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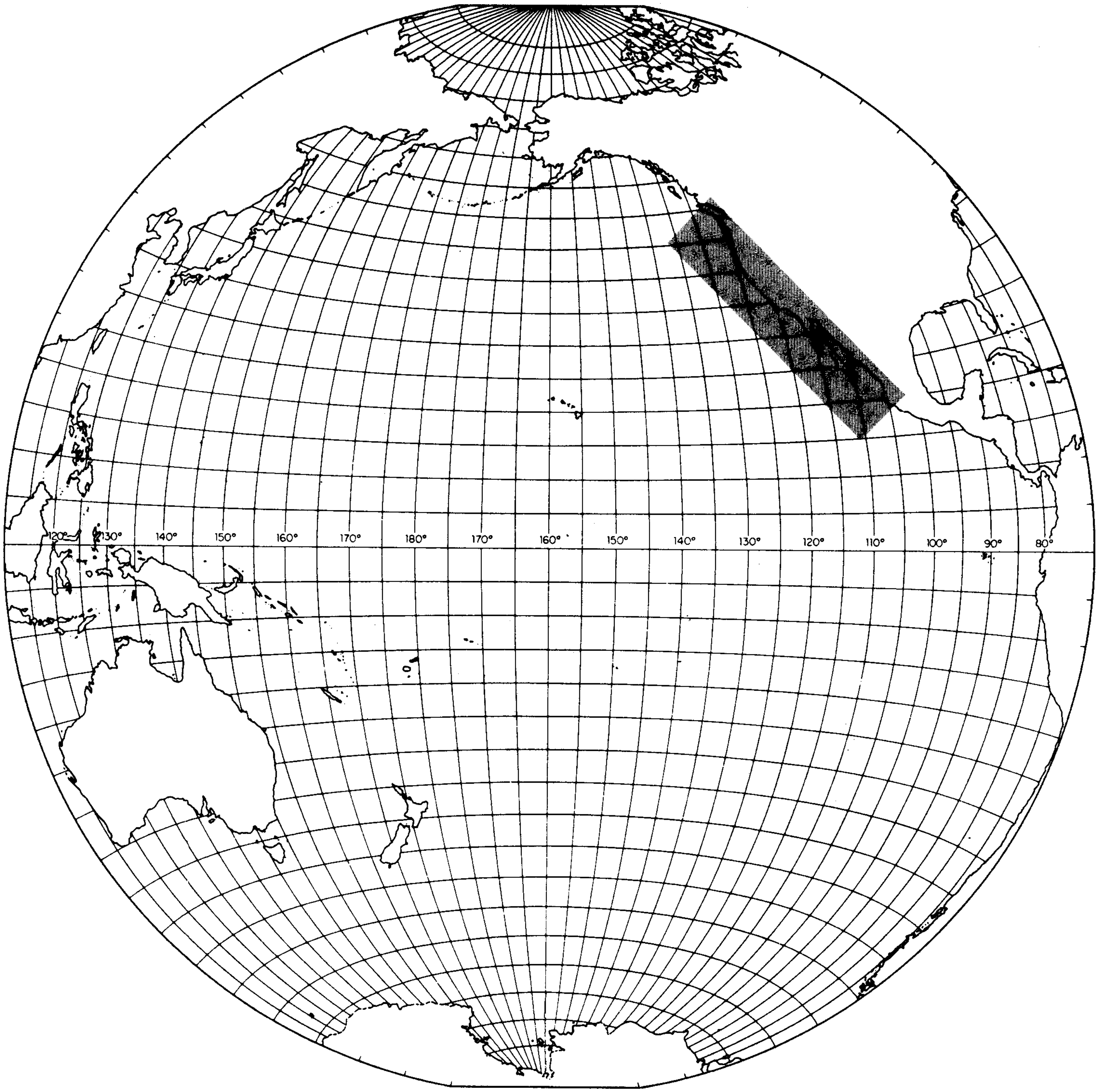
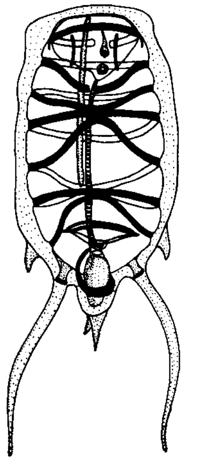


CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

ATLAS No. 14



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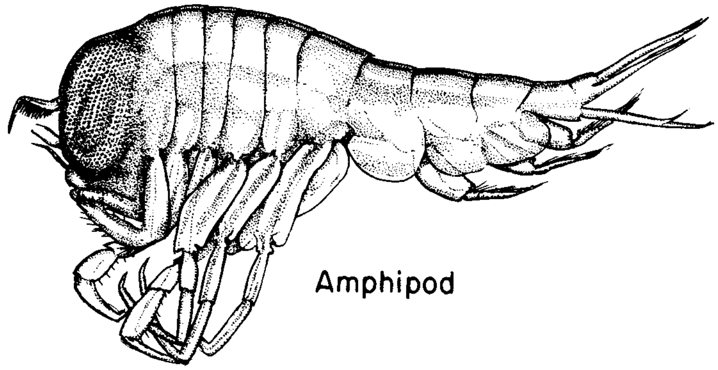

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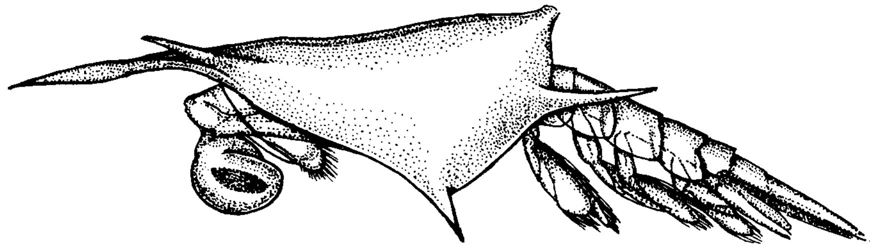

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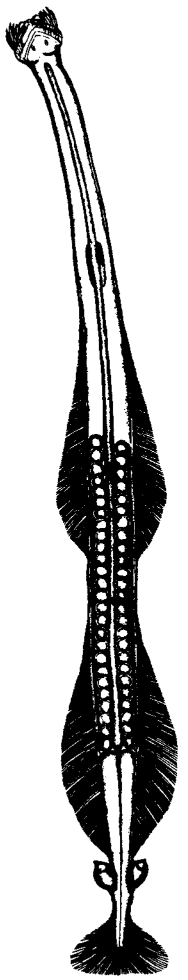

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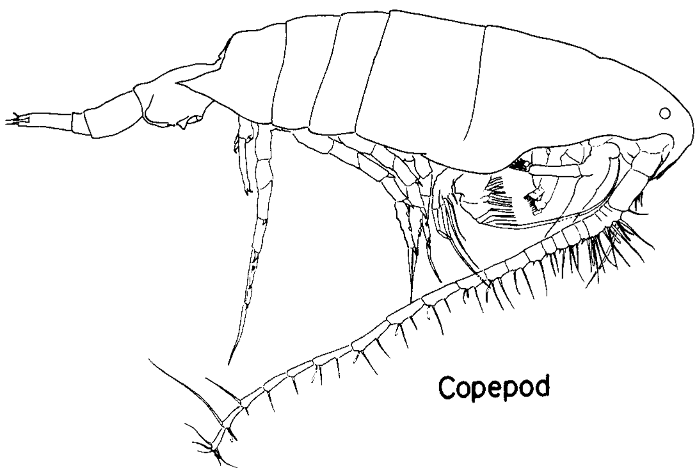
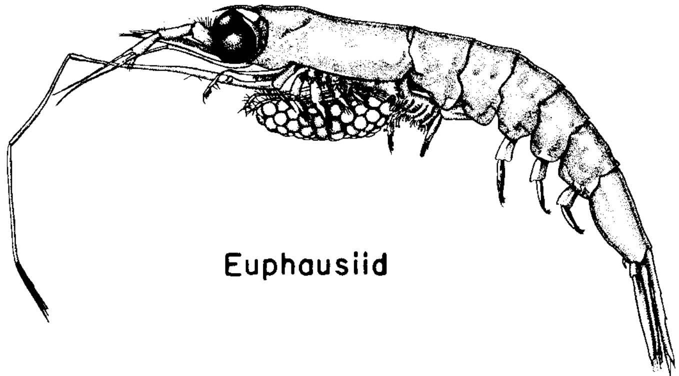


Copepod

Pteropod



Euphausiid

CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

Atlas No. 14

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 fourteenth 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 Service[2]
University of California, Scripps Institution of Oceanography

CalCOFI atlases[3] 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.

No. 8. Berner, L., 1967. Distributional atlas of Thaliacea in the California Current region.

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.

No. 14. Isaacs, J. D., A. Fleminger and J. K. Miller, 1971. Distributional atlas of zooplankton biomass in the California Current region: Winter 1955-1959.

[1]Usually abbreviated CalCOFI, sometimes CALCOFI or CCOFI.
[2]Formerly called U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries.
[3]For citation this issue in the series should be referred to as CalCOFI Atlas No. 14.

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DISTRIBUTIONAL ATLAS OF ZOOPLANKTON BIOMASS IN THE CALIFORNIA CURRENT REGION: WINTER 1955-1959

J. D. Isaacs, A. Fleminger and J. K. Miller

CALCOFI ATLAS NO. 14

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

June, 1971

DISTRIBUTIONAL ATLAS OF ZOOPLANKTON BIOMASS IN THE CALIFORNIA CURRENT REGION: WINTER 1955-1959

J. D. Isaacs, A. Fleminger and J. K. Miller[1]

Text

Introduction	v
Materials and Methods	vi
Sample Analyses: Procedures	viii
Presentation of Data	ix
Zooplankton Abundance and Diurnal Vertical Migration	xiii
List of Charts	xvii
References	xviii
Appendix I	xxi
Appendix II	xxii

Charts

CalCOFI Basic Station Plan	1
All Taxa Combined	2
Amphipoda	8
Chætognatha	18
Cladocera	23
Copepoda	28
Crustacean larvæ	36
Ctenophora	44
Decapoda	49
Euphausiacea	57
Heteropoda	67
Larvacea	73
Medusæ	78
Mysidacea	83
Ostracoda	88
Pteropoda	97
Radiolaria	104
Siphonophora	110
Thaliacea	117

INTRODUCTION

Beginning in 1949, the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program has systematically monitored a variety of oceanographic features across the California Current region. Standardized measurements and collections of physical, chemical and biological components are taken from a network of stations. The stations are usually spaced at 40-mile intervals between 25°N and 38°N and extend seaward to several hundred miles off the Pacific coast of North America (Chart 1). The California Current region, distinguished by upwelling and relatively high productivity, comprises the eastern boundary current of the north Pacific Ocean.

The CalCOFI Zooplankton Collection has already served a large number of specialized studies concerned with distribution and abundance of organisms among the epipelagic fauna of the region. For example, data in CalCOFI Atlases 2, 3 and 5 through 9 confirm the eastern features of the biogeographical patterns proposed for the mixed layers of the north Pacific Ocean (Beklemishev, 1967; McGowan, 1971). The CalCOFI data illustrate the relatively stable relationships among these features as well as their seasonal latitudinal displacement. In addition to seasonal variation, striking distributional changes have also occurred between periods of several years duration (Ahlstrom, 1960; Balech, 1960; Berner, 1960; Berner and Reid, 1961; Brinton, 1960; Radovich, 1960). Biological fluctuations are better understood when viewed in the context of a broad environmental perspective. The CalCOFI program is providing concurrent measurements of time and space related hydrographic, meteorological and biological events. The ecological insights to emerge will help formulate guidelines for conserving while utilizing pelagic natural resources.

The CalCOFI standard and vertically stratified zooplankton samples, are also a unique source for conducting qualitative and quantitative studies into the range of natural and man induced changes on open ocean populations. The CalCOFI samples represent all sectors of the California Current region, north to south and nearshore to offshore, in all seasons and for all years from 1949 to the present. The

[1]Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California.

35,000 samples, preserved in formaldehyde and stored under curatorial supervision as part of the Zooplankton Collections of Scripps Institution of Oceanography, have a useful research life expectancy of probably more than 50 years. That is, the accruing collection comprises a relatively permanent, quantitatively comparable historical record of environmental conditions in the eastern North Pacific epipelagic waters as expressed in terms of its zooplankton, an archive that coincides with the years of maximum sustained increase in variety as well as the level of man's intervention into the oceans. Thus, these samples may serve the present and the future in analytical research activities involving fluctuations of local chemical substances, of oceanic conditions and of the stocks of hundreds of pelagic species or groups representing a highly diverse assemblage of trophic, morphologic and ethologic types.

Displacement volumes of the CalCOFI plankton collections are routinely measured and have been presented in the CalCOFI Atlas series (Smith, 1971). Displacement volumes afford a rapid estimate of the standing crop of plankton at minimal cost. However, without qualification as to contents, their contribution to an understanding of the region's ecosystem is limited.

Quantitative estimates of phylogenetically different groups may provide an estimate of nutritive quality of the standing crop as well as an index of trophodynamic complexity in the region. Biomass estimates made species by species, however, are a practical impossibility for large collections. A simpler procedure would be to group together species of higher taxonomic categories since it is probable that the components of such categories occupy similar or overlapping trophic levels. Species within a category would tend to be like each other in morphology, nutrient storage and size, and therefore similar in terms of nutrient quality relative to other categories. For example, chaetognaths are primarily metazoan carnivores, salps are fine-screen filterfeeders and epiplanktonic copepods range from coarser screen filter-feeders to obligate secondary consumers. These three taxonomically high-ranking groups not only occupy somewhat different positions in the trophic spectrum but are quite different from one another with respect to body proportions, size range of adults, proportion of water in body weight and presumably mechanisms of defense against predation. In general, therefore, taxonomic categories may also be viewed ecologically and nutritionally as "functional groups."

The number of functional groups to be employed in analyzing the distribution of biomass in a set of samples must of necessity be determined by the optimum desired resolution versus the limitations of the laboratory. In the present study, zooplankton biomass is being measured in terms of 17 functional groups (Table 1). The wet weight of each functional group corrected for interstitial water is estimated in every sample. All of the standard zooplankton collections from 20 CalCOFI cruises, namely, mid-spring, mid-summer, mid-fall and mid-winter cruises from the years 1955 through 1959, are analyzed in this manner. Contoured biomass distributions of the 17 functional groups found in the mid-spring and mid-fall sets of samples were presented in CalCOFI Atlas No. 10 (Isaacs, Fleminger and Miller, 1969). The present atlas is concerned with mid-winter cruises.

MATERIALS AND METHODS

Selection of the years 1955 through 1959 for analysis of biomass distribution was dictated by interest in the occurrence and nature of patterns of seasonal and annual variability among the functional groups of zooplankton. During this time, yearly mean temperatures above the thermocline shifted upward from the relatively cold years of 1955 and 1956 to the relatively warm years of 1958 and 1959. These changes in the California Current region are well documented (Anon., 1963) and broader ramifications as experienced in other areas within the north Pacific were discussed in a

CalCOFI-sponsored symposium entitled "The Changing Pacific Ocean in 1957 and 1958," (Sette and Isaacs, Eds., 1960).

In the present atlas, winter is represented by the January cruises of 1955 through 1959 (Table 2). Similar analyses of the summer season, now in preparation, are scheduled to appear in a future CalCOFI atlas. The net and the procedures employed in obtaining CalCOFI plankton samples have already been described at length (Smith, 1971). Suffice it to say that the net is one meter in diameter at the mouth and about five meters long, the conical straining section having a mesh size of approximately 0.5 mm. The net, towed obliquely from a ship underway at about 2 knots, makes a traverse from the surface to 140 meters and return, requiring about 14.5 minutes and usually straining 400 to 600 cubic meters of sea water.

Analysis of samples for this atlas has been carried out by the Biomass Laboratory, a team established for this purpose within the Marine Life Research Group at Scripps Institution of Oceanography. This laboratory is regularly staffed by a small number of technically trained personnel and also employs temporary and part-time employees recruited from among the student body of the University of California at San Diego. Newcomers undergo a training phase followed by a prolonged apprenticeship. During this trial period their work is closely scrutinized and must satisfactorialy meet a number of quality control tests before their analyses of samples are included among the laboratory's data output. Plankton specialists at Scripps Institution participated with the lab-

Table 1. Number of epiplanktonic species in CalCOFI region.

Functional Group[1]	Approximate number of species found in regions between the surface and 140 meters depth; source of estimate.	
Amphipoda	≥ 41	(Bowman, 1953)
Chaetognatha	24	(Alvariño, 1965)
Cladocera	5	(Baker, 1938; Strickland, et al., 1968)
Copepoda	≥ 235	(Esterly, 1905; Olson, 1949; Fleminger, 1967)
Crustacean larvae	No estimate available	
Ctenophora	≥ 4	(Torrey, 1904)
Decapoda	No estimate available	
Euphausiacea	28	(Brinton, 1967a)
Heteropoda	13	(McGowan, 1967)
Larvacea	26	(Tokioka, 1960)
Medusae	24	(Alvariño, pers. comm.)
Mysidacea	≥ 14	(Banner, 1948; Tattersall, 1951; W. D. Clarke, pers. comm., 1969)
Ostracoda	≥ 16	(Juday, 1906; C. Miller, pers. comm., 1969)
Pteropoda	29	(McGowan, 1967)
Radiolaria, Tripylea[2]	≥ 20	(Kling, 1966; P. B. Helms and E. D. Milow, pers. comm., 1969)[2]
Thaliacea	≥ 23	(Berner, 1967)
Siphonophora	44	(Alvariño, pers. comm.)
All Taxa Combined	≥ 546	

[1] Fish eggs, fish larvae and squid are regularly removed from CalCOFI plankton samples by the La Jolla Laboratory, Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service and are being reported elsewhere. Within the functional group "Decapoda" we have included for convenience galatheid crabs, holoplanktonic Natantia, planktonic juveniles of other Natantia and planktonic juveniles of stomatopods (Hoplocarida). Our functional group "Crustacean larvae" is comprised of the pelagic larvae of Brachyura and Anomura without the galatheids. Other identifiable larvae, crustacean or otherwise, are included within their respective functional groups. In general the forms included herein are those large enough to be retained regularly by 0.5 mm mesh.

