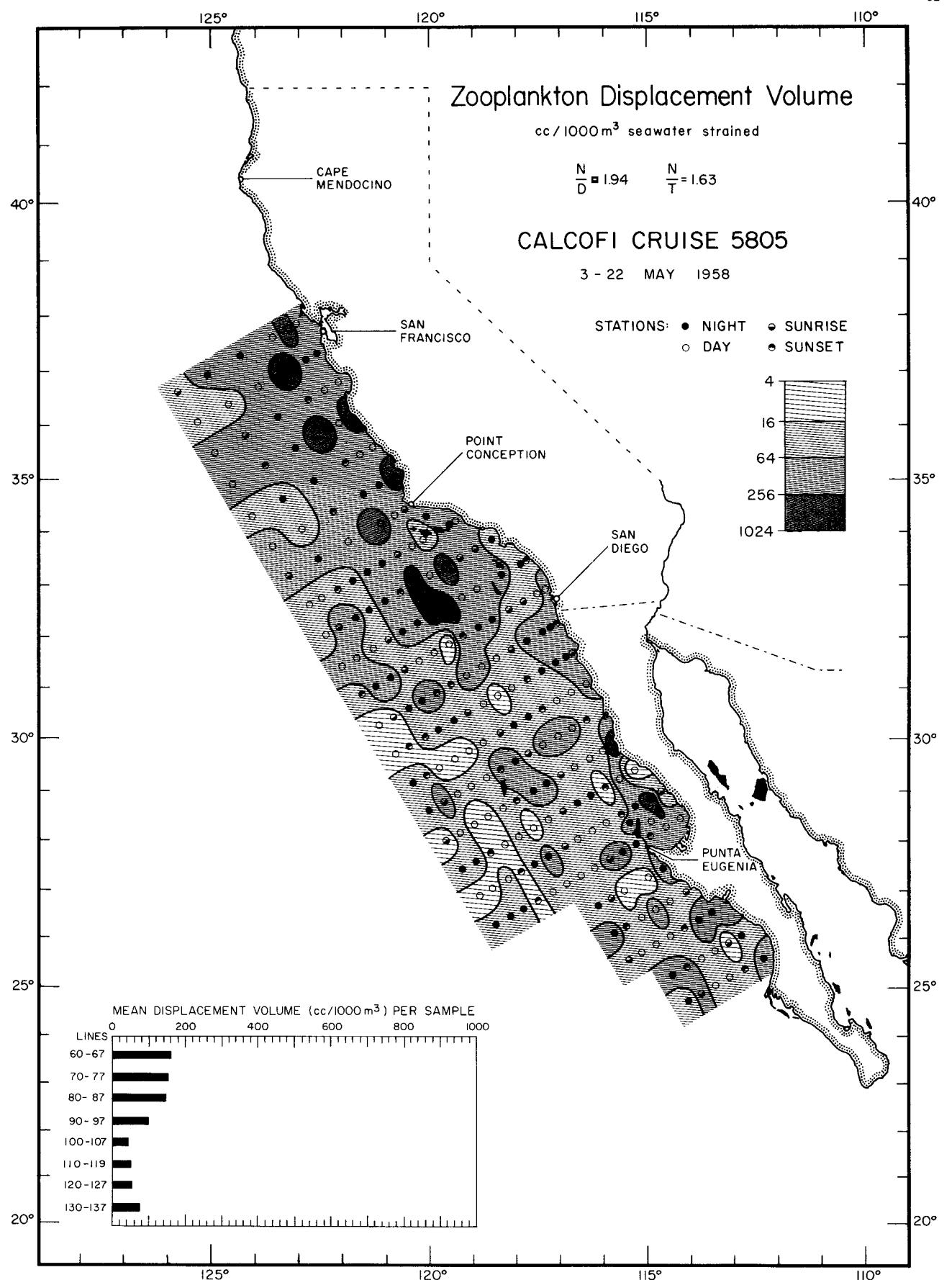
Zooplankton Displacement Volume

5605



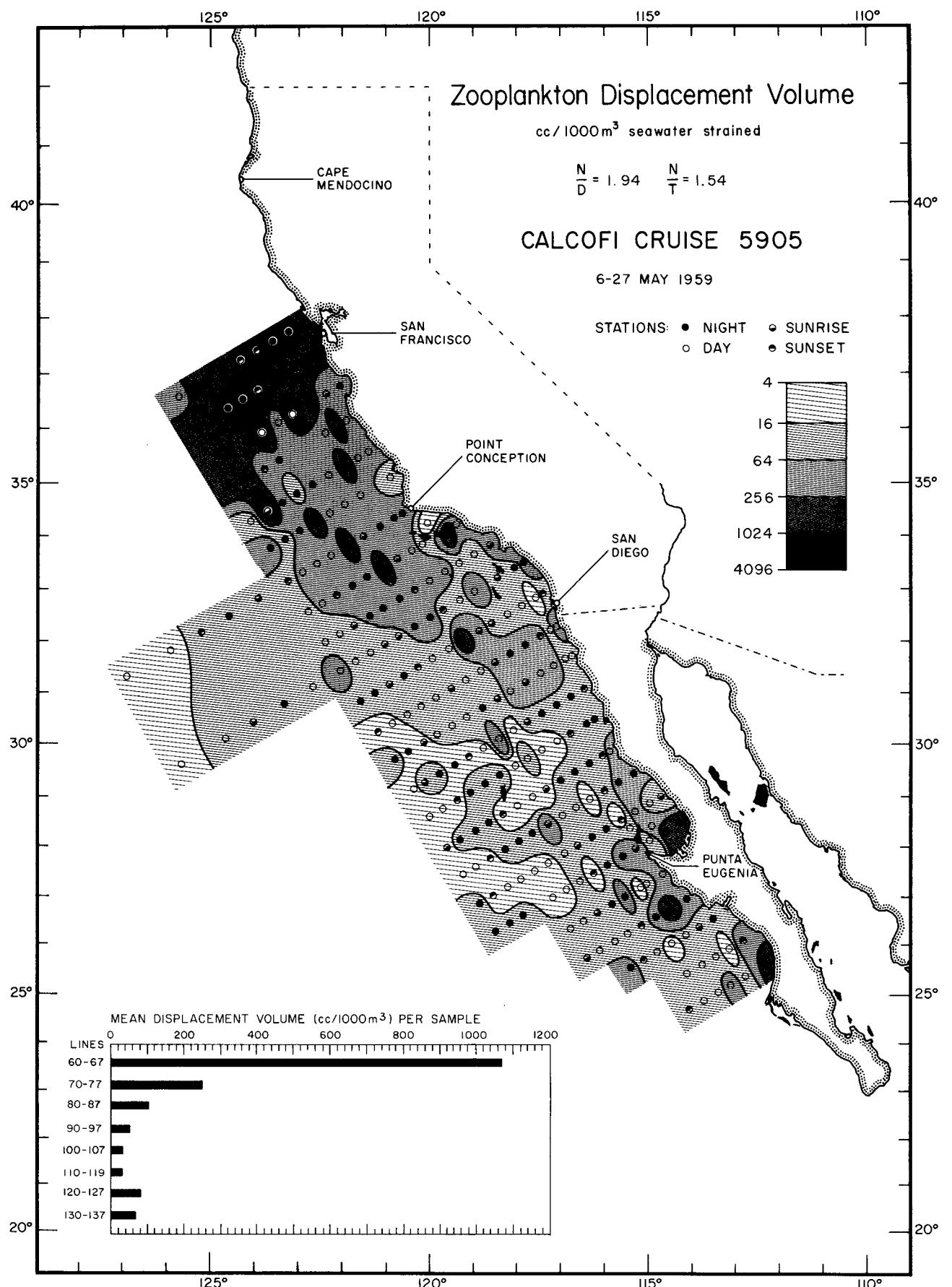
Zooplankton Displacement Volume

5705



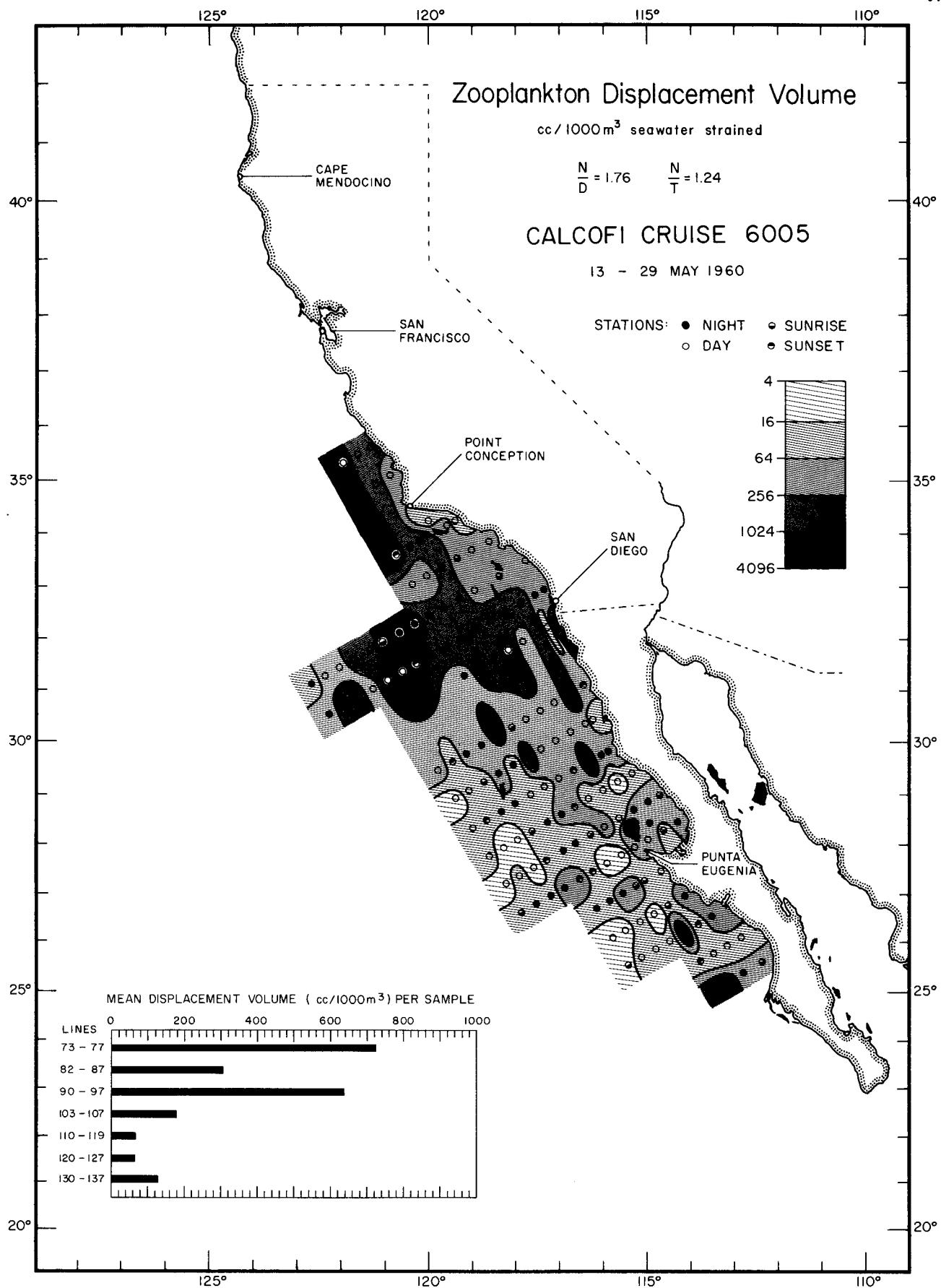
Zooplankton Displacement Volume

5805



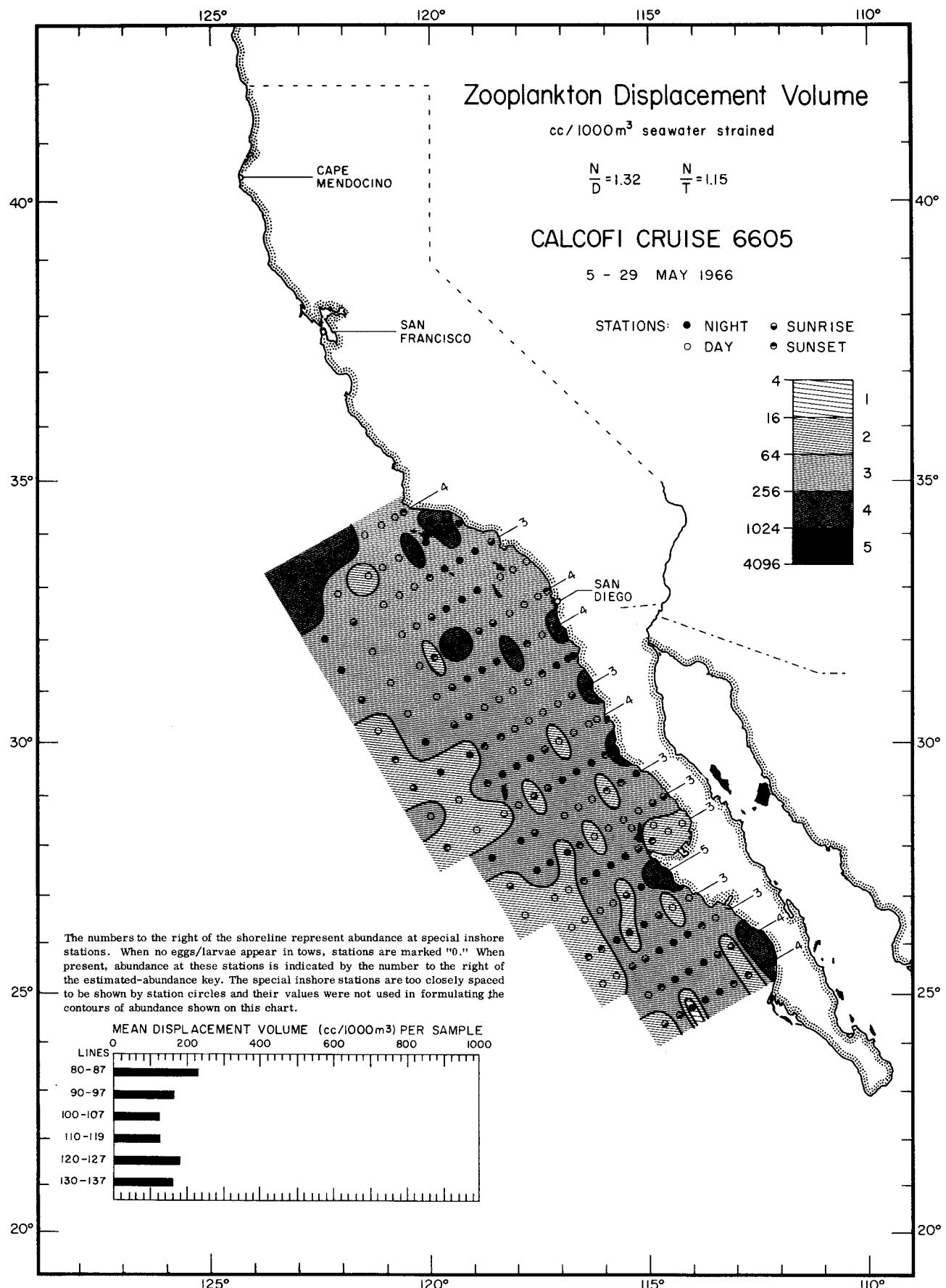
Zooplankton Displacement Volume

5905



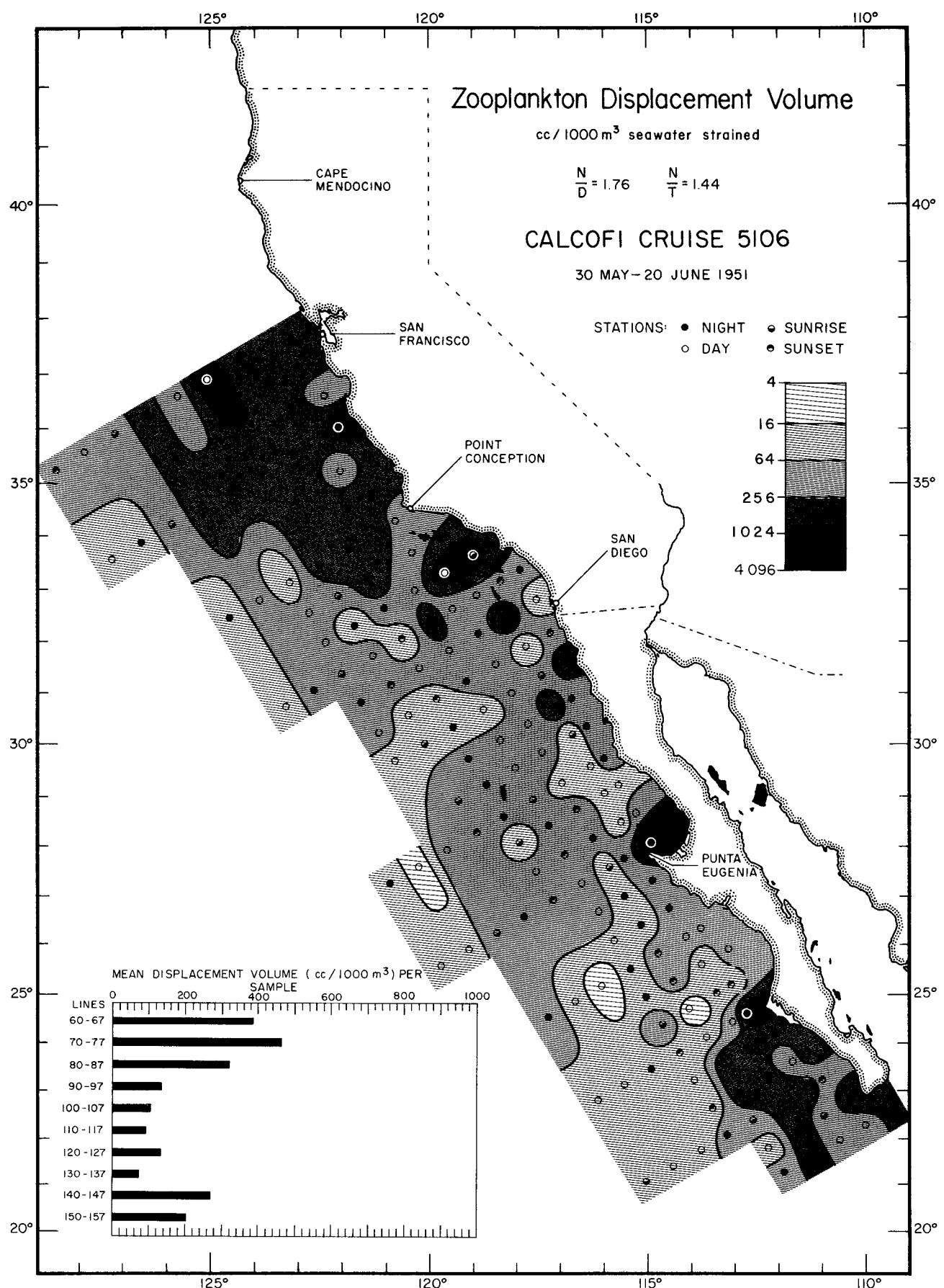
Zooplankton Displacement Volume

6005



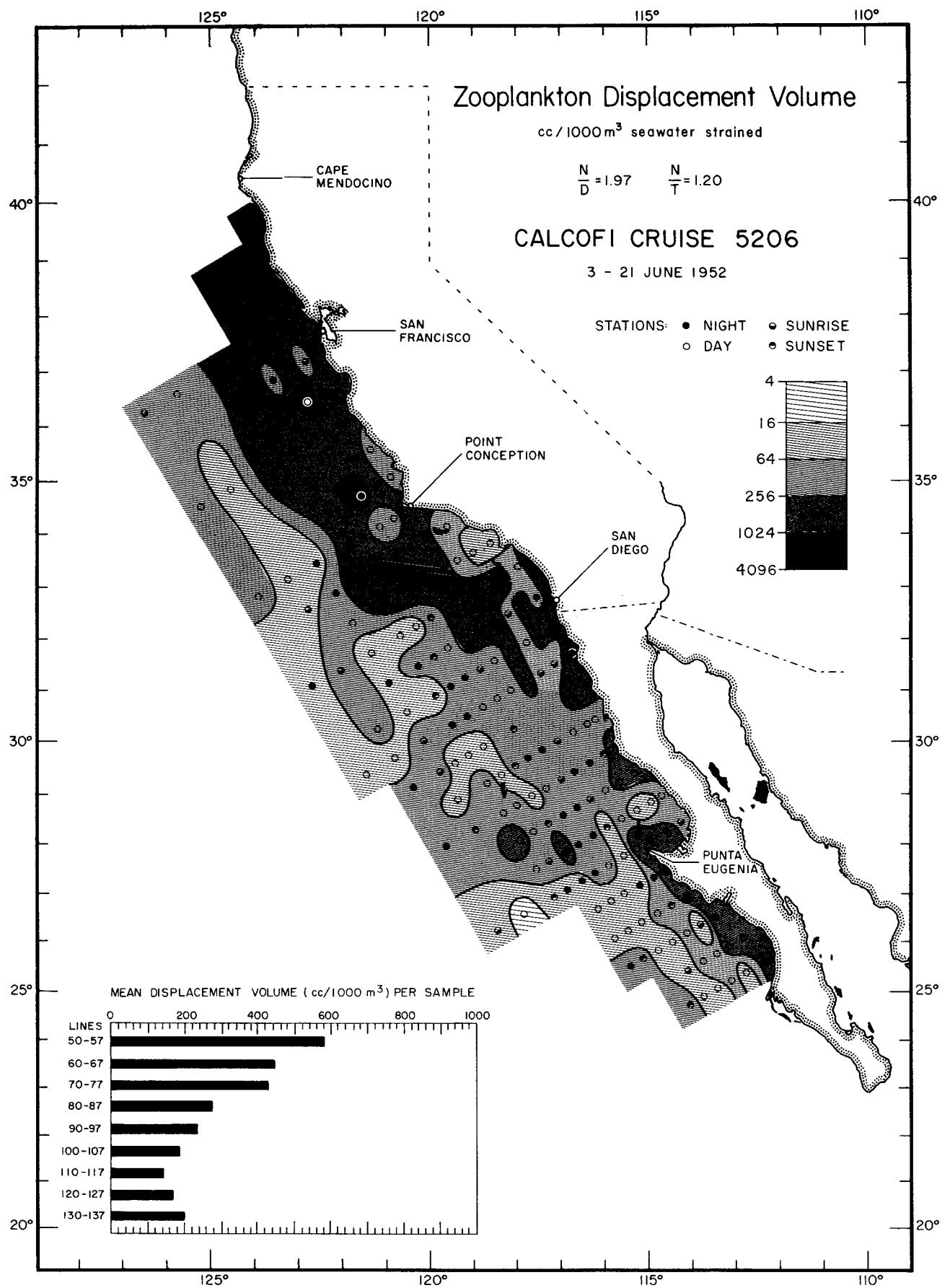
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6605