[2] Radiolarian counts usually do not include the acantharians, often poorly preserved, and the much smaller-sized polycystins; adding the latter two groups brings the number of radiolarian species in the California Current region to about 200 (R. Casey, pers. comm., 1969).

oratory supervisor, Mr. Julian K. Miller, in training the initial cadre of the Biomass Laboratory and subsequent recruits have been trained and tested by the Laboratory's senior personnel. The usual quality control test consists of re-submitting selected samples already analyzed but disguised by substituting a false label for the original one. Re-analysis is performed by either the same worker or some other member of the laboratory. Selection of the operator, the sample and the frequency of the test is random unless deviations from the standards are excessive. Variation of less than $\pm 5\%$ is regarded as an acceptable performance. The reliability of data produced in this laboratory has been tested independently by Professor E. W. Fager of Scripps Institution, who has kindly provided a summary of results in Appendix I.[3]

Table 2. CalCOFI zooplankton samples selected for analysis of winter conditions. The first two digits of the cruise number represent the year, the last two, the month of a cruise.

Cruise	Number of samples
Winter	
5501	111
5601	110
5701	57
5801	246
5901	238
	762

SAMPLE ANALYSES: PROCEDURES

The operator analyzing the samples seeks to obtain a representative wet weight, less interstitial water, standardized to grams per $1000 m^3$ of sea water, for each functional group present in the sample. These weights comprise an estimate of standing crop occurring between the surface and about 140 m depth. Weight has been determined indirectly by means of a standardized length, as described below.

In practice, analysis begins with displacement volumes following the method of Ahlstrom and Thrailkill (1963) taken before and after removal of "large jellies" (thaliaceans, cnidarians, heteropods). Remaining jellies are sorted into their respective functional groups and weight is estimated directly with the aid of an analytical balance. The biomass of the other functional groups is determined from an aliquot ranging in size from ½ to 1/32, depending upon the volume of the sample after removal of the large jellies. As a rule the size of the aliquot examined is at least 1 cc in displacement volume. Its adequacy is judged by comparison with the displacement volume of the total sample as described below. The aliquot is obtained with the aid of a Folsom splitter (McEwen, Johnson and Folsom, 1954).

The aliquot is poured into a square transparent dish of plexiglass 20 by 20 cm whose chamber is partitioned into seven equal subchambers by six equidistant parallel ridges. The contents are examined with the aid of a stereomicroscope at 7X magnification. One of the oculars is fitted with a ruled ocular disc bearing 100 equally spaced divisions (1 division = 0.167 mm at 7X magnification) that is used to estimate the length of each specimen. Standard length measurements for conversion to weight (conversion tables are presented in Appendix II) are made to the nearest division. The specimens are tallied in size classes which vary somewhat depending on the overall size range of the functional group. The points of reference for taking a standard length in each functional group are shown in Figure 1. Where practical, bent specimens are straightened and, based on experience, allowances are made for slight to moderate distortions. Grossly distorted specimens are removed and weighed on a balance. To eliminate the effect of interstitial

[3]We thank Prof. E. W. Fager for devising and analyzing this test and Mr. G. T. Hemingway for requesting the test and for supervising the gathering of the data.

water the standard weight is corrected by reducing it to two-thirds of the gross weight (Ahlstrom and Thrailkill, 1963). This correction for interstitial water has been incorporated in the length-weight conversion tables of Appendix II. Weights are also taken directly of functional groups dominated by a single growth stage or a species that is morphometrically atypical with respect to its functional group. The conversion tables are based upon typical samples in which each functional group consists of a heterogeneous mixture of species and growth stages.

The estimated weight of all functional groups within a sample are summed, and to be acceptable, must be within 10% of the normalized weight based upon displacement volume of the total sample. Use of the displacement volume to estimate weight is predicated upon the relationship of volume and weight in stabilized preserved samples, as determined by Ahlstrom and Thrailkill (1963).

PRESENTATION OF DATA

In general, practices established in earlier atlases of this series have been followed. The results of each cruise is shown separately by functional group and plotted on standard charts. We have departed from previous contouring practices by using contour intervals based upon a factor of 4. The change from our usual factor of 10 was dictated by (1) the range of the biomass values extending below as well as above unity, (2) the desirability of having the value, one gram (i.e., one part organism in 10^9 parts sea water) coincide with a contour line, (3) the need for a system of interpolable logarithmic contours and (4) the range (0.5 to 2 times) of the 95% confidence limits of any single estimate with respect to variability from laboratory procedures employed in sample analysis (see Appendix I).

The biomass estimates are expressed in terms of grams wet weight per 1000m³ of sea water strained (corrected for interstitial water) per functional group. Contour intervals are factors of 4 and contour lines coincide with a sequence of values as follows: 0.016, 0.062, 0.25, 1, 4, 16, 64. The contour intervals increase exponentially and the contours are defined by the equation:

$$C_n = KB^{an}$$

where

C_n is the value of a contour for a value of the exponent n,
B is the base,
K is a constant,
a is constant, and
n is a variable with integer values.

As employed here, $K = 1$, $B = 4$, $a = 1$, and $n = -3, -2, -1, 0, 1, 2, 3$, etc. The system permits indefinite extension above and below unity. Interpolation or extrapolation into a finer or coarser series of logarithmic intervals can be readily accommodated.

No more than seven contour intervals are shown per chart and seven grades of shading are applied in the same sequence of increasing abundance. The sequence of seven values within the exponential series used on a specific chart is the one that best fits the range of abundance estimates shown by a functional group in a specific cruise. The highest and the lowest estimates of biomass (greater than zero) are shown in Arabic numerals to the right alongside the index of contour interval shadings in the chart legend. The charts have been arranged by functional groups which follow an alphabetical sequence, the sum total of the functional groups appearing first under the heading "All Taxa Combined." Within each category the charts are arranged by season, each seasonal set of five cruises following in chronological order.

In addition to the contoured estimates of biomass overlying the station plan, each chart presents two graphic summaries pertaining to the abundance of the functional group (Fig. 2). Latitudinal distribution of biomass is estimated in terms of the mean weight per station in each set of three successive lines of stations. This is shown as a histogram to the left of the distribution. The proportion of the functional group to the category All Taxa Combined, i.e.,

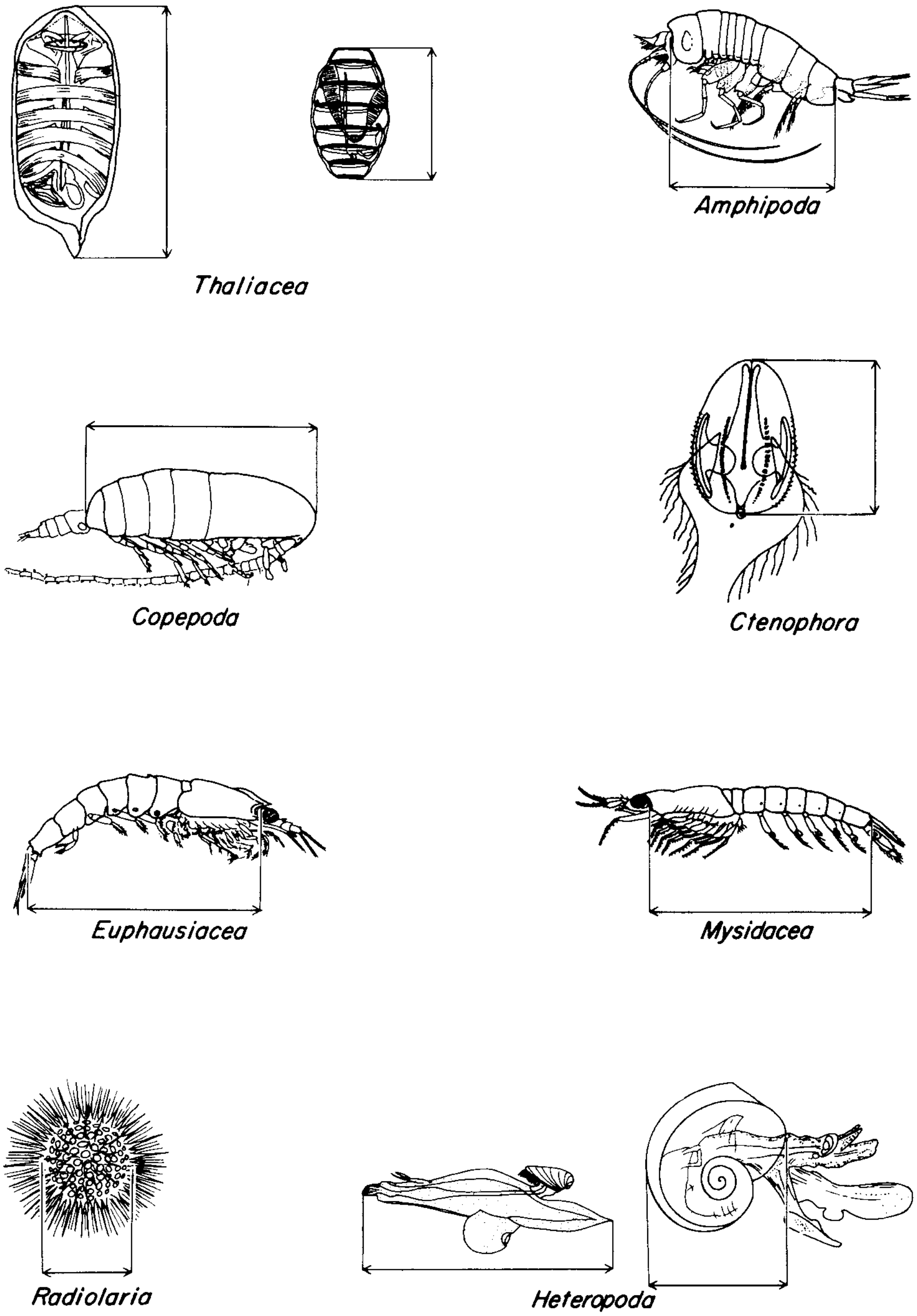


Figure 1. Standard lengths used in this study. The measurements delimited by arrows are taken with the aid of an ocular micrometer at 7X magnification.

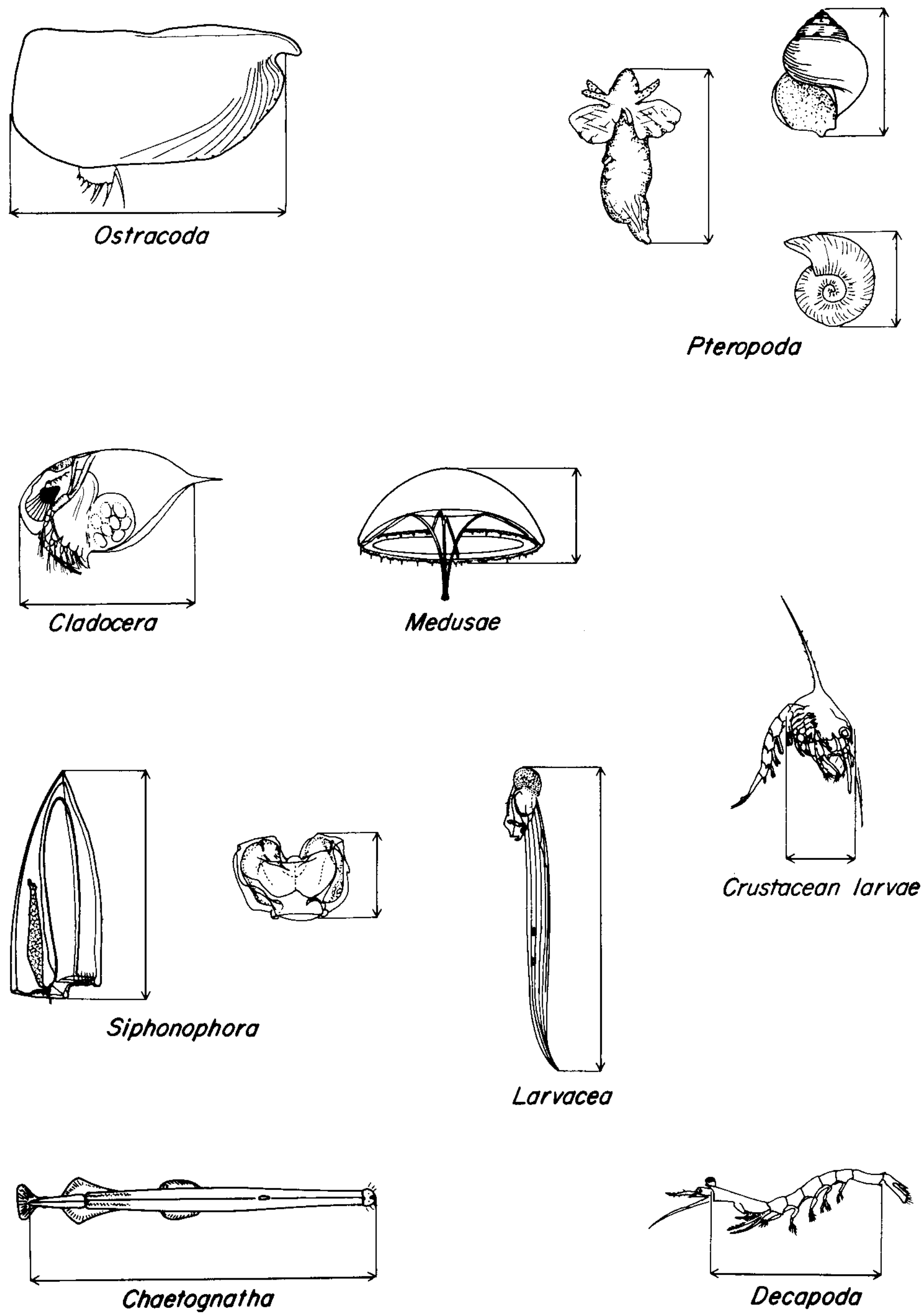


Figure 1, cont. Tables showing the relationship of standard length to weight among zooplankton from the California Current region appear in Appendix II.

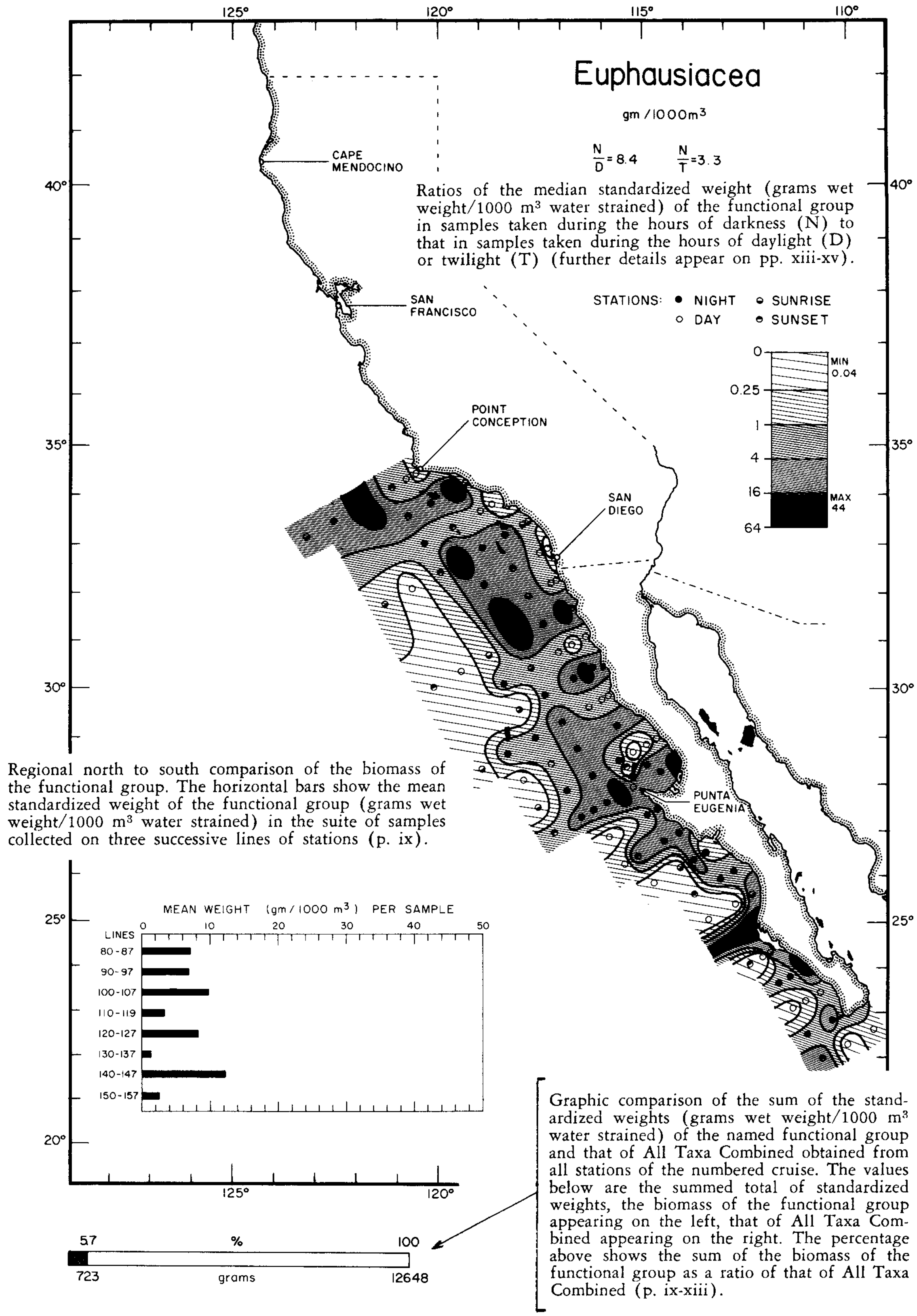


Figure 2. An example of the charts presented in this Atlas. Special quantitative summaries include: 1. ratio of quantity caught in night samples relative to that in twilight and day samples; 2. north to south comparison of abundance; 3. total amount of the functional group taken relative to that of the entire catch (All Taxa Combined).

the total zooplankton biomass per cruise less fish eggs, fish larvae and squid is shown in actual values and in percentage in a bar diagram located in the lower left margin of the chart.