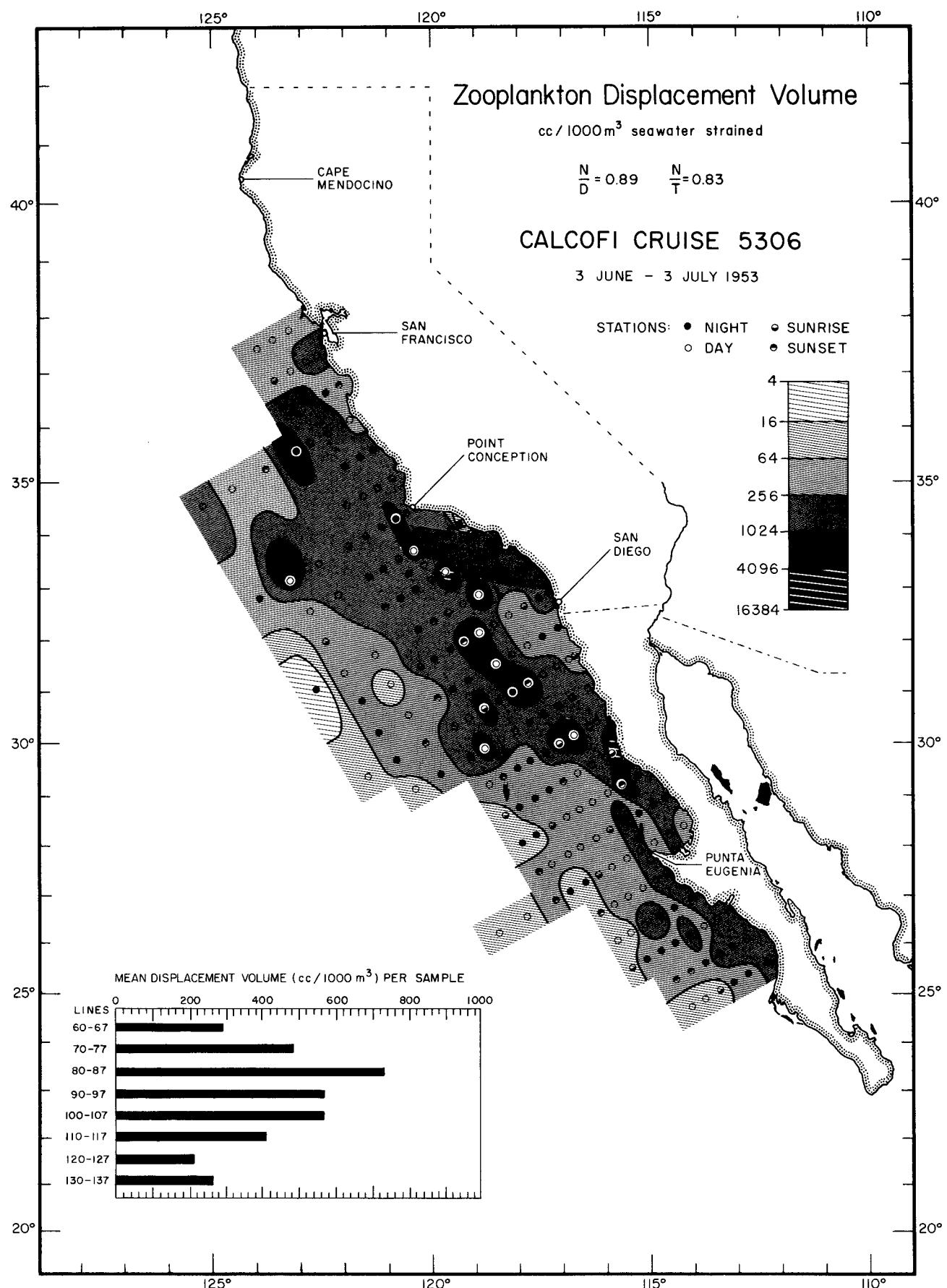
Zooplankton Displacement Volume

5106



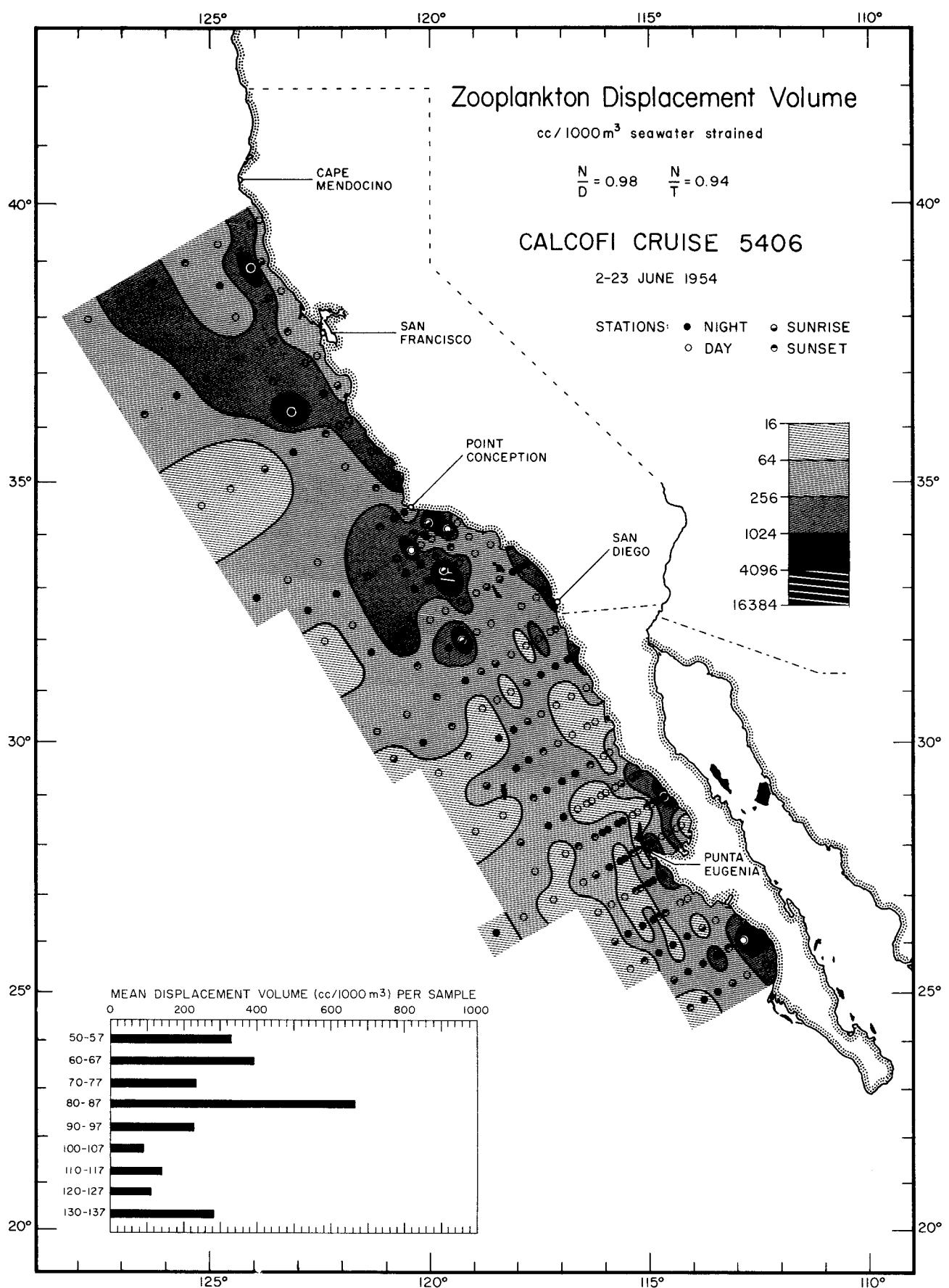
Zooplankton Displacement Volume

5206



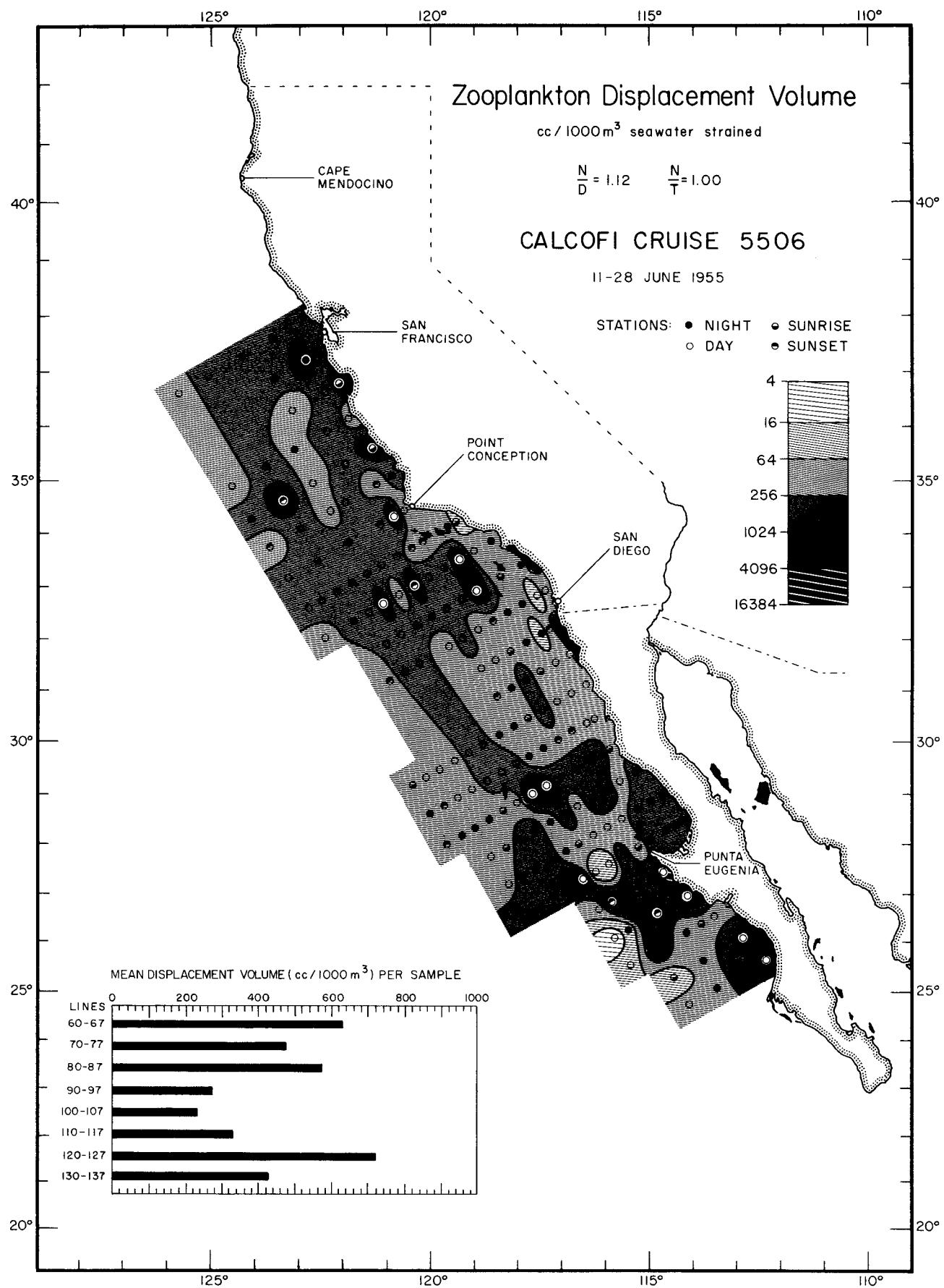
Zooplankton Displacement Volume

5306



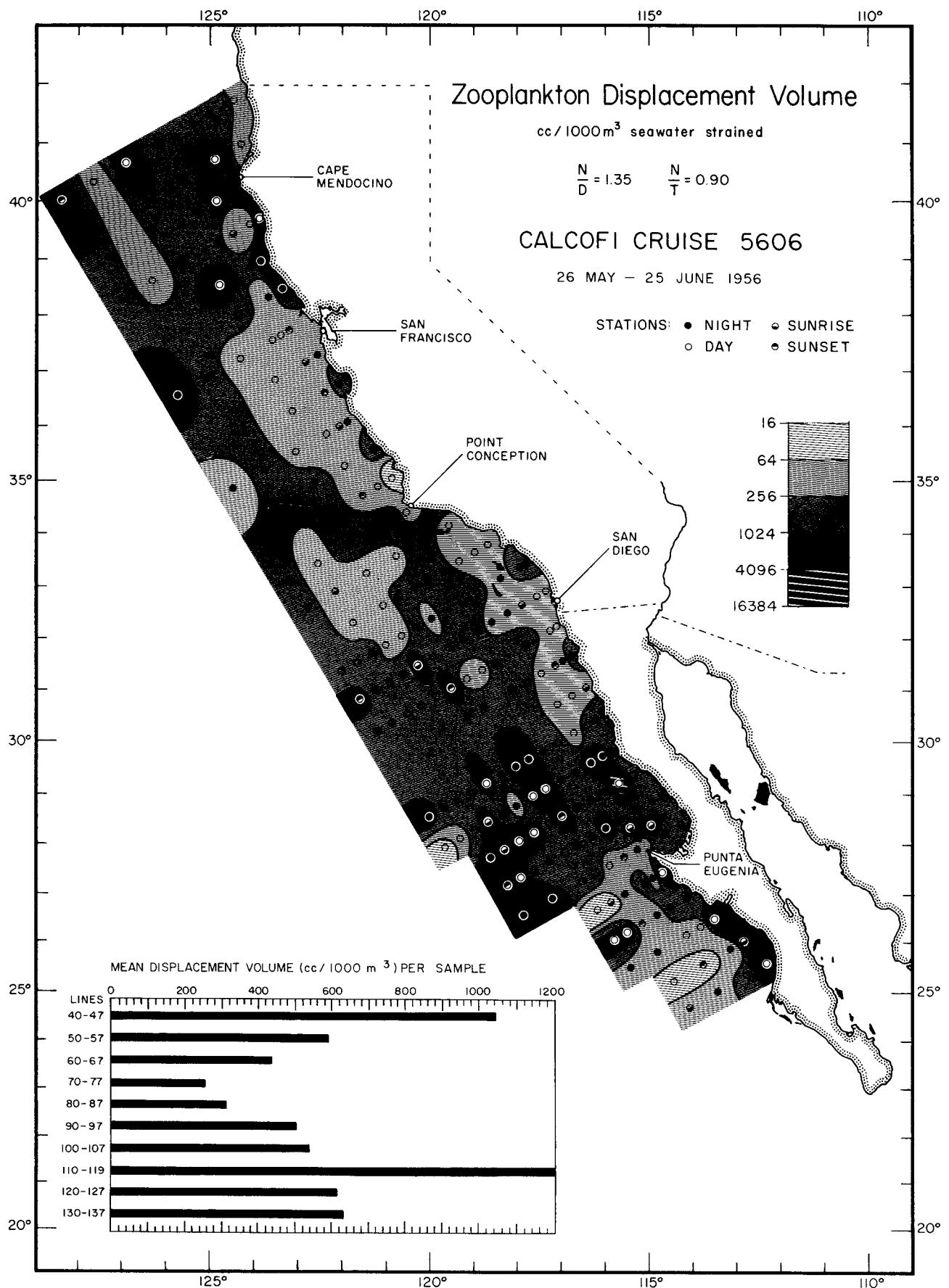
Zooplankton Displacement Volume

5406



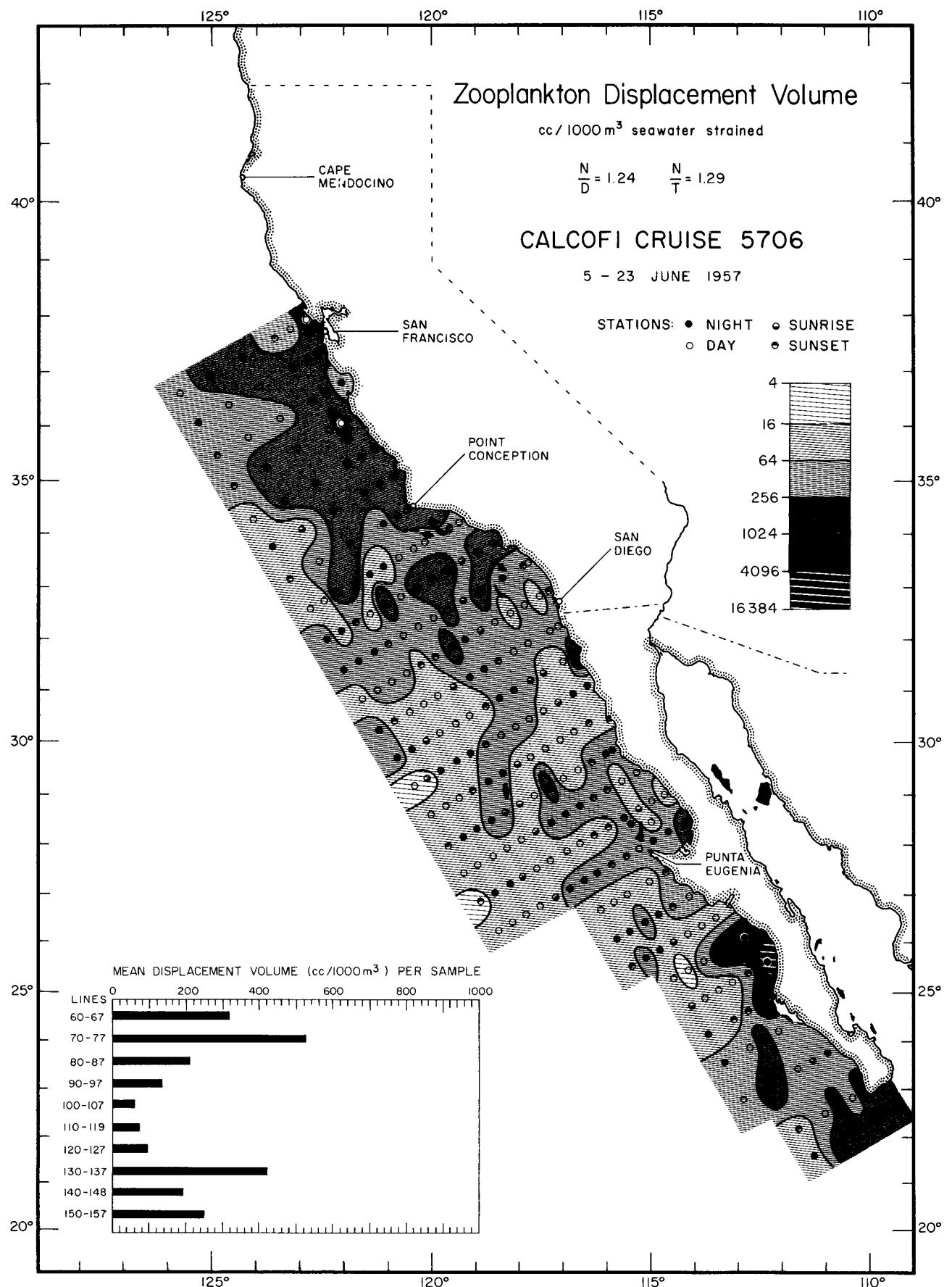
Zooplankton Displacement Volume

5506



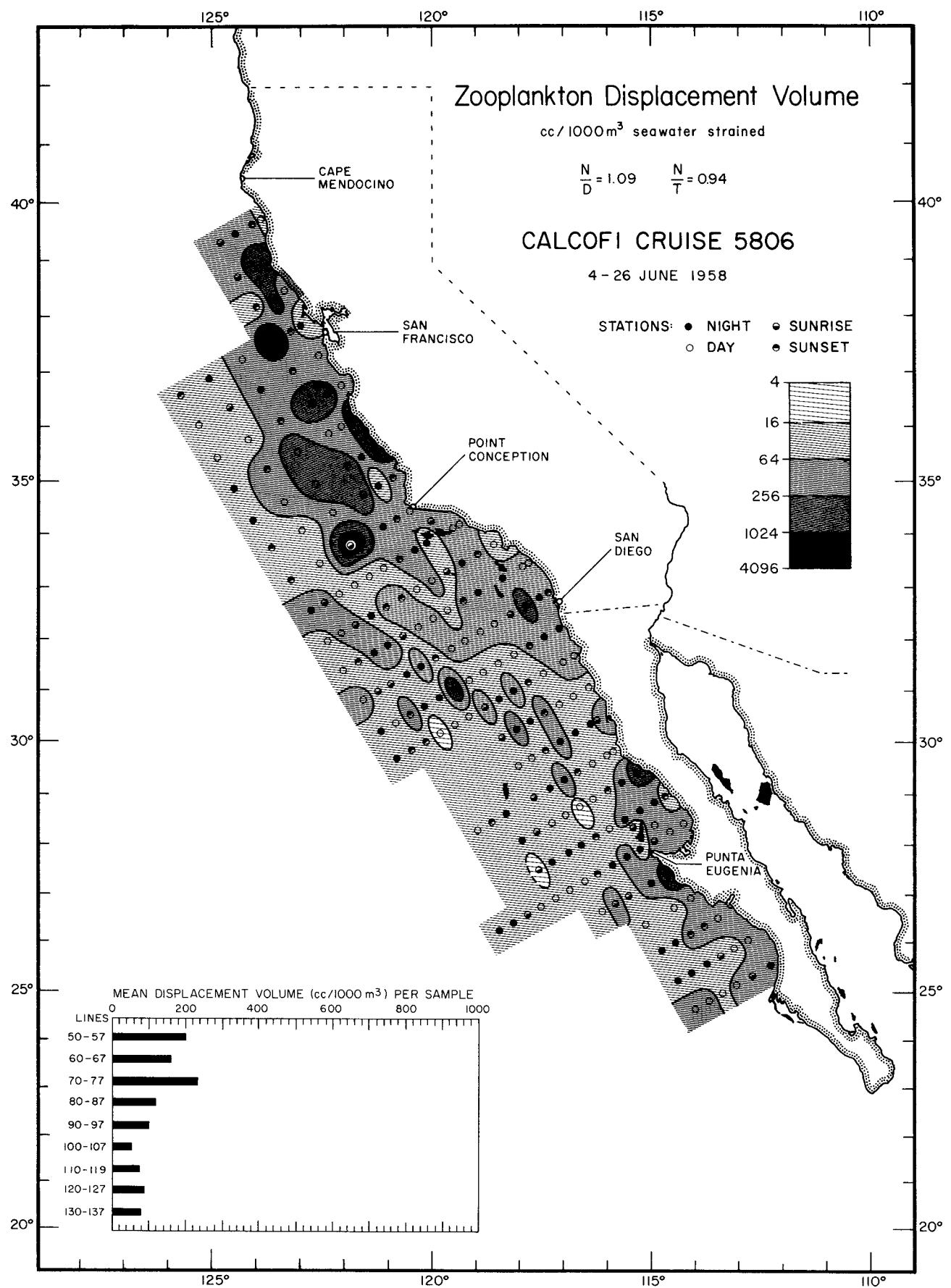
Zooplankton Displacement Volume

5606



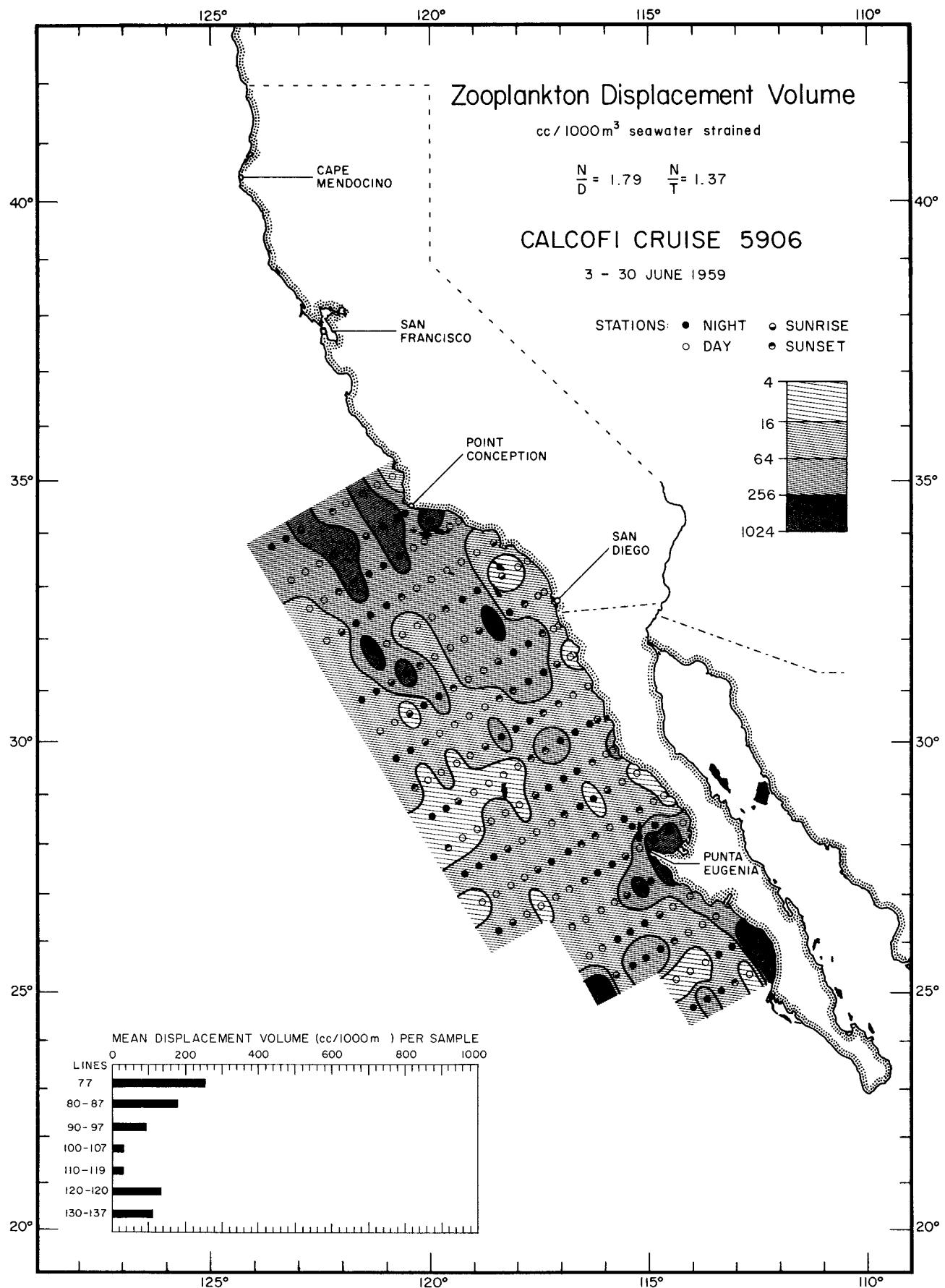
Zooplankton Displacement Volume

5706



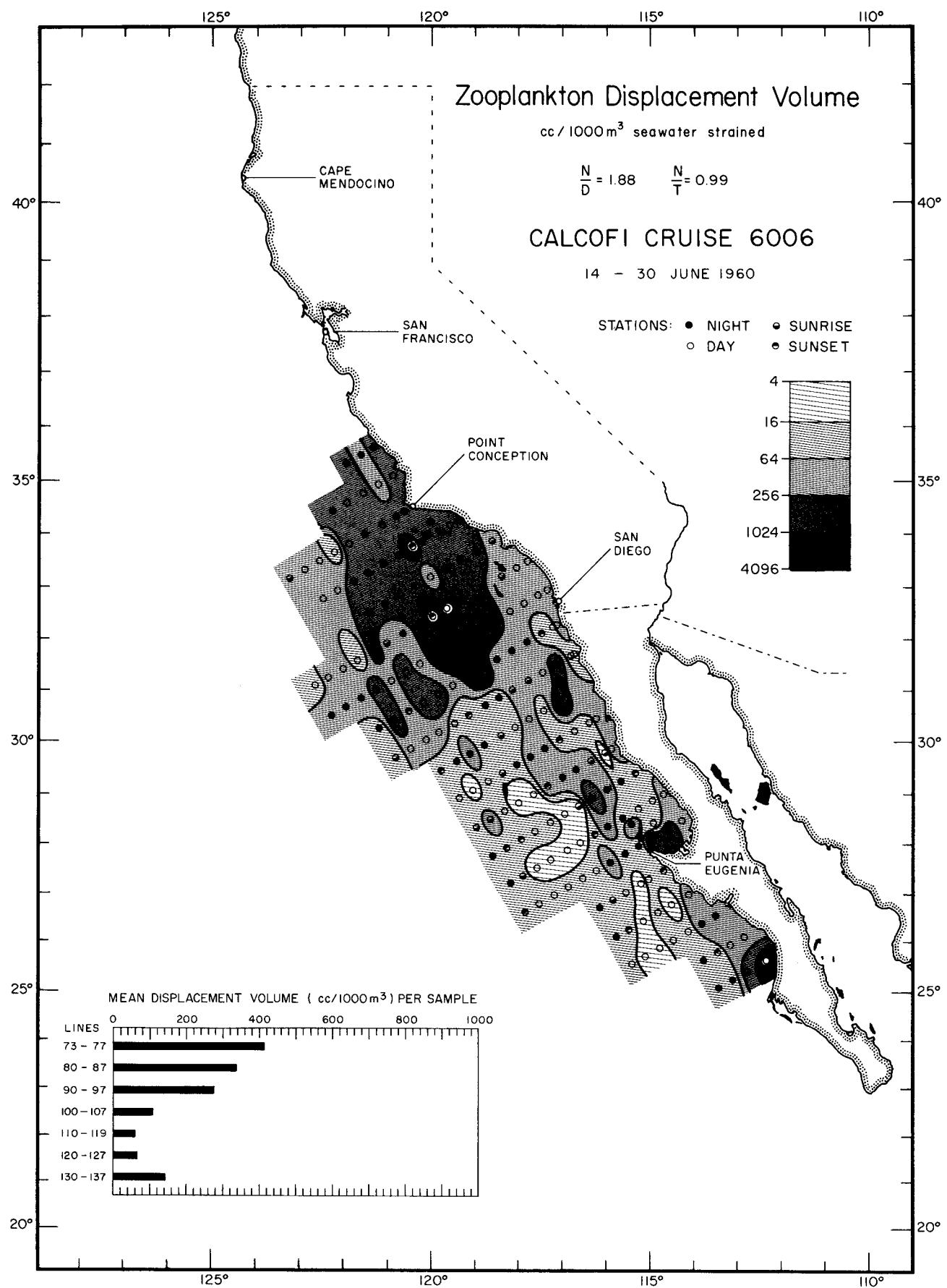
Zooplankton Displacement Volume

5806



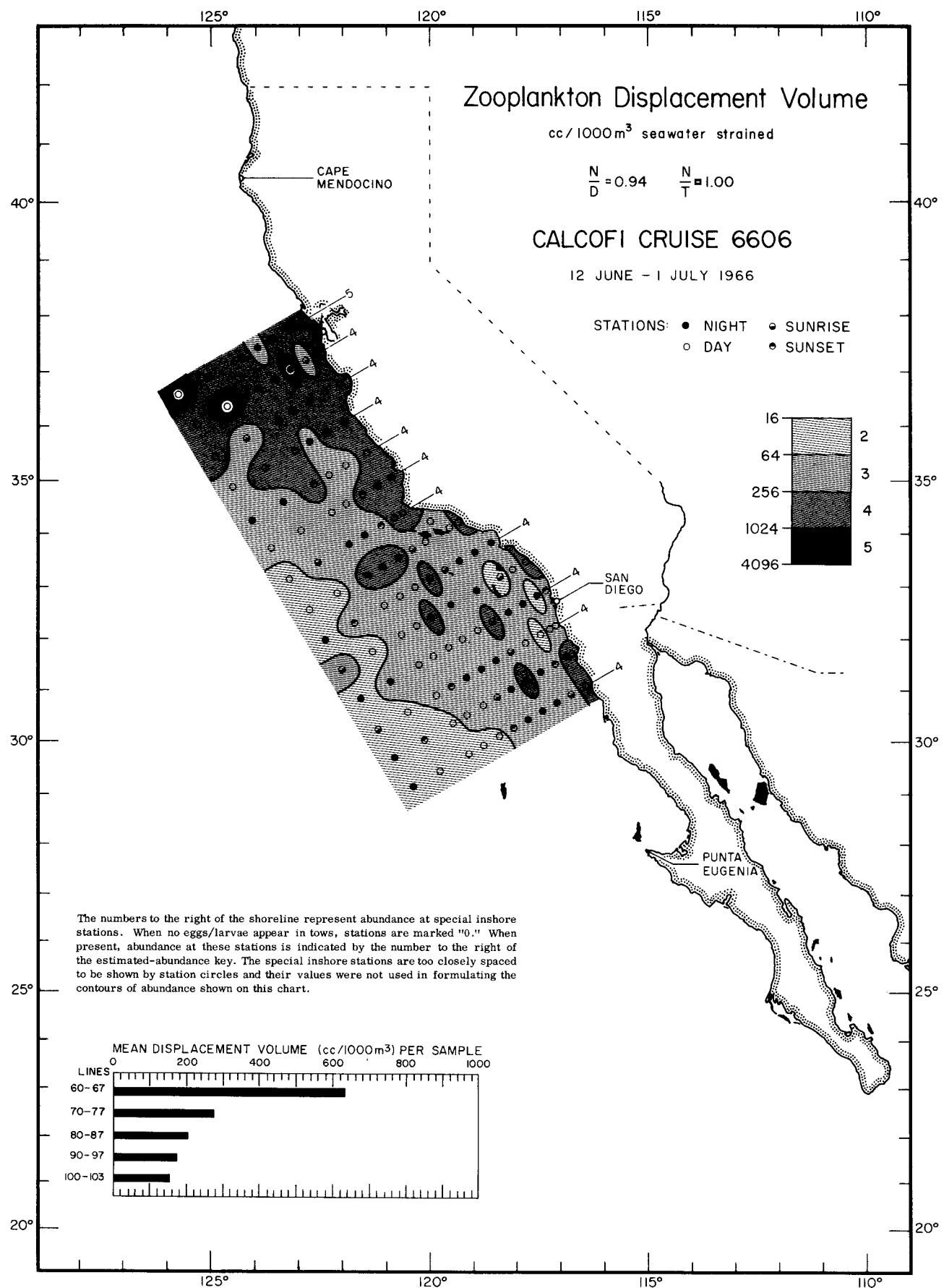
Zooplankton Displacement Volume

5906



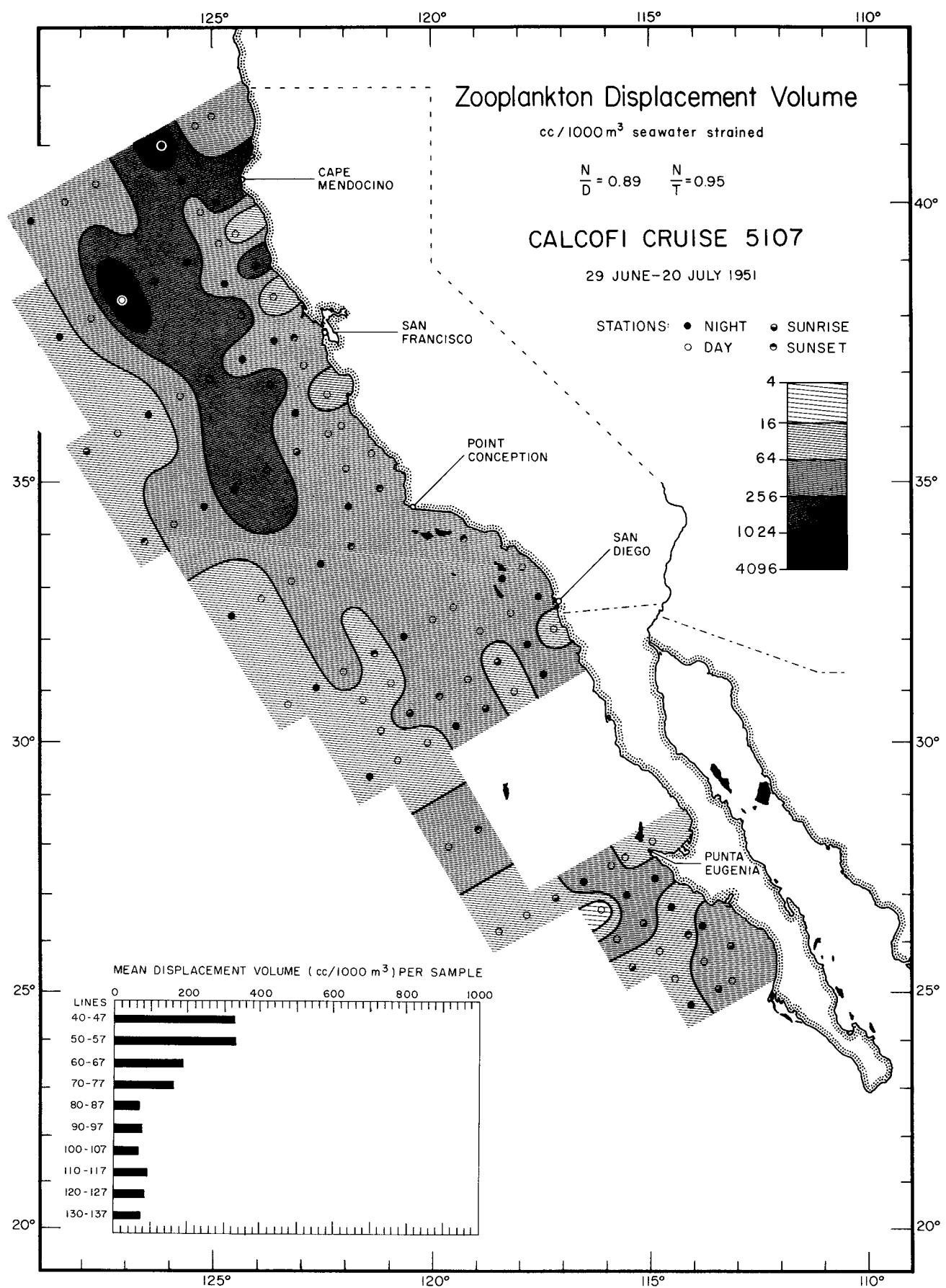
Zooplankton Displacement Volume

6006



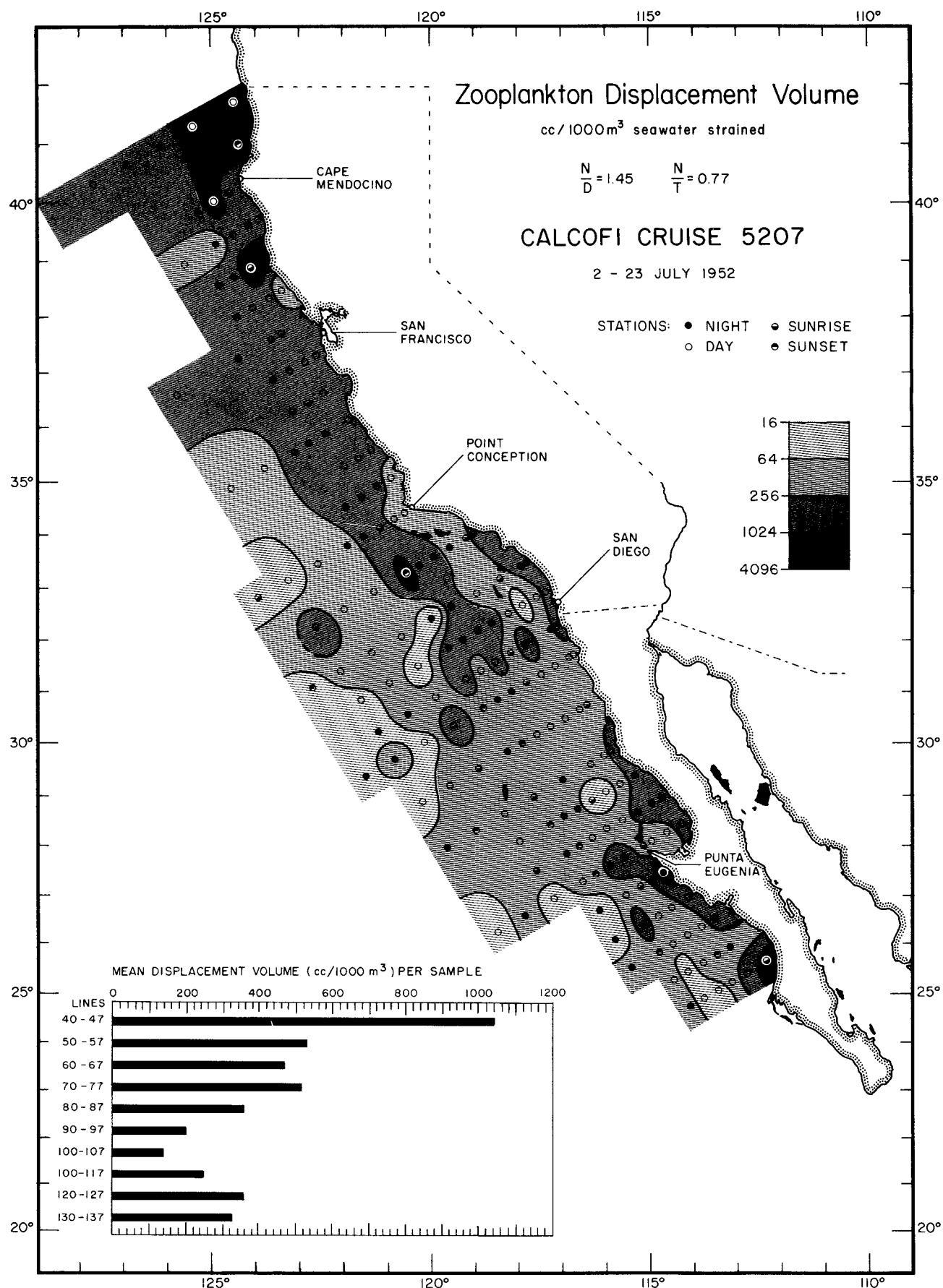
Zooplankton Displacement Volume

6606



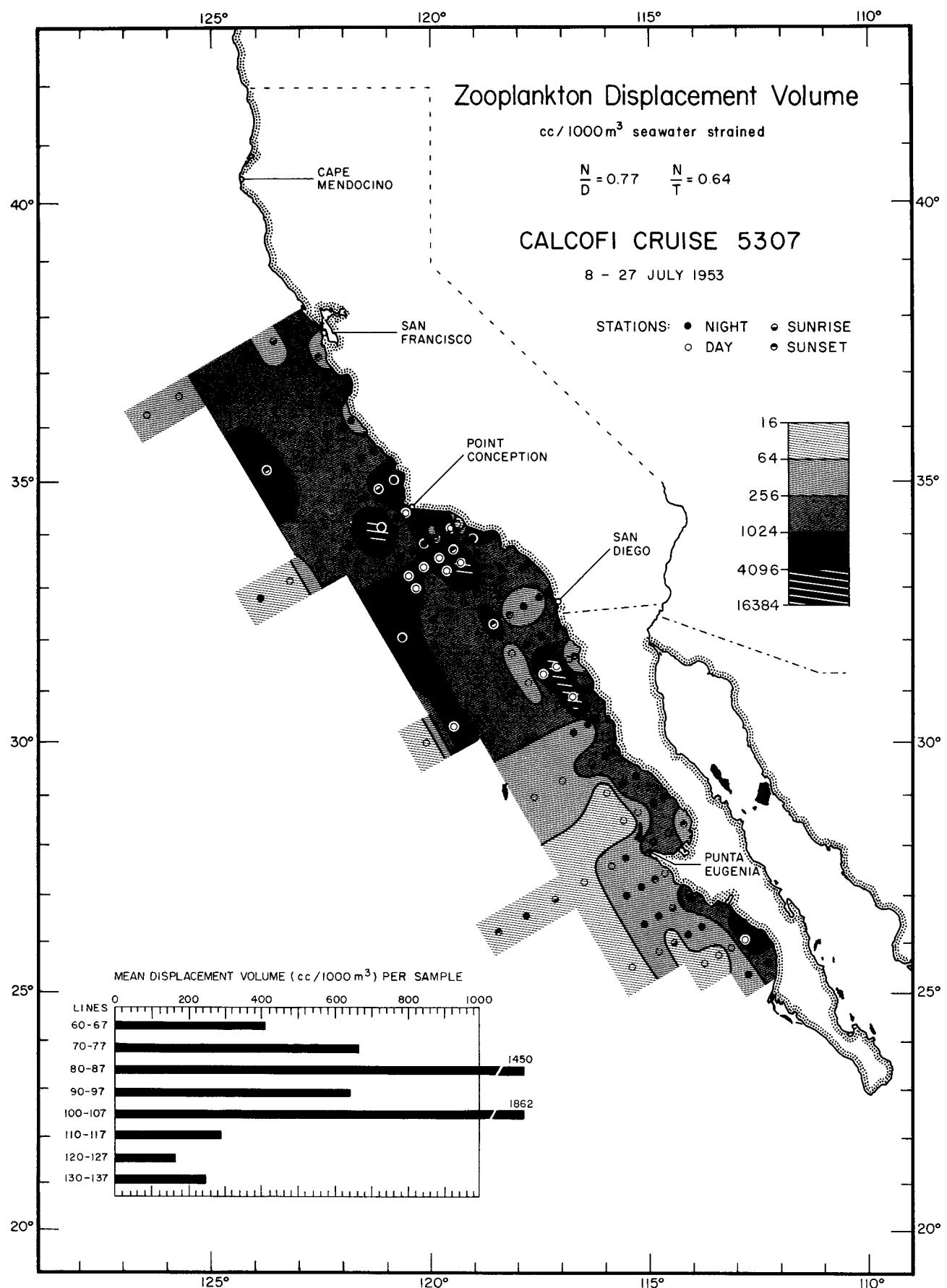
Zooplankton Displacement Volume

5107



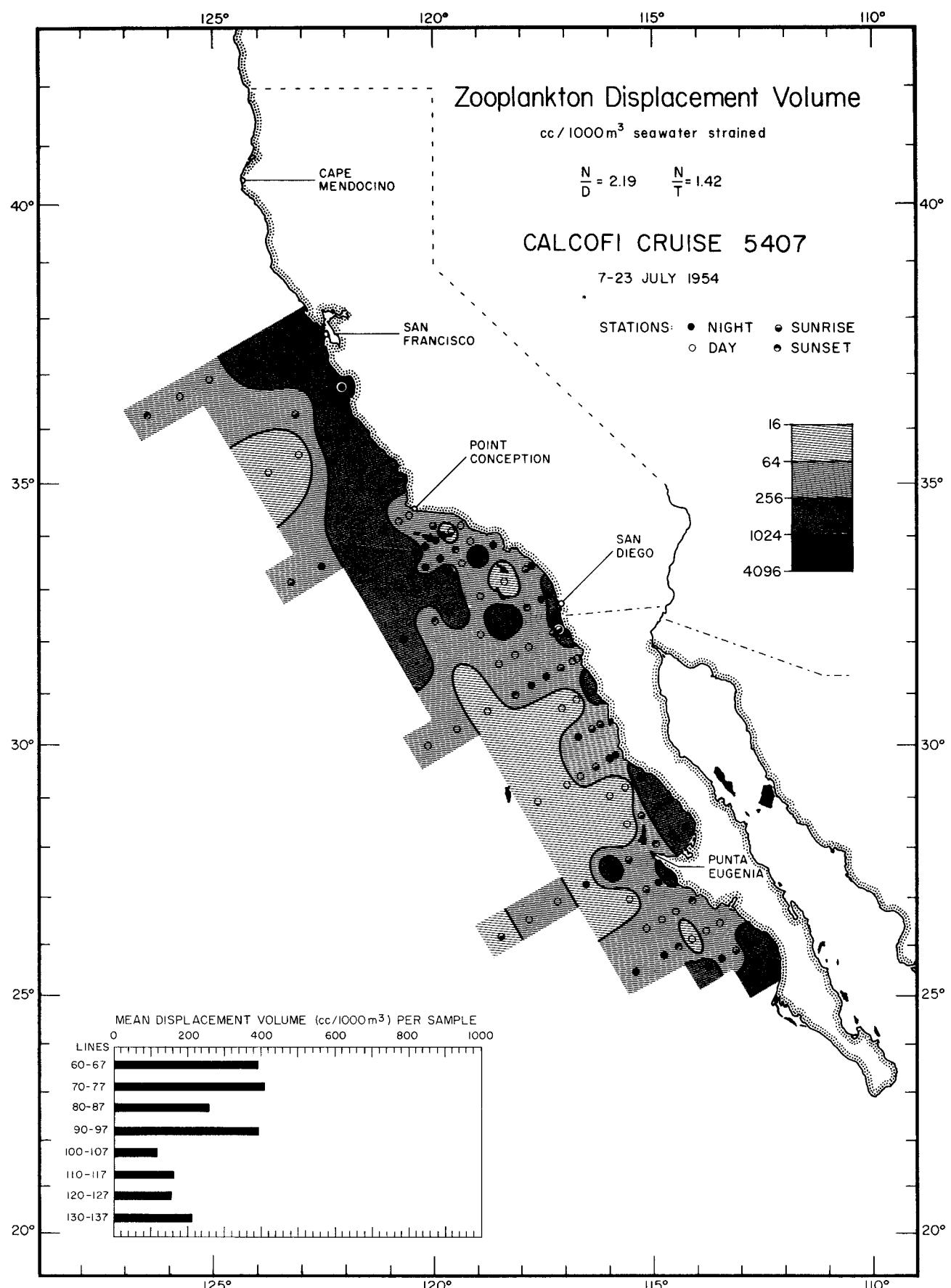