ZOOPLANKTON ABUNDANCE AND DIURNAL VERTICAL MIGRATION

CalCOFI monitoring cruises usually survey large areas exceeding 200,000 square miles and occupy 200 or more stations during a 30 to 40-day period. The severe time limitations imposed upon the sampling program do not permit the sampling of zooplankton with regard to time of day, intensity and quality of light striking the sea surface or water transparency. It is well known that samples of zooplankton from the mixed layer vary appreciably in both quality and quantity when collected under similar conditions but at different times within a 24-hour cycle (King and Demond, 1963; King and Hida, 1954, 1957a, b). This phenomenon is known to prevail in the California Current region (e.g., Kramer, 1963), and Brinton (1962, 1967) has shown that species of euphausiids may vary in abundance by an order of magnitude or more in replicate samples differing primarily in the hour of collection.

Seasonal influences on biotic and abiotic factors, extent of cloud cover, moon phase, water transparency, etc., may influence in part the abundance and quality of day and night samples of zooplankton. At present, however, the level of understanding of horizontal and vertical distribution in local waters is inadequate to standardize abundance and quality of samples taken at different times within a 24-hour cycle.

Some of the functional groups considered here fail to show consistent day-night differences. Moreover, among the highly diverse groups such as copepods some taxa do not ordinarily migrate below the sampling level (e.g., *Clausocalanus,* most candaciids, pontellids), others may virtually disappear from the uppermost 140 meters in daylight (e.g., *Pleuromamma, Undeuchaeta*) while still others may be predominantly epipelagic in one portion of the region and mesopelagic when present elsewhere (e.g., *Calanus, Eucalanus, Rhincalanus*).

We have provided three visual aids to assist in recognizing possible artifacts in a distribution introduced by time of sampling. Each station symbol shows whether the sample was obtained during the hours of daylight, twilight (sunrise or sunset) or night. Twilight is used here to denote a period of time extending one-and-one-half hours before and one-and-one-half hours after local sunrise or local sunset. The terms day and night are restricted to the hours between the two twilight periods.

Ratios of the median values of night (N), twilight (T) and Day (D) catches are shown in the chart legend as N/D and N/T. When these ratios are close to unity it is assumed that the contour intervals absorb much if not all of the variability due to time of sampling. The relationship between these ratios and the distribution of day, twilight and night values for a few typical examples is shown in Figure 3.

The less abundant functional groups were frequently absent from one-half or more of the total number of observations per cruise. In these instances, N/D and N/T ratios were estimated graphically. Abundance was ranked by cruise and rank was plotted against abundance. To normalize differences in the number of observations between time periods under comparison, the linear distance between units along the scale of ranks for the set of fewer observations was adjusted to match the distance required for the ranks of the set with the higher number of observations. If the two resulting curves are roughly parallel the N/D and N/T ratios are determined by the distance between the two lines along the ordinate scale (Fig. 3). If the curves were strongly oblique or crossing, the differences were assumed to be due to factors other than time of day and N/D or N/T ratios were not estimated.

Contoured distributions may be noticeably influenced by the time of sampling when the ratio of the median exceeds 2. Accordingly, to compensate for artifacts when N/D or N/T equalled or exceeded 2, an additional chart was prepared in which day and twilight catches were multiplied by N/D and N/T, respectively, so as to more closely approximate an equivalent night-time distribution. Each of the adjusted charts is preceded by a contoured presentation of the unfactored data.

Variability due to the hour of collection appears to have a consistent and noticeable effect on the charted distributions in only certain of the functional groups, namely euphausiids, amphipods and perhaps copepods. Adjustment of the estimated abundances in these cases, however, has resulted in only moderately improved coherence within the distributions. Due to the general agreement among the large number of samples in our data and evidence based on repeated sampling of euphausiids (Brinton, 1962; Figs. 16-23), we believe the charts reflect real geographical variations in relative abundance, irrespective of accumulated errors from escapement, avoidance, patchiness and

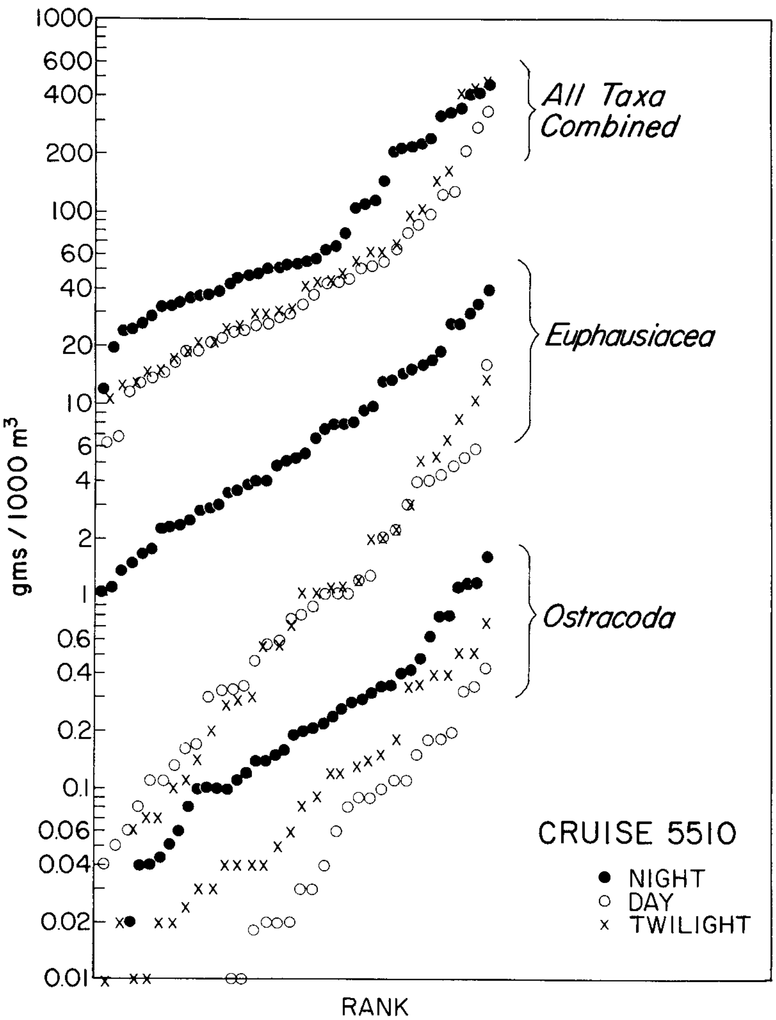


Figure 3. Scatter diagram of three representative examples showing the distribution of biomass ranked in order of increasingly higher values. Each set of data consists of all measurements of a functional group derived from a single cruise. Day, twilight and night samples are differentiated and the scale of ranked position (abscissa) is adjusted so that the number of samples per time period extends over the same length irrespective of the number of observations. Further comments in the text.

vertical migration.

Questions arose over the use of medians derived from unpaired sets of observations to determine the ratios, N/D and N/T. Paired observations may be simulated by pairing samples from adjacent stations along the cruise track which were occupied successively in different time phases (day, twilight or night). Pairing increases the likelihood that differences in the catch reffect variability due primarily to time of collection; i.e., the sets of observations were made on ecologically and biogeographically similar assemblages of organisms. Comparisons between the ratios of such simulated pairs with unpaired data were carried out for various representative functional groups (Table 3).

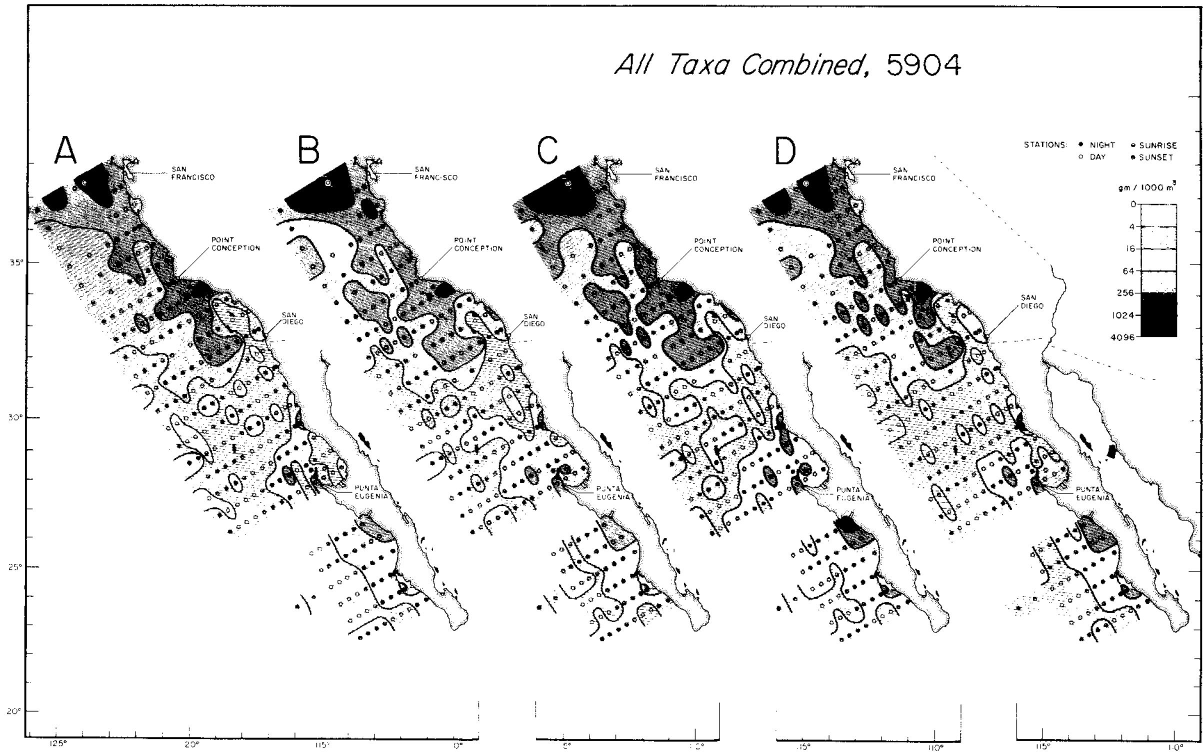
Table 3. N/D ratios for paired and unpaired observations.

	Unpaired observations		Paired observations
	$\frac{\text{mean N}}{\text{mean D}}$	$\frac{\text{median N}}{\text{median D}}$	Median $\frac{N}{D}$
Cruise 5510			
All Taxa Combined	1.5	1.9	1.9
Euphausiacea	4.0	6.5	6.8
Copepoda	1.5	2.0	2.0
Pteropoda	1.9	3.8	2.4
Ostracoda	3.5	6.7	8.0
Cruise 5910			
All Taxa Combined	1.0	1.4	1.5

The ratios of paired observations were found to scatter broadly. No more than about one-third were within $\pm$ 0.5 of either the ratio of the medians or the general trend observable in graphed data similar to Figure 3. On the other hand, the median ratio of the paired sets (Table 3) is remarkably similar to the ratio of the medians of unpaired observations as well as to the trend of the differences between the day and night curves in Figure 3. We conclude that simulating paired observations does not noticeably improve upon the use of the ratio of the medians, N/D and N/T, in compensating for day, twilight and night effects on standing-crop estimates from standard CalCOFI tows.

Our method for adjusting catch size relative to time of sampling was chosen over the sine curve method employed on mid-Pacific plankton by King and Hida (1954, 1957a, b) for several reasons. Chief among them are: (1) our practice of estimating biomass separately for each functional group; (2) our region of study which spans a biogeographical gradient from the boreal to the tropical and an ecological gradient from coastal-neritic water to central waters overlying the ocean basin; (3) the full range of variability shown by our samples with respect to their individaul extent of faunal homogeneity. We are reluctant to assume that different combinations of faunally heterogeneous species comprising a functional group will tend to behave diurnally in a similar manner. In fact, N/D and N/T may show considerable variability within functional groups (Fig. 3) and the ratio of the medians differs appreciably between groups. It might also be noted that compared to the sine curve method, calculation and employment of the ratio of the medians was carried out more easily.

Using the data for All Taxa Combined from Cruise 5904 and for euphausiids, from Cruise 5704, both selected solely for the sake of convenience, direct comparisons of contour patterns were made between values adjusted for differences in the time of catch by means of the King and Hida sine curve factor and the ratio of the medians factor. With N/D being 2.04 for All Taxa Combined and 24.5 for the euphausiid data, the two examples approximate the breadth of the range in the ratio of the medians encountered during the study. We



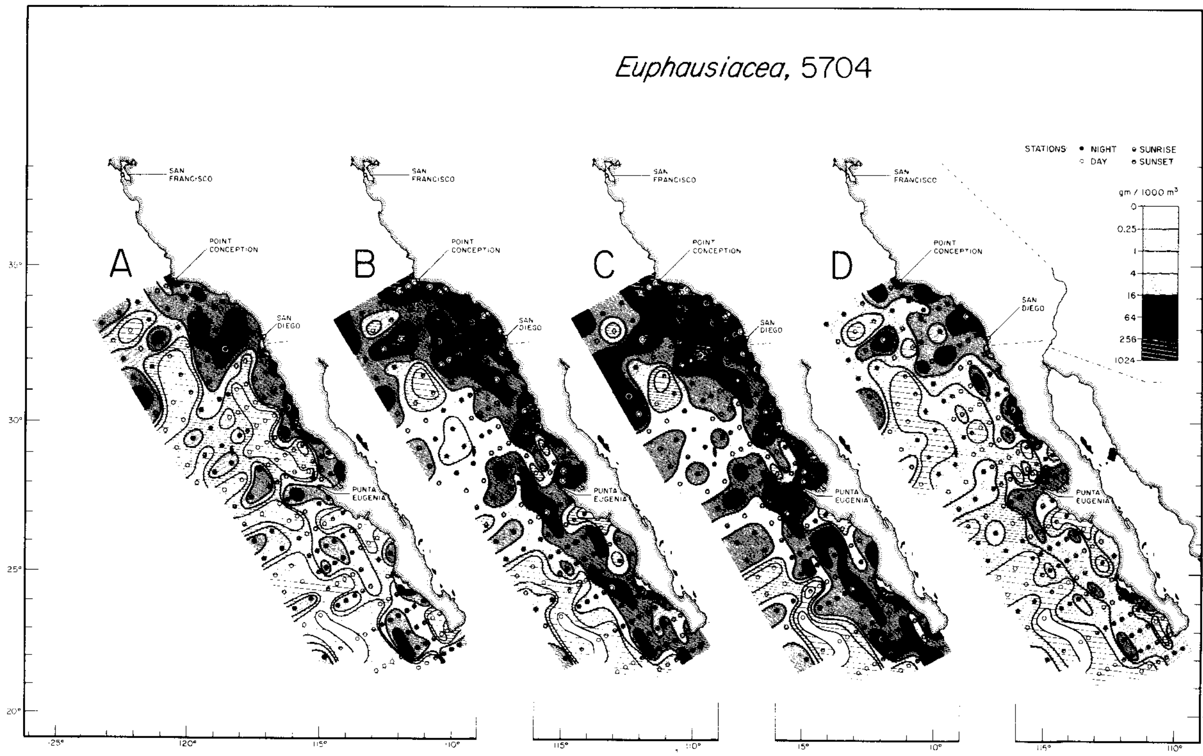


Figure 4. Comparison of two methods to compensate for the effect of diurnal vertical migration on plankton abundance. Categories "All Taxa Combined" and "Euphausiacea" were selected as examples to show moderate and pronounced differences in abundance, respectively, among samples taken at different times of the 24-hour cycle. In B, C and D the abundance of samples taken in hours other than the desired sampling time has been adjusted by the appropriate factor. The distribution of the biomass estimates is contoured in the usual manner.

(A) unadjusted values; (B) day and twilight values adjusted by the ratio of the medians method to approximate median night values; (C) values adjusted by the sine curve method (King and Hida, 1954) to approximate abundance at 0000 hours; (D) as in C, above, but adjusted to approximate abundance at 0600 and 1800 hours when sine is zero as originally employed by King and Hida (1954). Additional explanation and comments in text.

found no noticeable differences in either the general pattern or in coherence of the contours between the sets of data adjusted by the two different procedures (Fig. 4).

It should be noted that in contrast to the adjustments by King and Hida, we have normalized data to represent median night values, typically the period of time yielding the highest standing crop for most of the functional groups. Computer programs for adjusting catch size by the sine curve method or by the ratio of the medians method are on file at Scripps Institution of Oceanography. A copy may be obtained by writing Prof. E. W. Fager.

Table 4. List of charts.

			Winter		
Cruise Number	5501	5601	5701	5801	5901
All Taxa Combined	2	3	4	5	6
All Taxa Combined, adjusted					7
Amphipoda	8	10	12	14	16
Amphipoda, adjusted	9	11	13	15	17
Chaetognatha	18	19	20	21	22
Cladocera	23	24	25	26	27
Copepoda	28	30	31	32	34
Copepoda, adjusted	29			33	35
Crustacea larvae	36	38	39	41	43
Crustacea larvae, adjusted	37		40	42	
Ctenophora	44	45	46	47	48
Decapoda	49	51	53	54	55
Decapoda, adjusted	50	52			56
Euphausiacea	57	59	61	63	65
Euphausiacea, adjusted	58	60	62	64	66
Heteropoda	67	68	69	70	71
Heteropoda, adjusted					72
Larvacea	73	74	75	76	77
Medusae	78	79	80	81	82
Mysidacea	83	84	85	86	87
Ostracoda	88	89	91	93	95
Ostracoda, adjusted		90	92	94	96
Pteropoda	97	98	100	101	102
Pteropoda, adjusted		99			103
Radiolaria	104	106	107	108	109
Radiolaria, adjusted	105				
Siphonophora	110	111	113	114	115
Siphonophora, adjusted		112			116
Thaliacea	117	118	119	120	121
Thaliacea, adjusted					122

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APPENDIX I[1]

Reliability of Laboratory Measurements

There are a number of possible sources of error in making the counts involved in this program: incorrect splitting of samples to obtain the aliquots, operator bias, differences in efficiency in counting different classes of organisms and differences in efficiency associated with differences in relative numbers.

The first two have been examined by having replicate counts done on the same sample. In five cases the same operator made the counts but was unaware the same sample was being recounted; in 17 cases, different operators counted the same sample and the second person did not know the sample had already been counted. The median number of categories counted in each sample was 12 (range: 9–16). The signed-ranks test was applied to the paired counts on each of the samples. All five of the cases involving two counts by the same person and 15 of the 17 involving two operators were non-significant at the 20% level. This probably represents random error because it is just over the expected number at this level, namely 1.1.

Six operators were involved in the preceding test. Examination of the paired counts in the 17 cases where two persons did the counts revealed only one operator whose counts were consistently below or above those of all others who counted the same sample. This operator, D, recorded counts that were on the average somewhat below those of her partners in 7 of 8 cases (p. = 0.10). In no case was the operator sufficiently far below the partner to make the difference significant by the signed-ranks test. From these tests one can conclude that bias in sample splitting or in counting by the operators is no greater than would be expected as a result of random errors.

In order to determine whether the type of organism counted or its relative abundance had an effect on the counts, samples representing high, medium and low abundances of 10 classes of organisms were selected. Three replicate counts were done on each sample in such a manner that the operators did not know whether a sample had been counted before or not. In addition to the counts, weights were determined in the standard fashion. An analysis of variance was run on both sets of data. The average counts for the different classes of organisms ranged from 25 to 5532; the corresponding weights ranged from 0.029 to 1.924 grams. The average counts for the three abundance classes of samples were 2623, 1026 and 47; the corresponding weights were 1.035, 0.864 and 0.047 grams. As was expected, mean squares for both of these factors and for their interaction were highly significant.

Only one of the total of six mean squares for replicate, type of organism, replicate interaction and abundance-replicate interaction was significant and this was at the 20% level. From these tests it may be concluded that neither the type of organism nor the relative abundance of the organisms have any significant effect on either the counts or the weights. The error mean square can, therefore, be used to set confidence limits for the observations. In order to make these most useful, the analyses were rerun with the data transformed to logarithms, 95% confidence limits were calculated and then transformed to antilogarithms. The results indicate that conservative 95% confidence limits for both counts and weights are given by 0.45 and 2.20 times the observed value. These account only for the variability introduced in the laboratory handling of the samples and do not include any that may have been introduced by the sampling procedures in the field.

[1]Prepared by E. W. Fager, Scripps Institution of Oceanography.

APPENDIX II[1]

Relationship of Length to Weight, California Current Region

Oc. Micro. Units[2]	No./gm	Oc. Micro. Units	No./gm	Oc. Micro. Units	No./gm
Amphipods					
10	1023	230	16	7	2762
20	376	240	14	10	949
30	159	250	13	13	500
40	101	260	11	15	200
50	64	270	9	25	65
60	48	280	6		
70	29	290	5	(c) Megalopa	
80	26			15	500
90	14	**Cladocerans**		20	235
100	10	3	11731	30	105
110	7	6	3921	40	68
				50	39
Chaetognaths		**Copepods**		60	23
20	6994	5	5814		
30	3808	10	1873	**Ctenophores**	
40	2168	15	698	Usually weighed	
50	1522	20	254		
60	762	25	123	**Decapods**	
70	614	30	70	(a) Galatheids	
80	425	35	50	30	286
90	330	40	31	40	125
100	253			50	36
110	200	**Crustacean larvae**		60	28
120	142	(a) Anomuran Zoea		70	18
130	110	3	752	80	15
140	75	5	254	90	10
150	61	10	162		
160	44	15	146	(b) Hoplocarids	
170	40	20	128	8	1368
180	34	25	111	20	775
190	31	30	100	30	253
200	27			40	217
210	23	(b) Brachyuran Zoea		50	157
220	18	4	3403	60	83

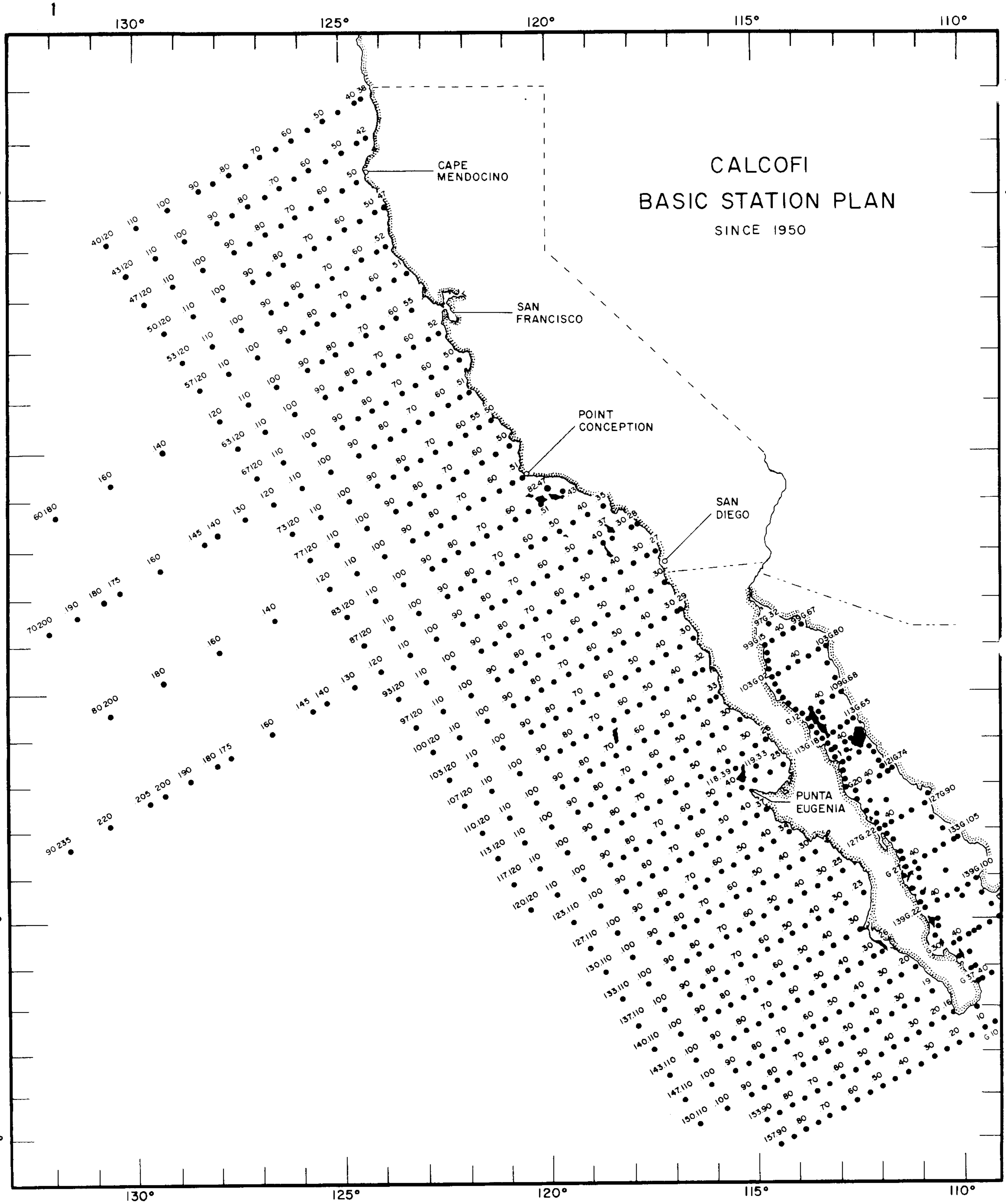
[1] This table was prepared by J. K. Miller and is based upon 1-gram samples of each size category of a functional group sorted from a variety of plankton collections characterized by pronounced diversity in species and in developmental stages.

[2] One Ocular Micrometer Unit = 0.167 mm at 7X magnification.

Oc. Micro. Units	No./gm
70	71
80	50
90	40
(c) Natantians	
5	7143
15	1744
25	765
35	539
45	379
55	147
65	54
75	42
85	29
95	20
105	18
115	15
125	13
135	11
145	8
155	7
165	6
175	5
185	4
195	3
205	2
215	1.5
250	1
Euphausiids	
5	11111
10	6243
15	4200
20	1426
25	930
30	778
35	451
40	308
50	175
55	125
60	99
65	89
70	60
80	45
90	31

Oc. Micro. Units	No./gm
100	21
110	17
120	13
130	10
140	8
150	7
160	6
170	5
210	4
240	3
270	2
300	1
330	1
360	1
390	1
Heteropods	
5	7000
10	2147
15	941
20	525
30	375
40	222
50	185
60	158
70	105
80	83
90	61
100	48
Larger forms usually weighed	
Larvaceans	
10–15	13200
15–20	7173
20–25	5200
25–30	3848
30–35	2564
35–40	2197
40–50	1923
50–60	405
60–70	267
Medusae	
Usually weighed	

Oc. Micro. Units	No./gm
Mysids	
15	5400
25	3420
35	2500
45	1075
55	625
65	300
75	154
85	133
95	48
100	15
Ostracods	
5	3465
10	1496
15	501
20	341
25	96
30	87
Pteropods	
5	3520
10	1444
15	910
20	327
25	185
30	140
35	122
40	100
45	62
50	42
55	33
Radiolarians	
4	5106
5	3998
6	2431
Thaliaceans	
Usually weighed	
Siphonophores	
Usually weighed	