Zooplankton Displacement Volume

5207



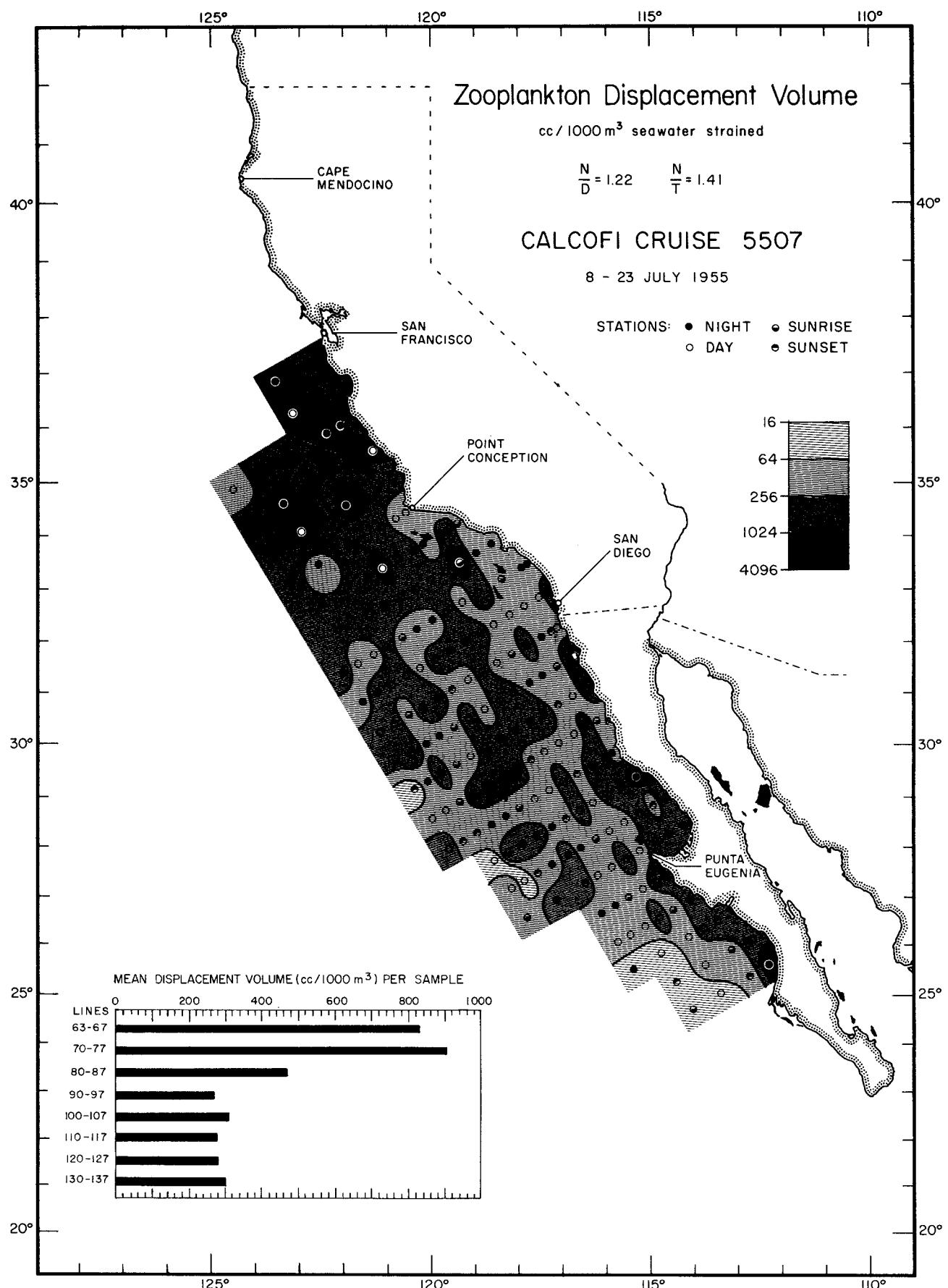
Zooplankton Displacement Volume

5307



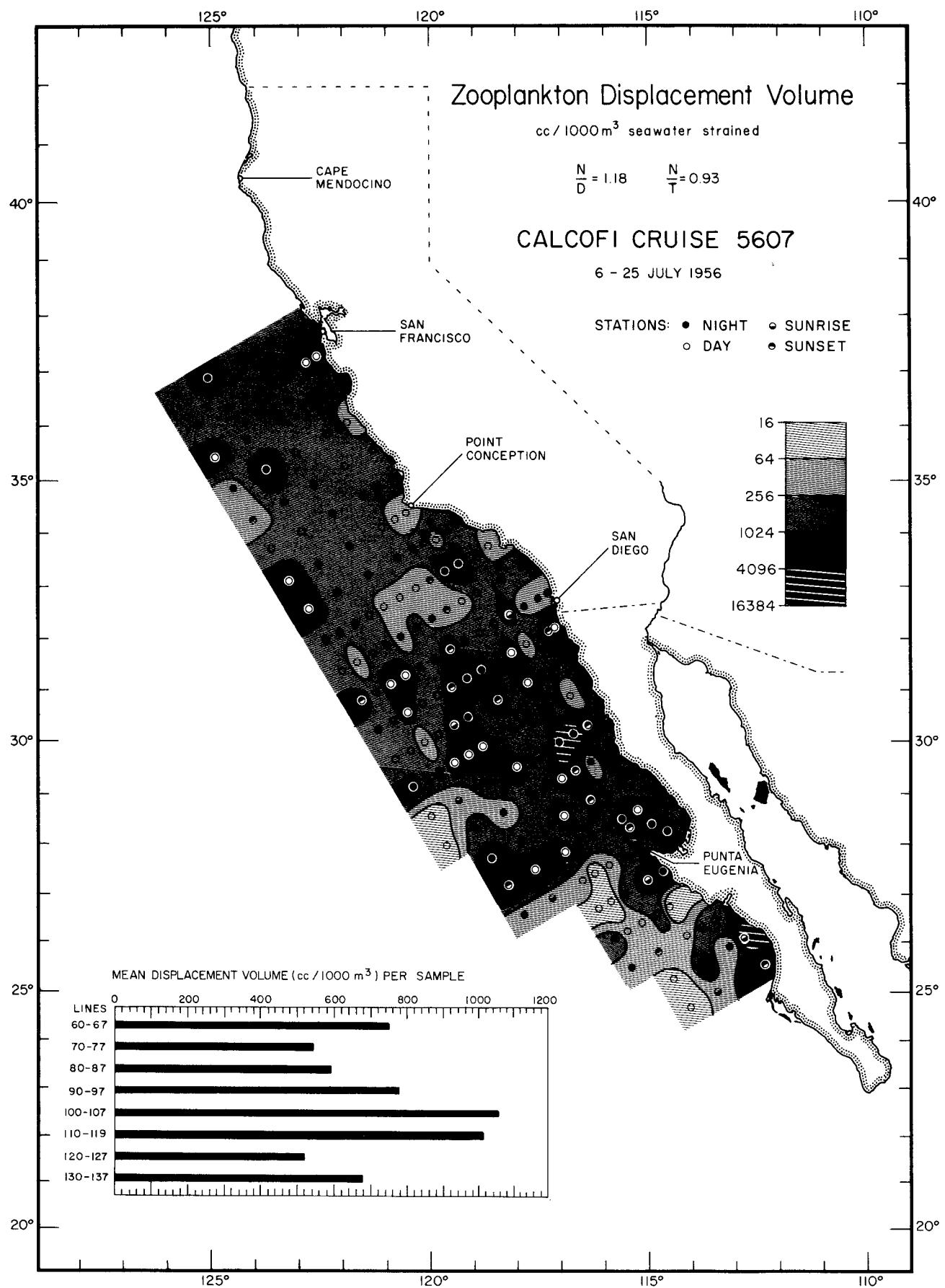
Zooplankton Displacement Volume

5407



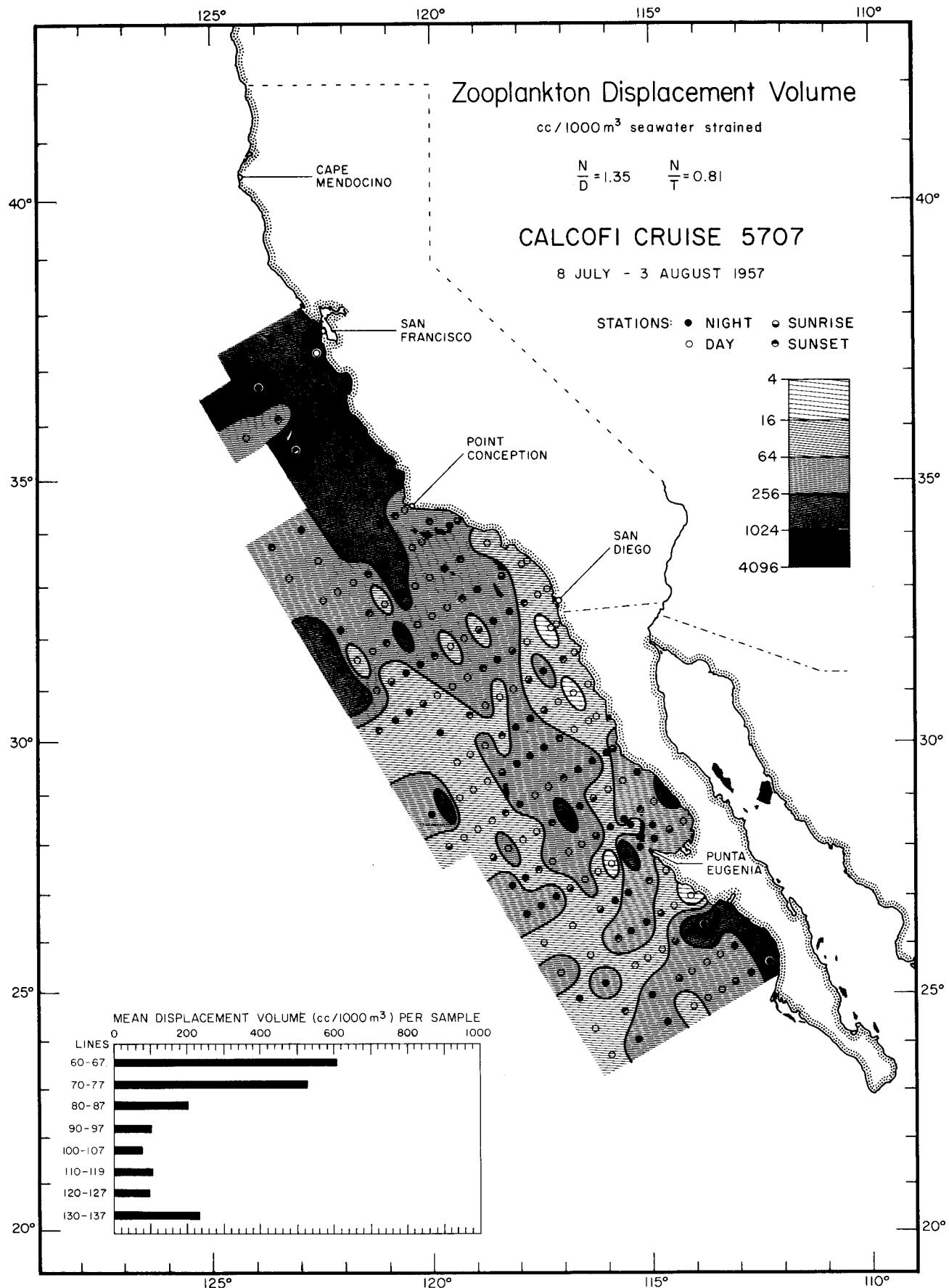
Zooplankton Displacement Volume

5507



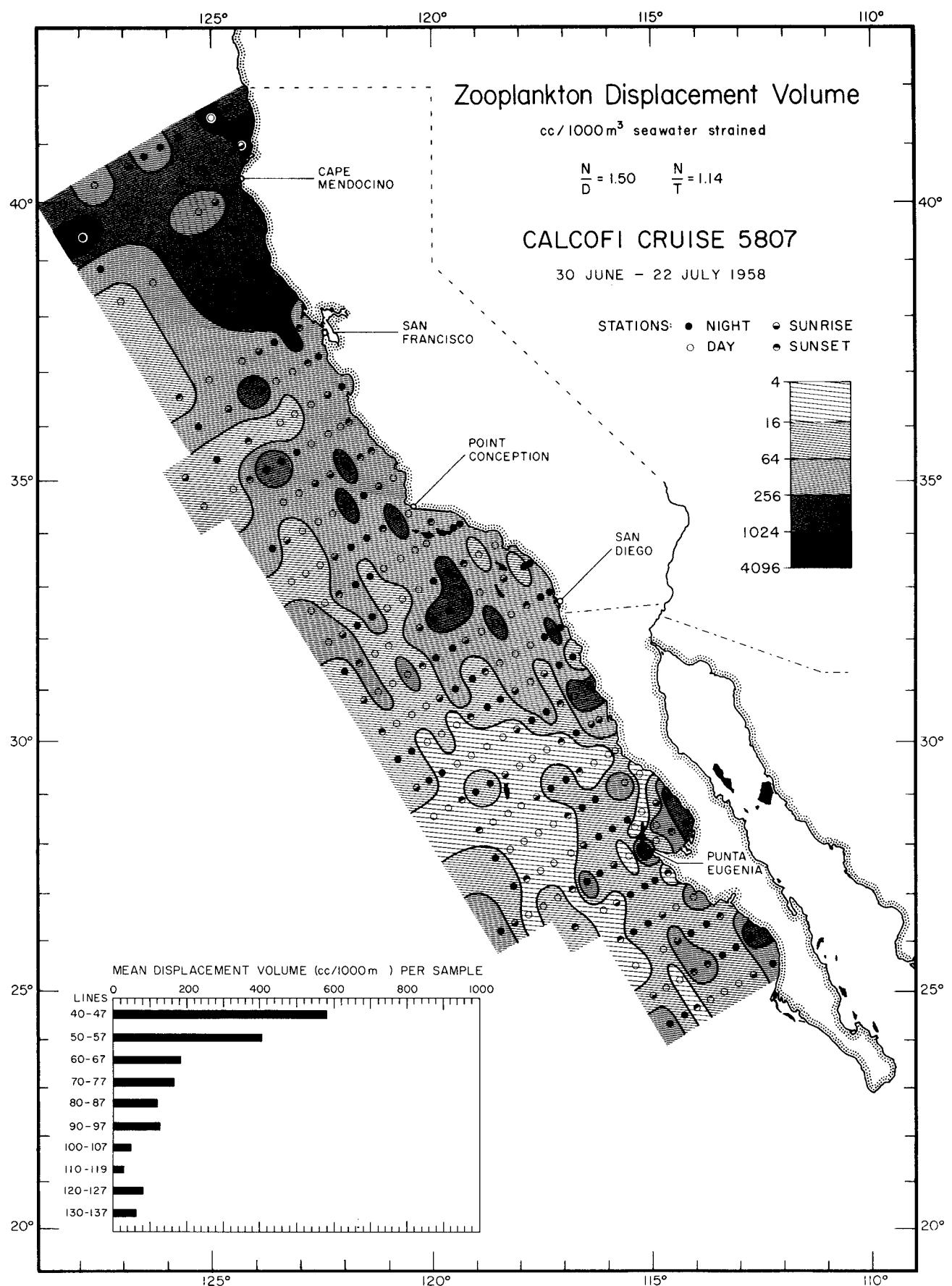
Zooplankton Displacement Volume

5607



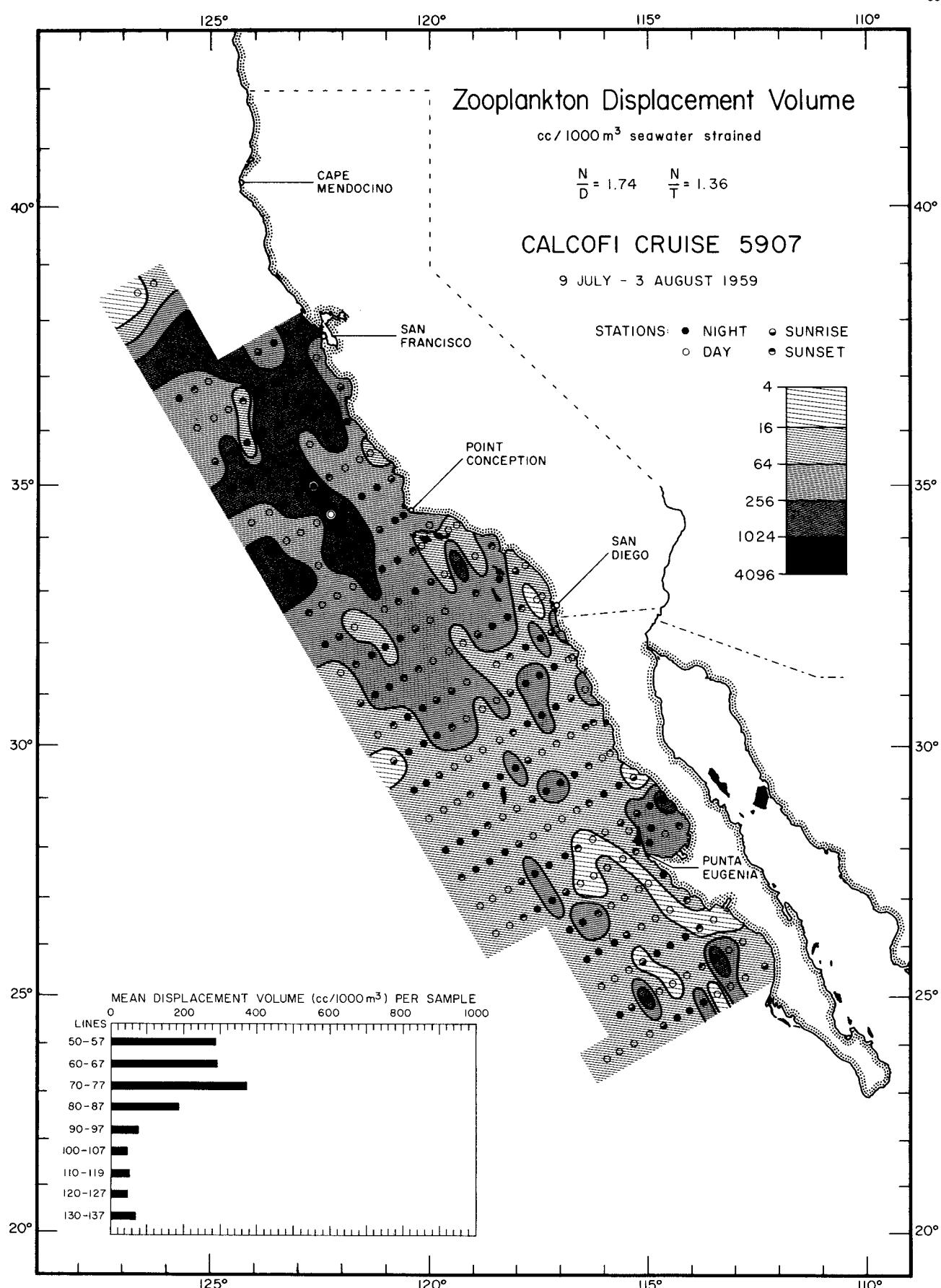
Zooplankton Displacement Volume

5707



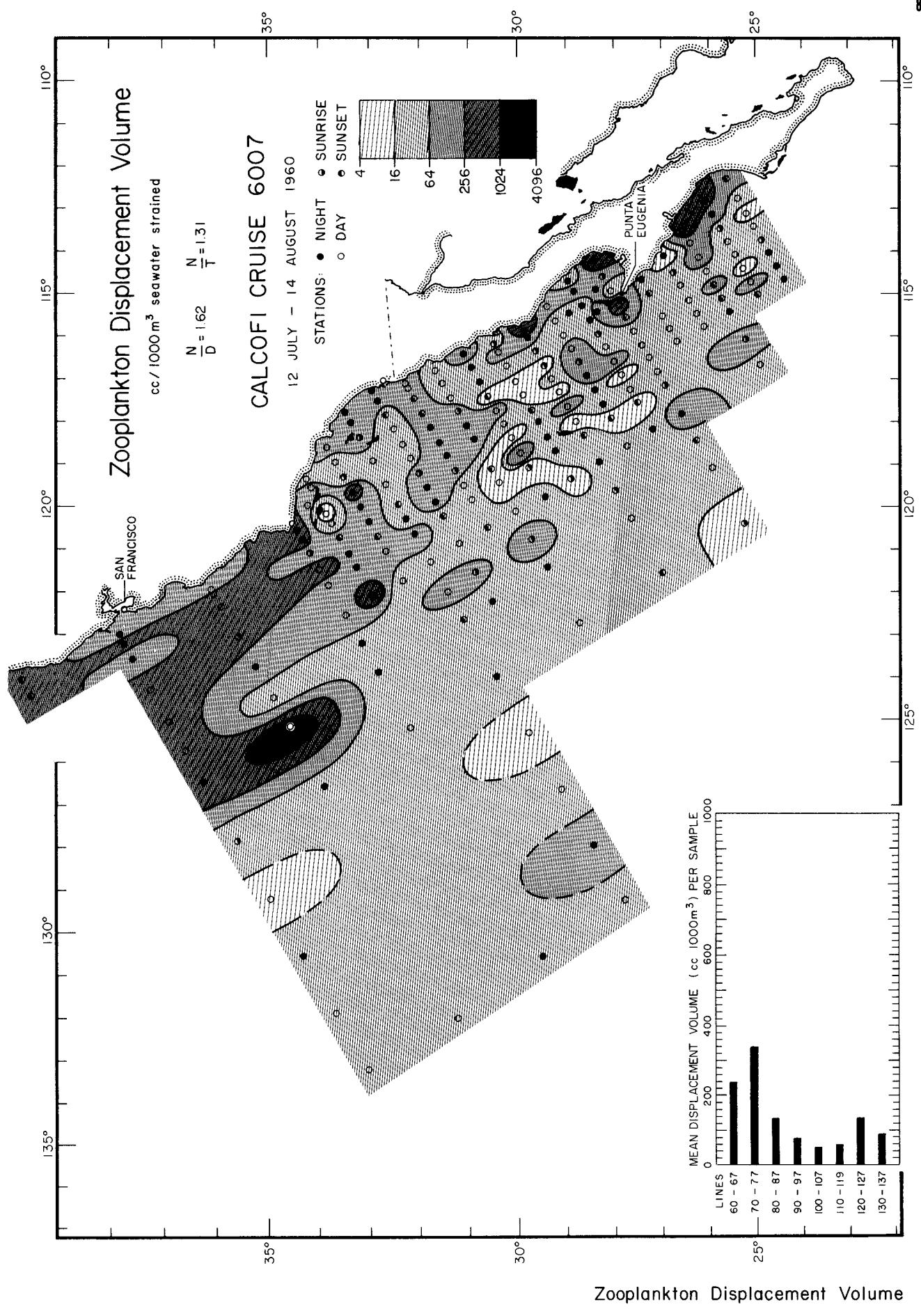
Zooplankton Displacement Volume

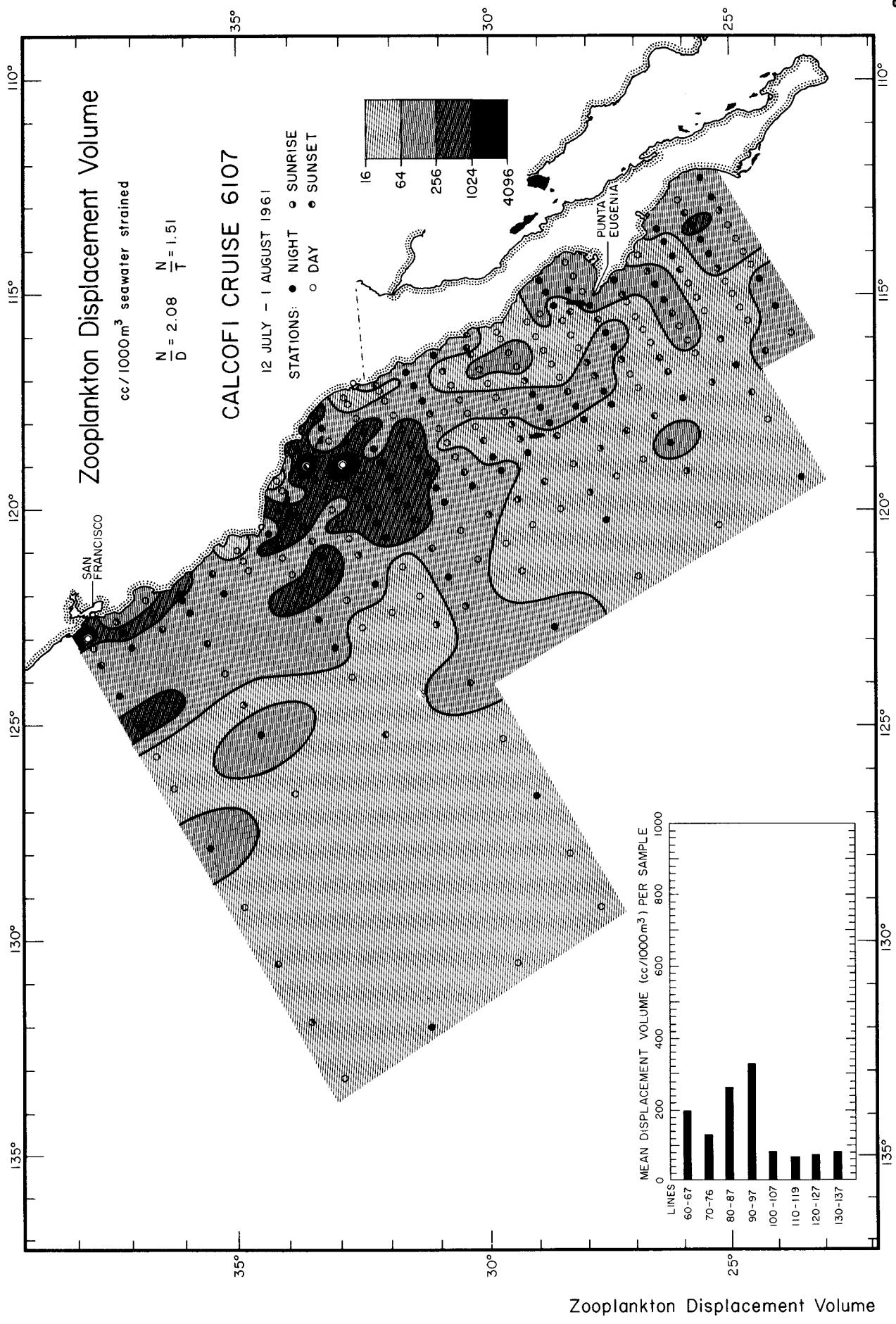
5807

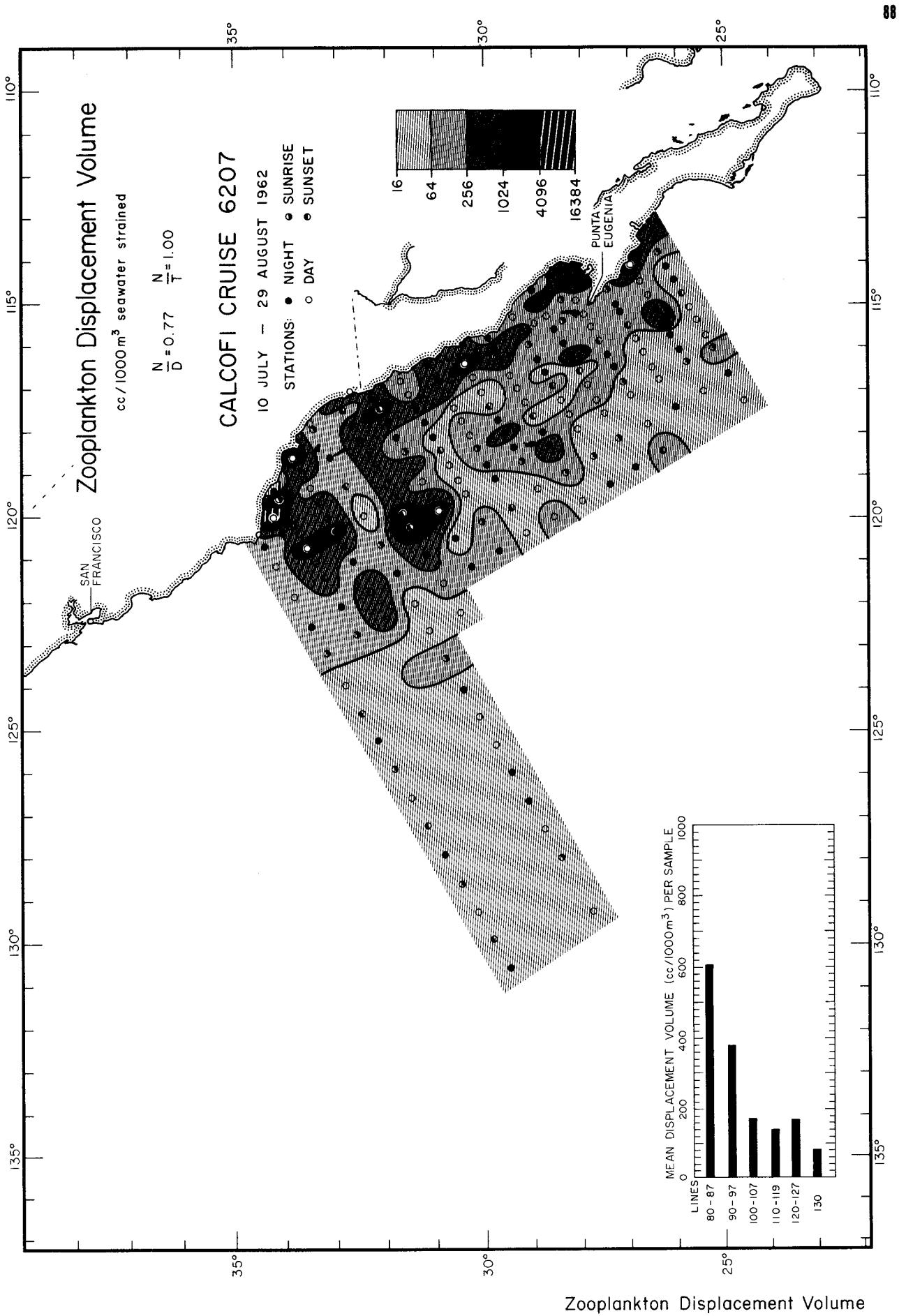


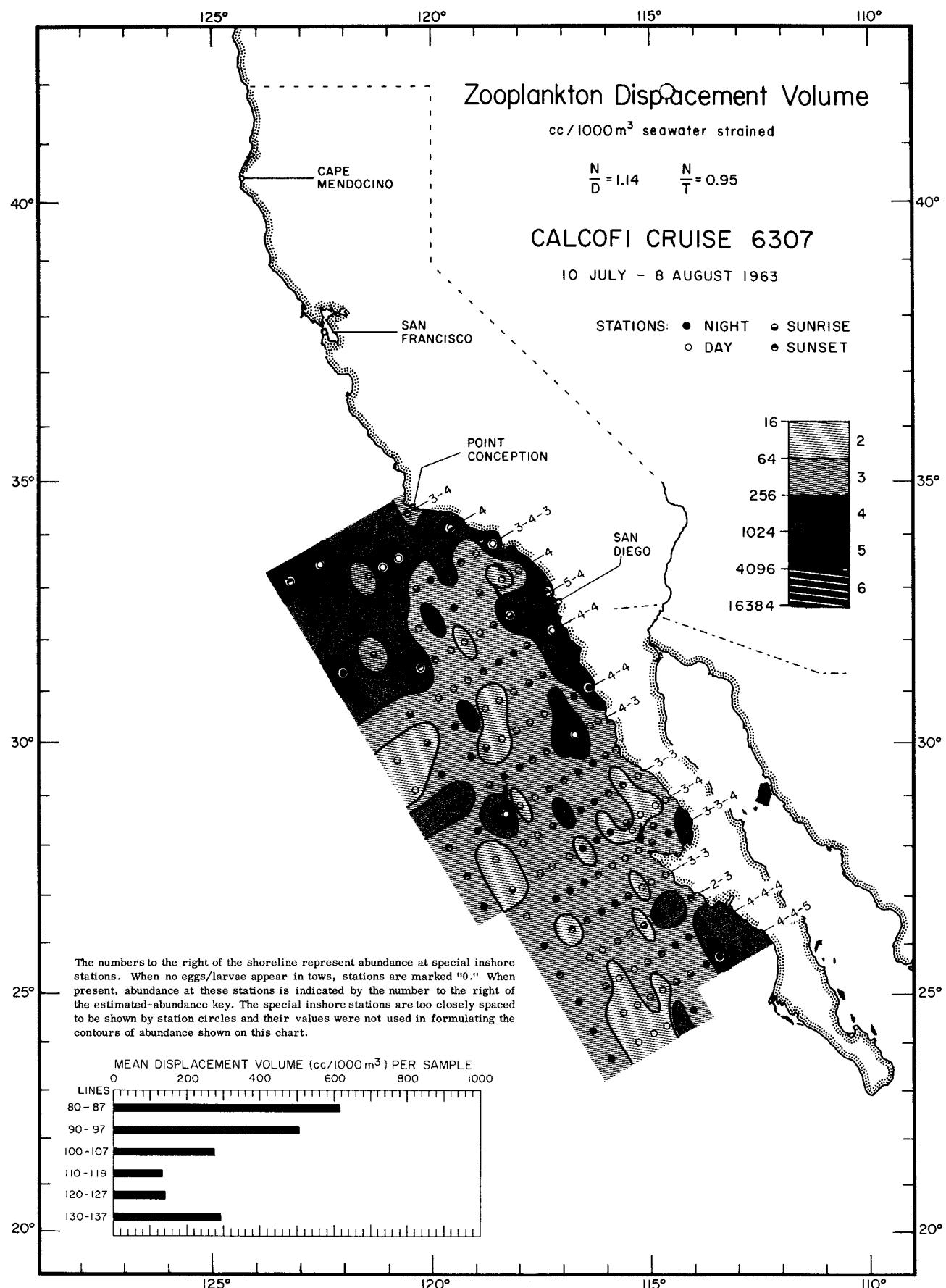
Zooplankton Displacement Volume

5907



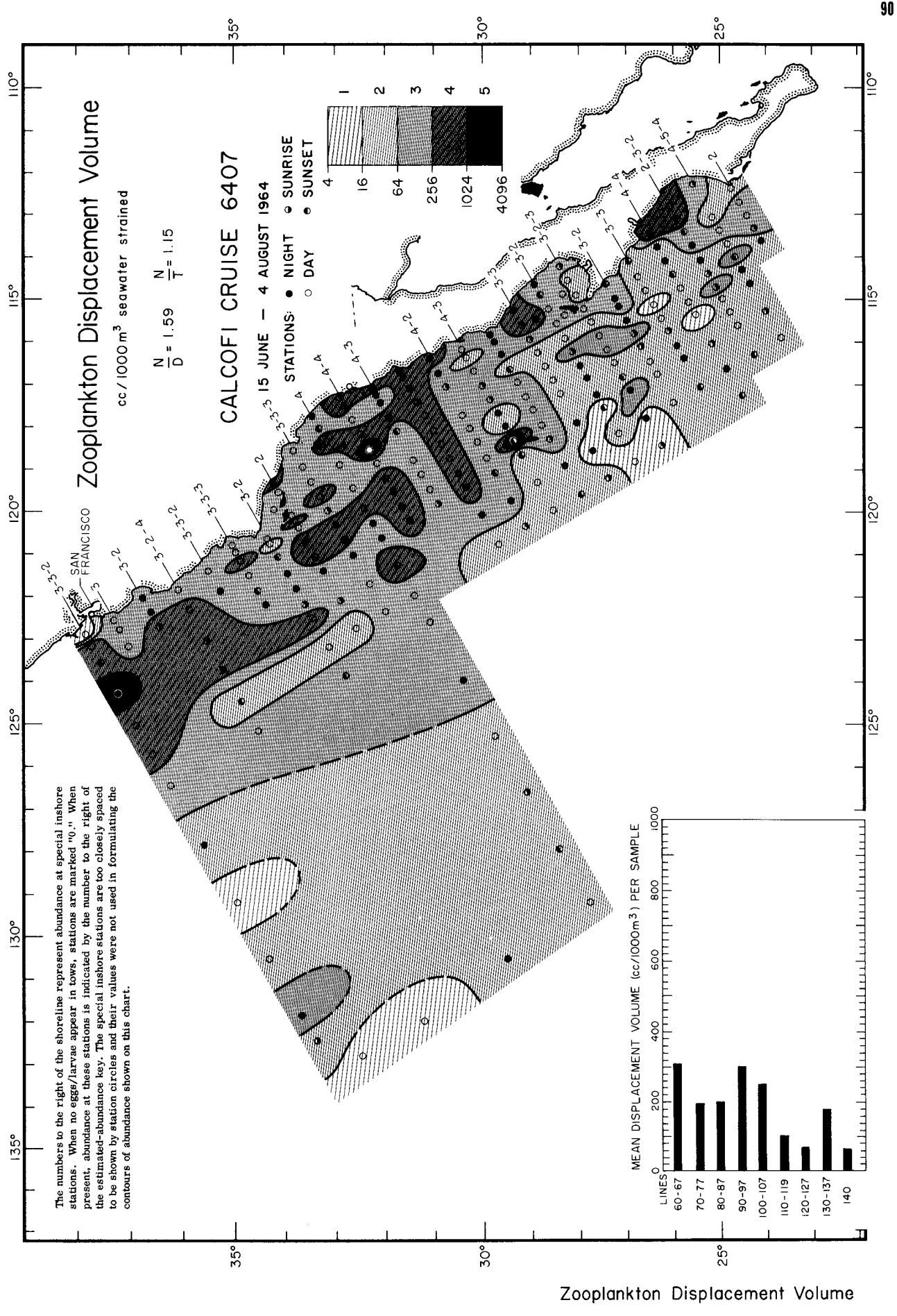


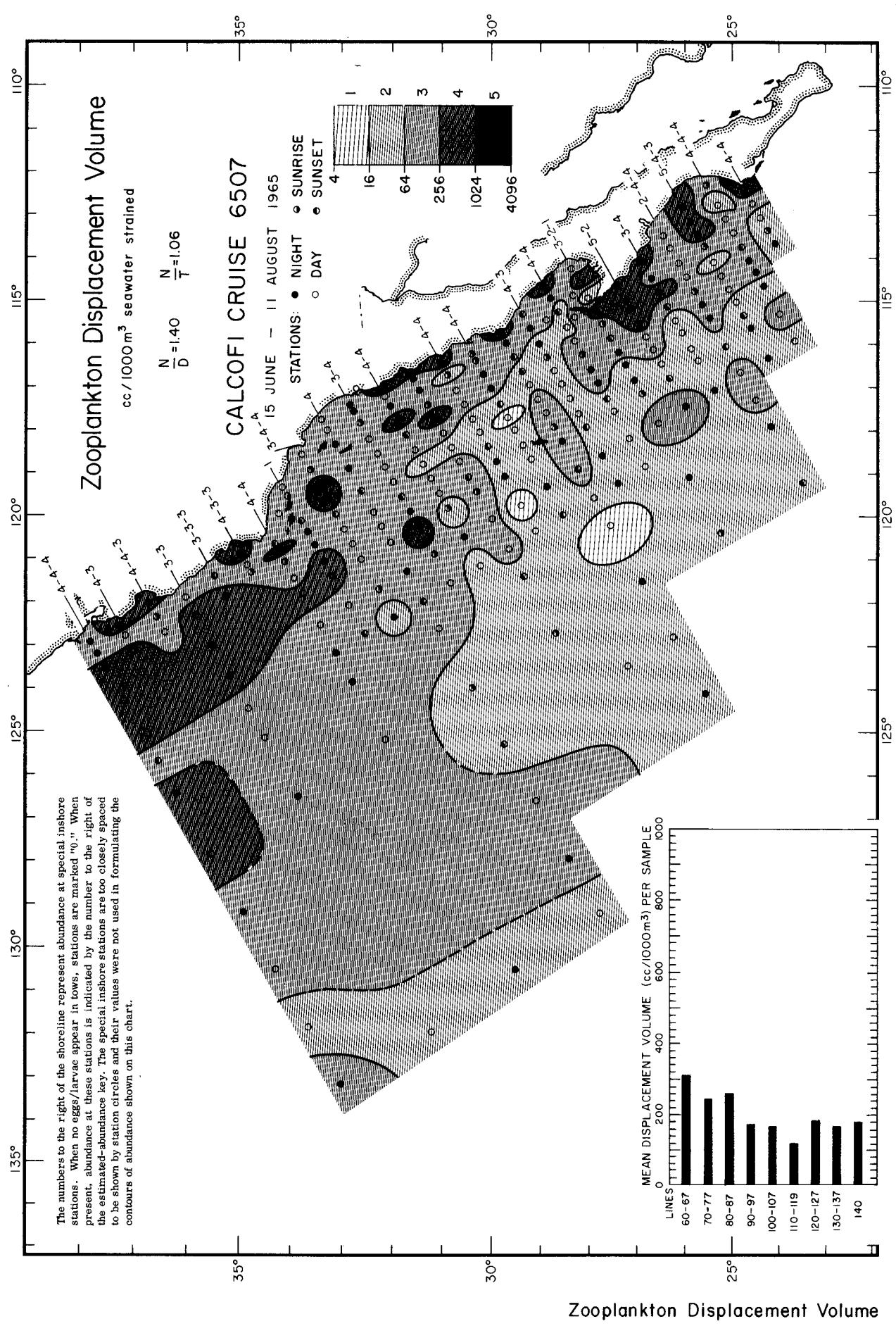


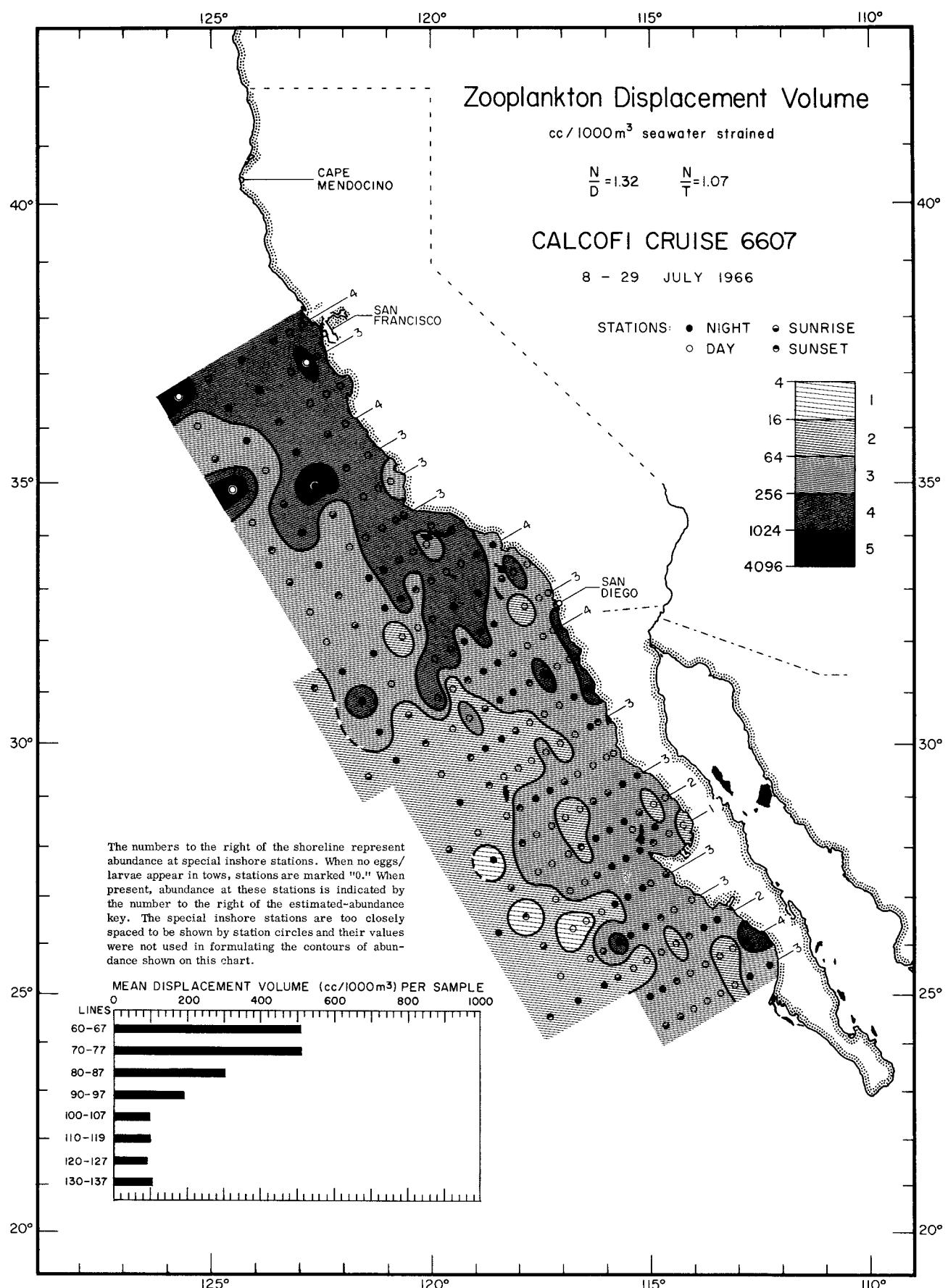


Zooplankton Displacement Volume

6307

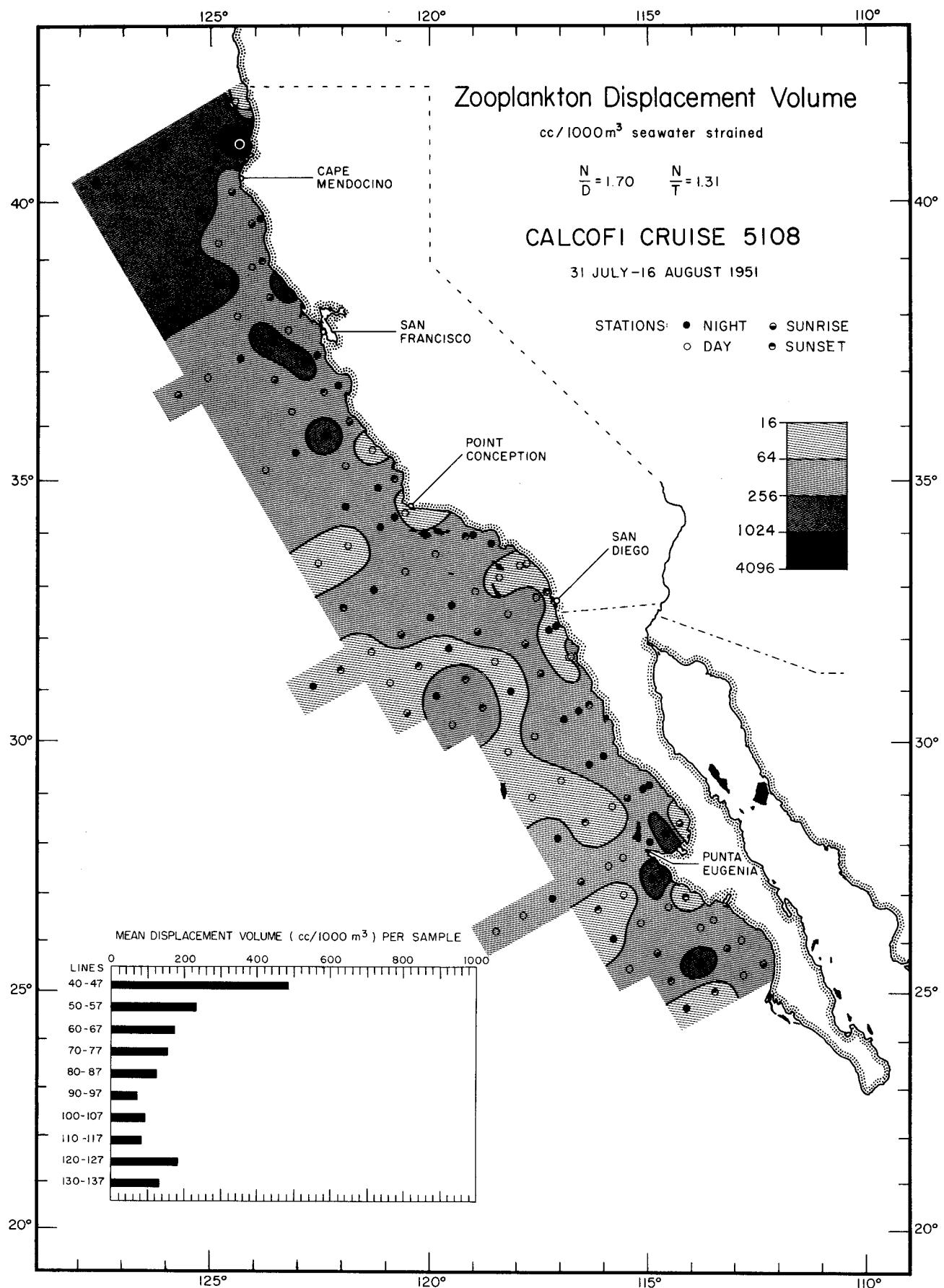






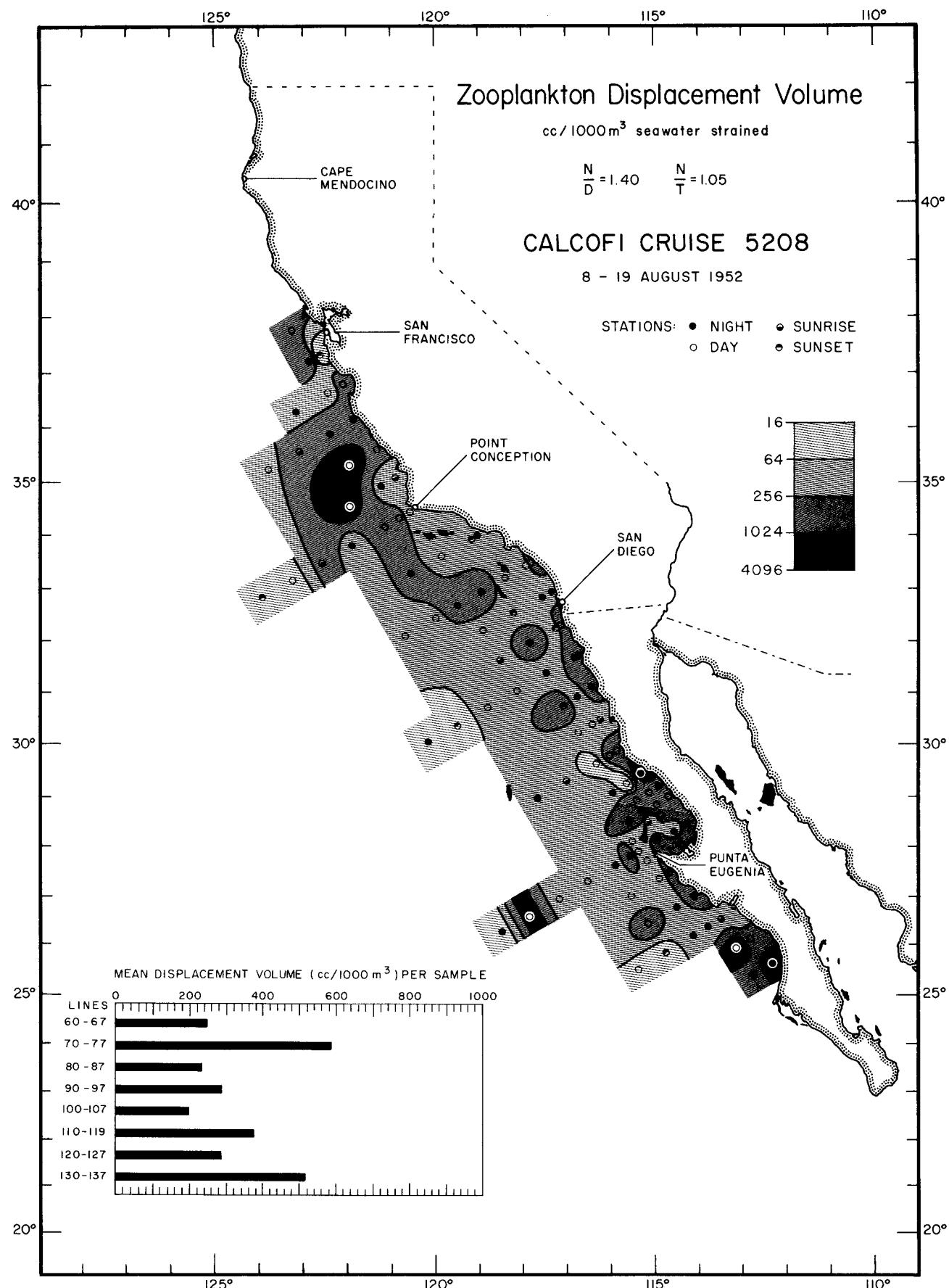
Zooplankton Displacement Volume

6607



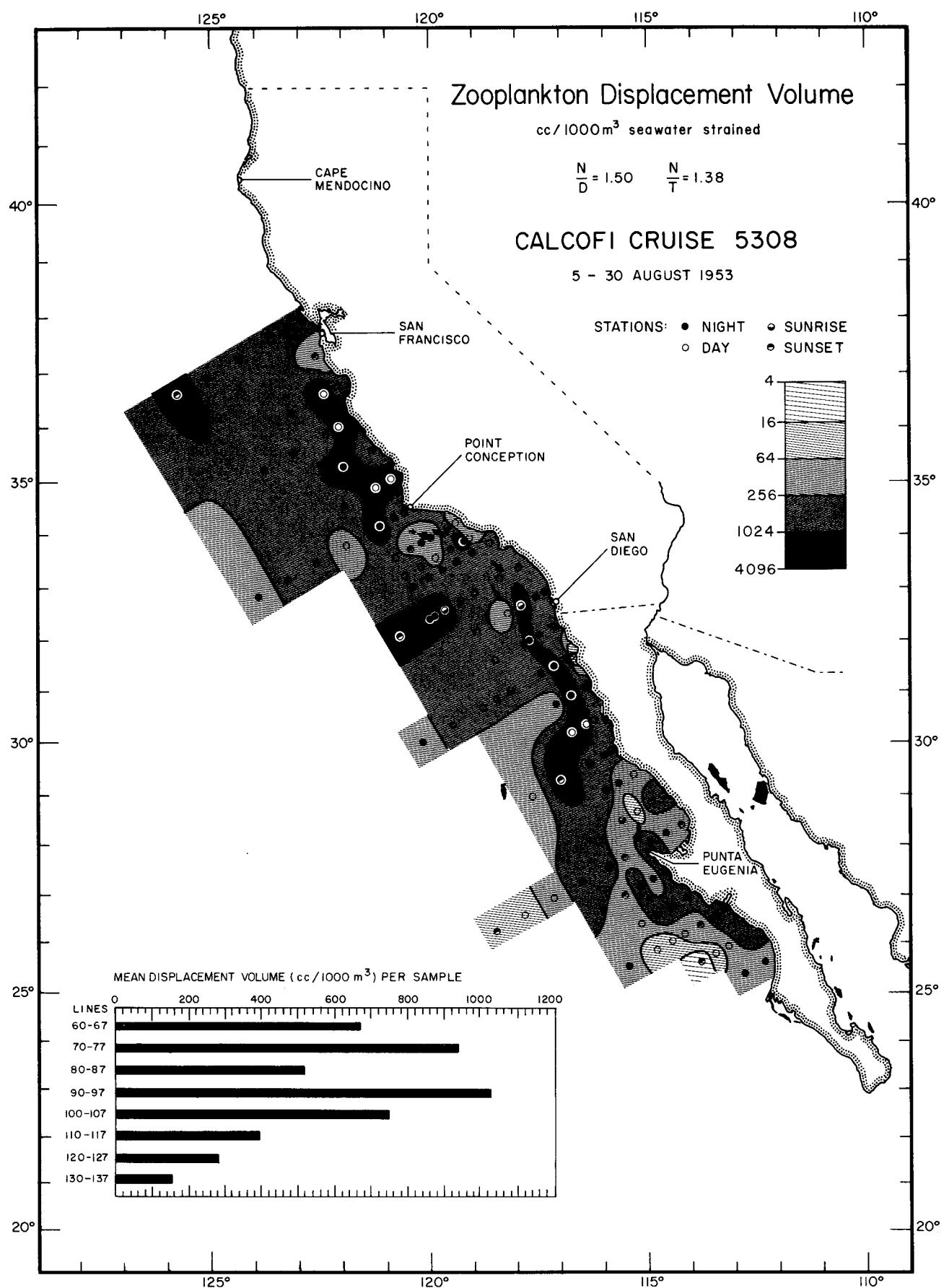
Zooplankton Displacement Volume