CALCOFI

BASIC STATION PLAN
SINCE 1950

All Taxa combined

Amphipoda

Chaetognatha

Cladocera

Copepoda

Crustacean larvae

Ctenophora

Decapoda

Euphausiacea

Heteropoda

Larvacea

Medusae

Mysidacea

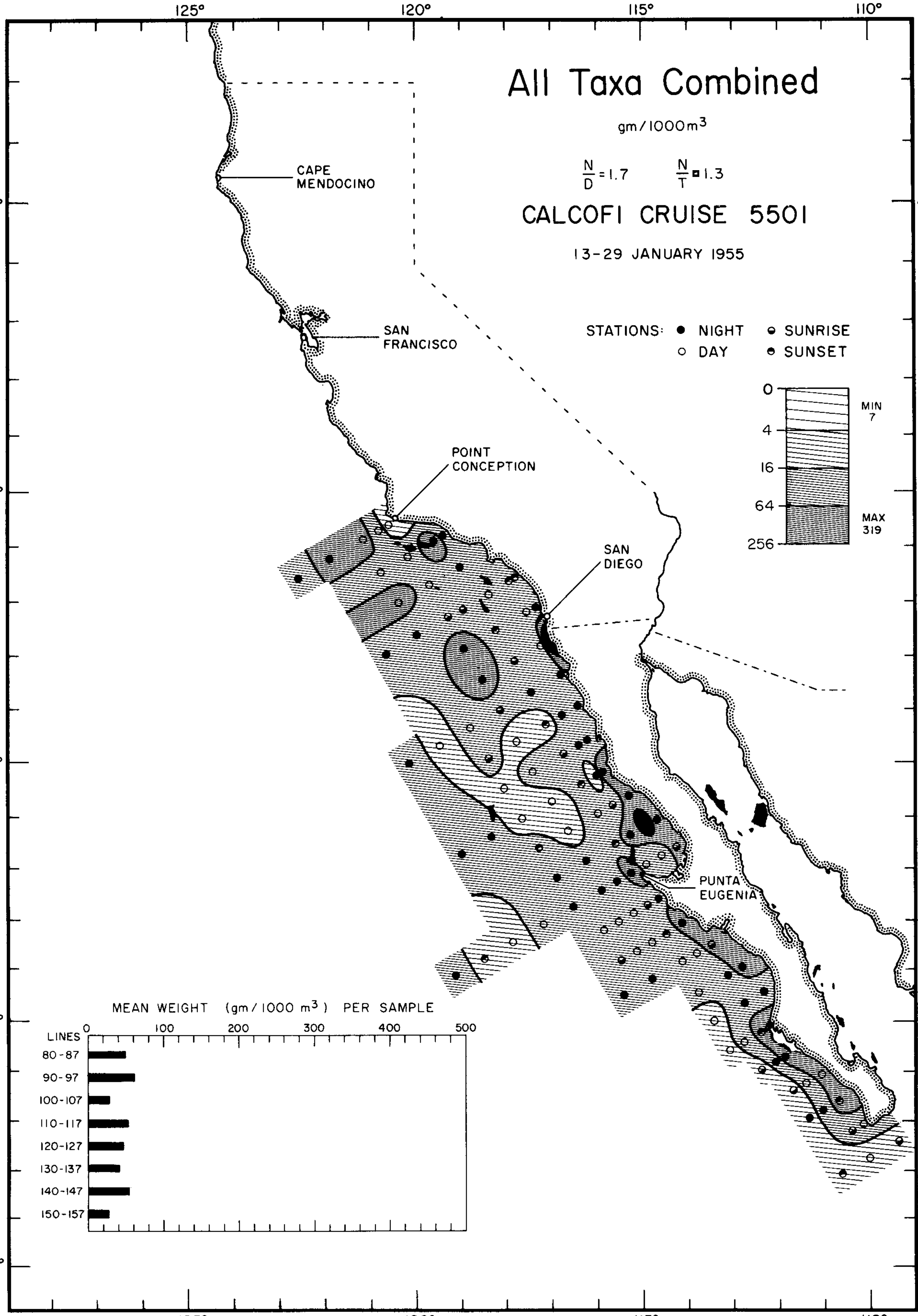
Ostracoda

Pteropoda

Radiolaria

Siphonophora

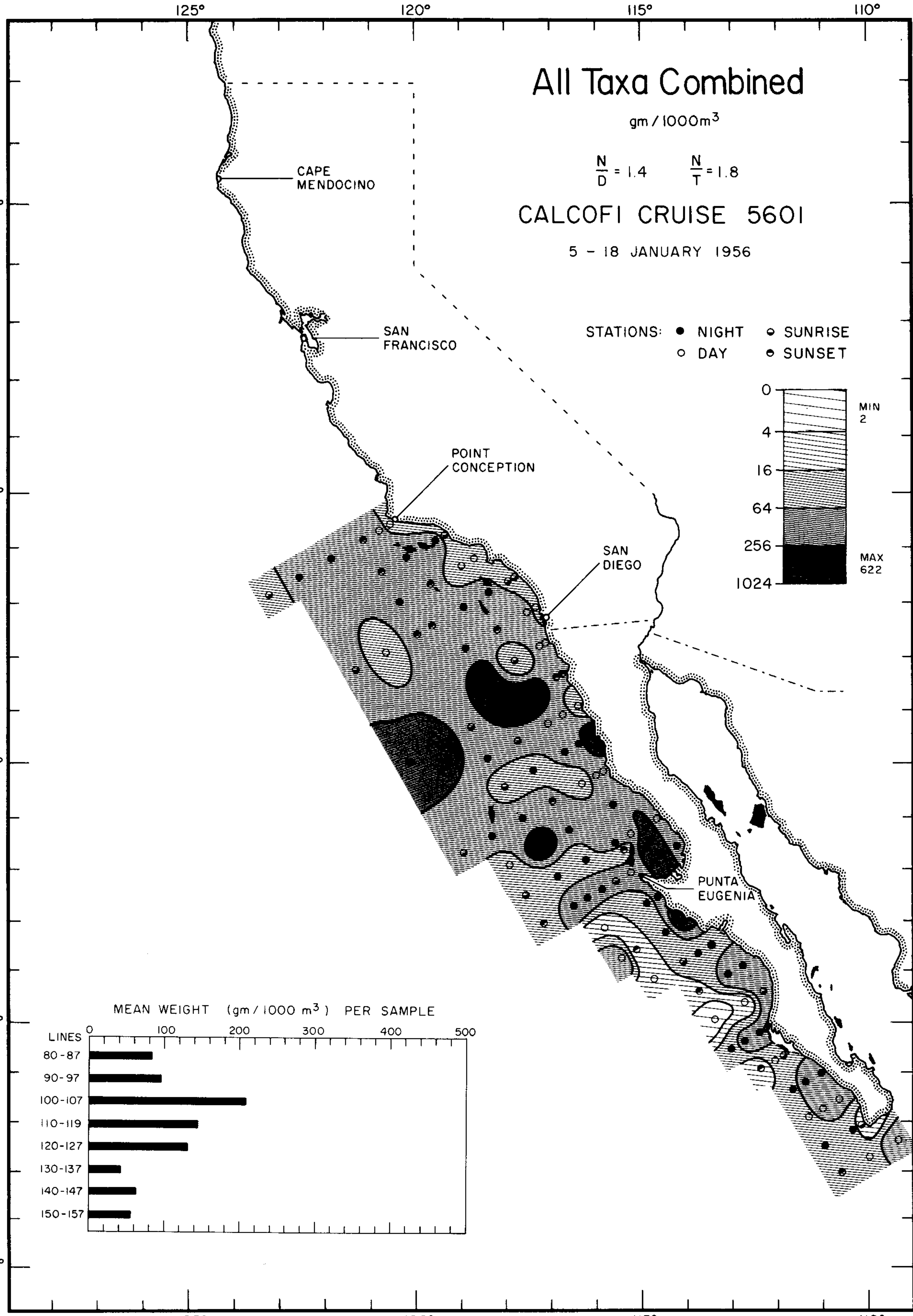
Thaliacea



Biomass

All Taxa Combined

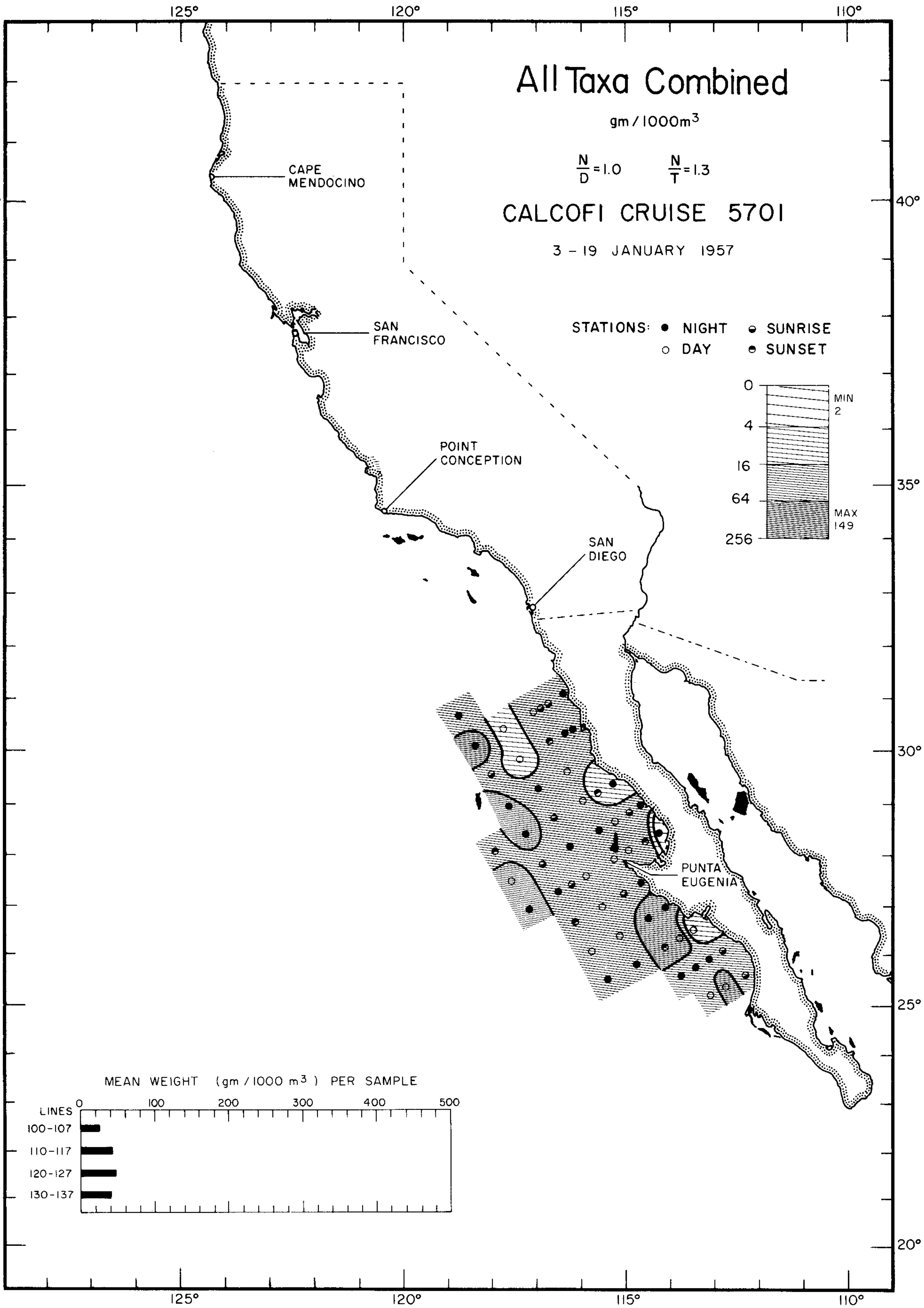
5501



Biomass

All Taxa Combined

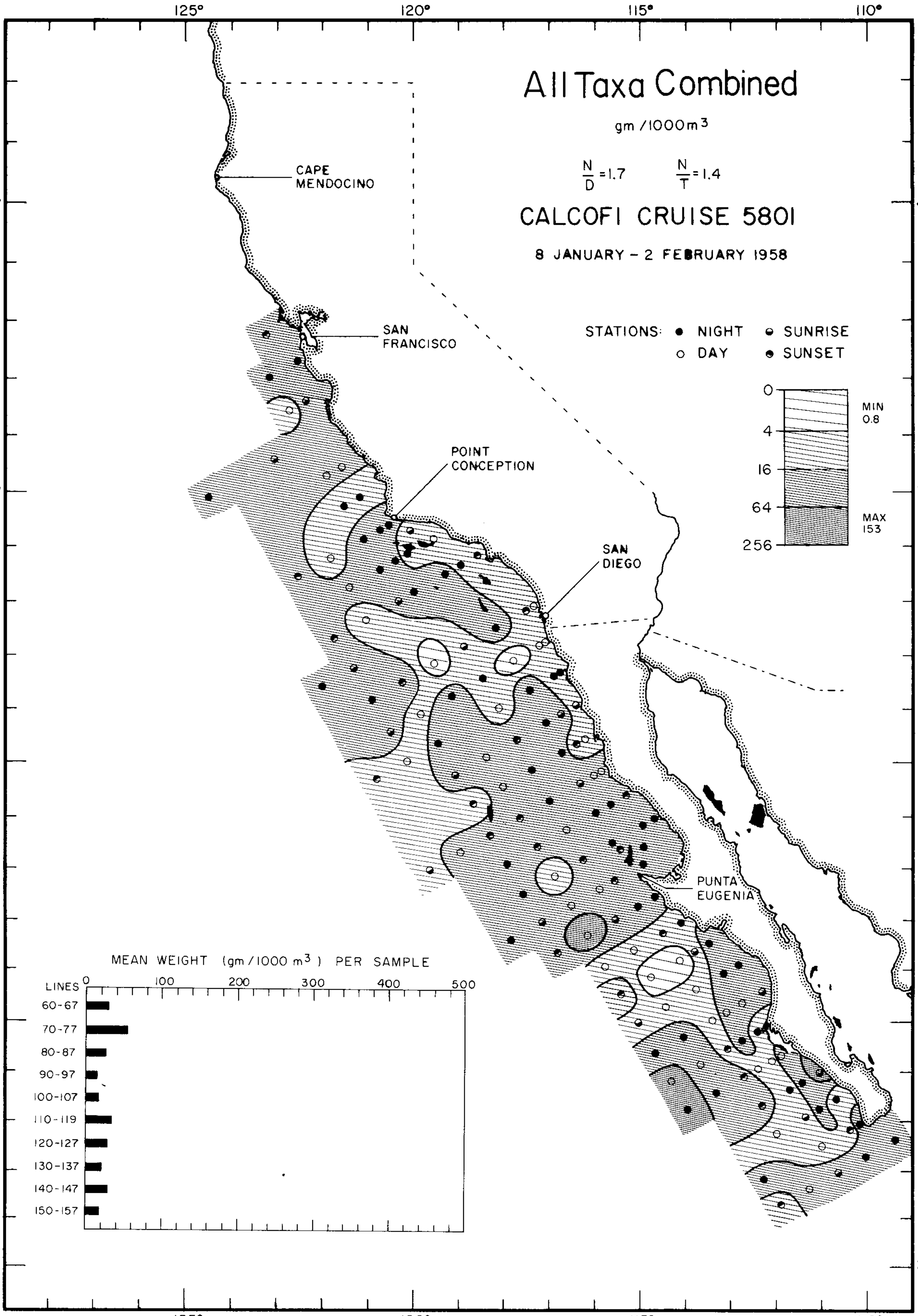
5601



Biomass

All Taxa Combined

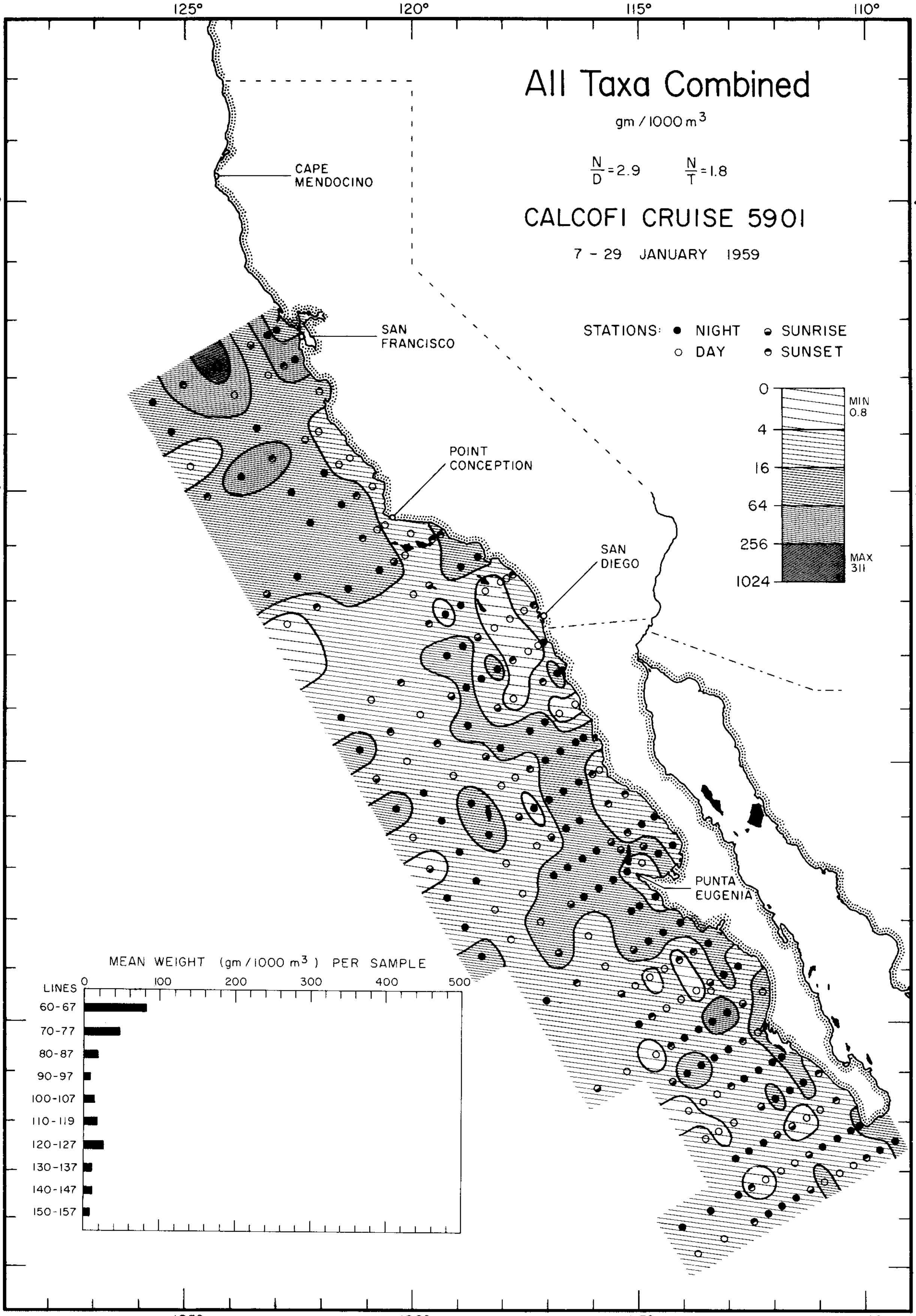
5701

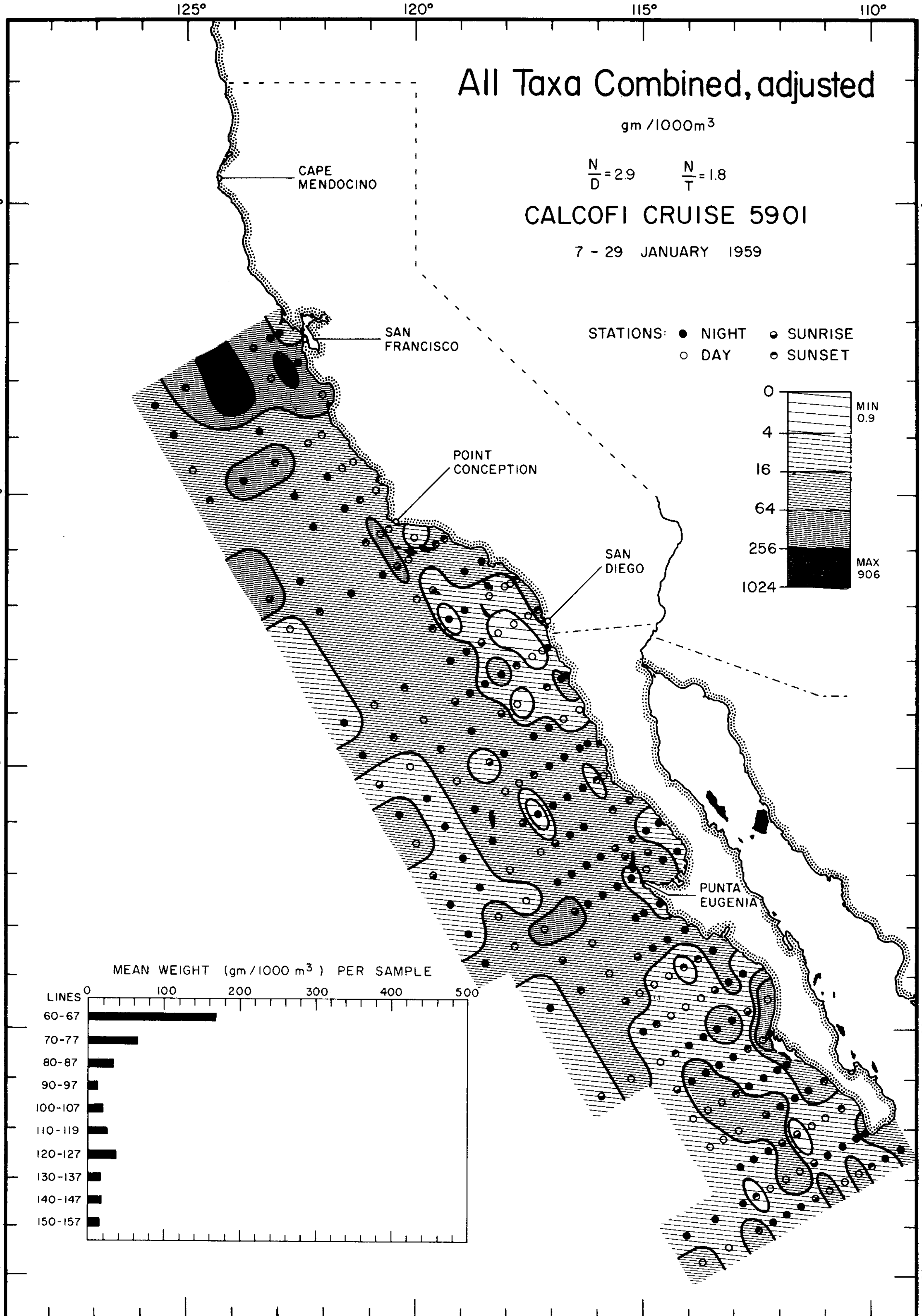


Biomass

All Taxa Combined

5801

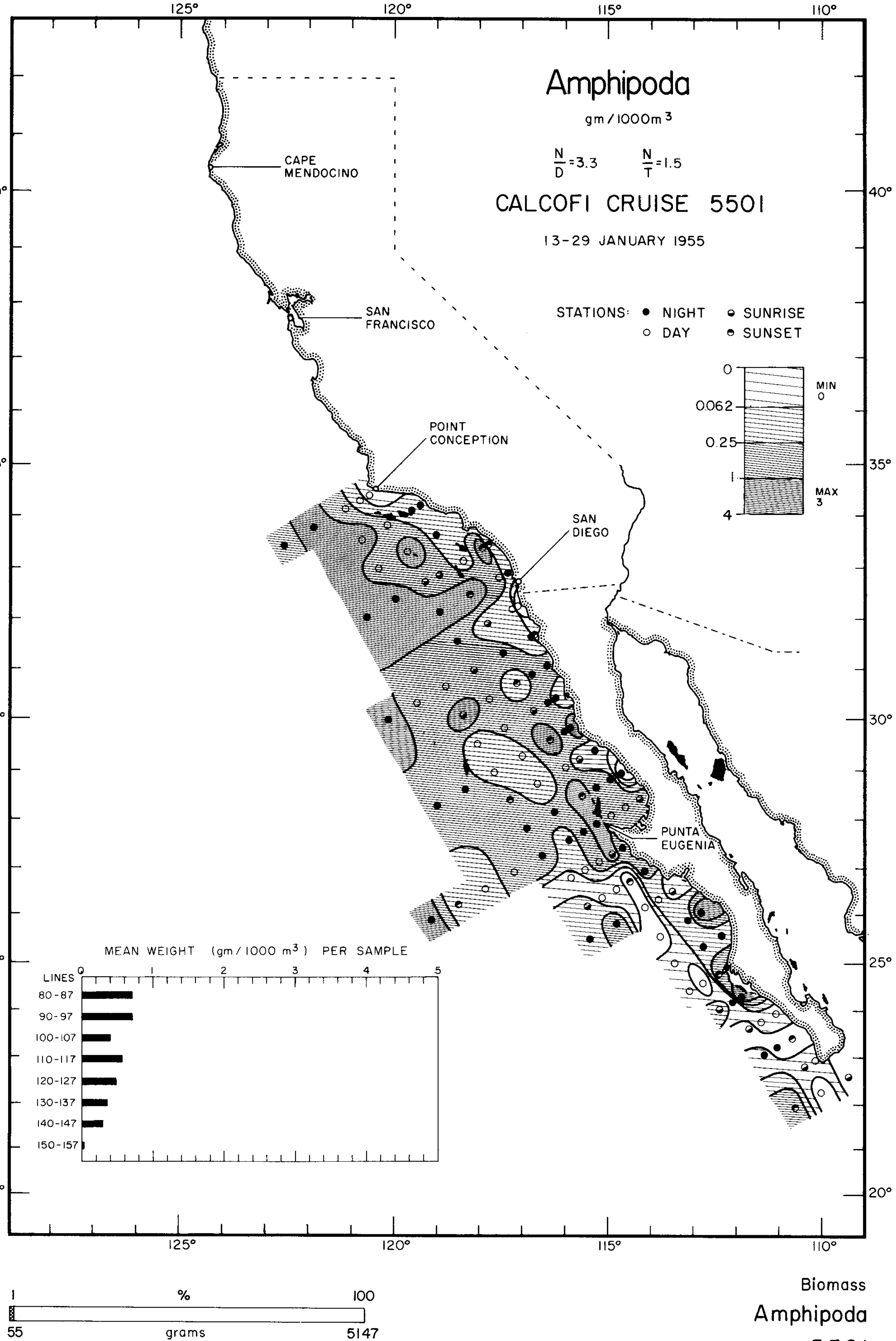

All Taxa Combined
gm / 1000 m³
N/D = 2.9
N/T = 1.8
CALCOFI CRUISE 5901
7 - 29 JANUARY 1959
STATIONS: NIGHT SUNRISE DAY SUNSET
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
0
4
16
64
256
1024
MIN 0.8
MAX 311
125°
120°
115°
110°
40°
35°
30°
25°
20°
MEAN WEIGHT (gm / 1000 m³) PER SAMPLE
0
100
200
300
400
500
LINES
60-67
70-77
80-87
90-97
100-107
110-119
120-127
130-137
140-147
150-157



Biomass

All Taxa Combined, adjusted

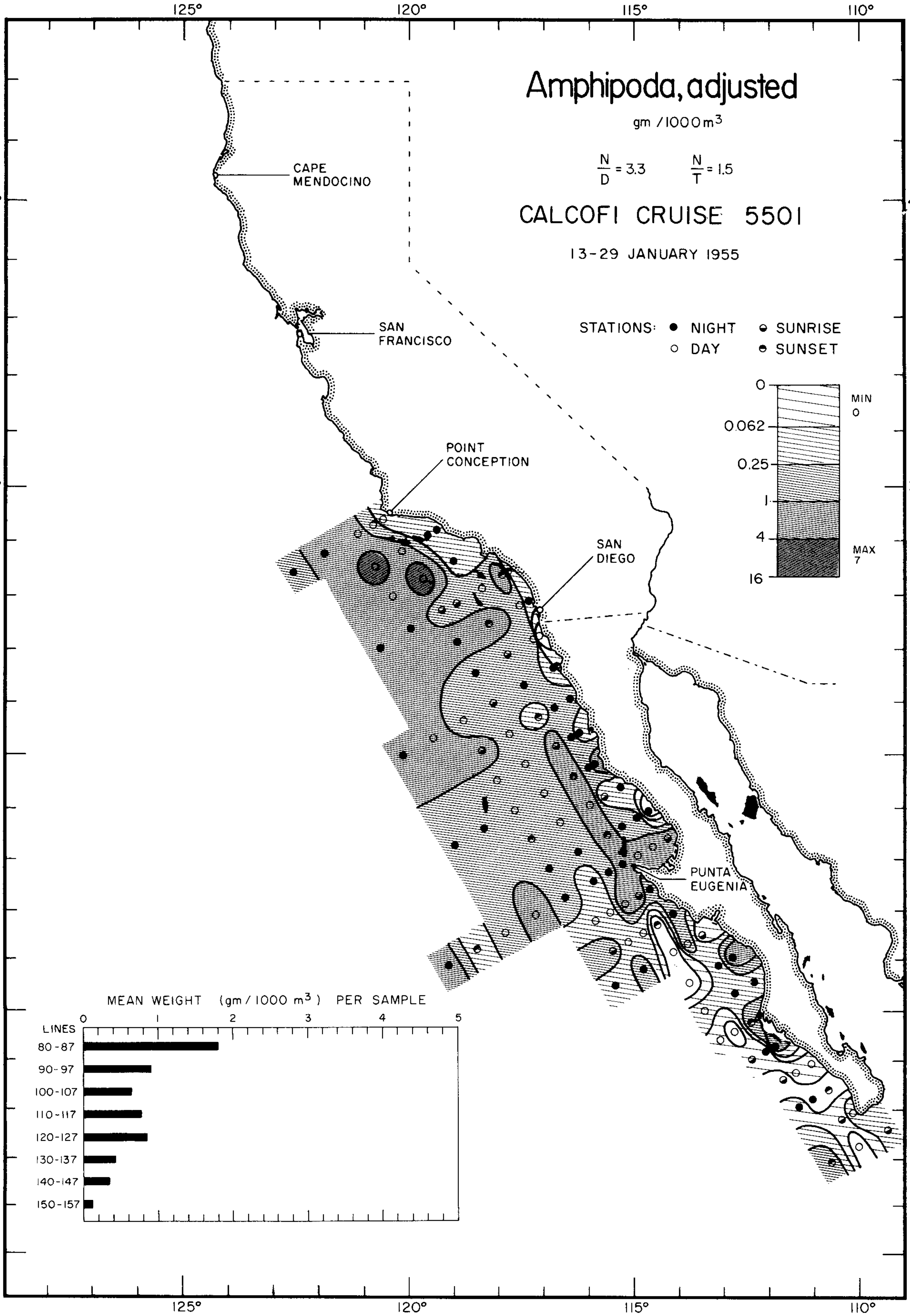
5901



Biomass

Amphipoda

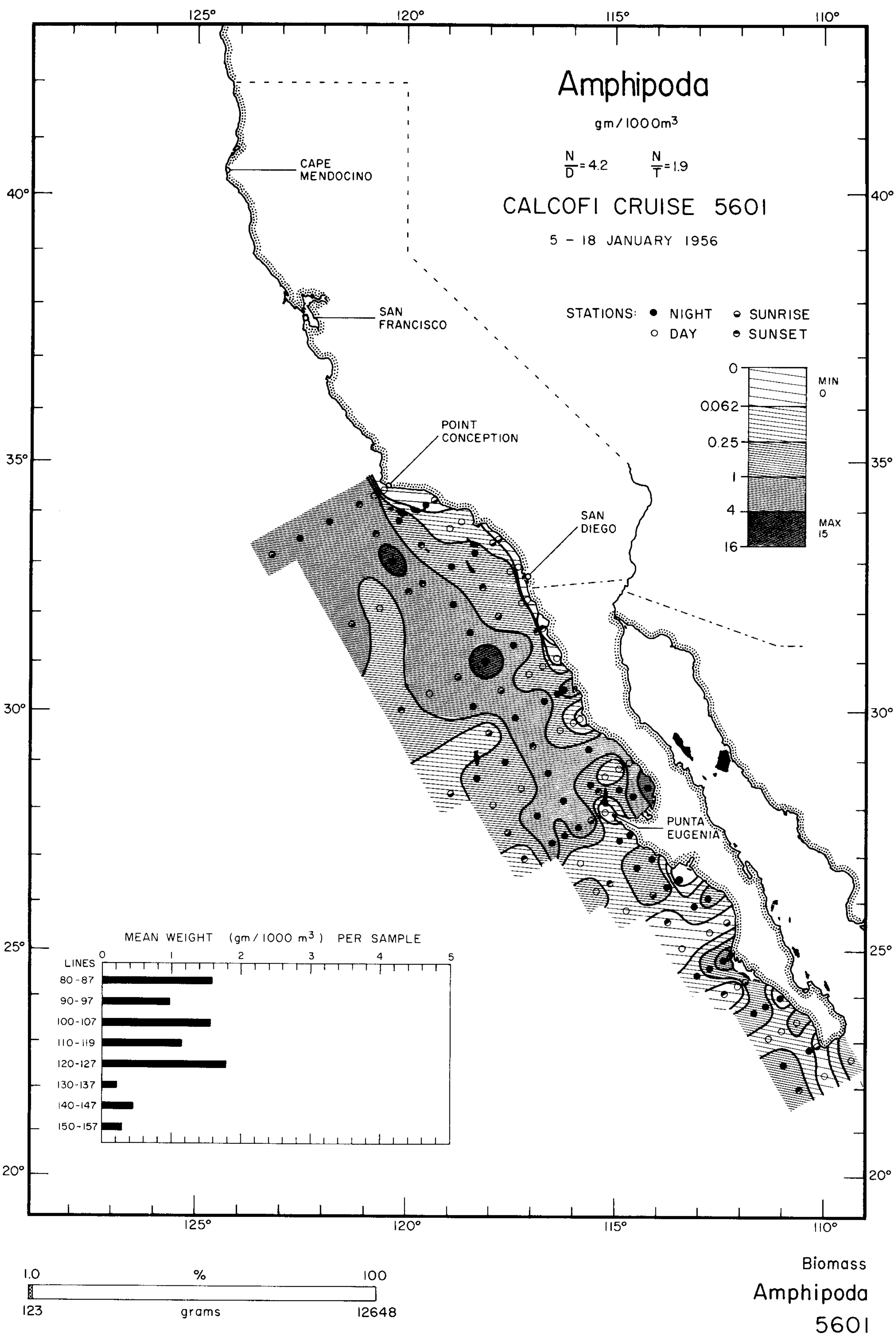
5501



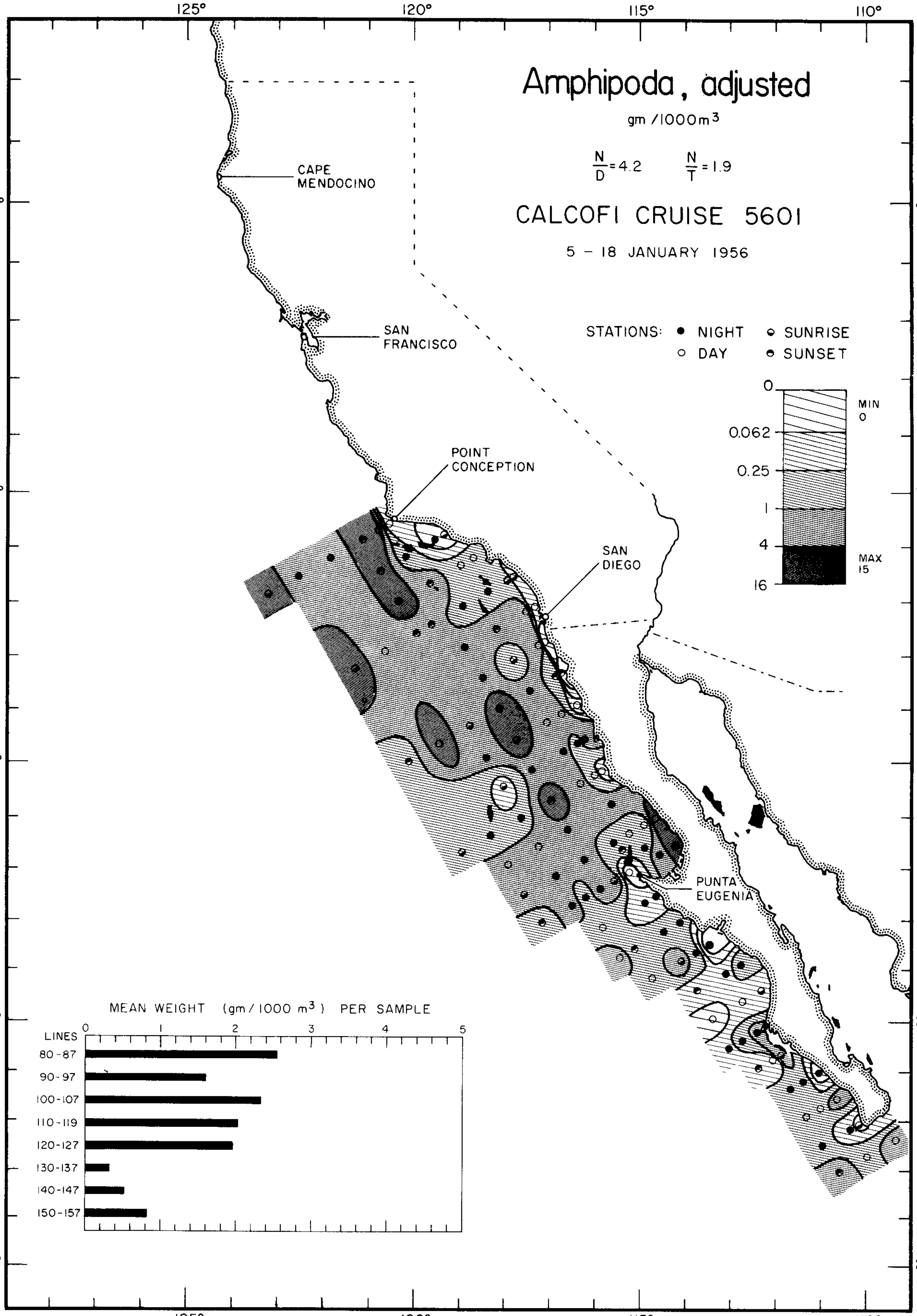
Biomass

Amphipoda, adjusted

5501



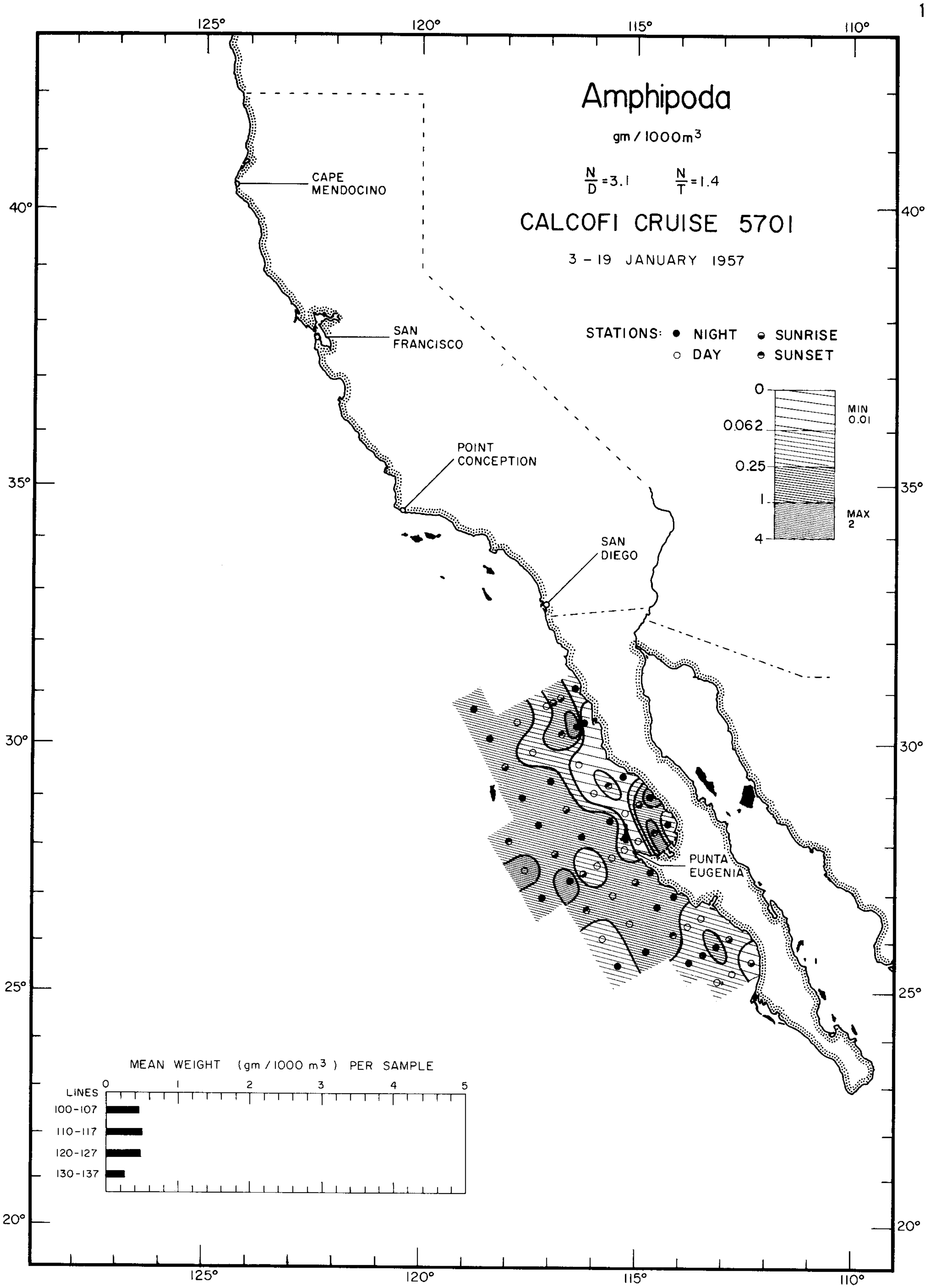
Biomass
Amphipoda
5601

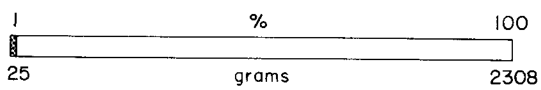


Biomass

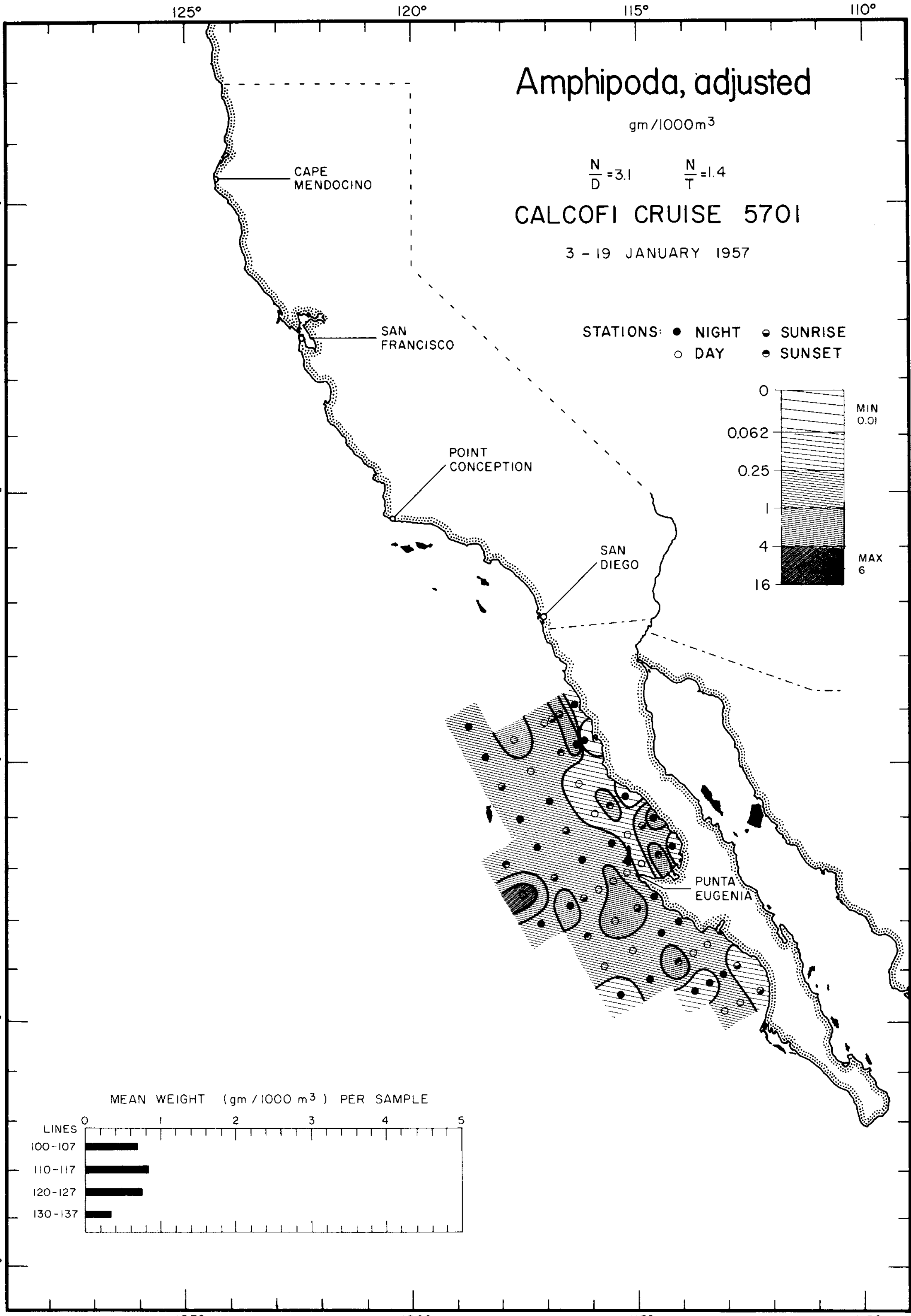
Amphipoda, adjusted

5601





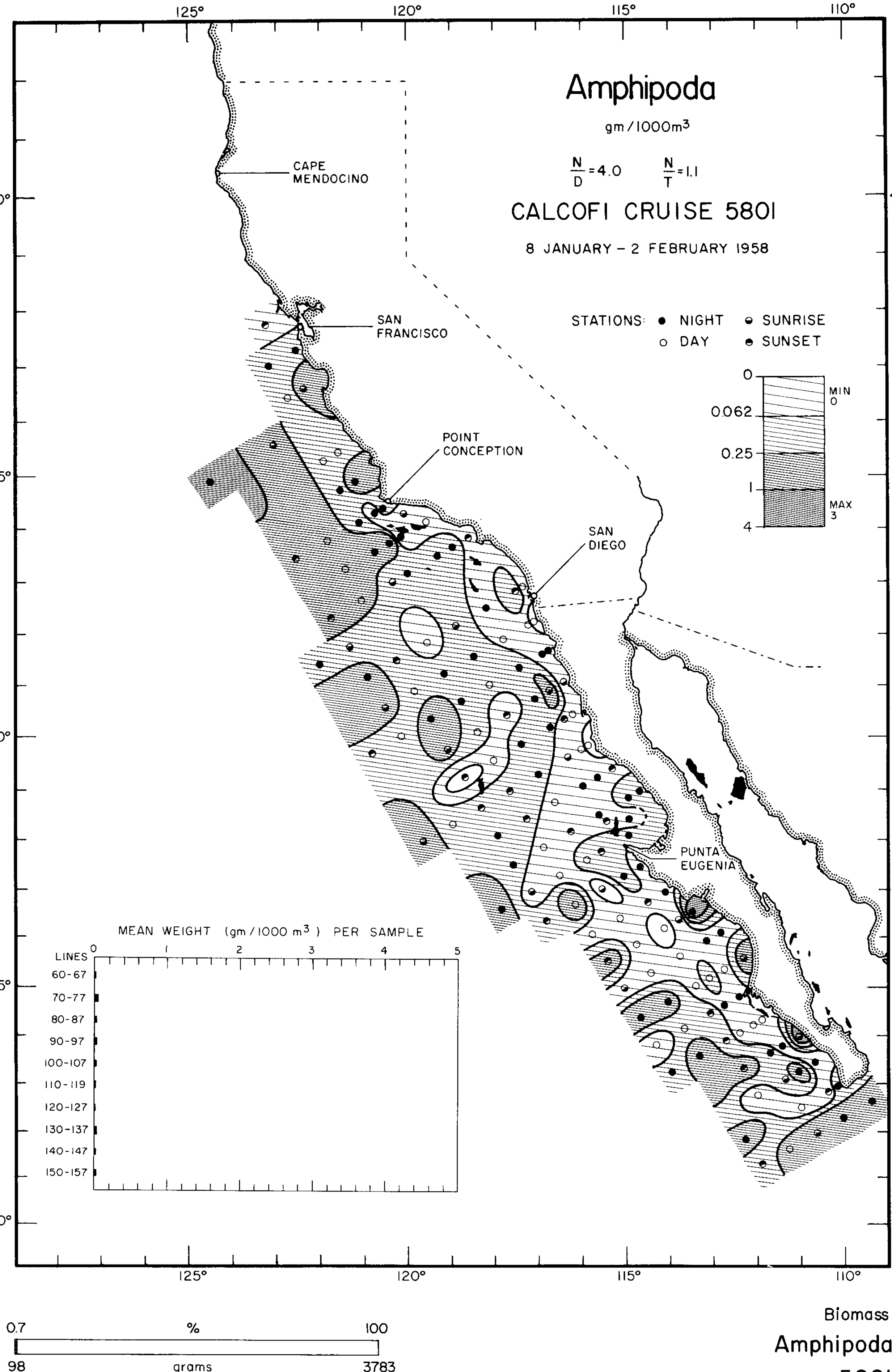
Biomass
Amphipoda
5701