5108



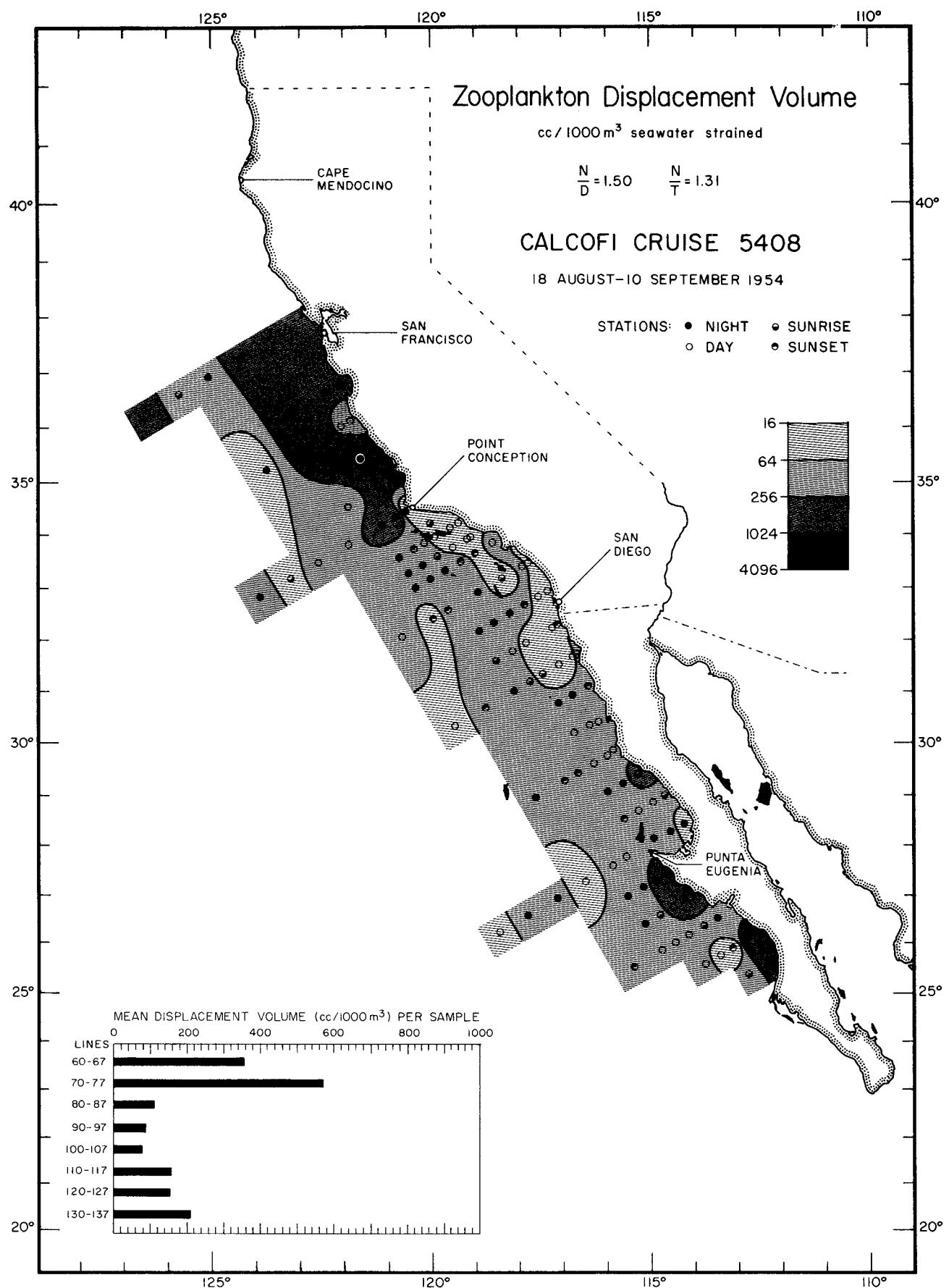
Zooplankton Displacement Volume

5208



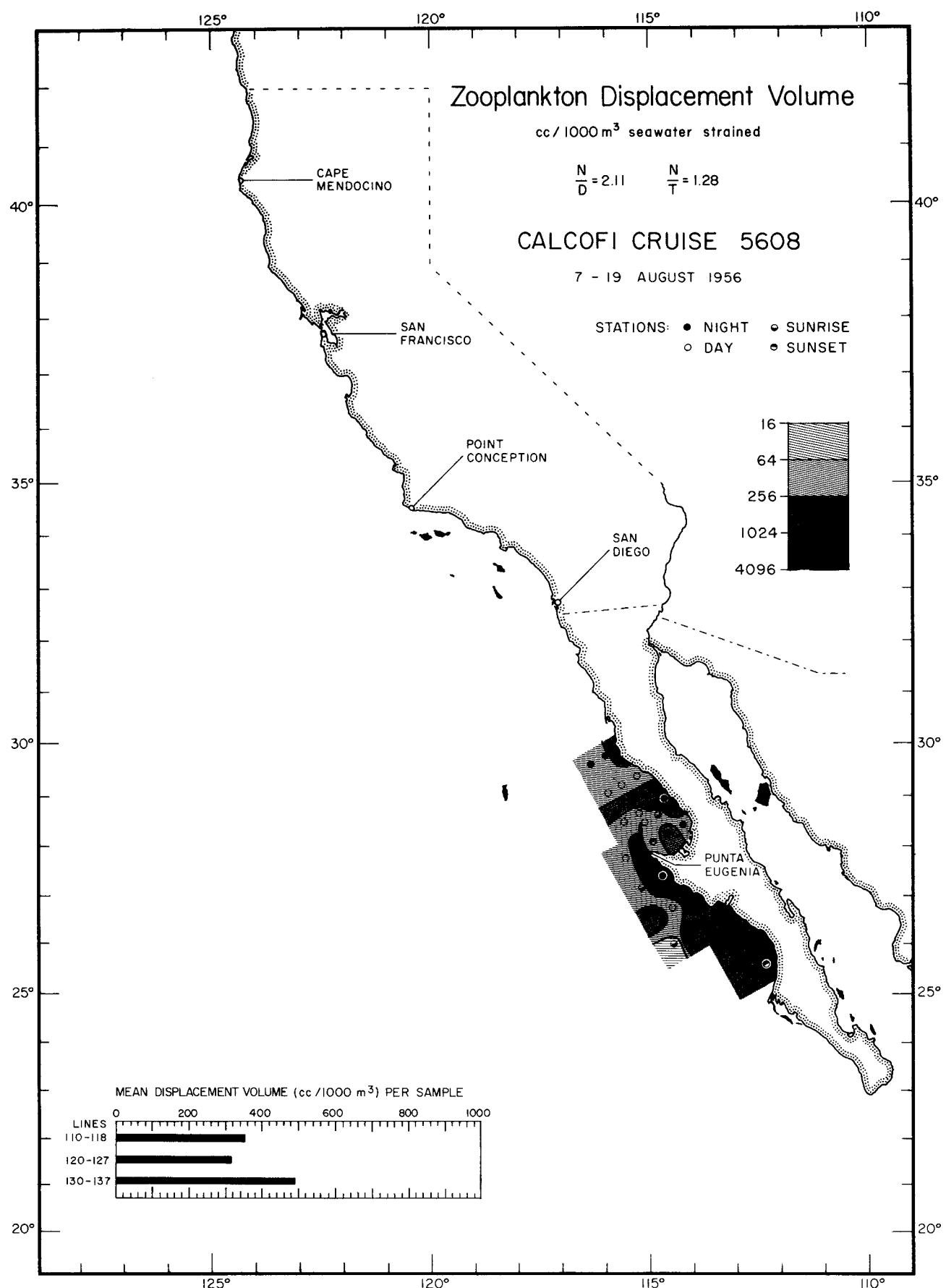
Zooplankton Displacement Volume

5308



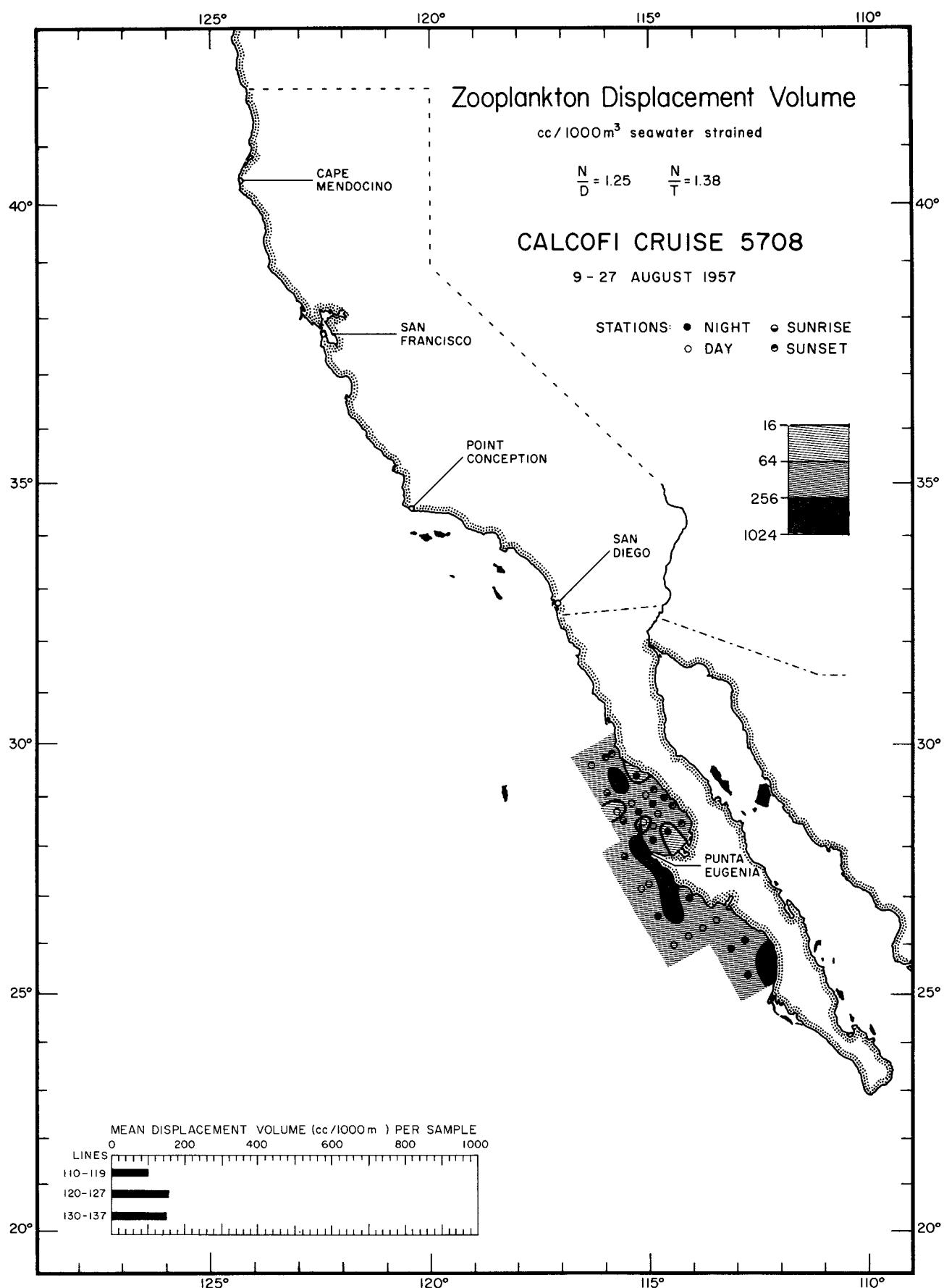
Zooplankton Displacement Volume

5408



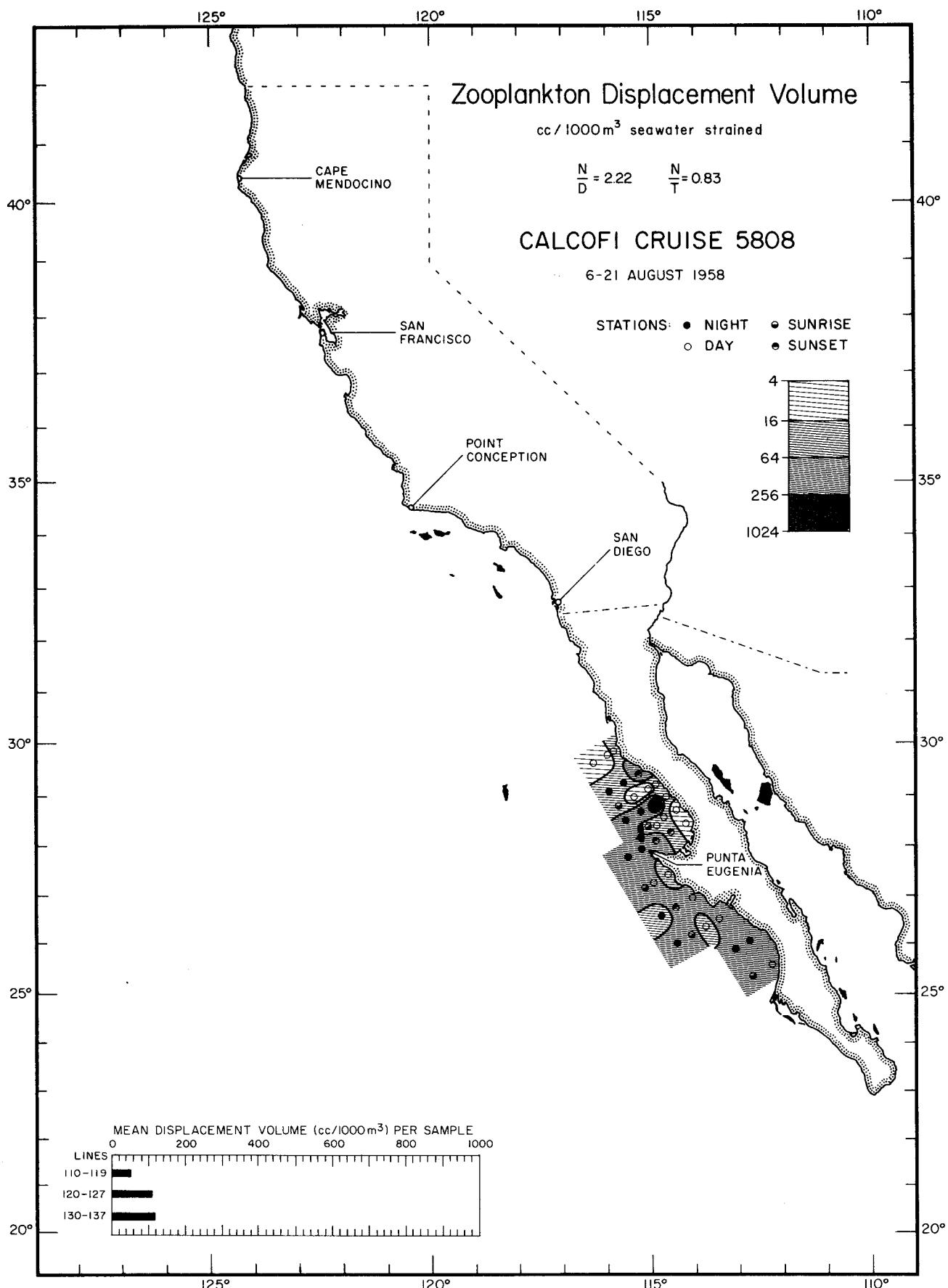
Zooplankton Displacement Volume

5608



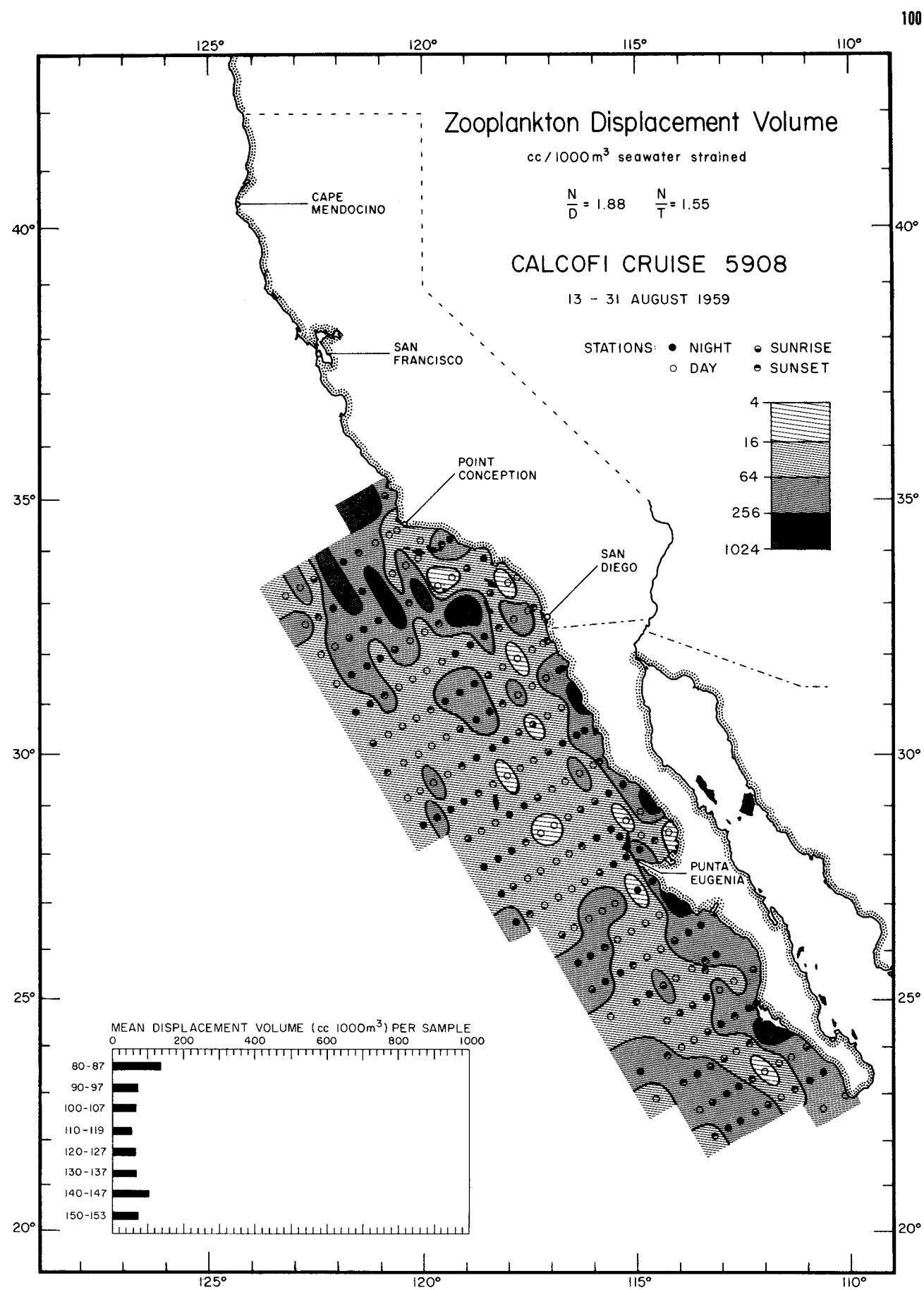
Zooplankton Displacement Volume

5708



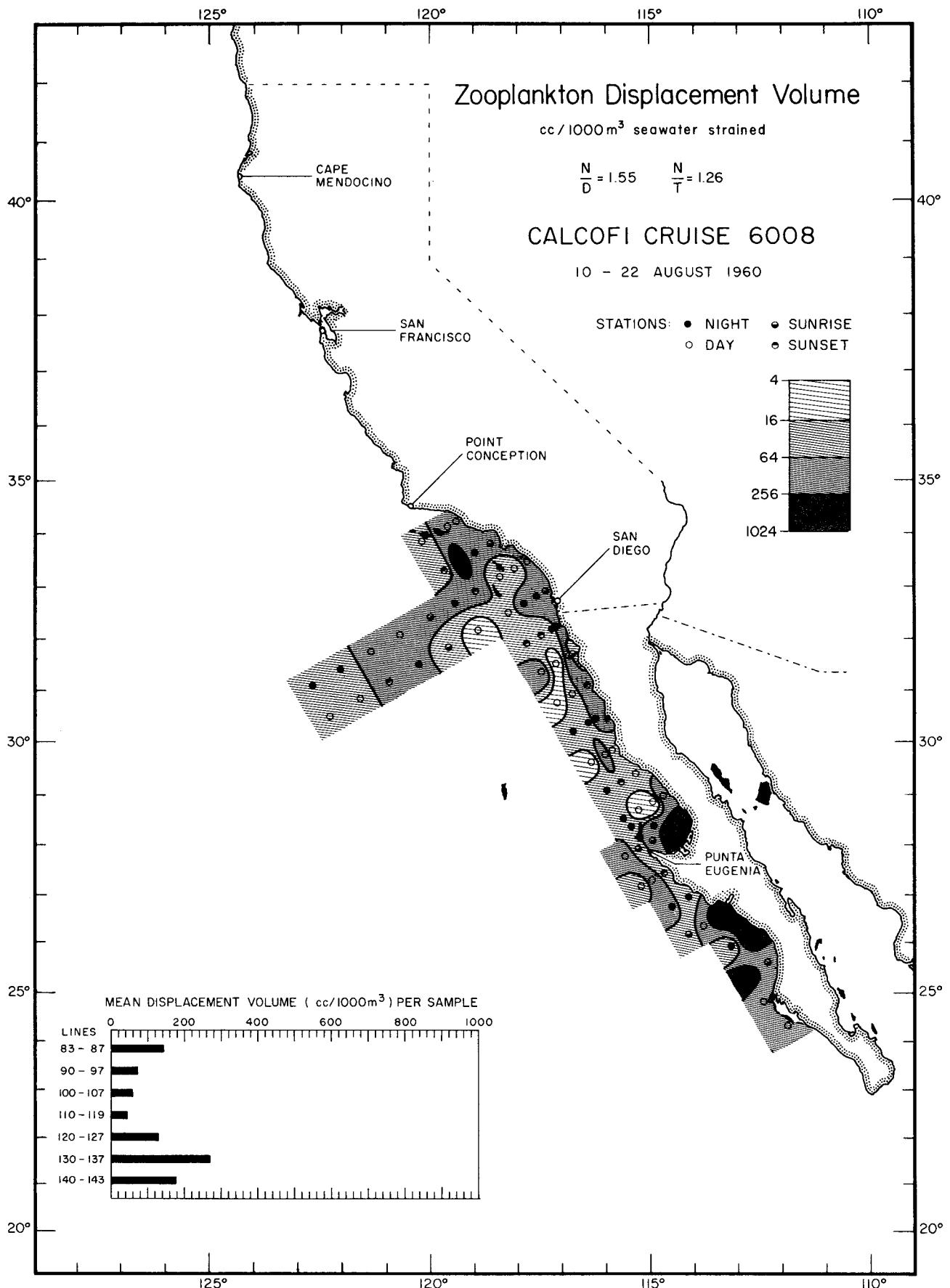
Zooplankton Displacement Volume

5808



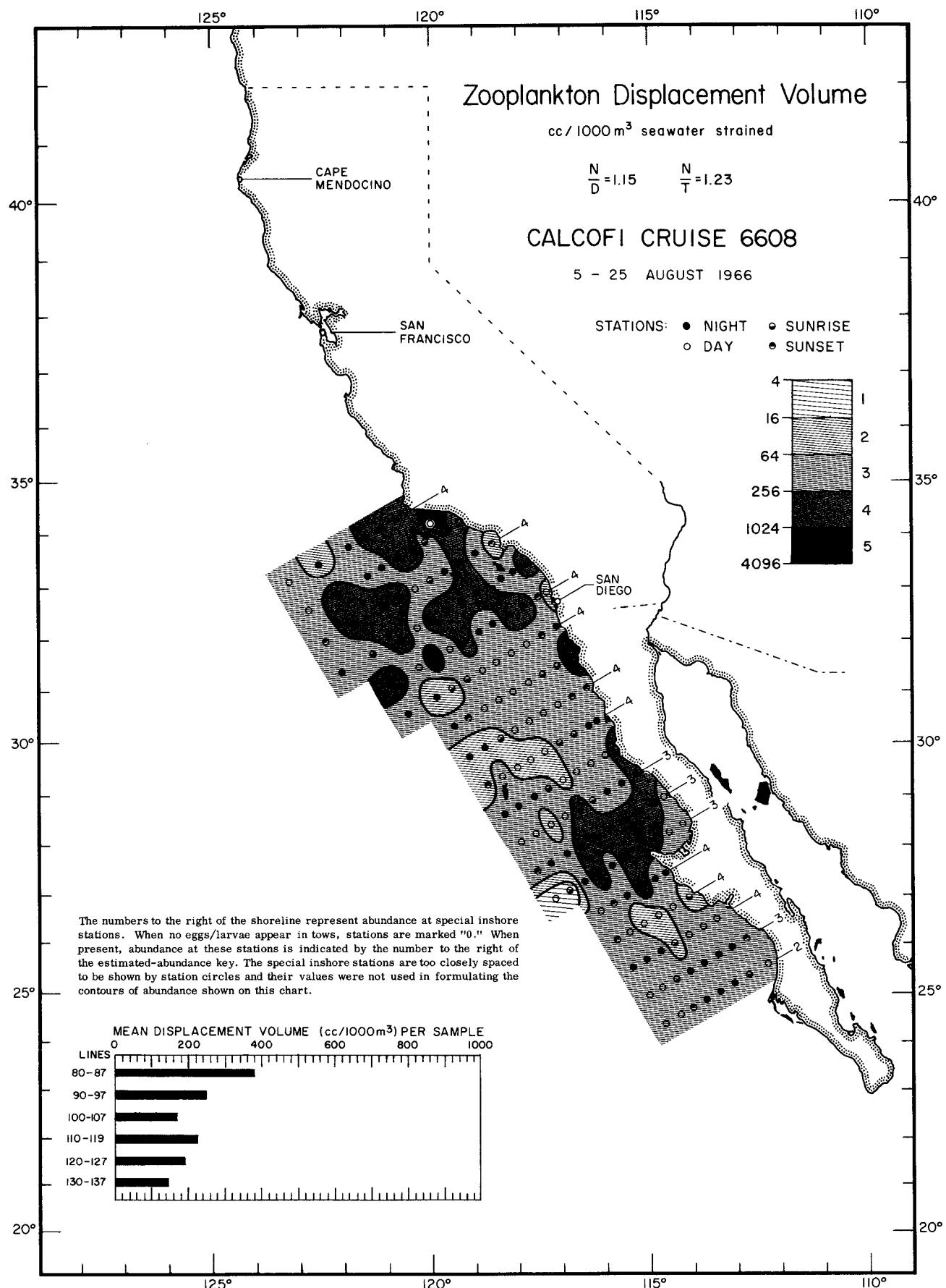
Zooplankton Displacement Volume

5908



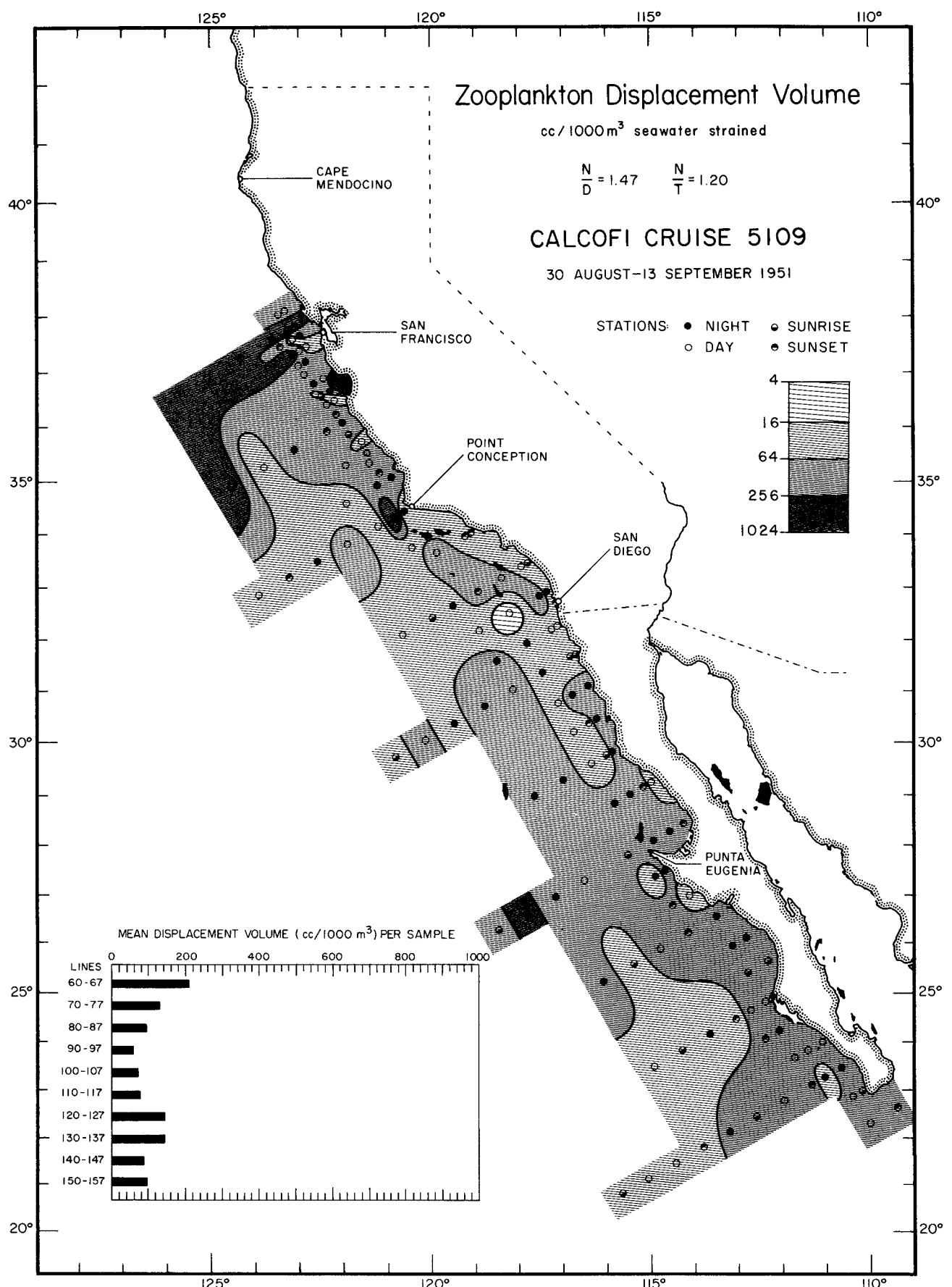
Zooplankton Displacement Volume

6008



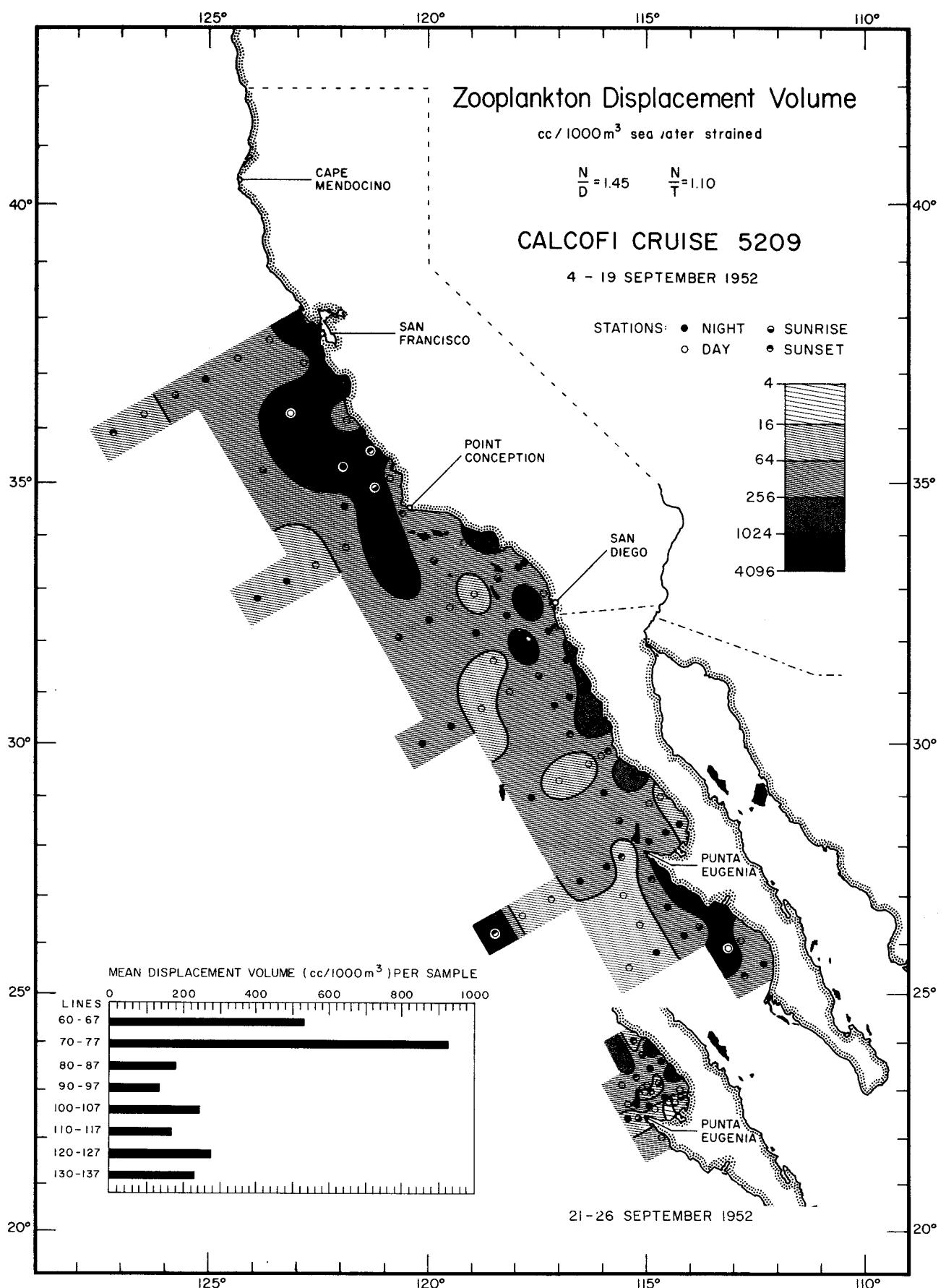
Zooplankton Displacement Volume

6608



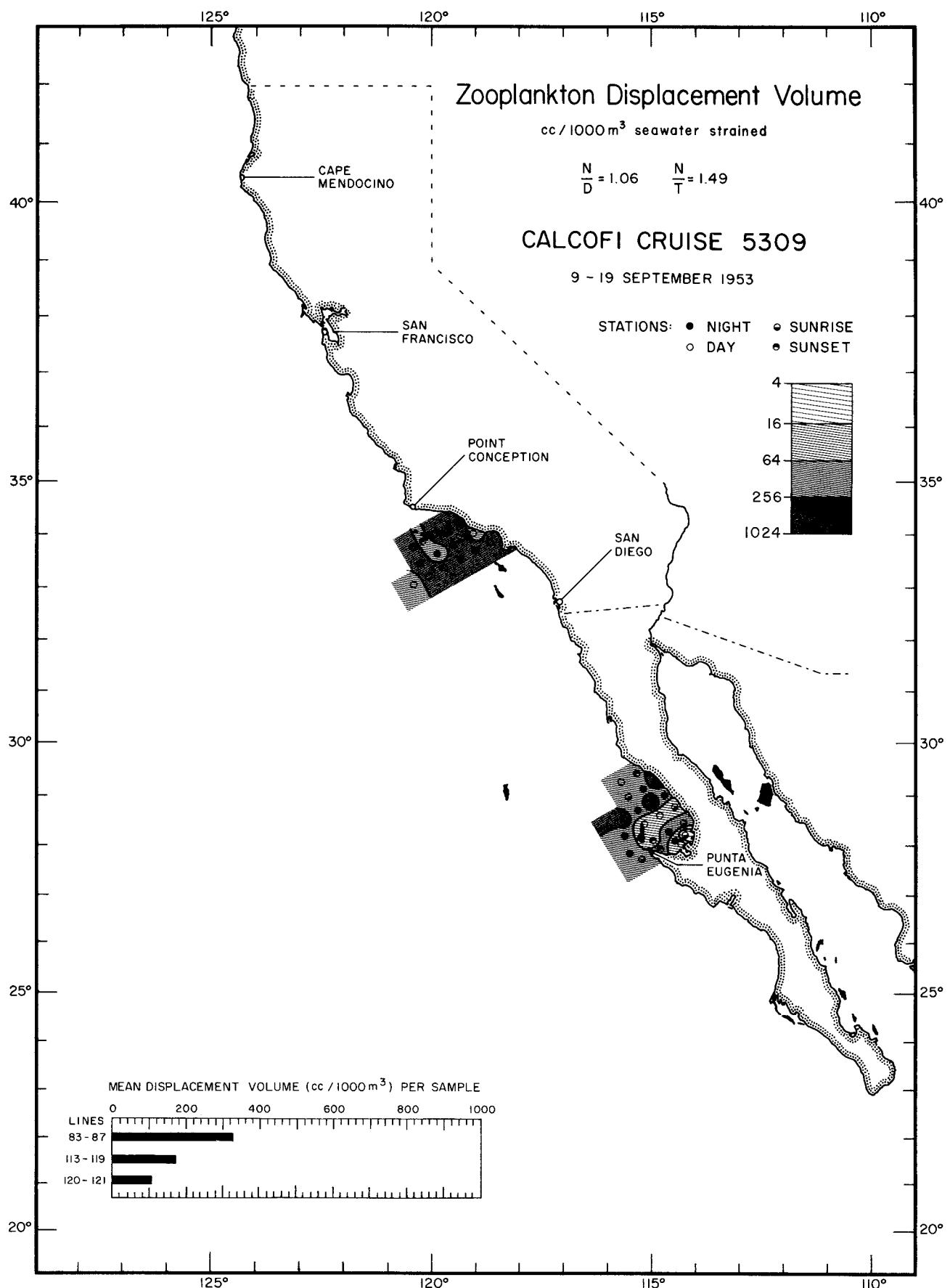
Zooplankton Displacement Volume

5109



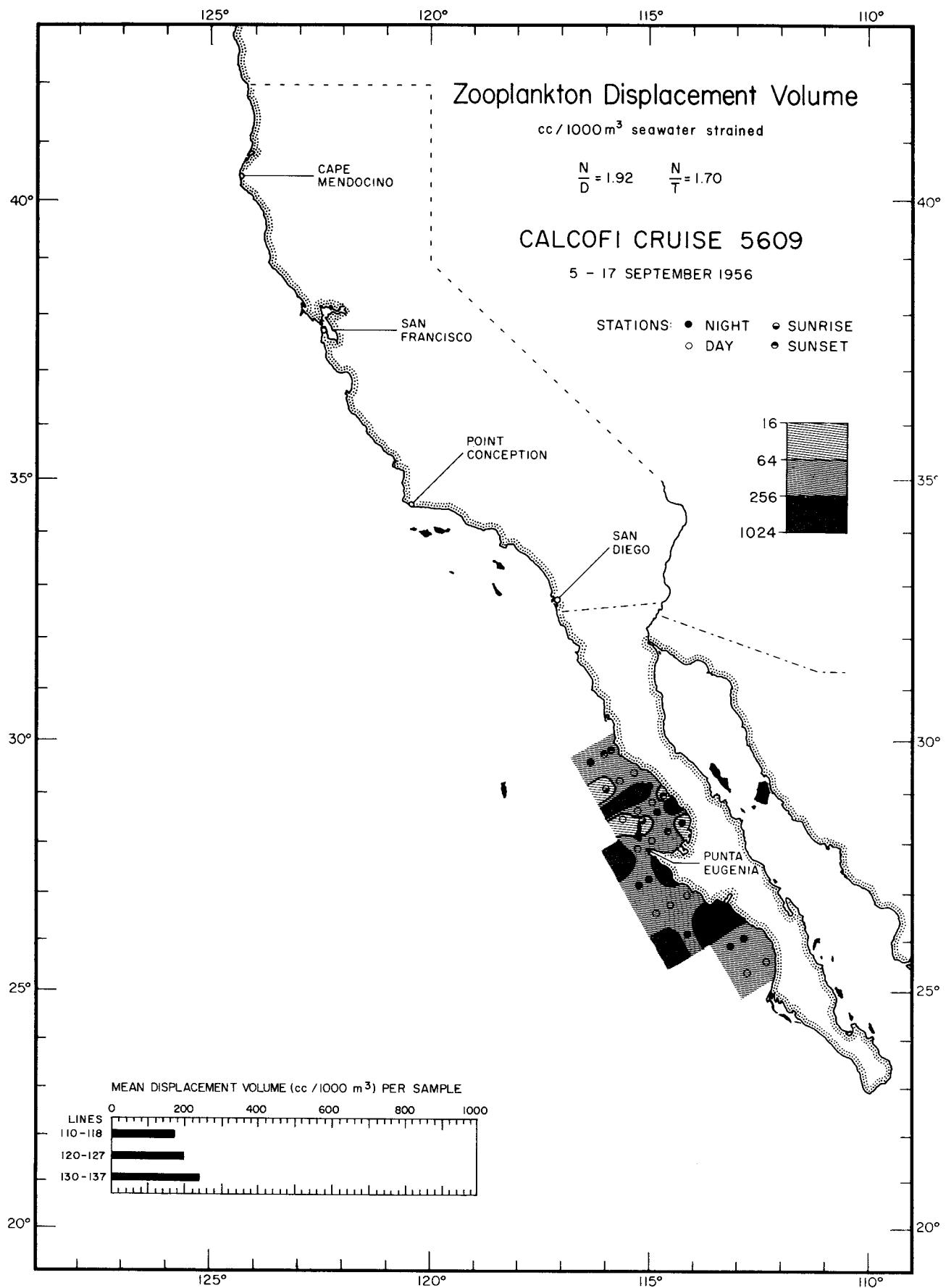
Zooplankton Displacement Volume

5209



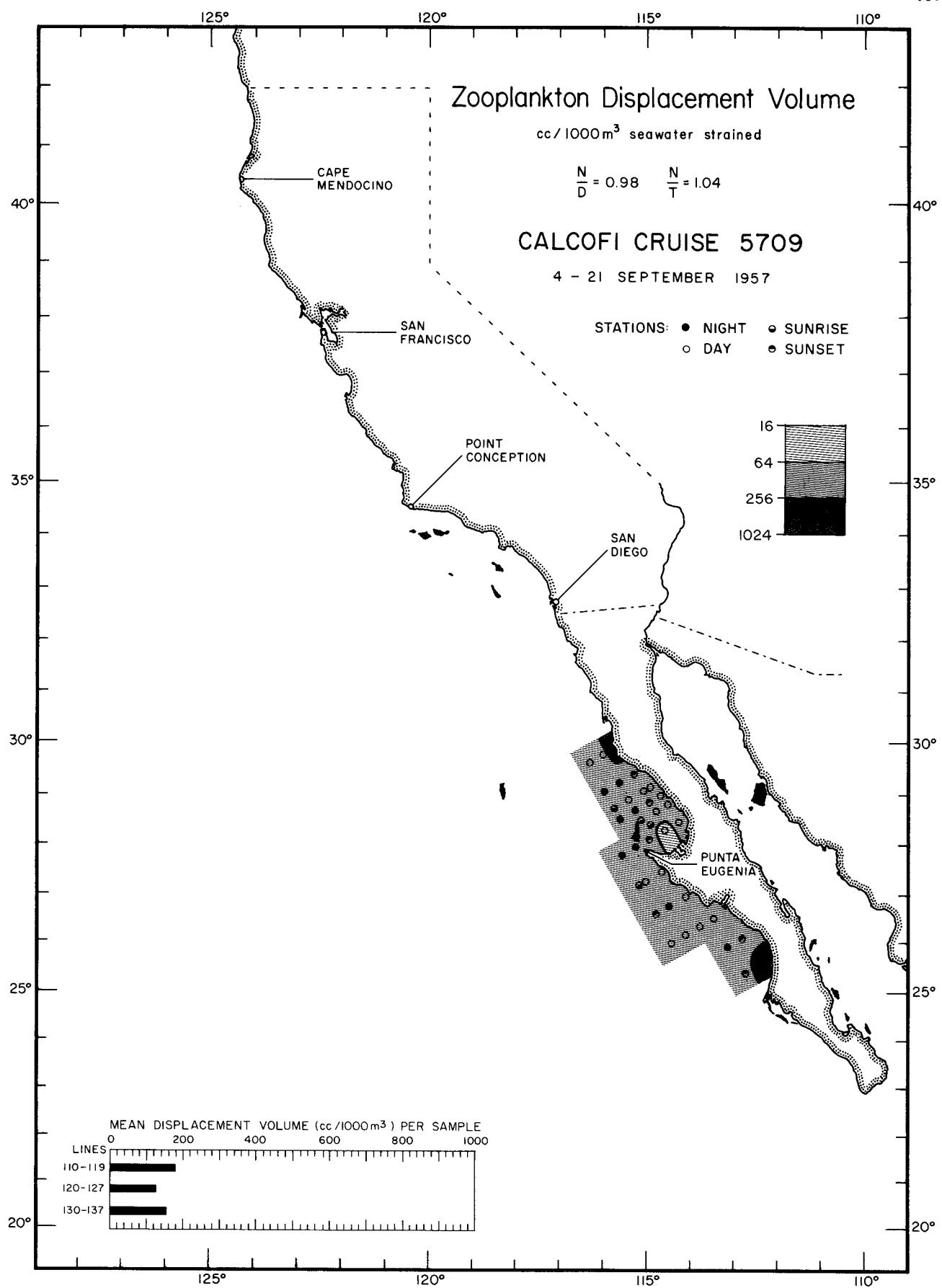
Zooplankton Displacement Volume

5309



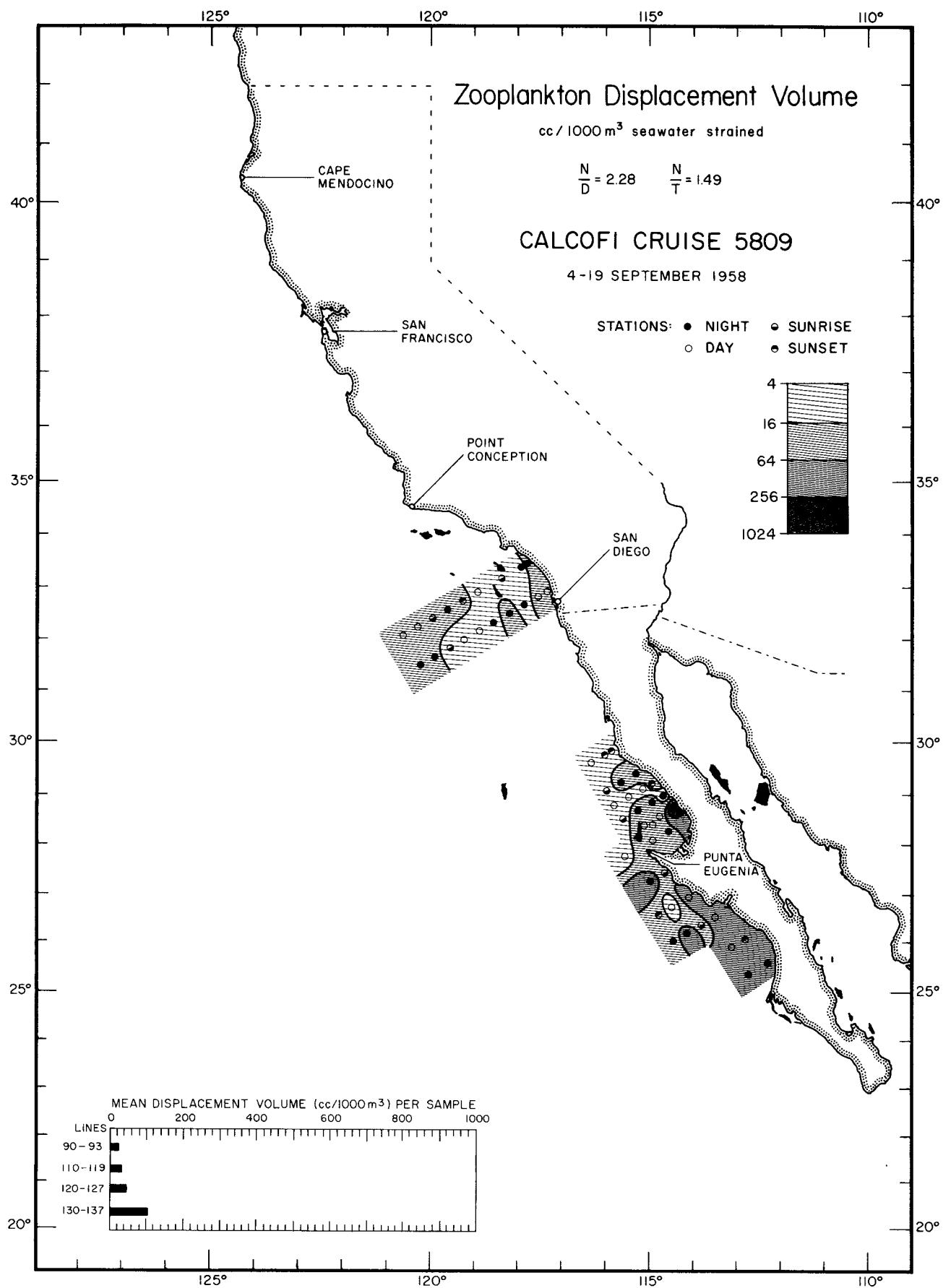