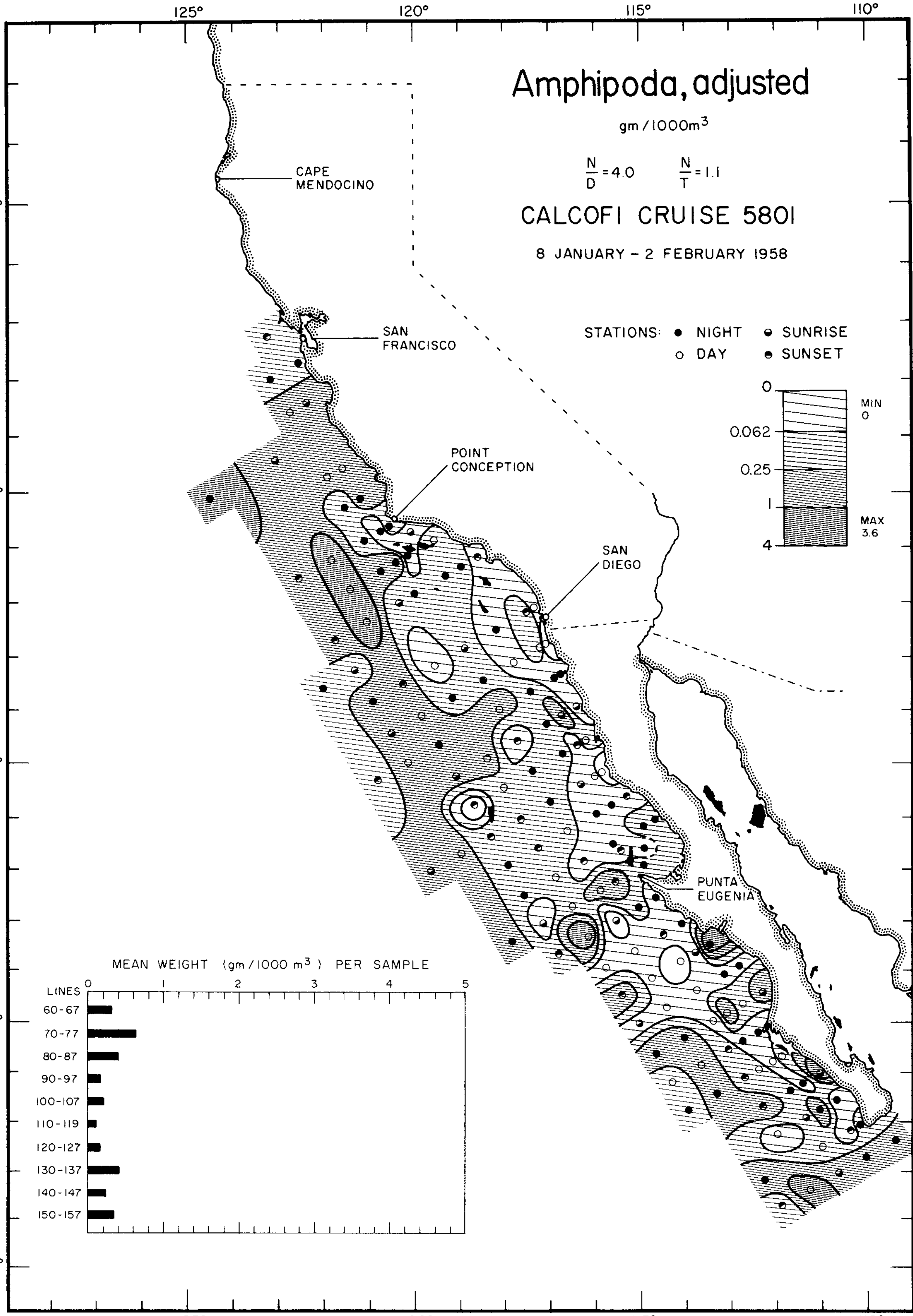
Biomass

Amphipoda, adjusted

5701



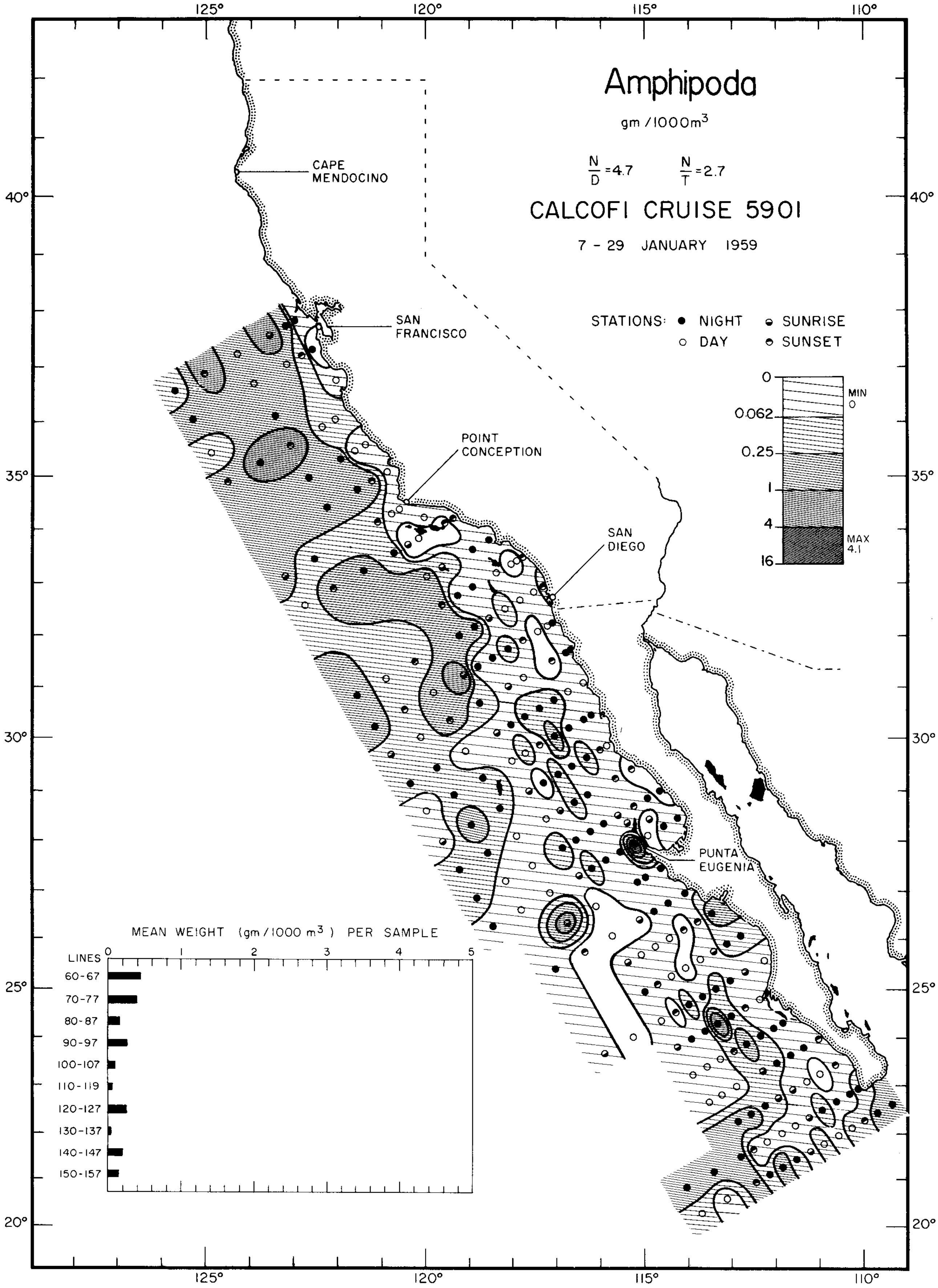
Biomass
Amphipoda
5801



Biomass

Amphipoda, adjusted

5801



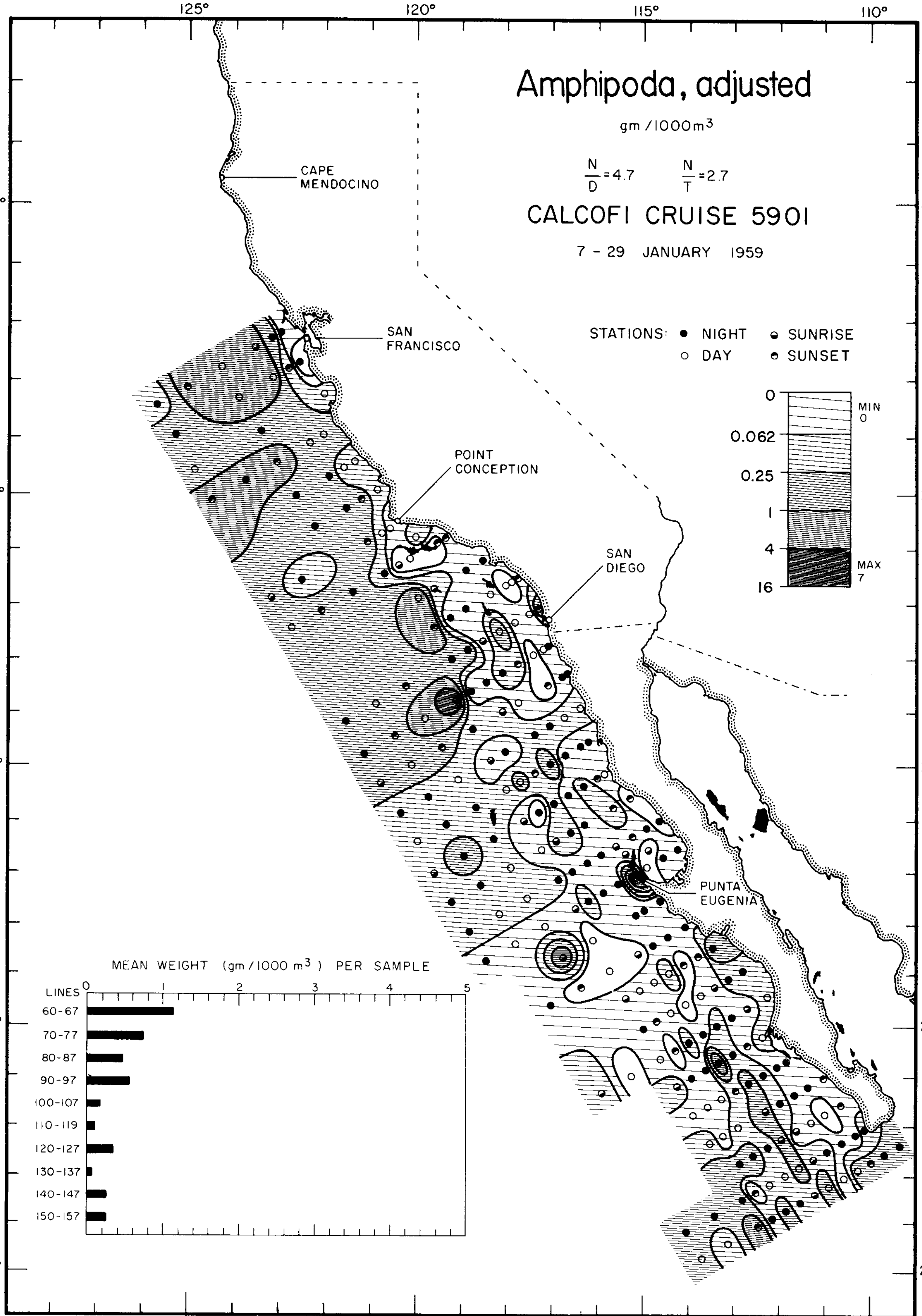
0.9 % 100

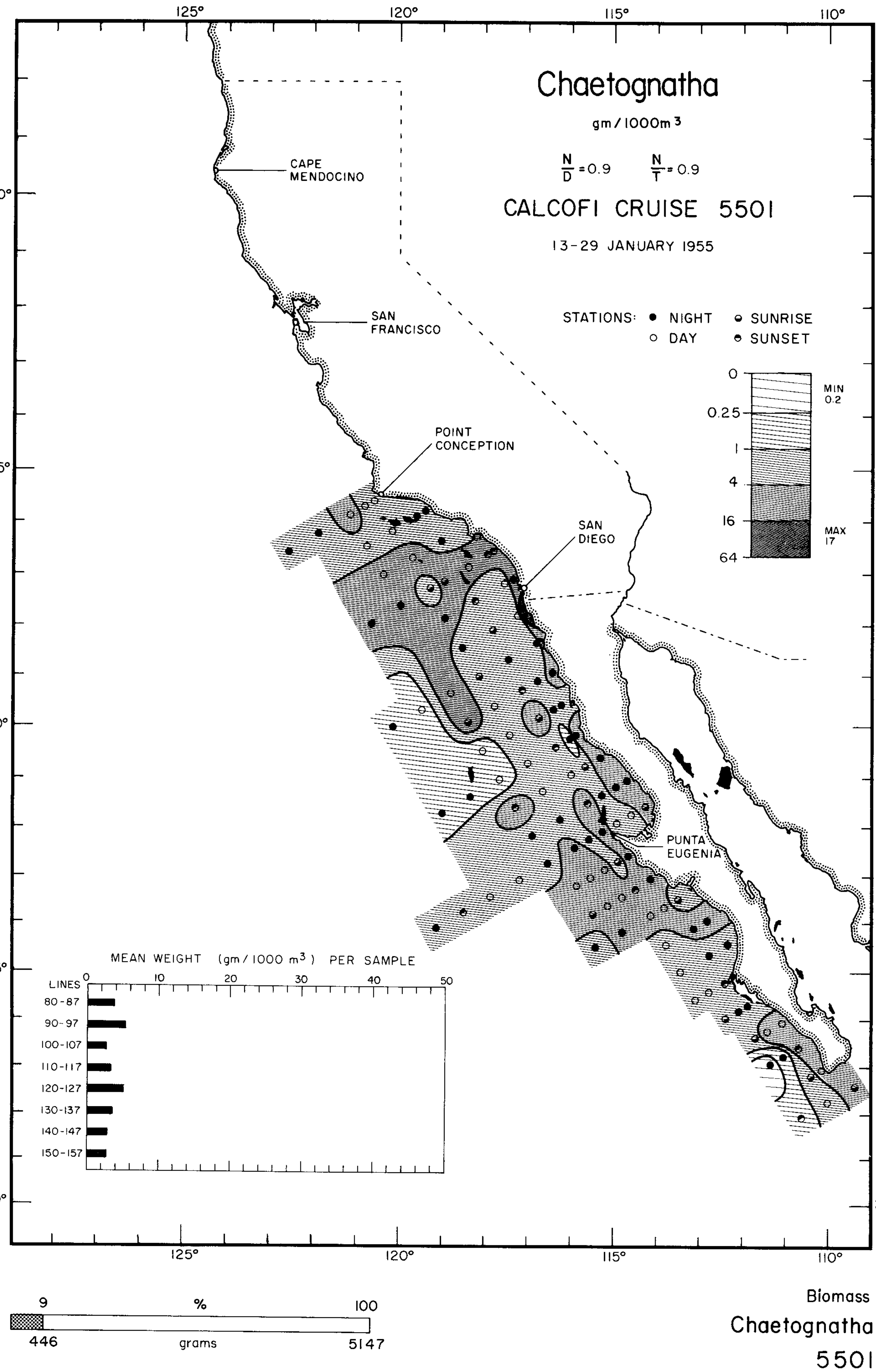
43 grams 4755

Biomass

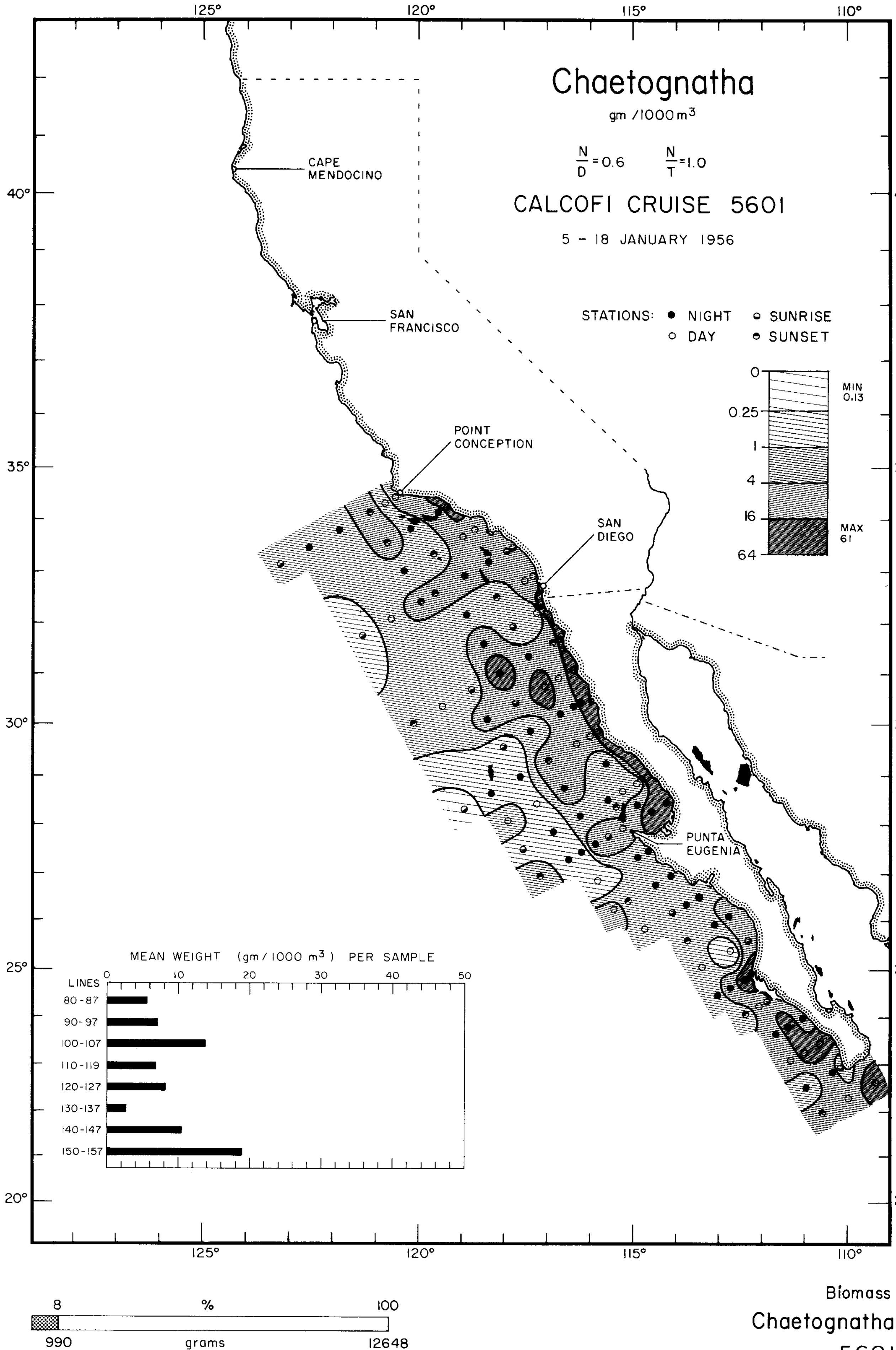
Amphipoda

5901


Amphipoda, adjusted
gm /1000m3
N/D = 4.7
N/T = 2.7
CALCOFI CRUISE 5901
7 - 29 JANUARY 1959
STATIONS: NIGHT SUNRISE DAY SUNSET
0
0.062
0.25
1
4
16
MIN 0
MAX 7