Zooplankton Displacement Volume

5609



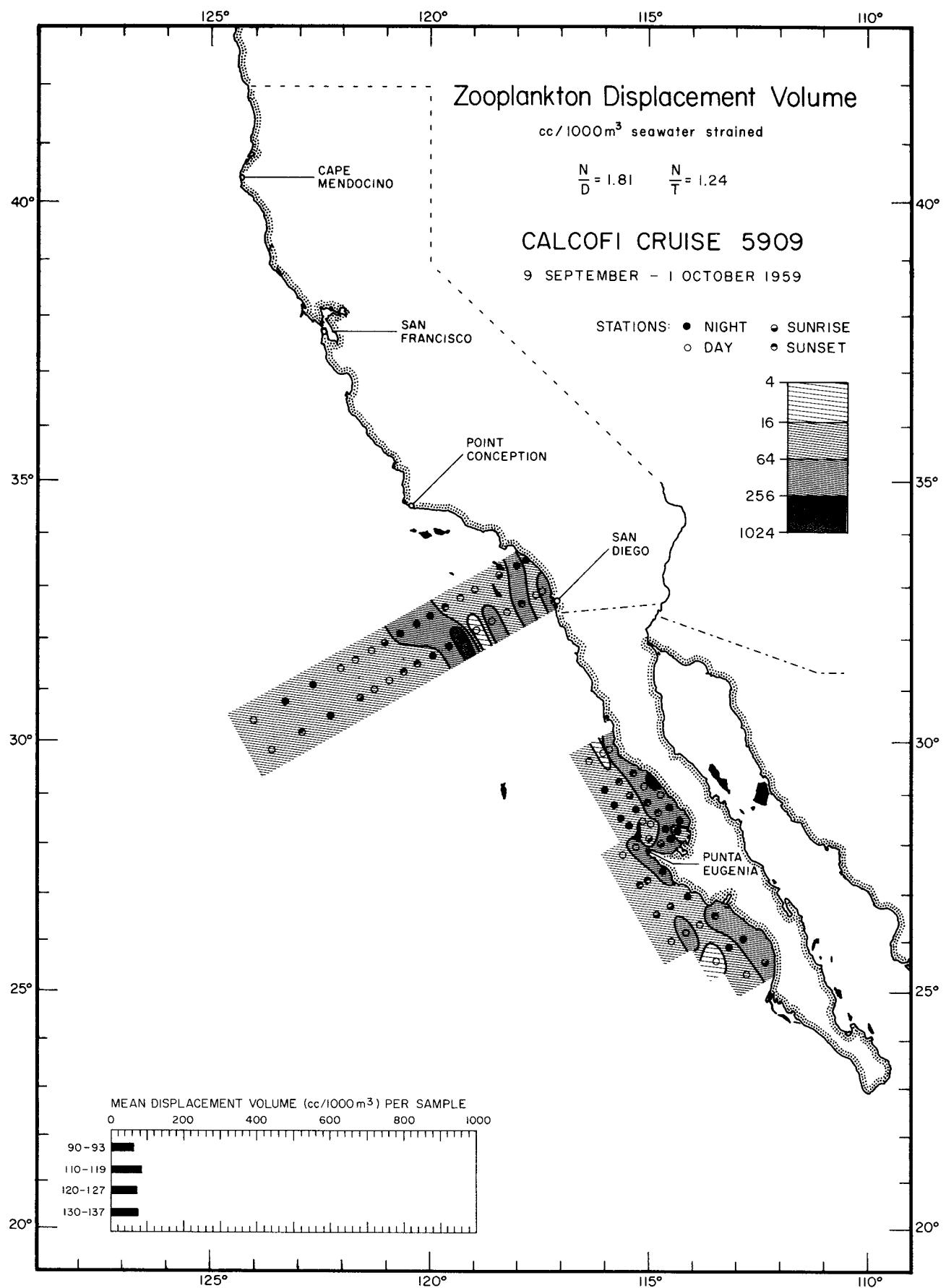
Zooplankton Displacement Volume

5709



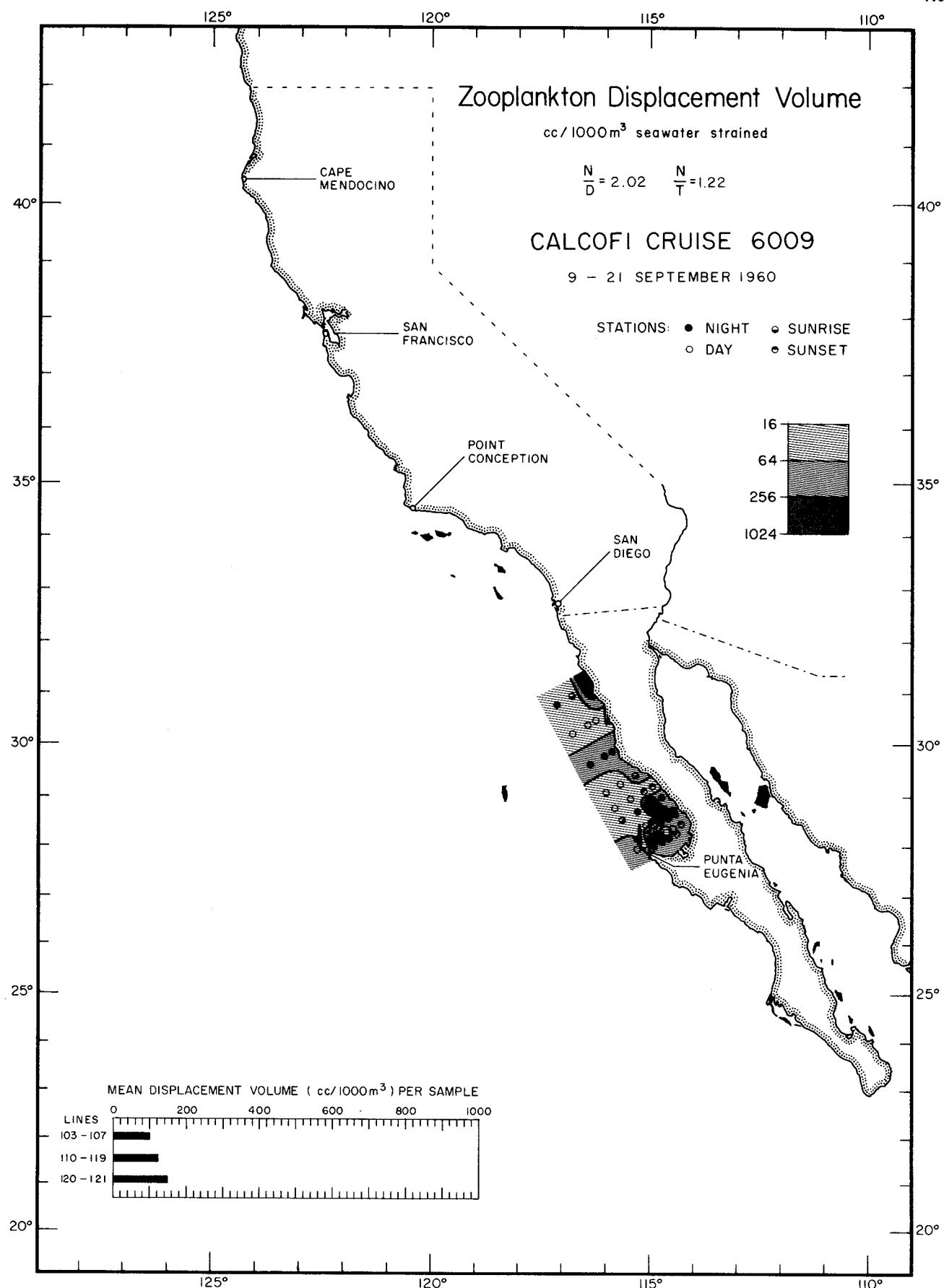
Zooplankton Displacement Volume

5809



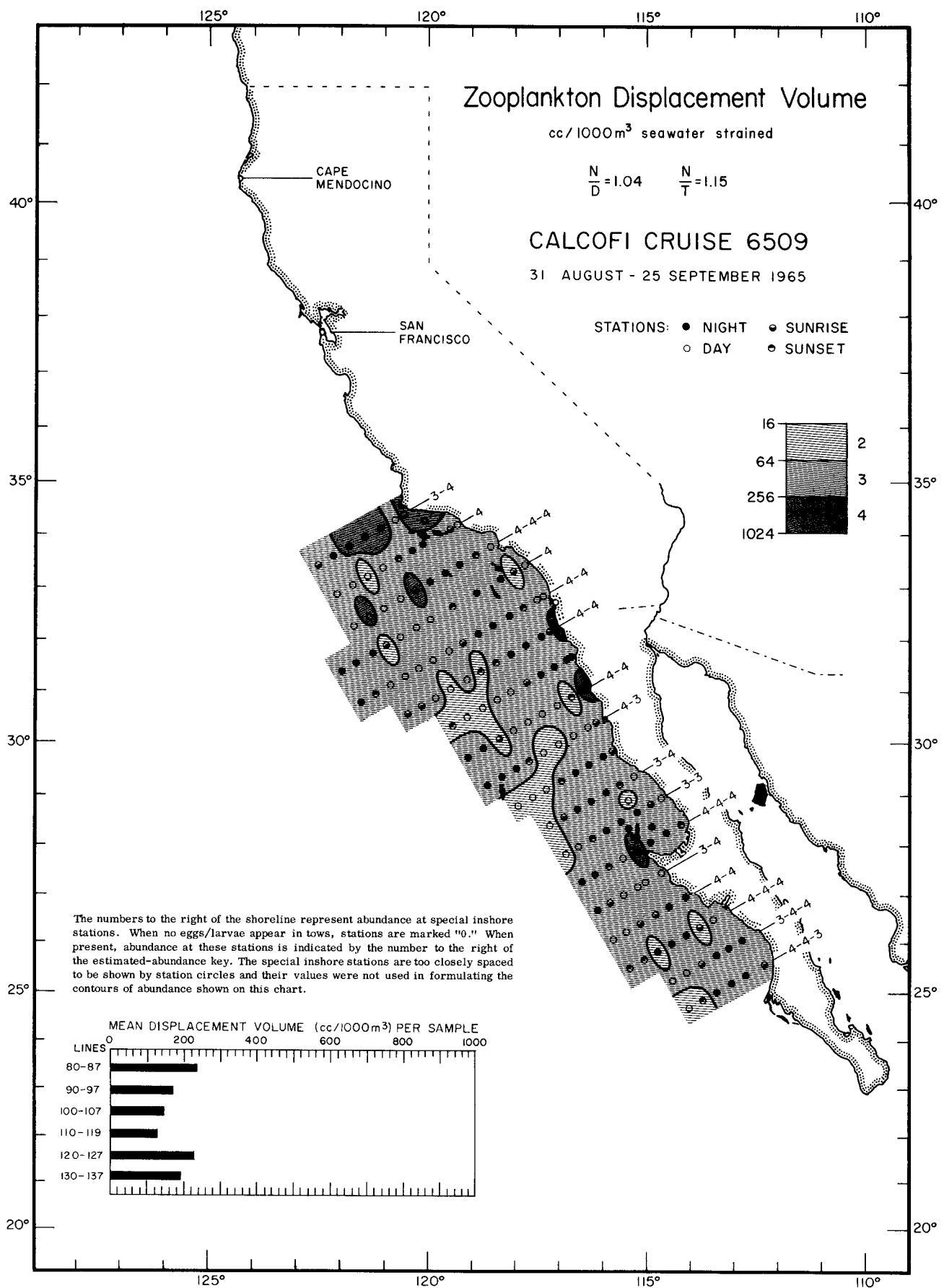
Zooplankton Displacement Volume

5909



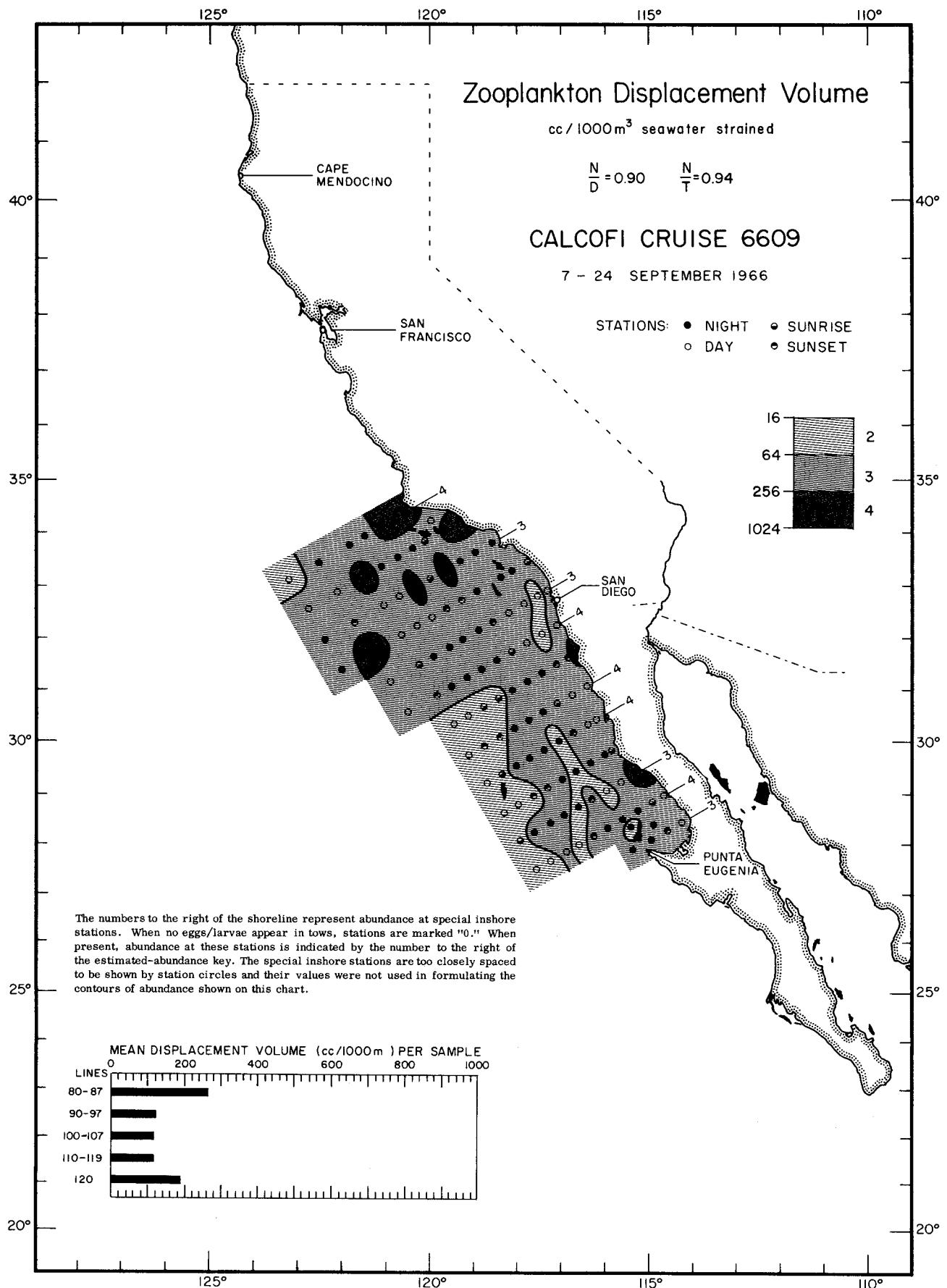
Zooplankton Displacement Volume

6009



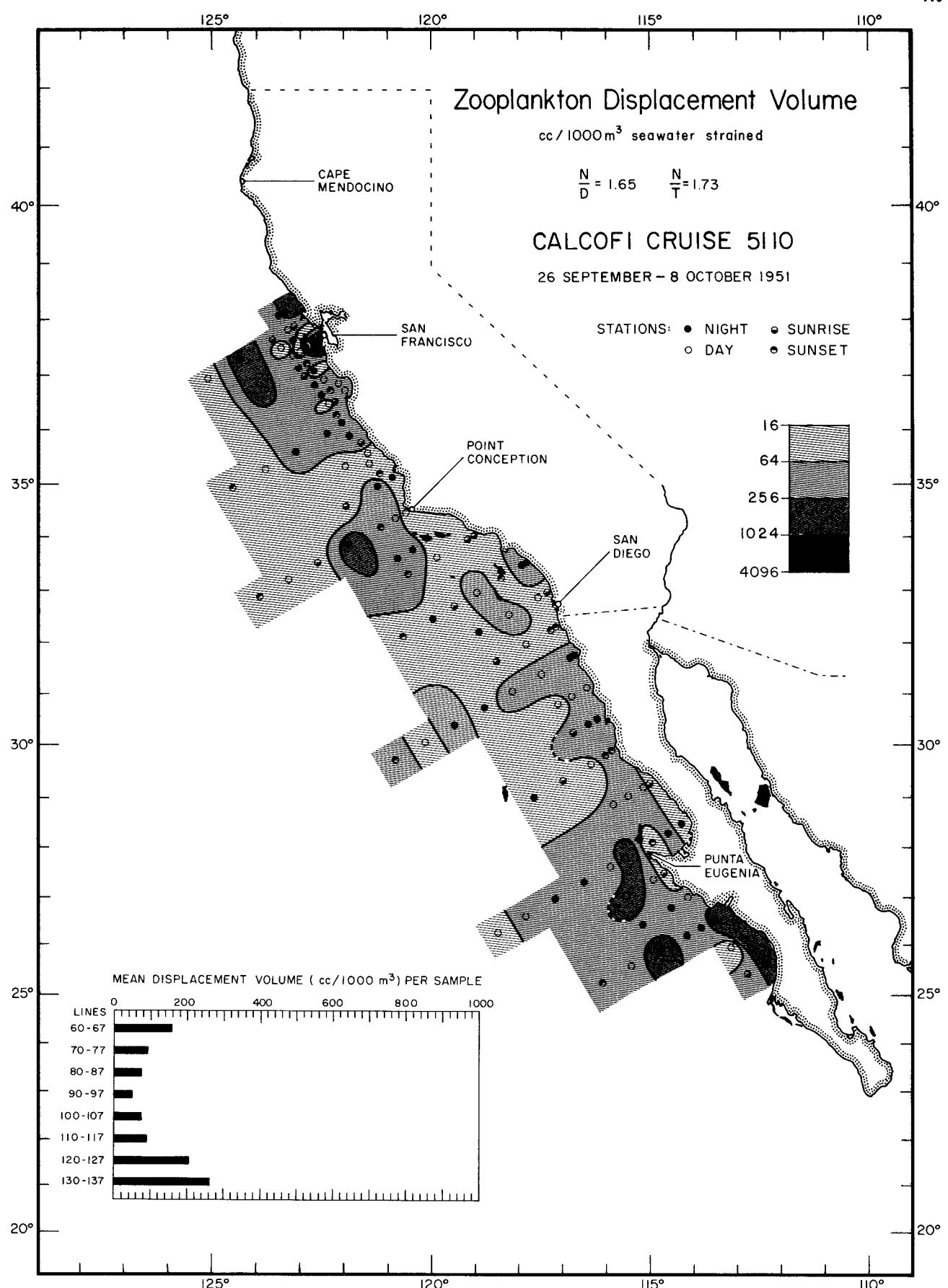
Zooplankton Displacement Volume

6509



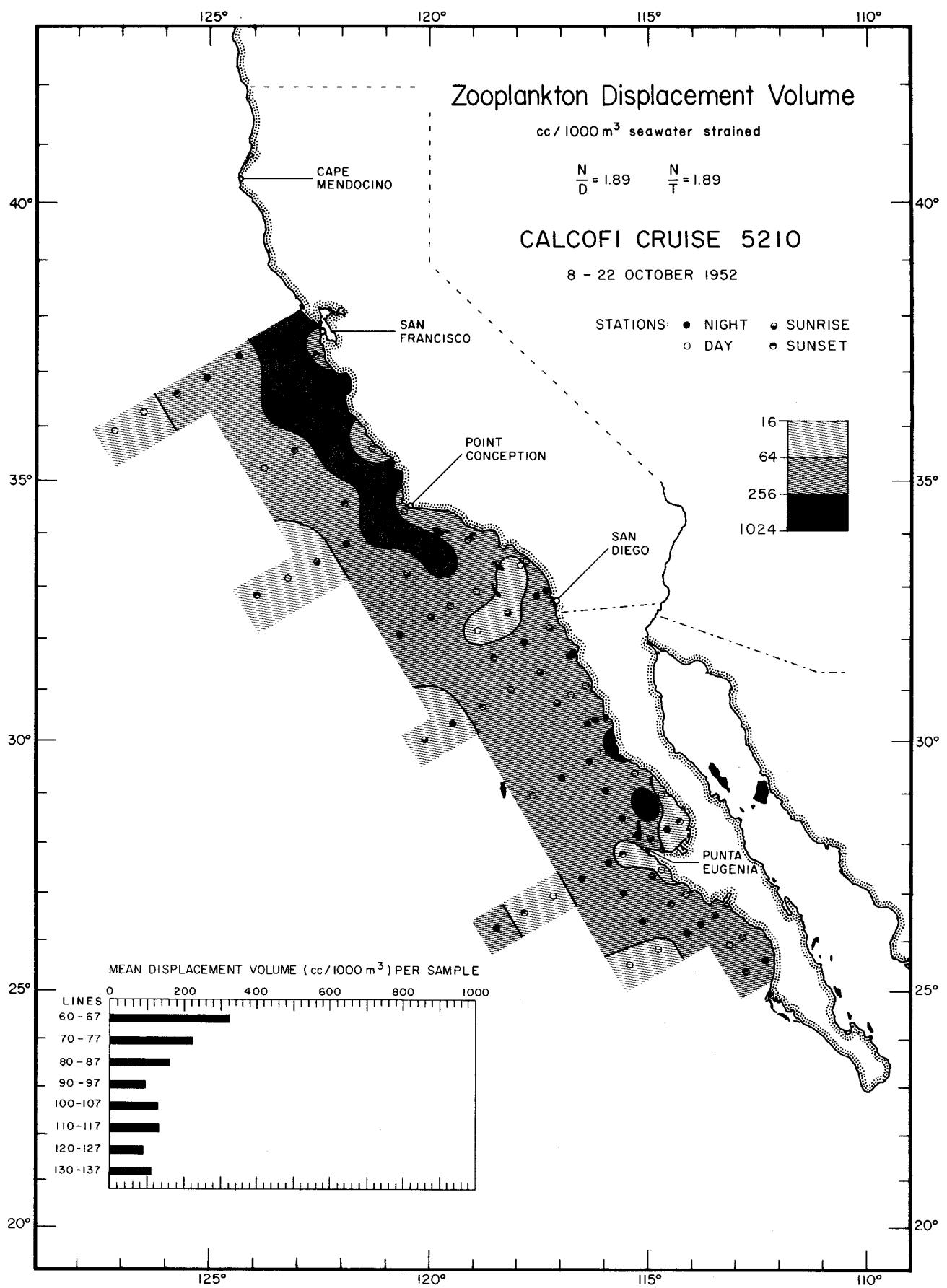
Zooplankton Displacement Volume

6609



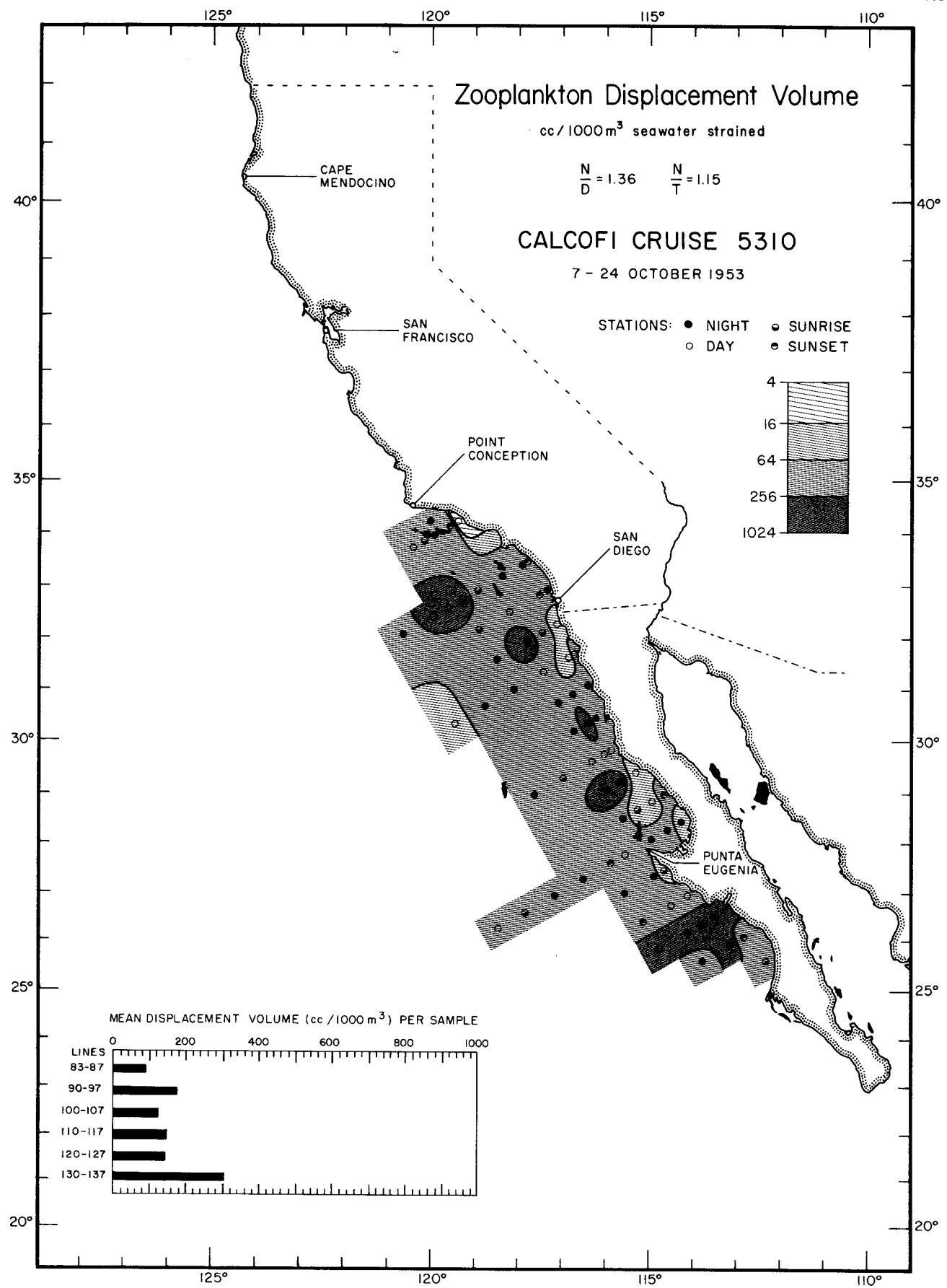
Zooplankton Displacement Volume

5110



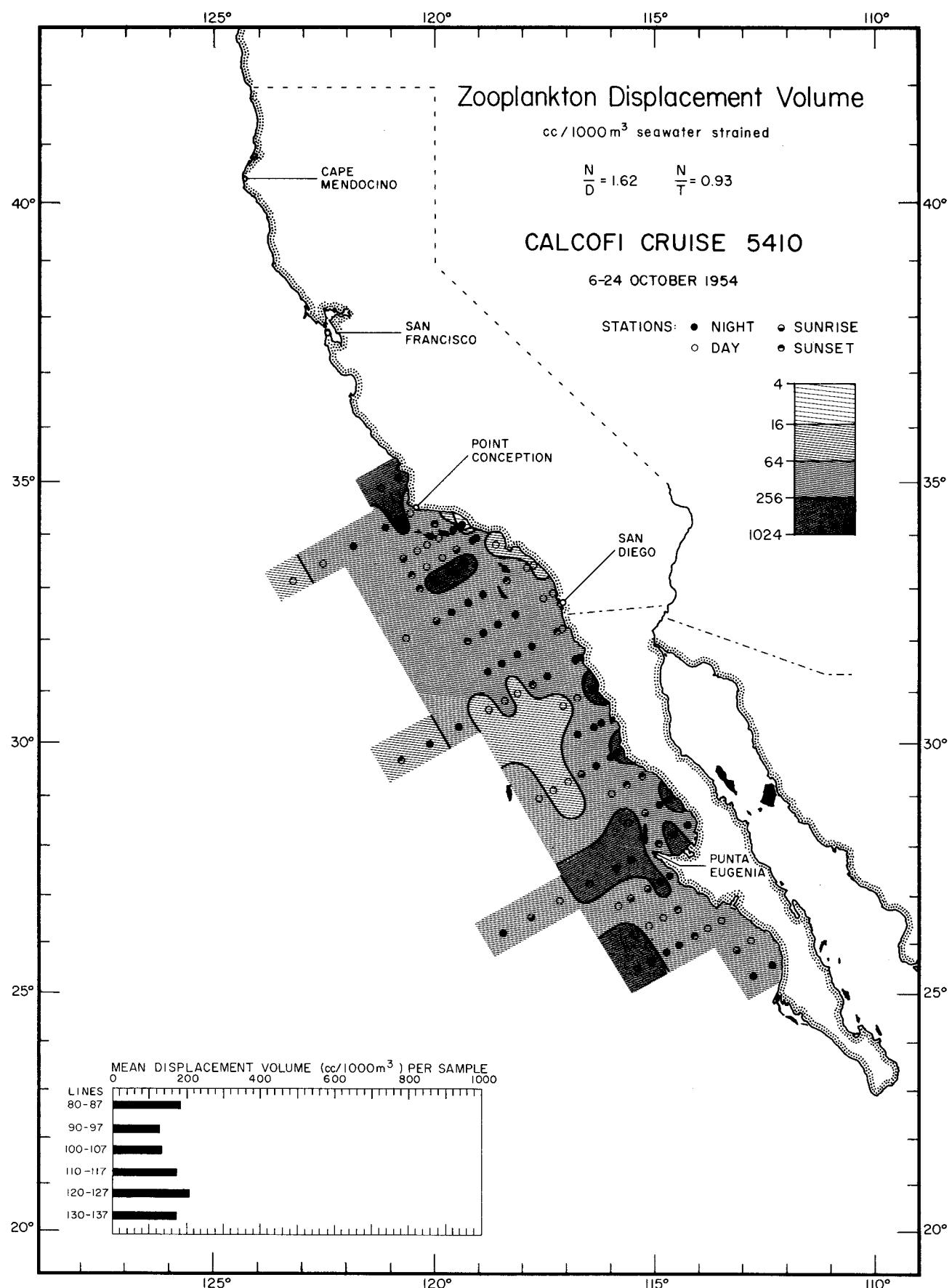
Zooplankton Displacement Volume

5210



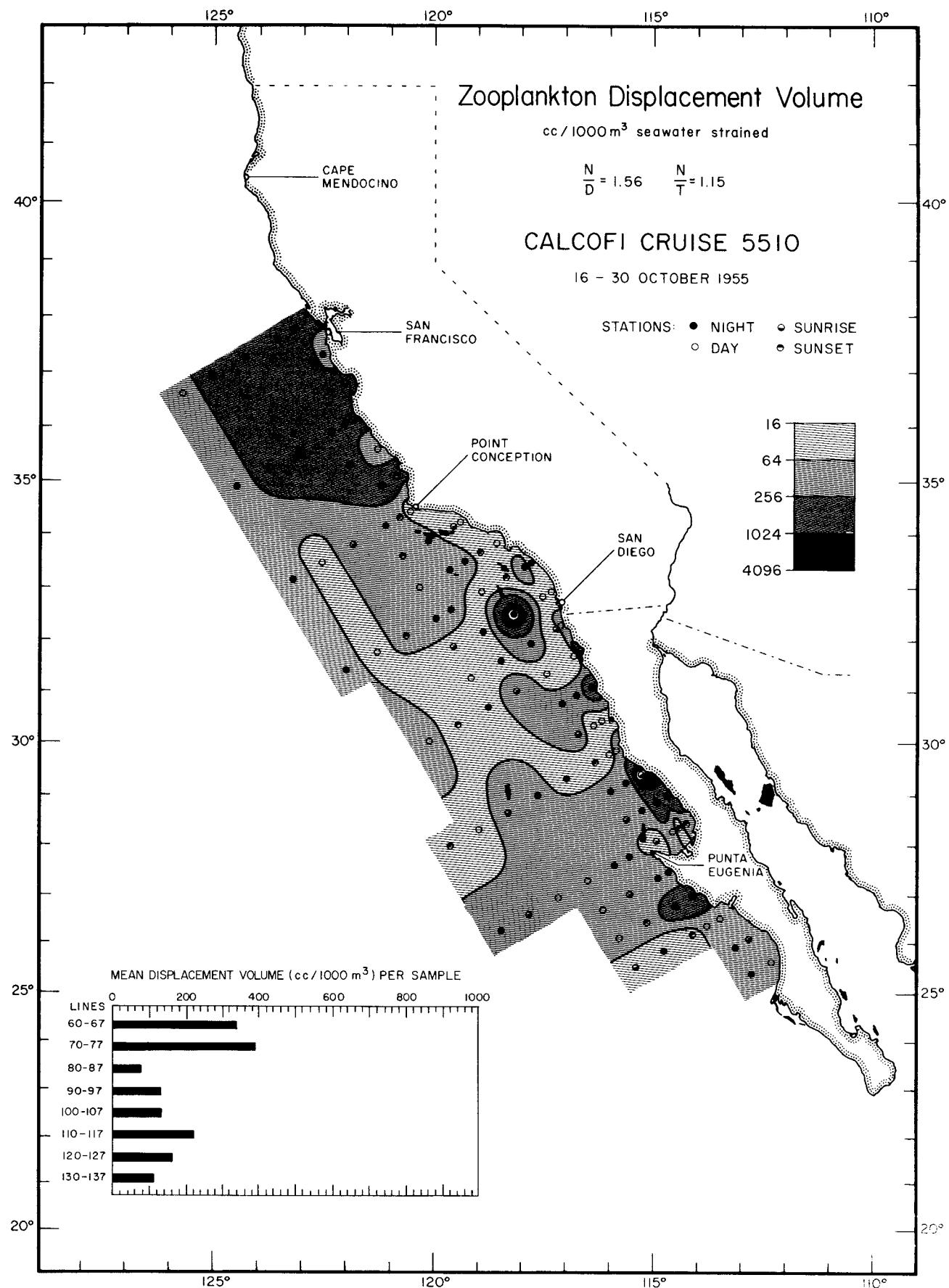
Zooplankton Displacement Volume

5310



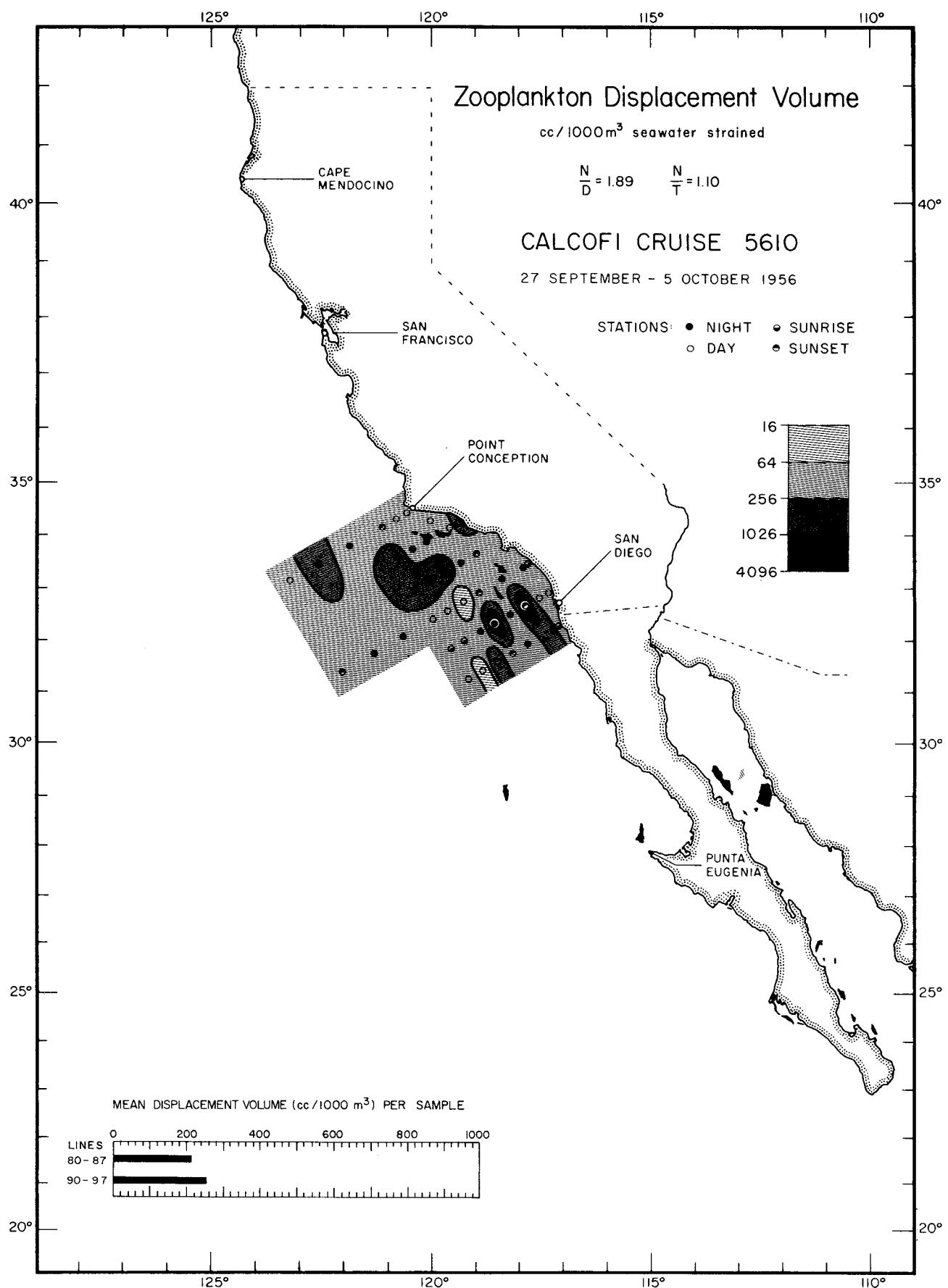
Zooplankton Displacement Volume

5410



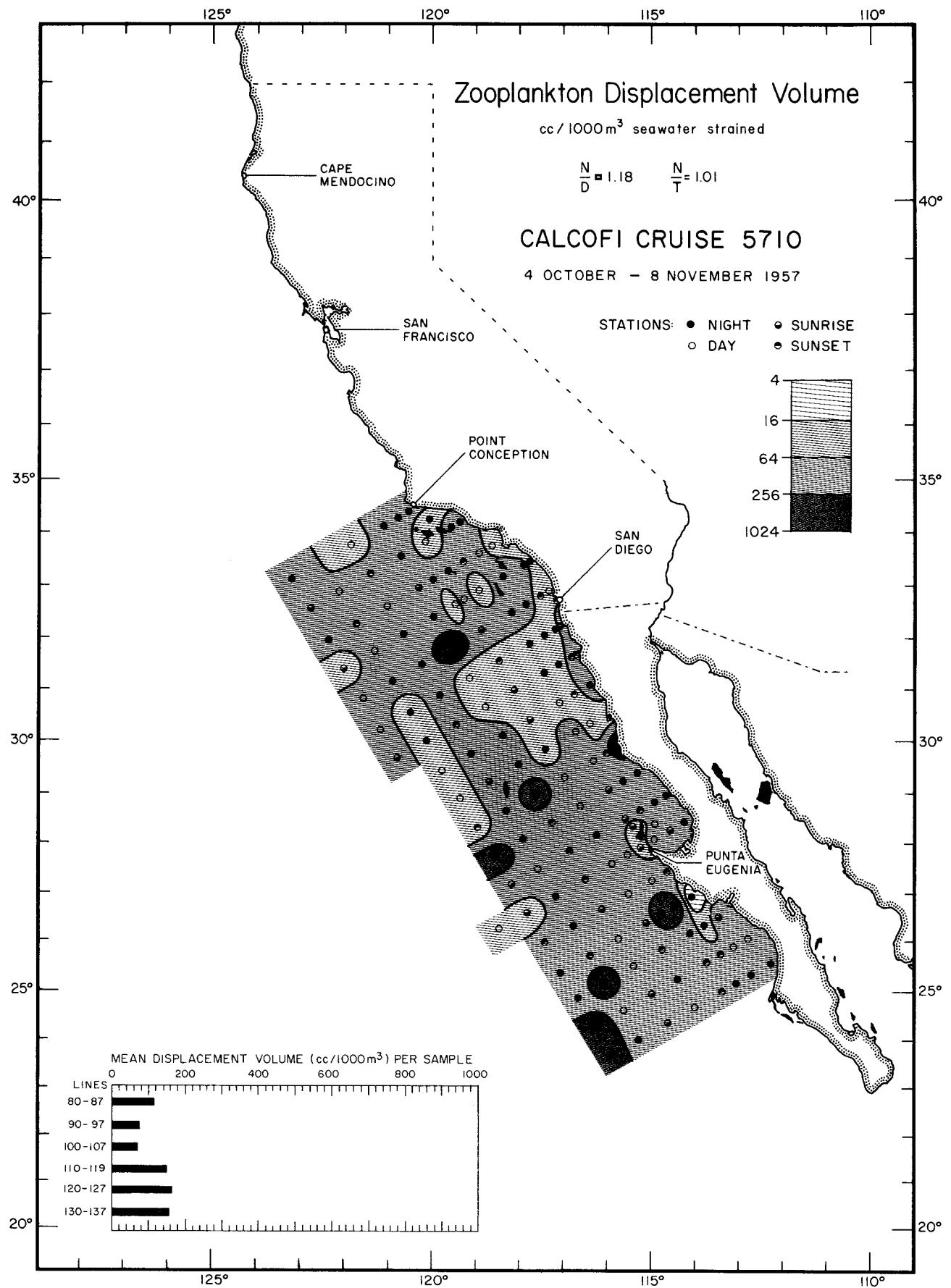
Zooplankton Displacement Volume

5510



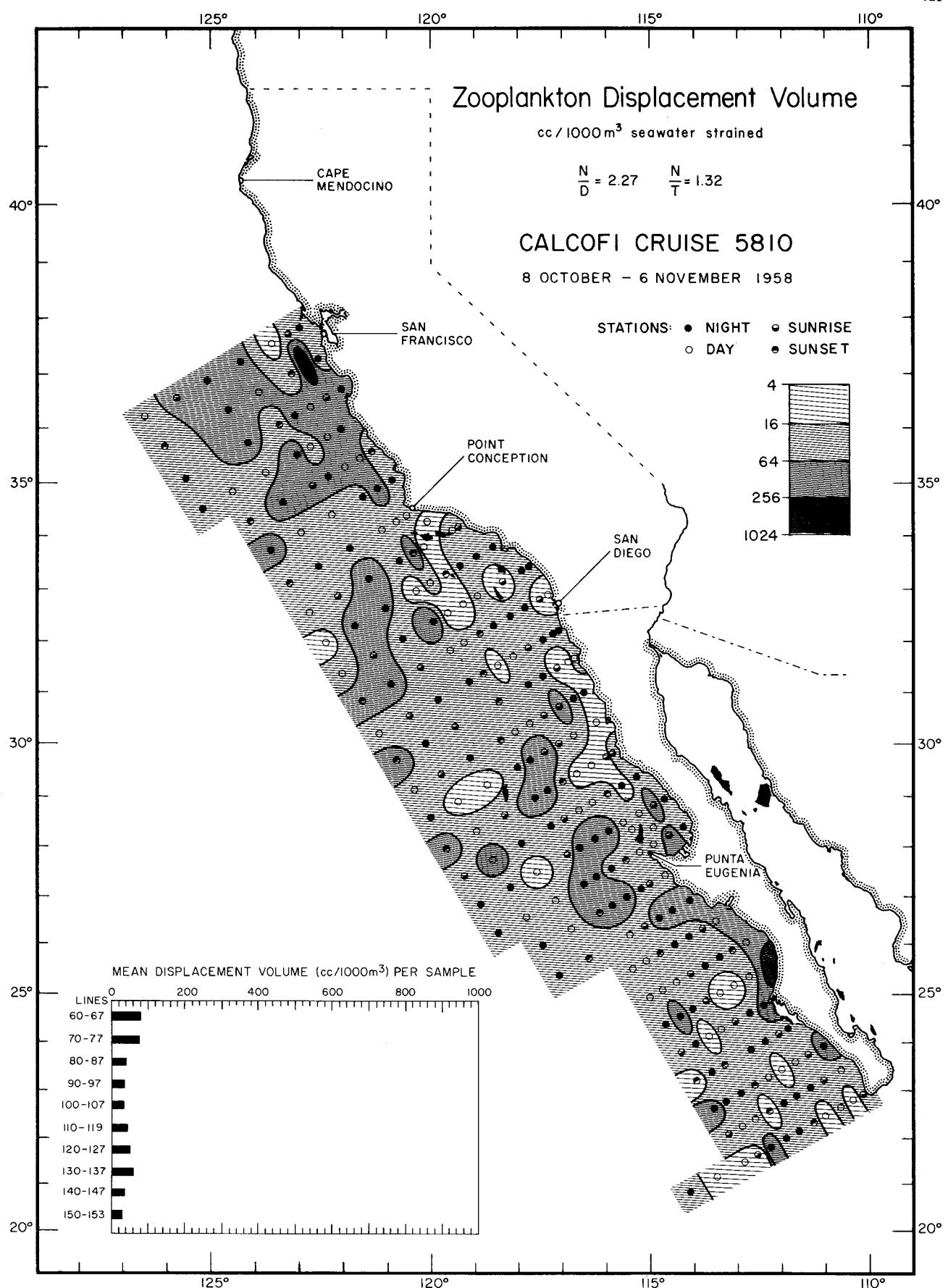
Zooplankton Displacement Volume

5610



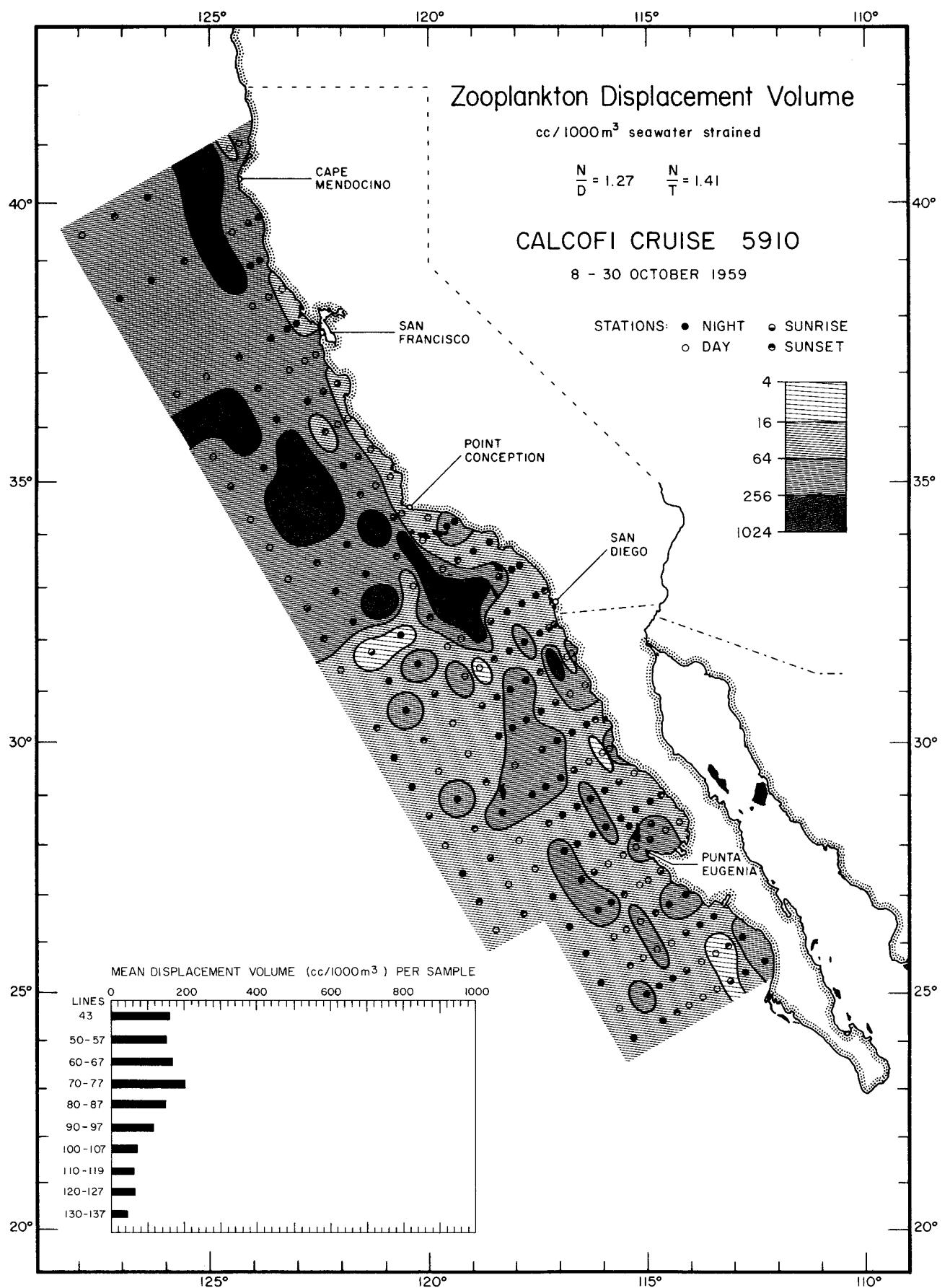
Zooplankton Displacement Volume

5710



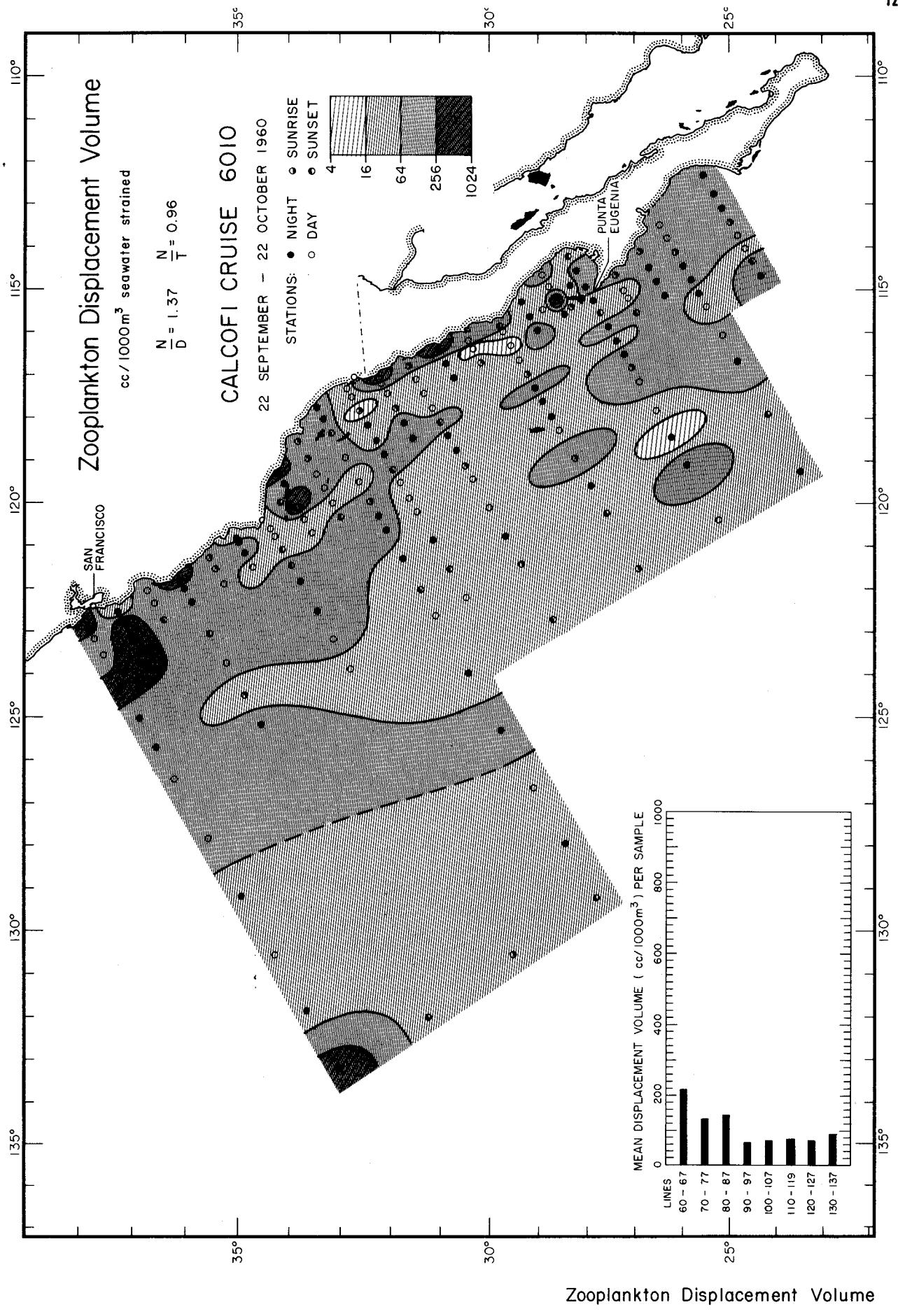
Zooplankton Displacement Volume

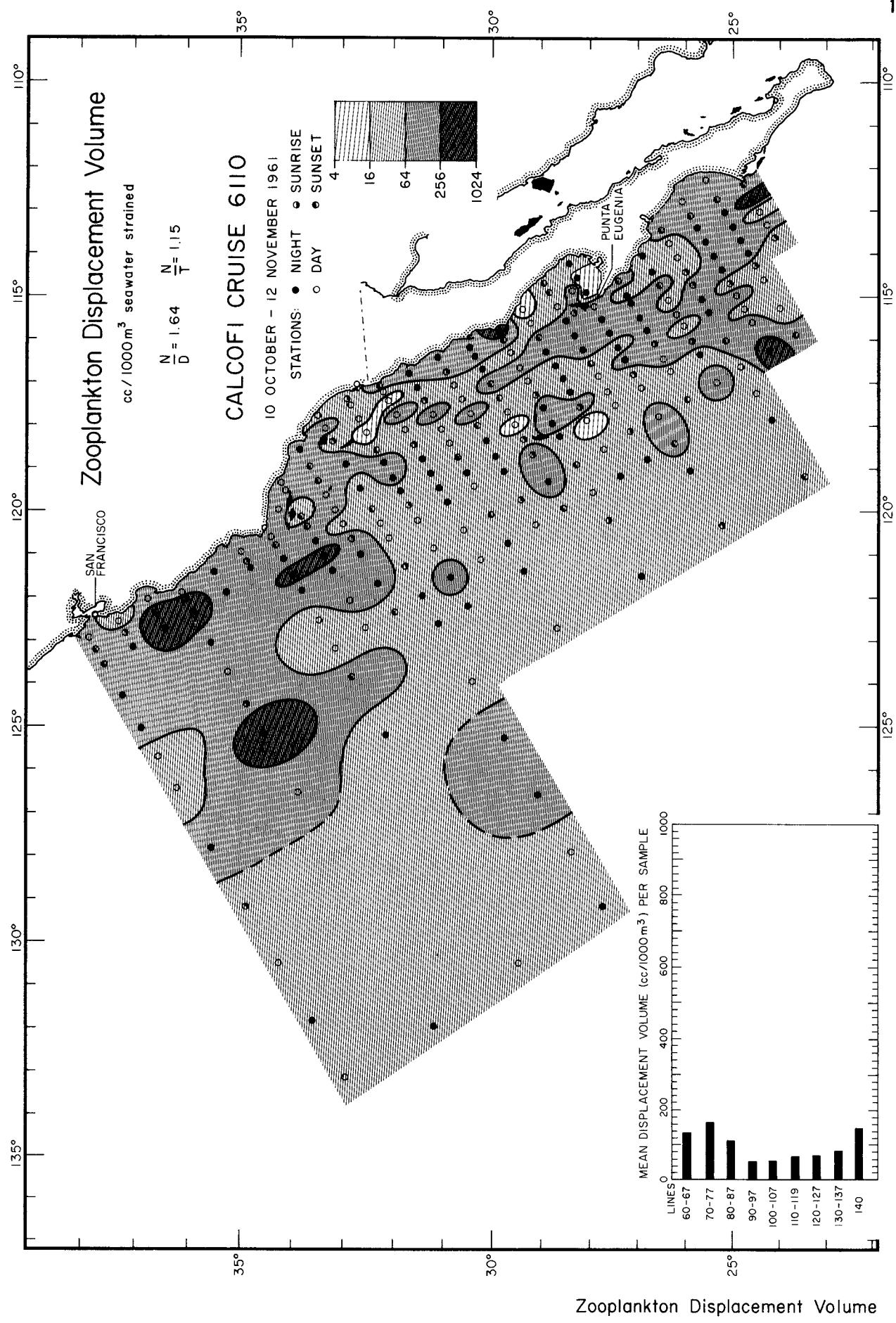
5810

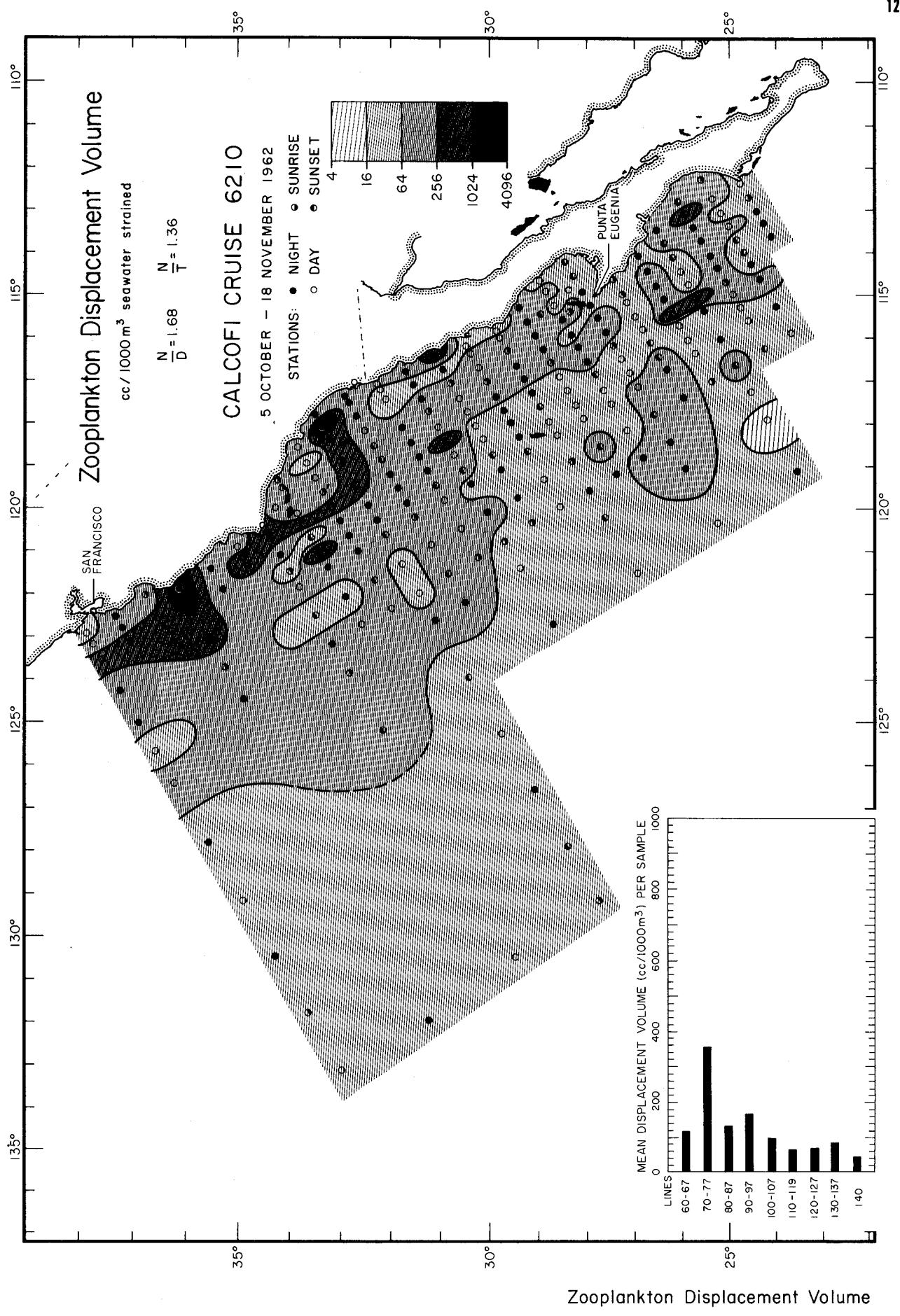


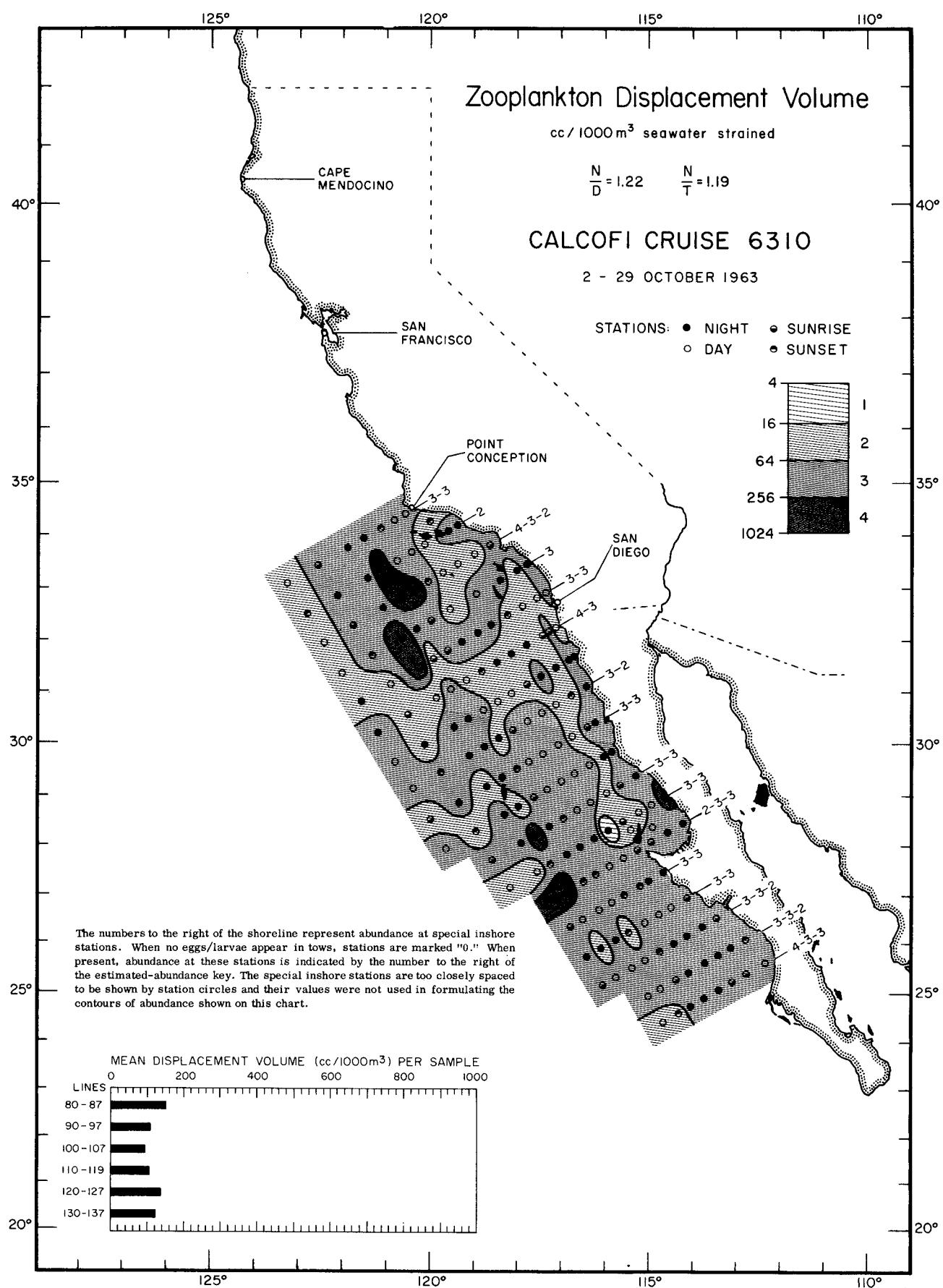
Zooplankton Displacement Volume

5910



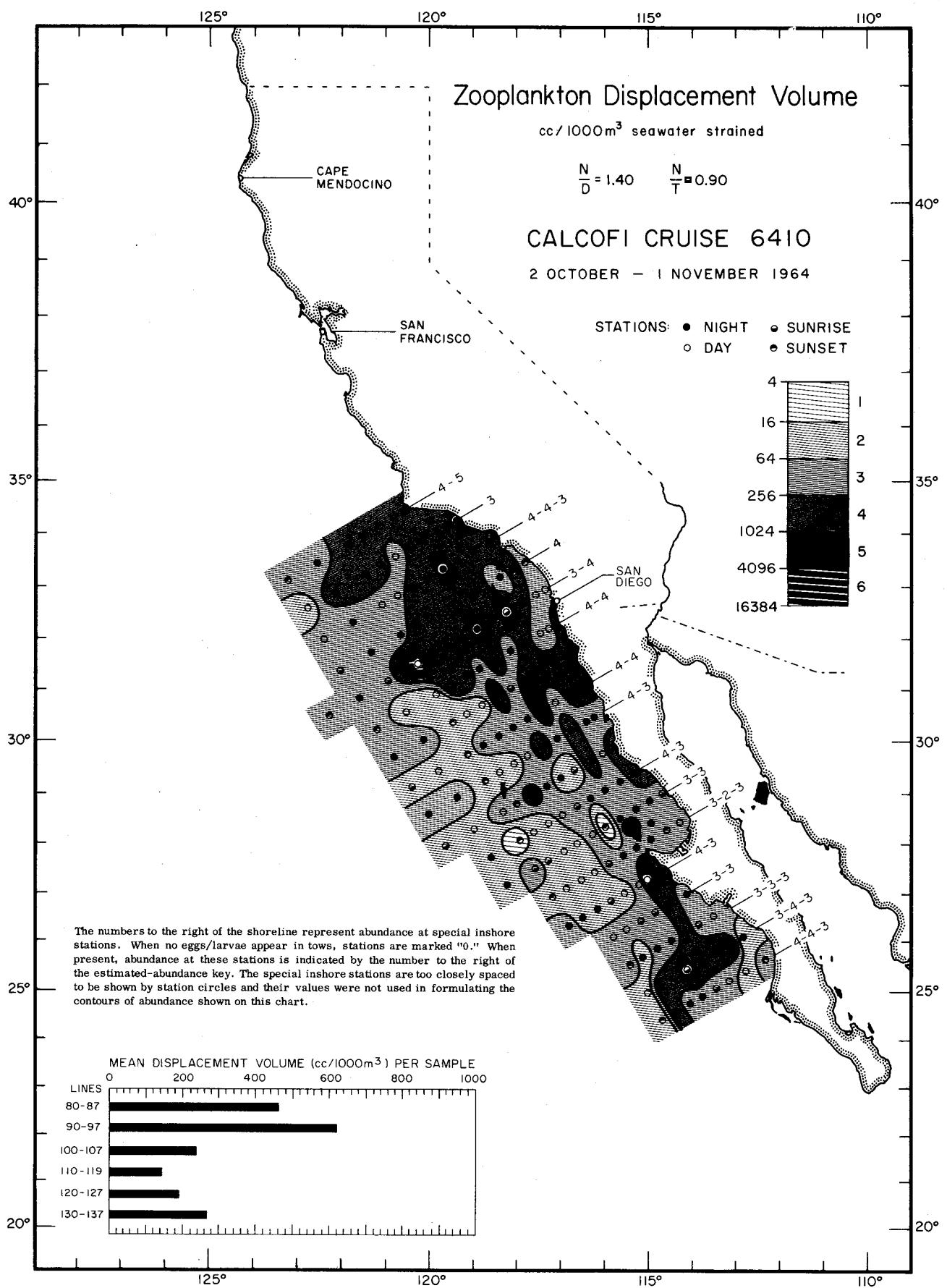






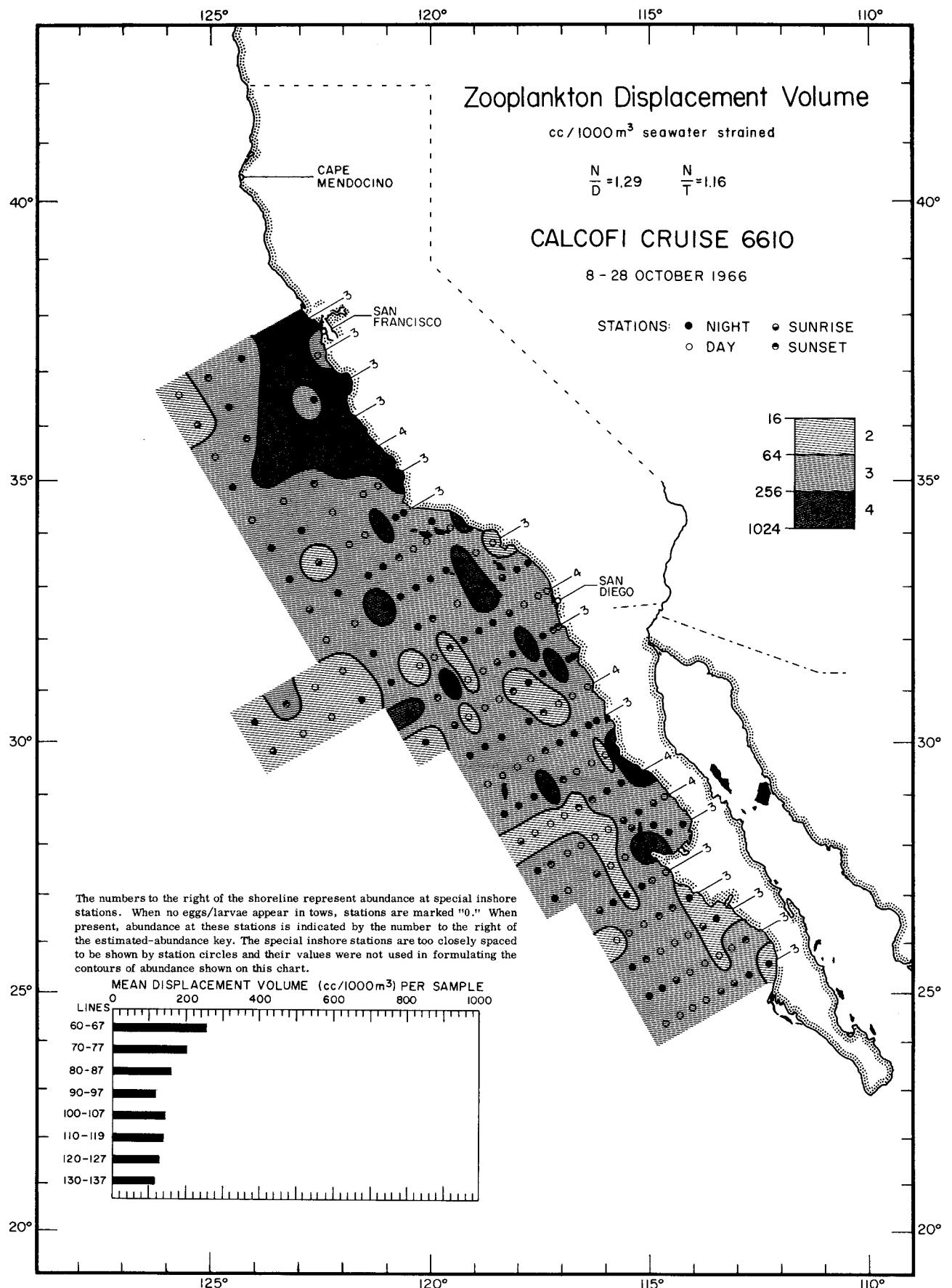
Zooplankton Displacement Volume

6310



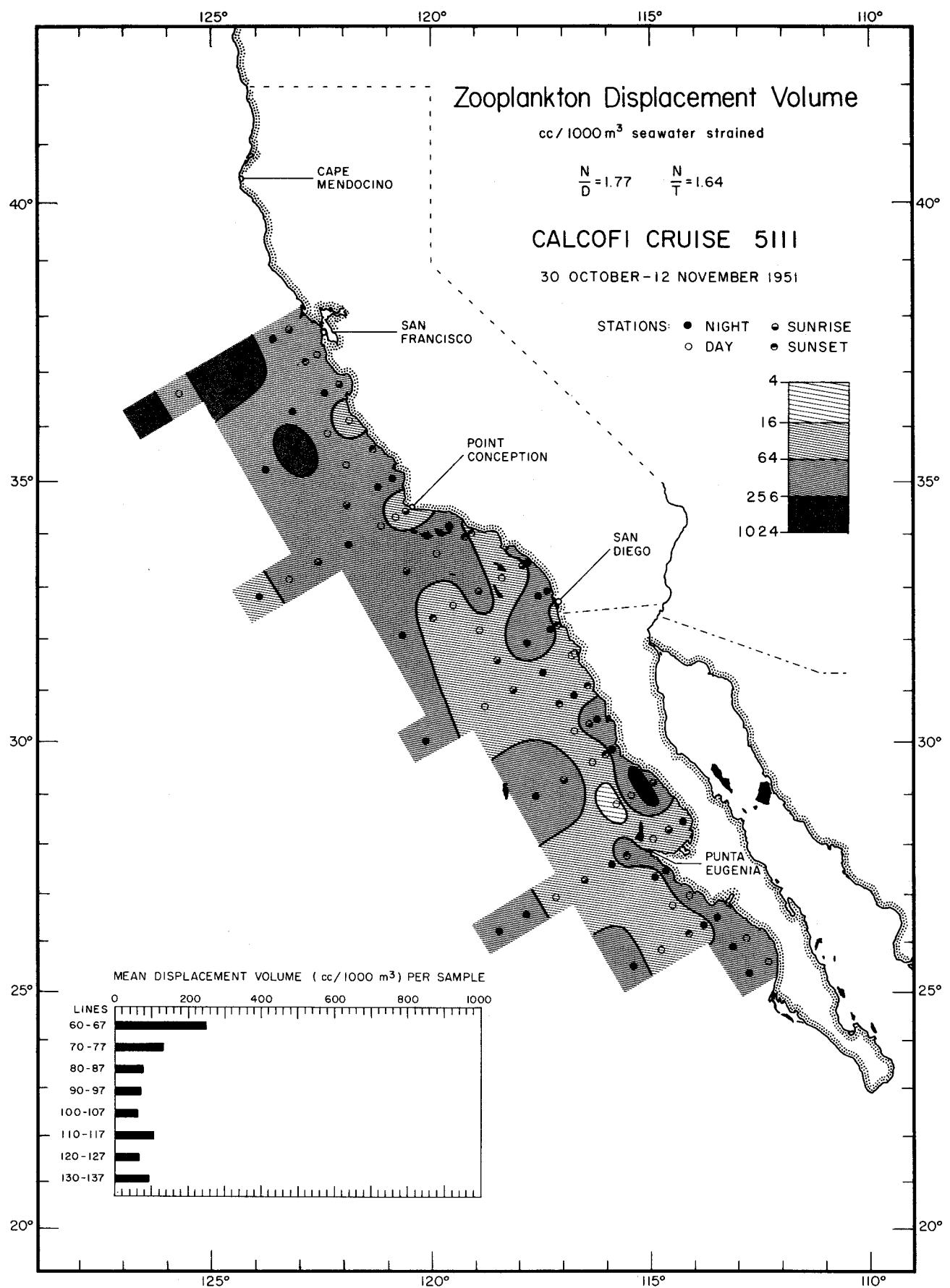
Zooplankton Displacement Volume

6410

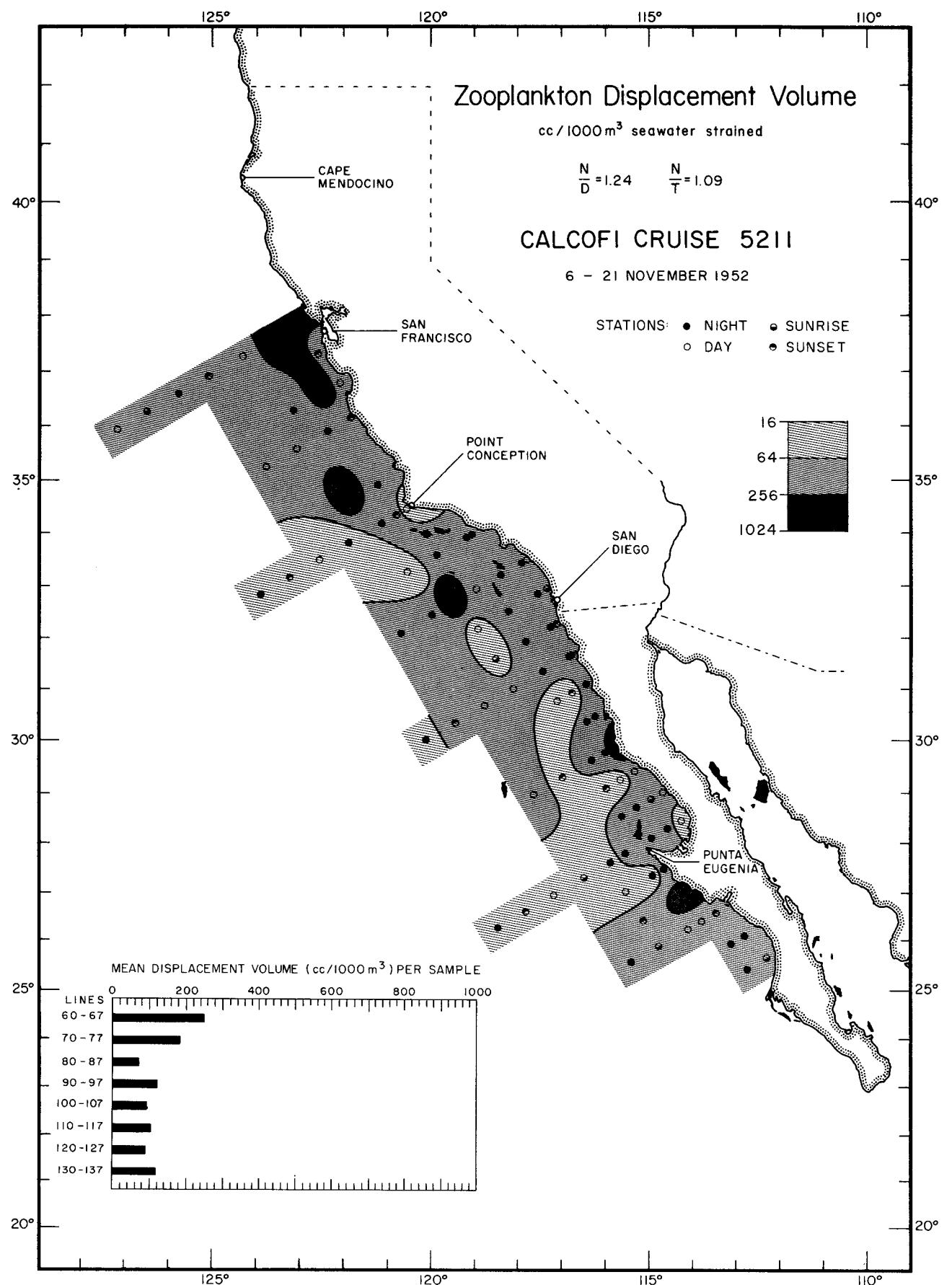


Zooplankton Displacement Volume

6610

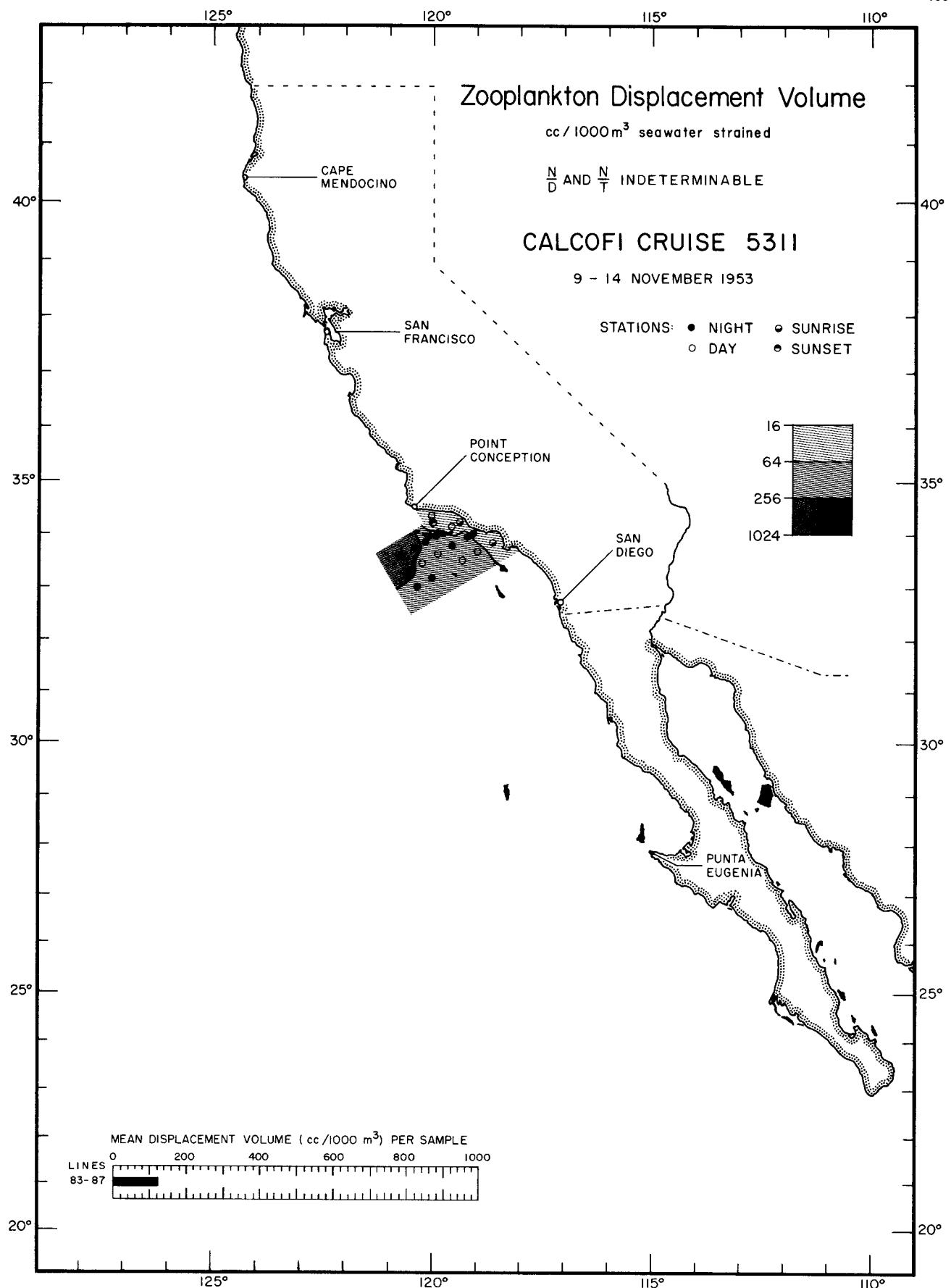


Zooplankton Displacement Volume

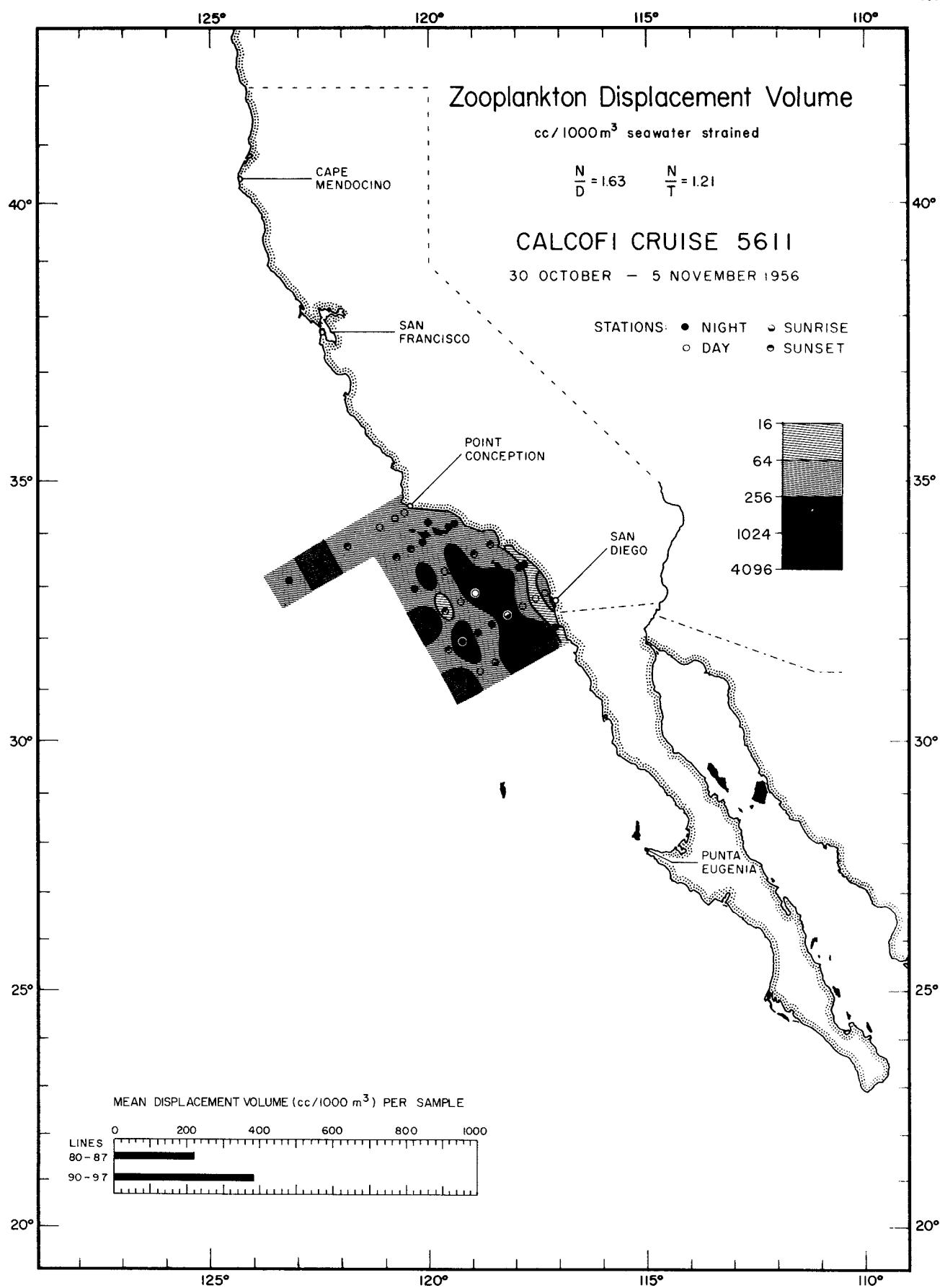


Zooplankton Displacement Volume

5211

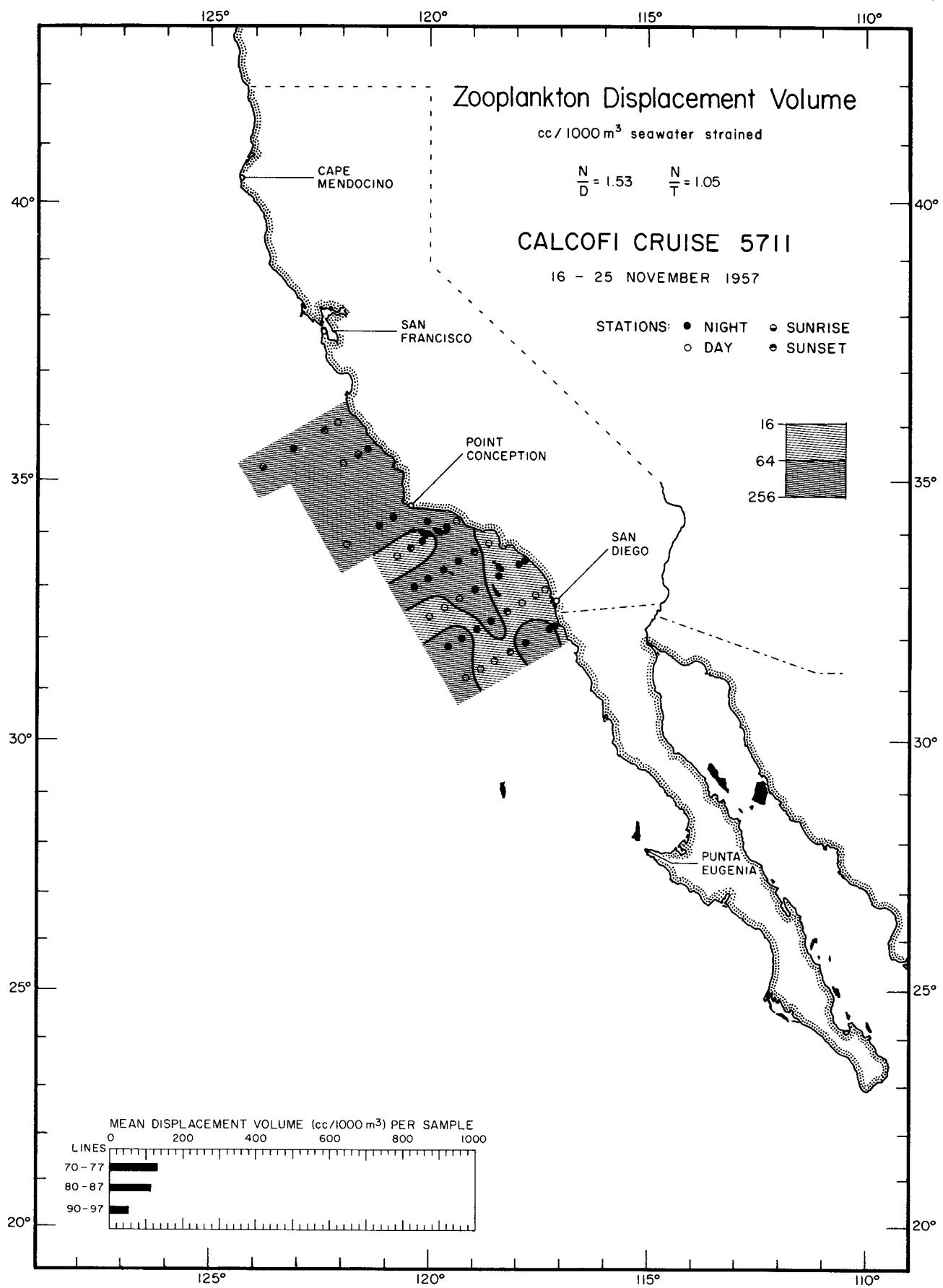


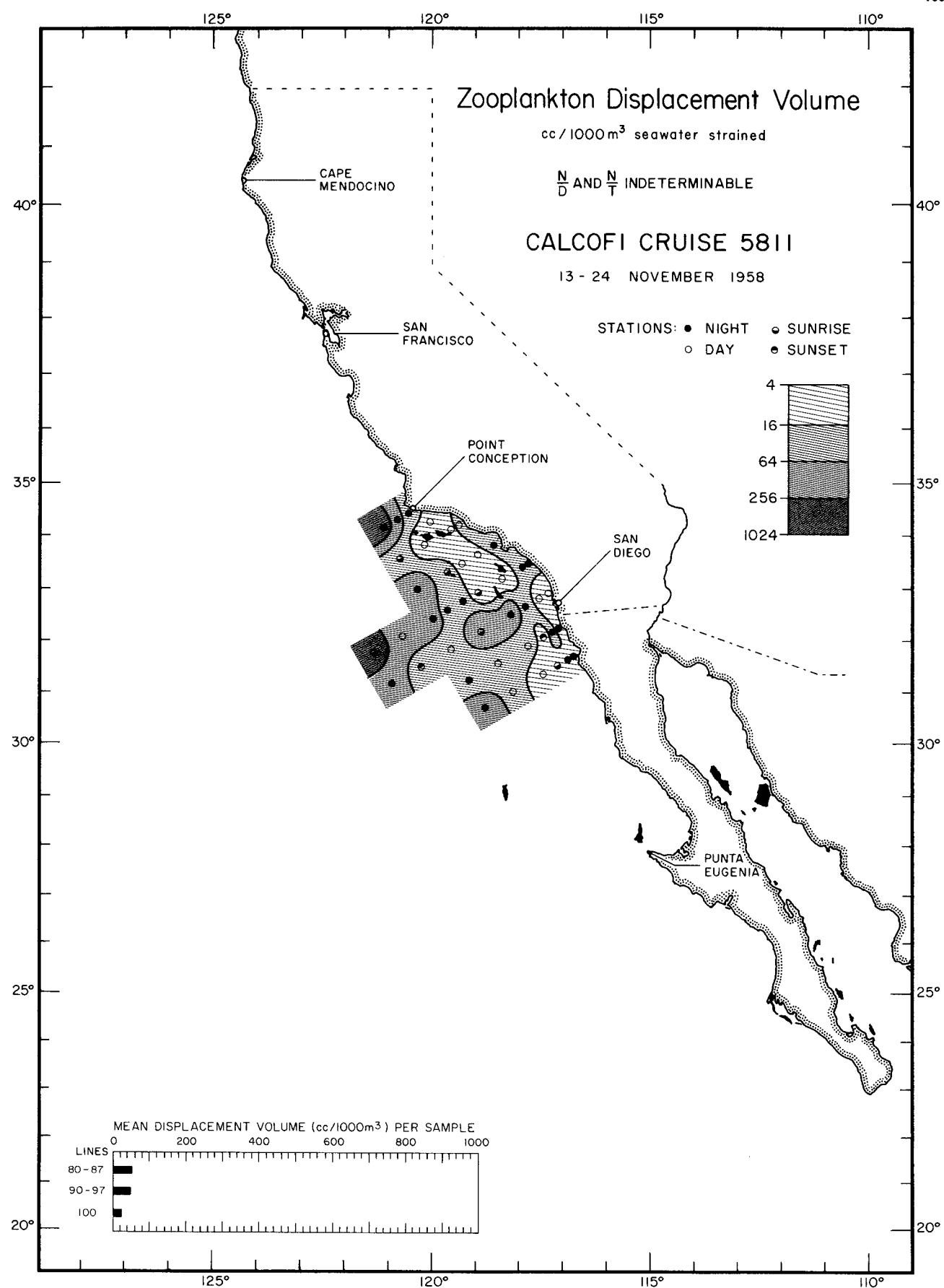
Zooplankton Displacement Volume



Zooplankton Displacement Volume

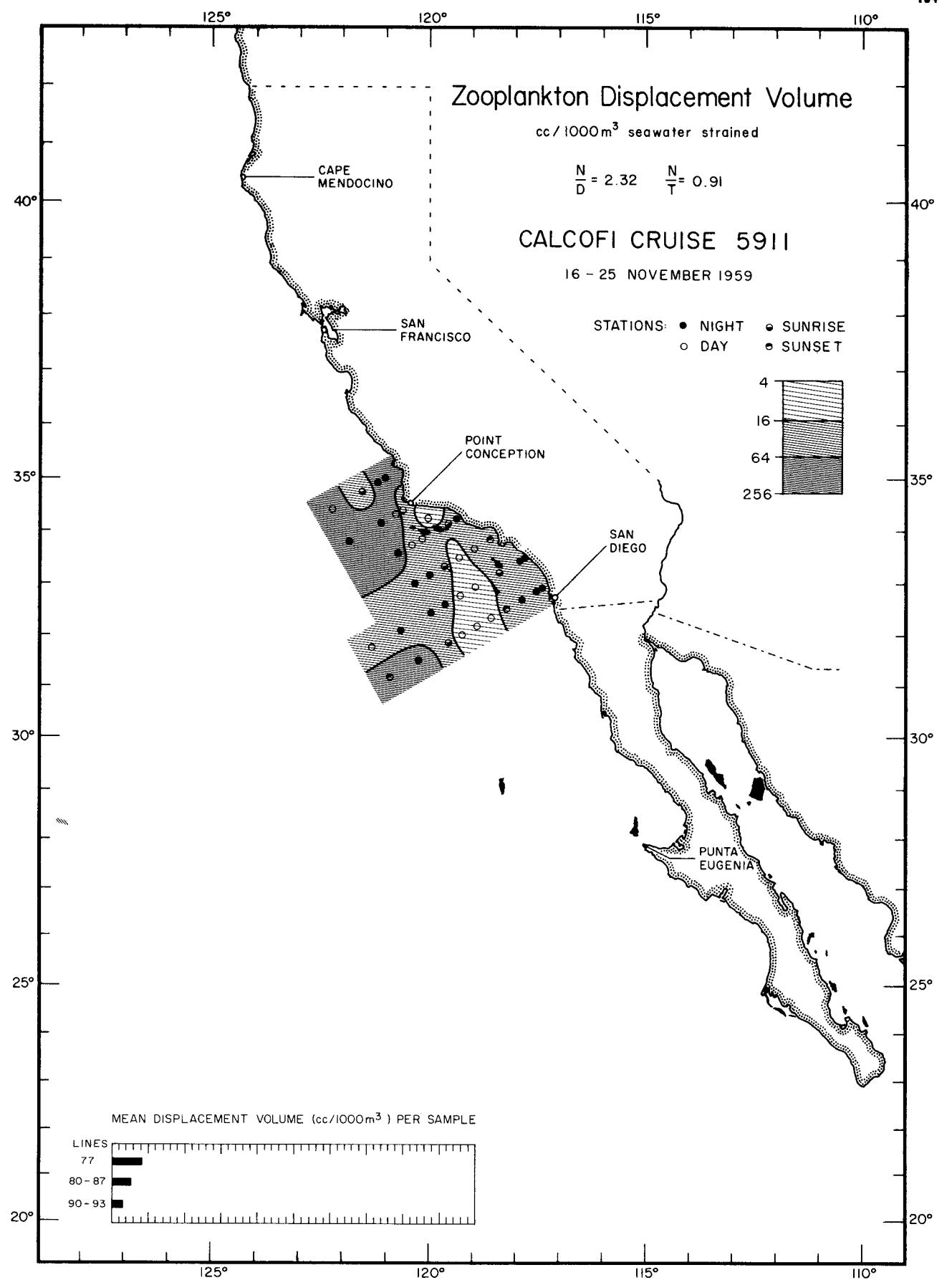
5611





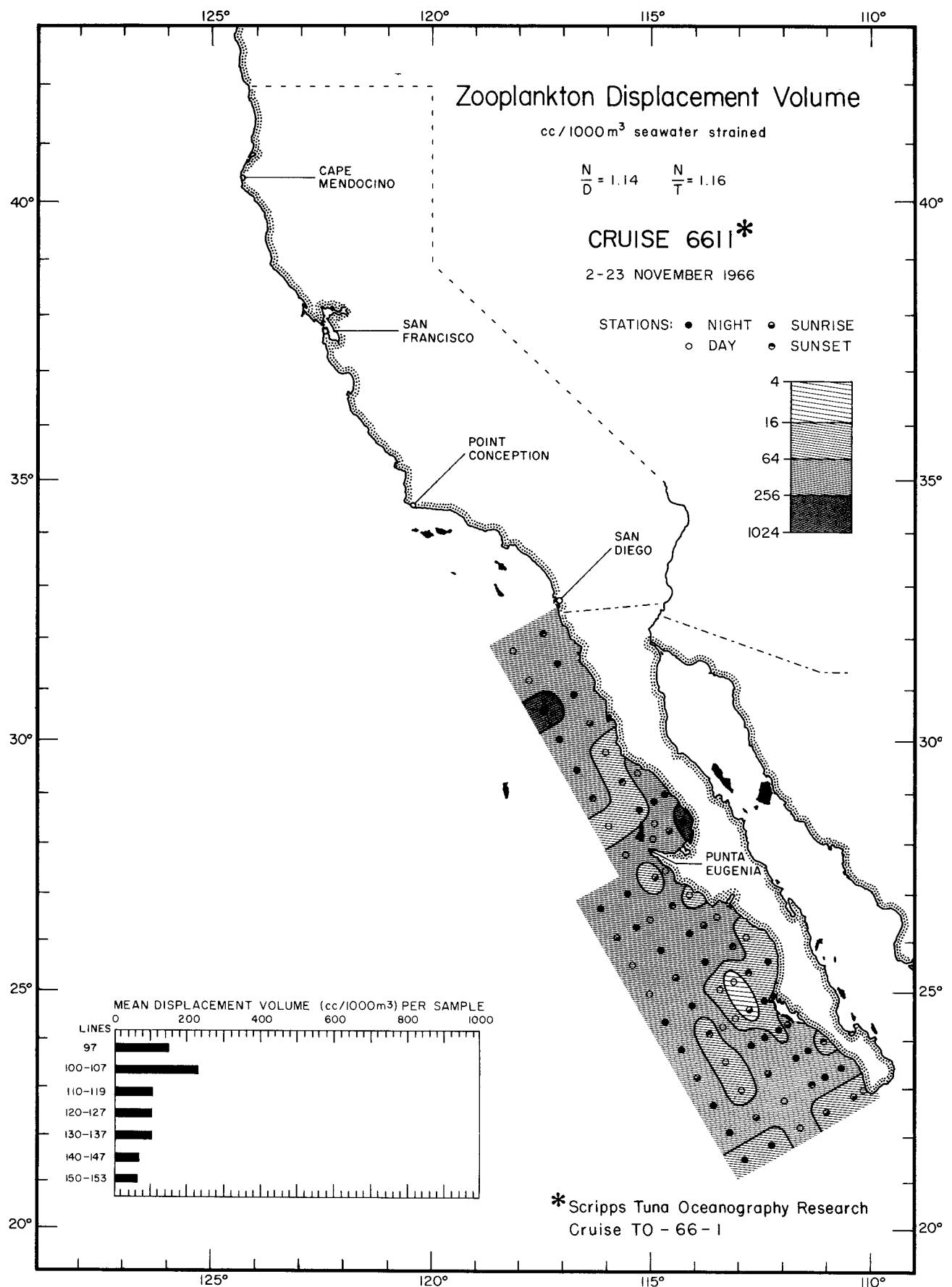
Zooplankton Displacement Volume

5811



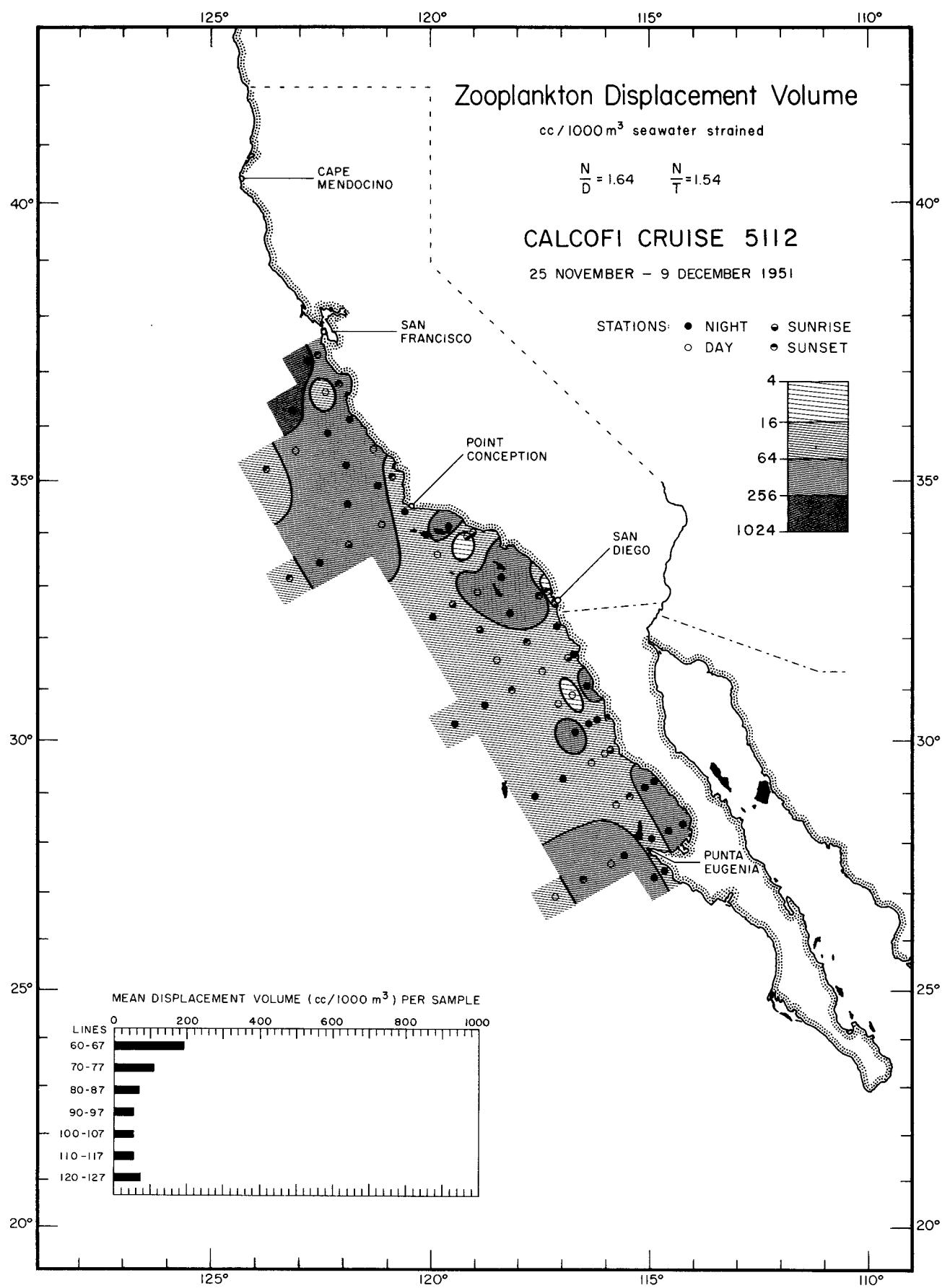
Zooplankton Displacement Volume

5911



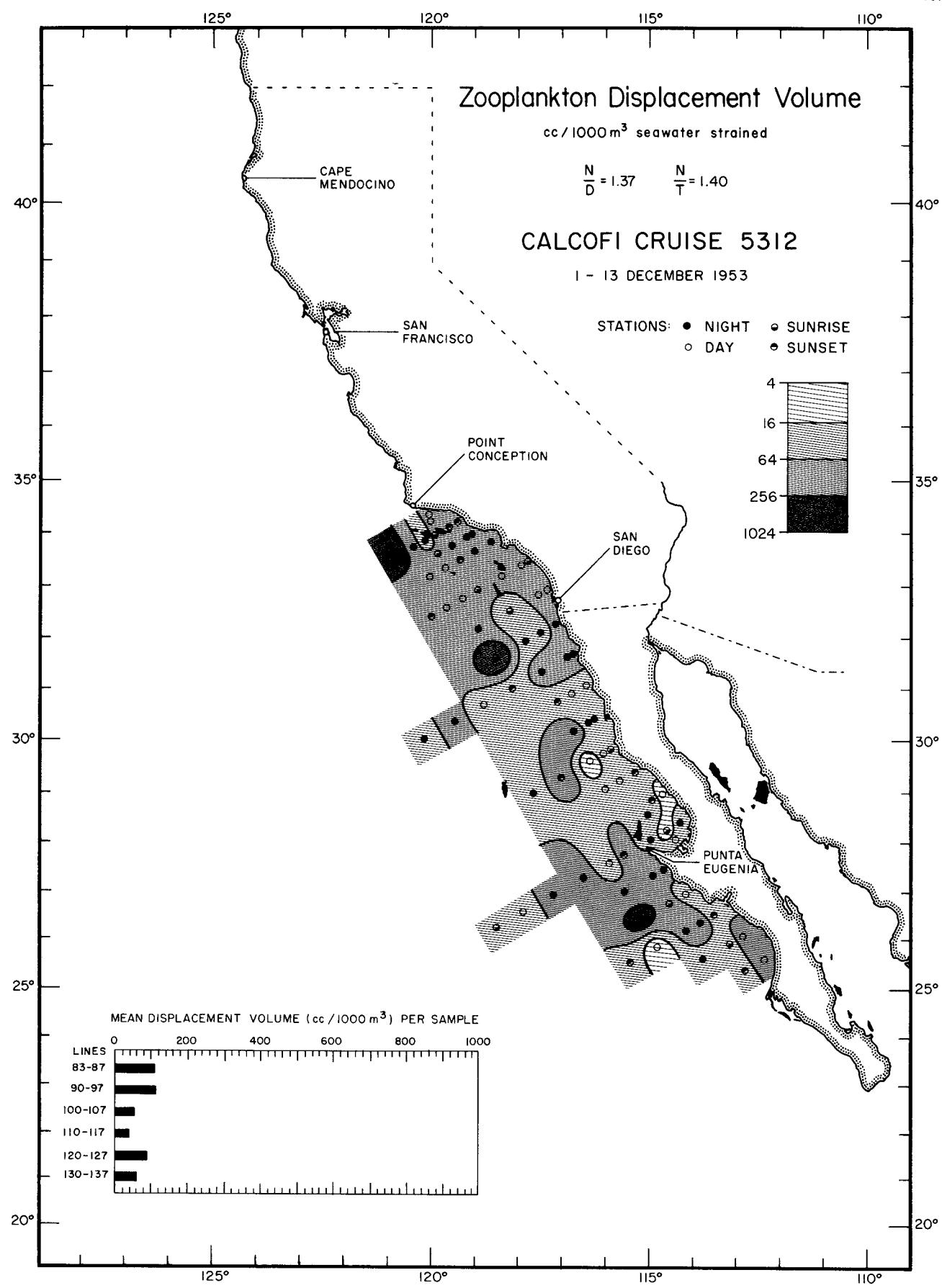
Zooplankton Displacement Volume

66II



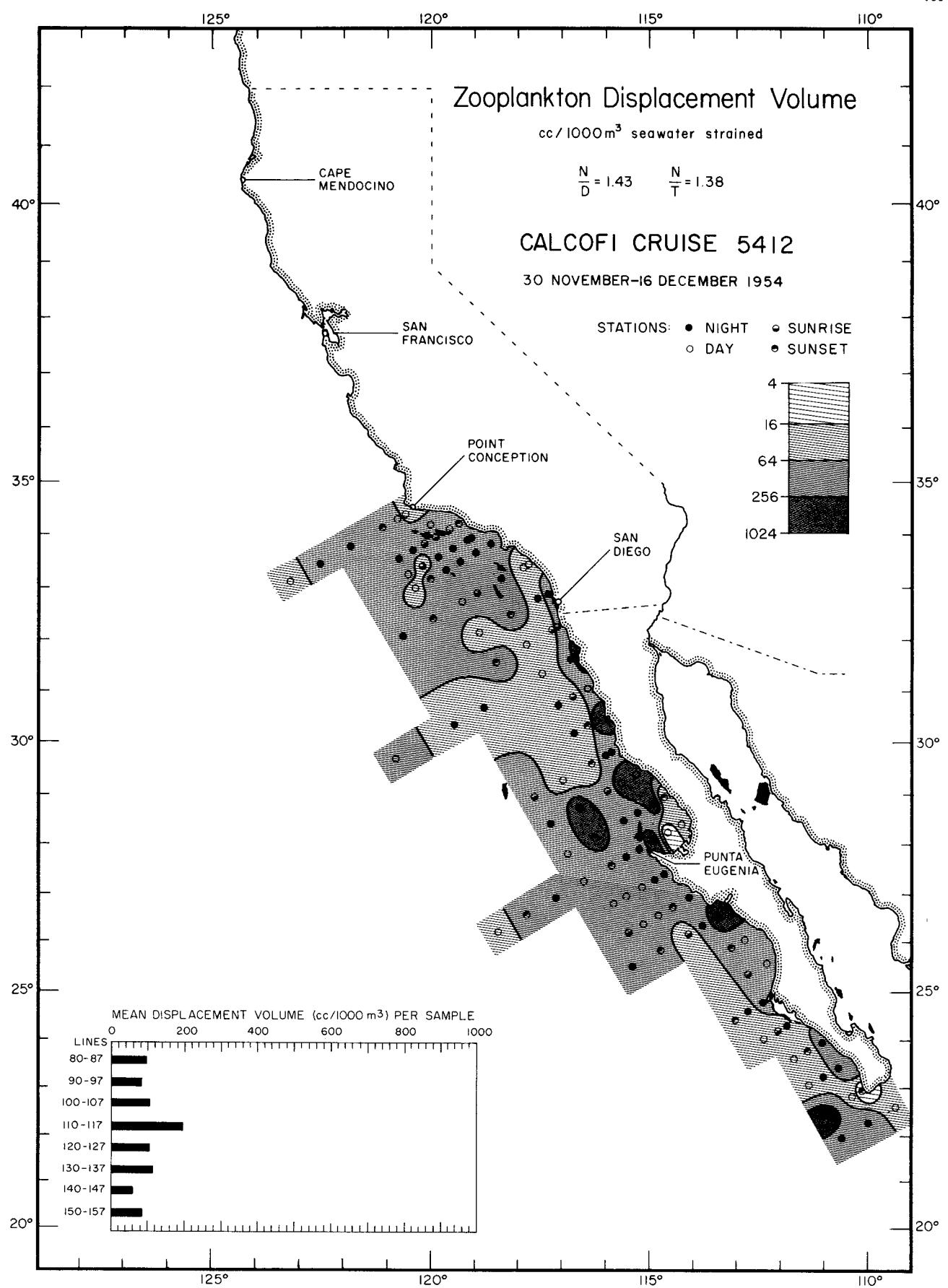
Zooplankton Displacement Volume

5112



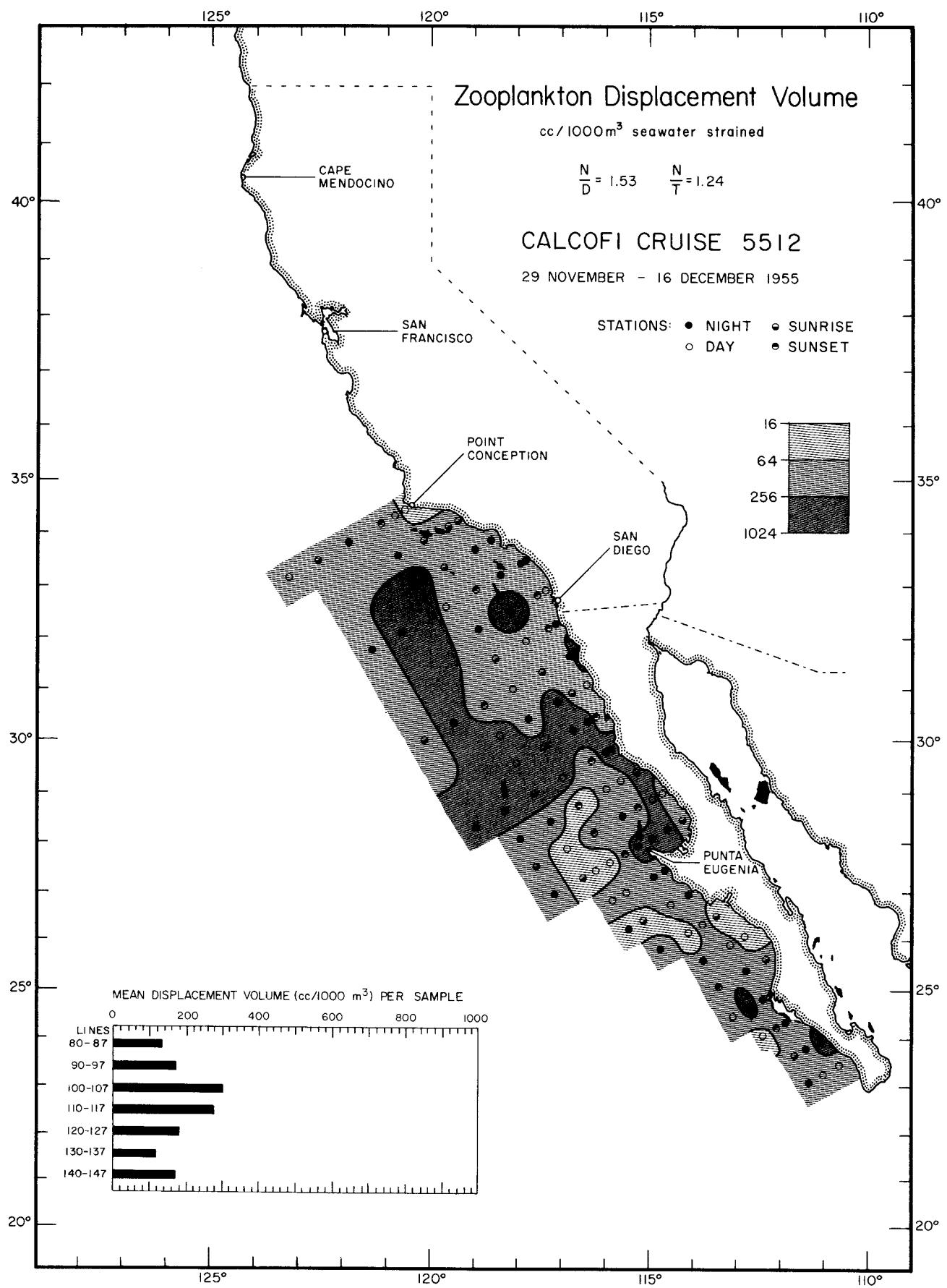
Zooplankton Displacement Volume

5312



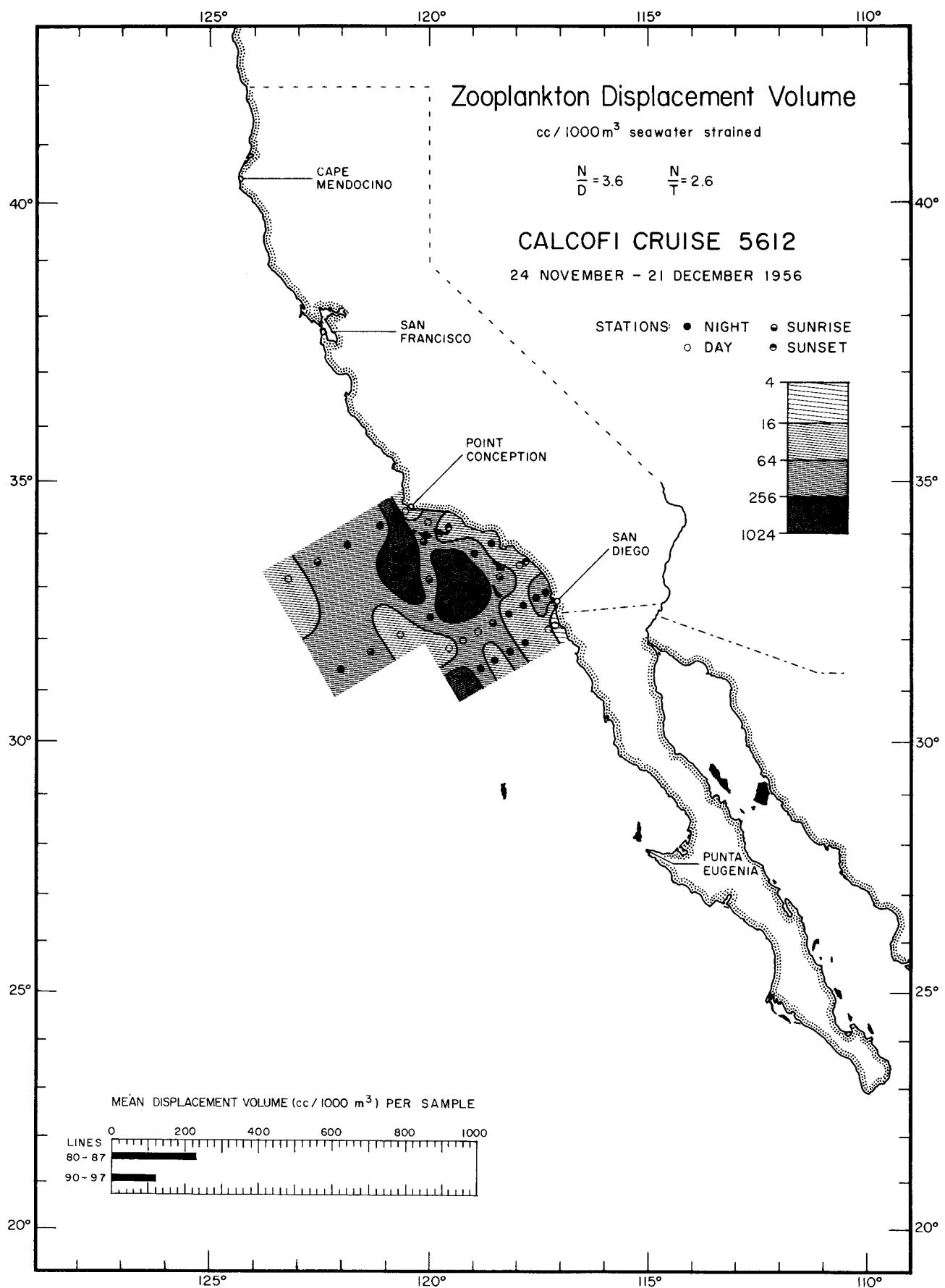
Zooplankton Displacement Volume

5412



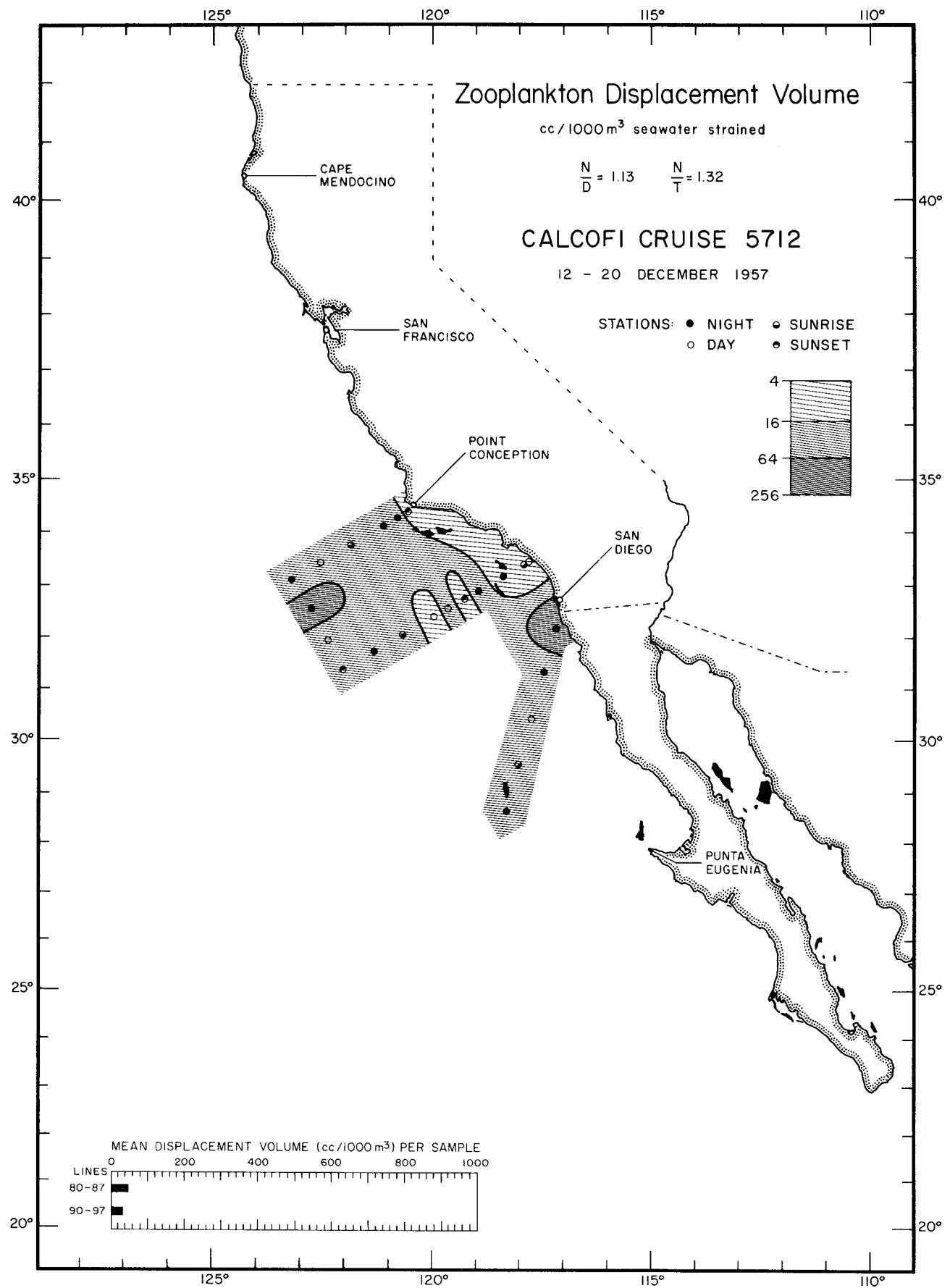
Zooplankton Displacement Volume

5512



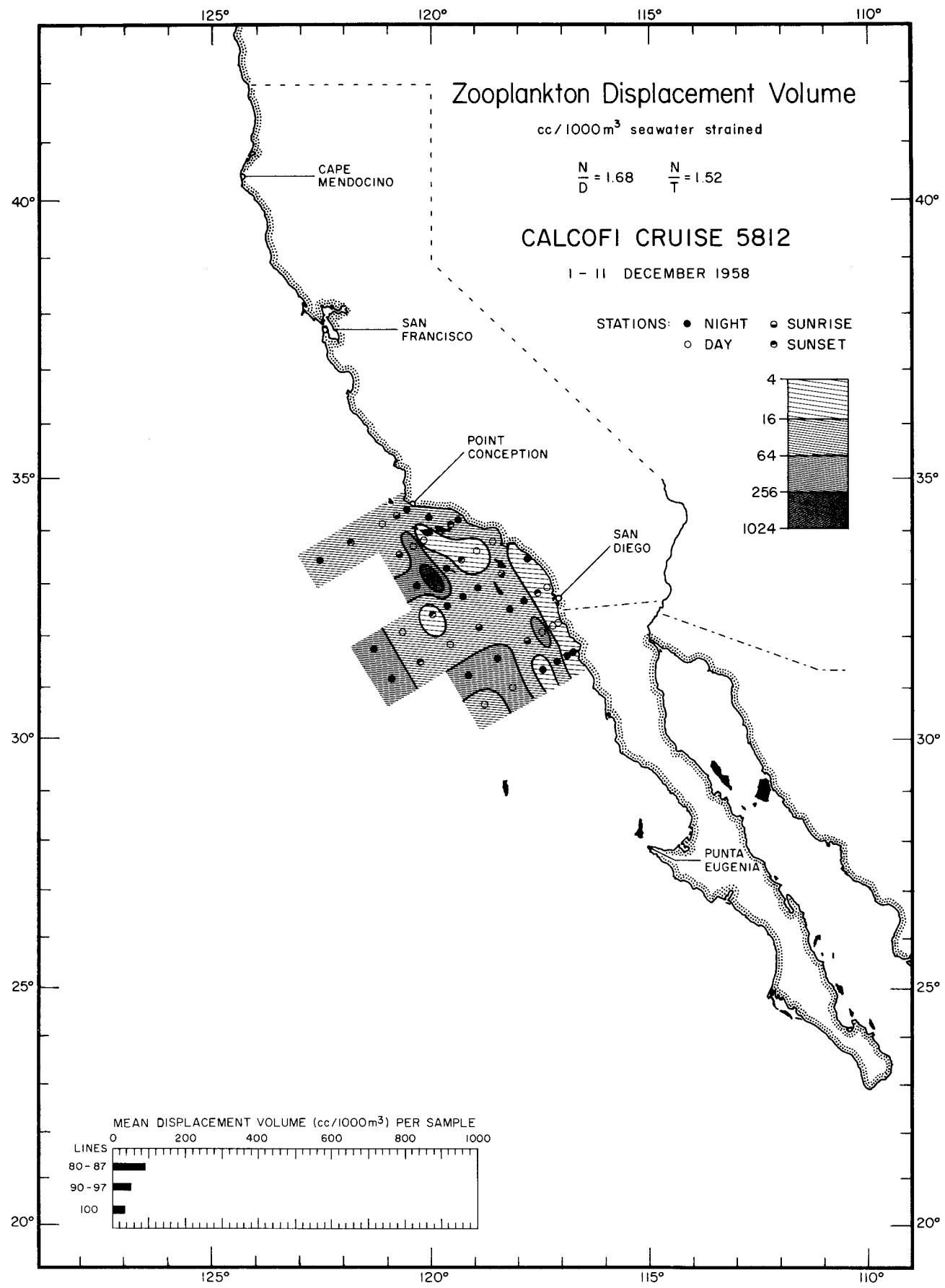
Zooplankton Displacement Volume

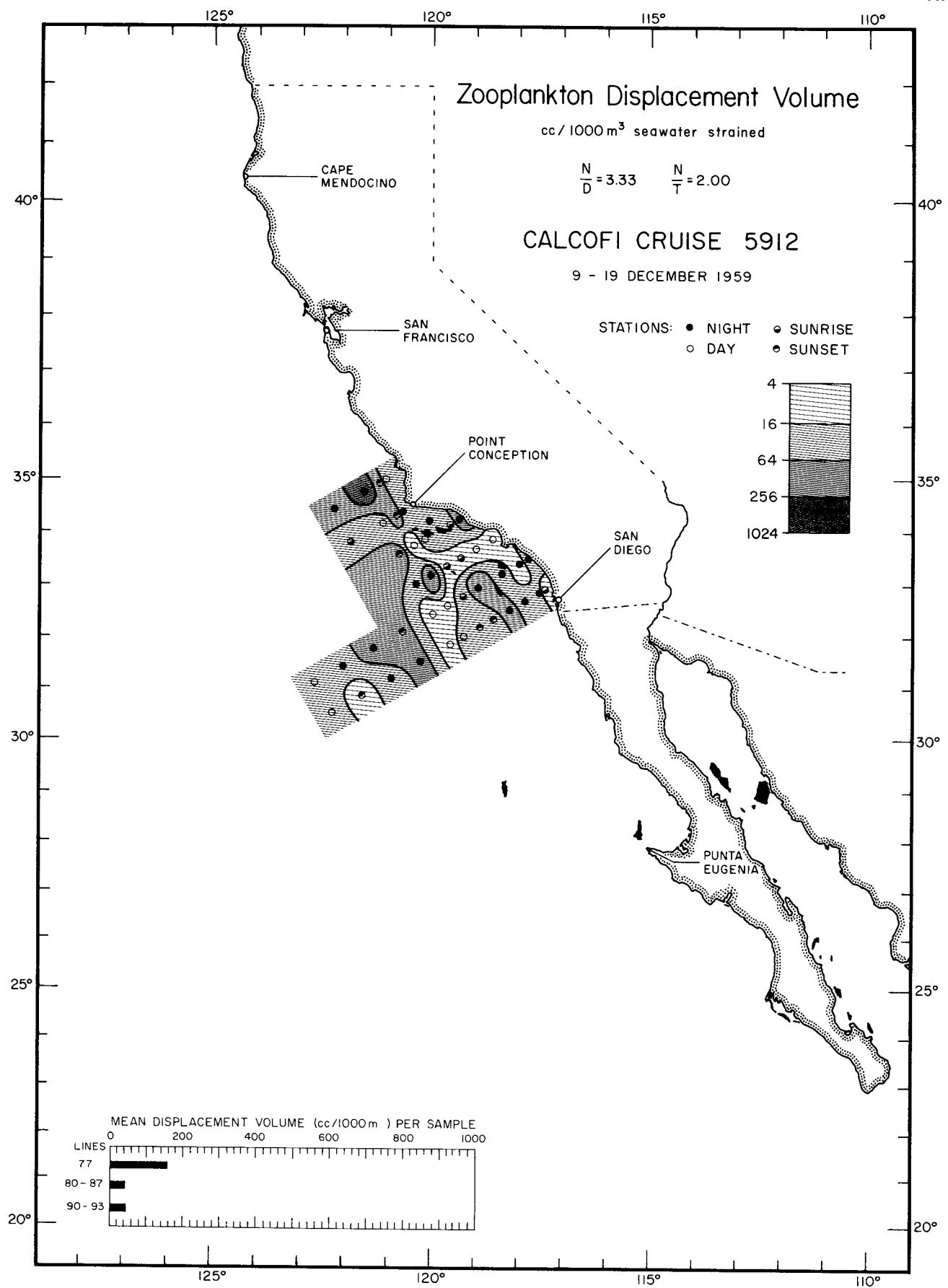
5612



Zooplankton Displacement Volume

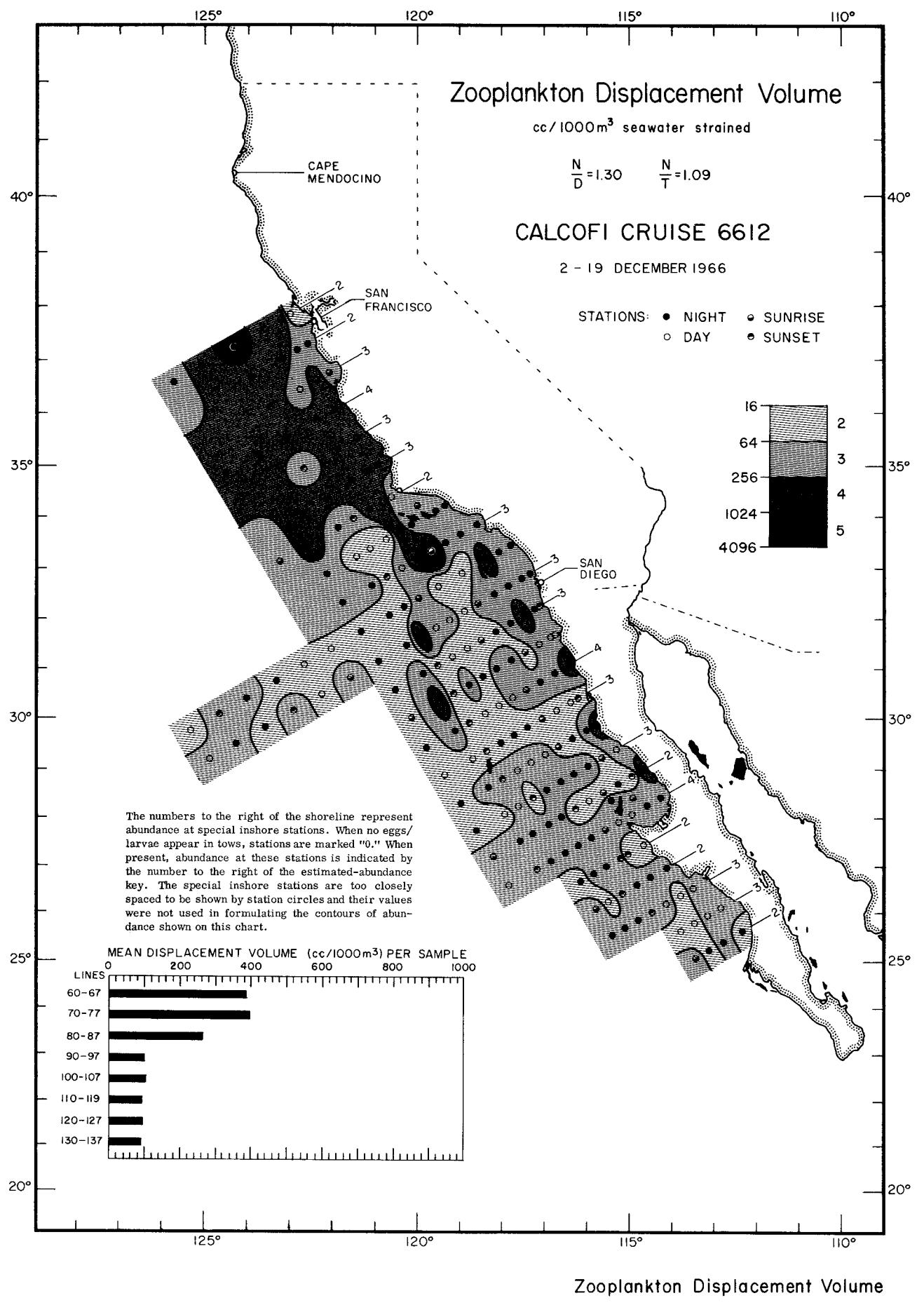
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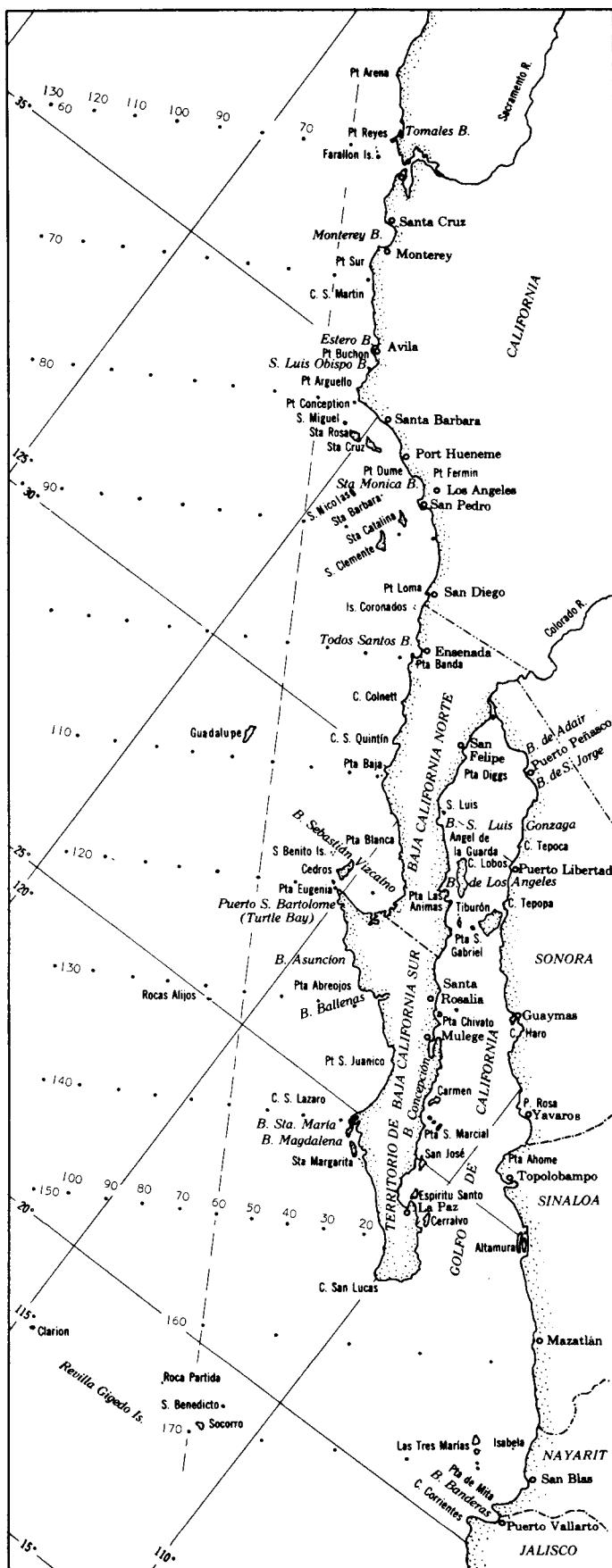
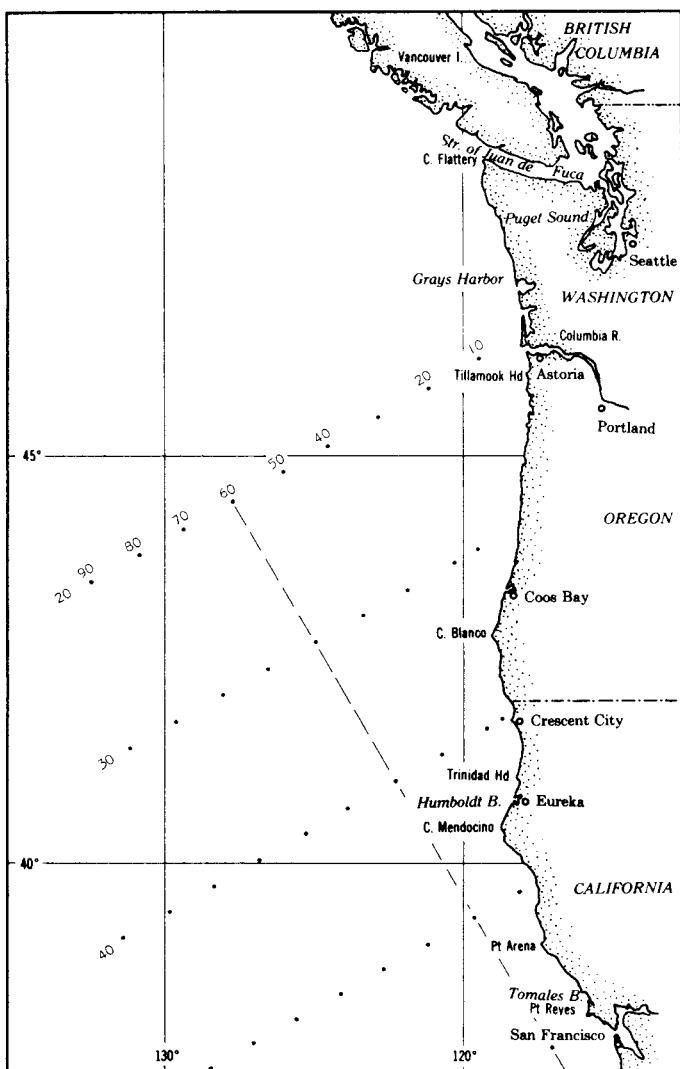




Zooplankton Displacement Volume

5912





These maps are designed to show essential details of the area most intensively studied by the California Cooperative Oceanic Fisheries Investigations. This is approximately the same area as is shown in color on the front cover. Geographical place names are those most commonly used in the various publications emerging from the research. The cardinal station lines extending southwestward from the coast are shown. They are 120 miles apart. Additional lines are utilized as needed and can be as closely spaced as 12 miles apart and still have individual numbers. The stations along the lines are numbered with respect to the station 60 line, the numbers increasing to the west and decreasing to the east. Most of them are 40 miles apart, and are numbered in groups of 10. This permits adding stations as close as 4 miles apart as needed. An example of the usual identification is 120.65. This station is on line 120, 20 nautical miles southwest of station 60.

The projection of the front cover is Lambert's Azimuthal Equal Area Projection. The detail maps are a Mercator projection.

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Paul E. Smith

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