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
MEAN WEIGHT (gm / 1000 m3) PER SAMPLE
LINES
60-67
70-77
80-87
90-97
100-107
110-119
120-127
130-137
140-147
150-157
0
1
2
3
4
5



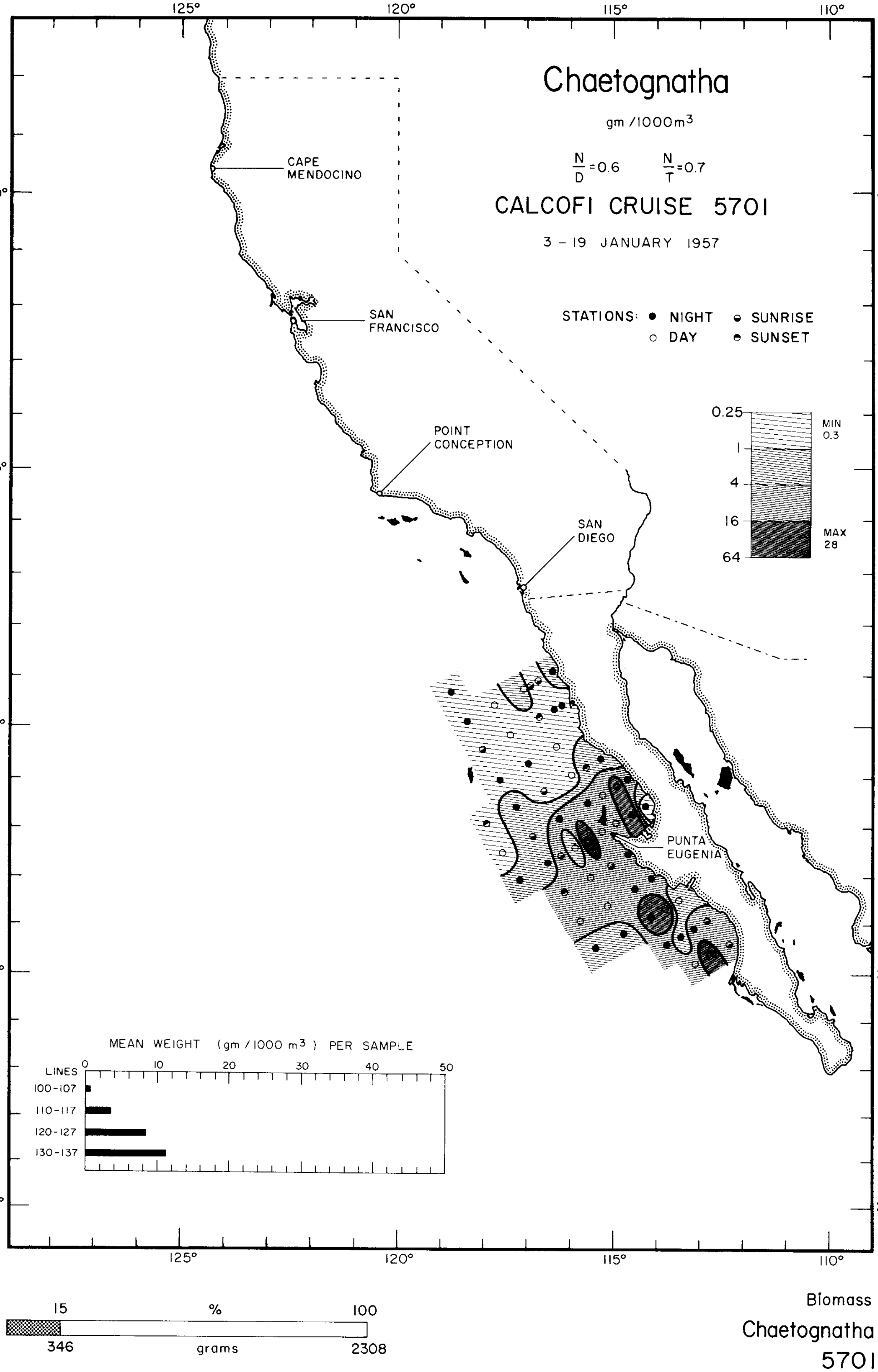
Biomass
Chaetognatha
5501



Biomass

Chaetognatha

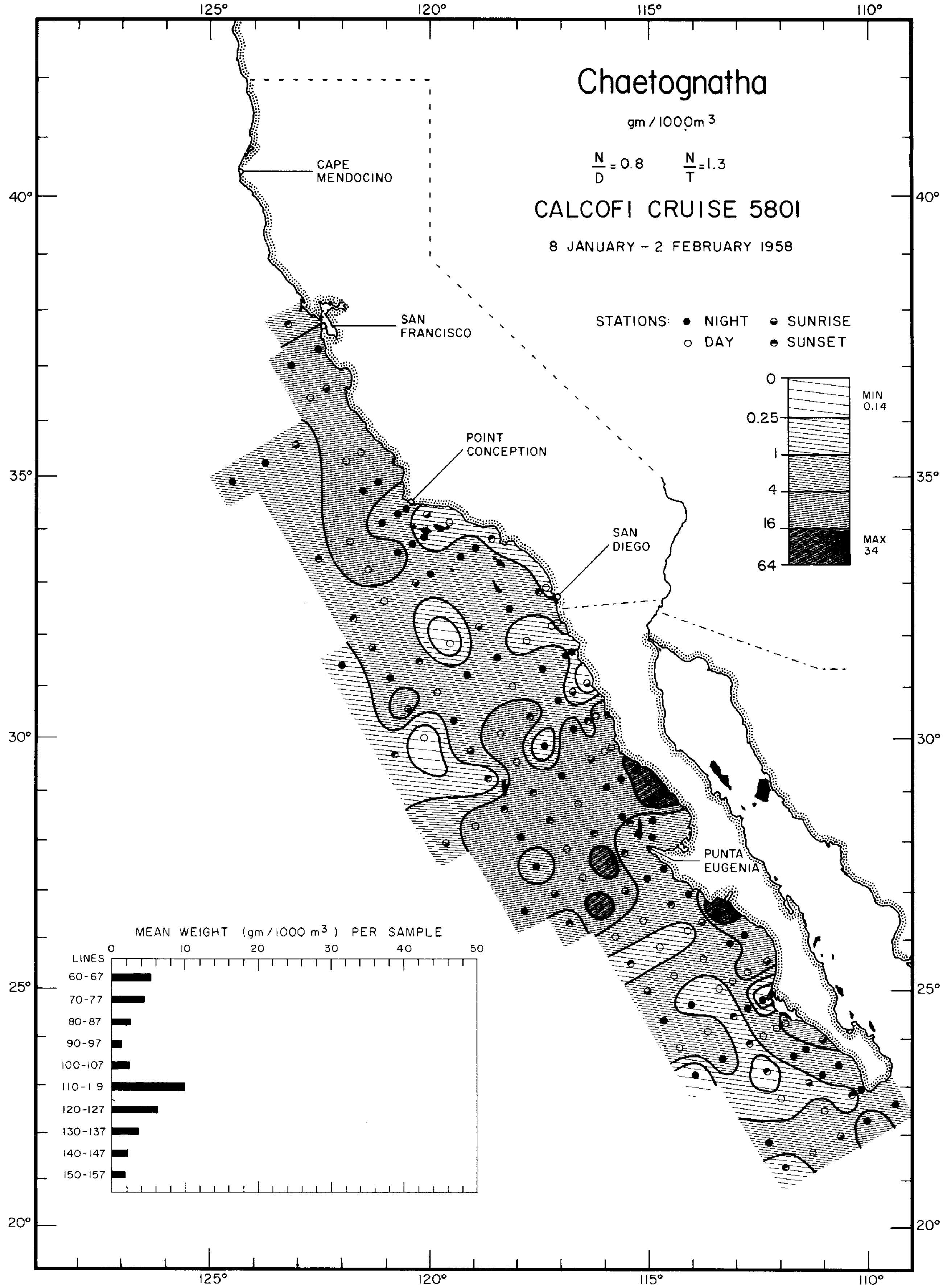
5601

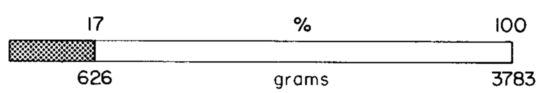


Biomass

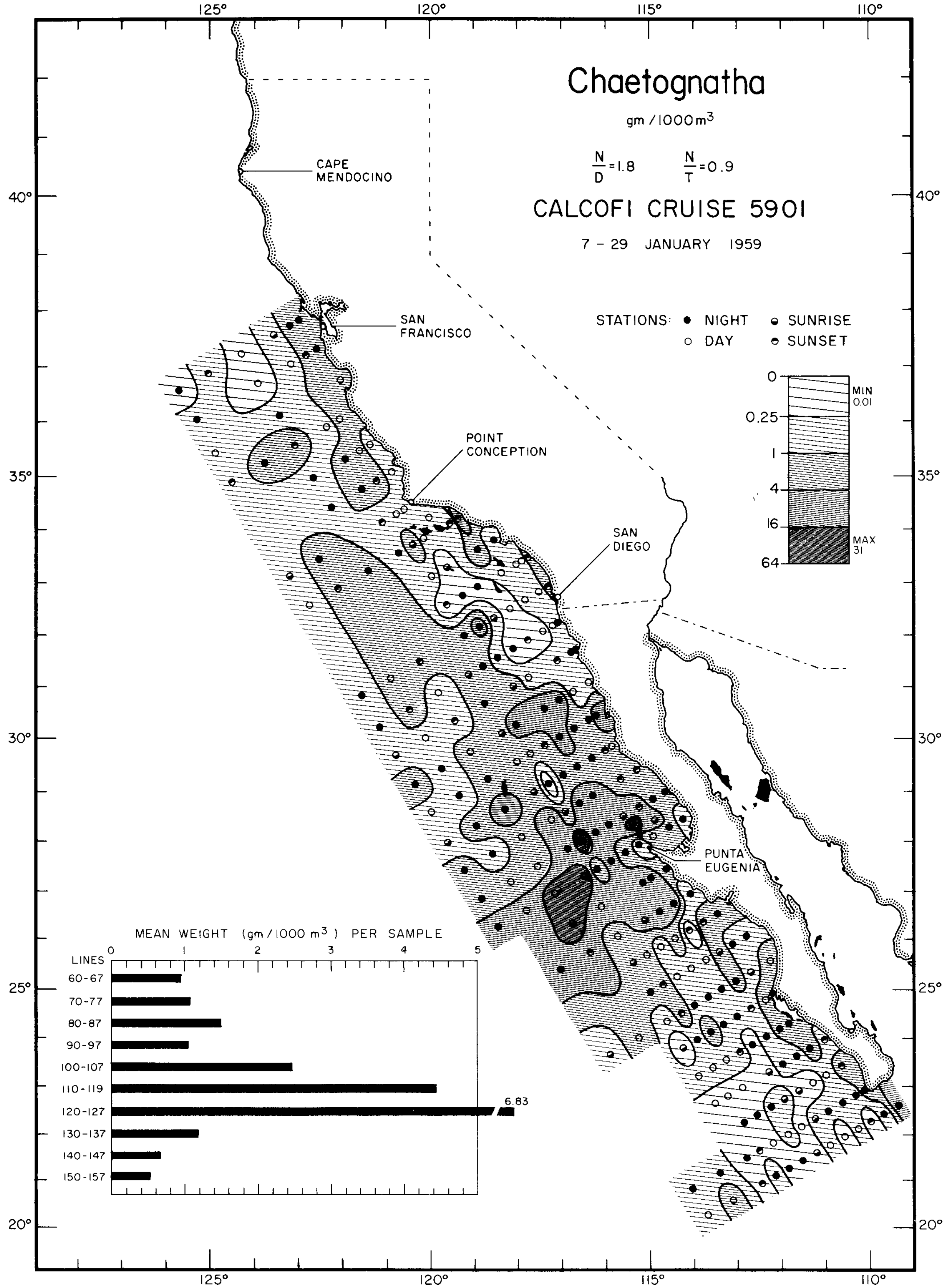
Chaetognatha

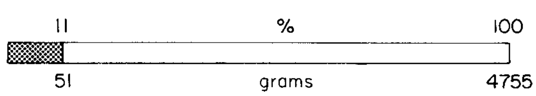
5701





Biomass
Chaetognatha
5801

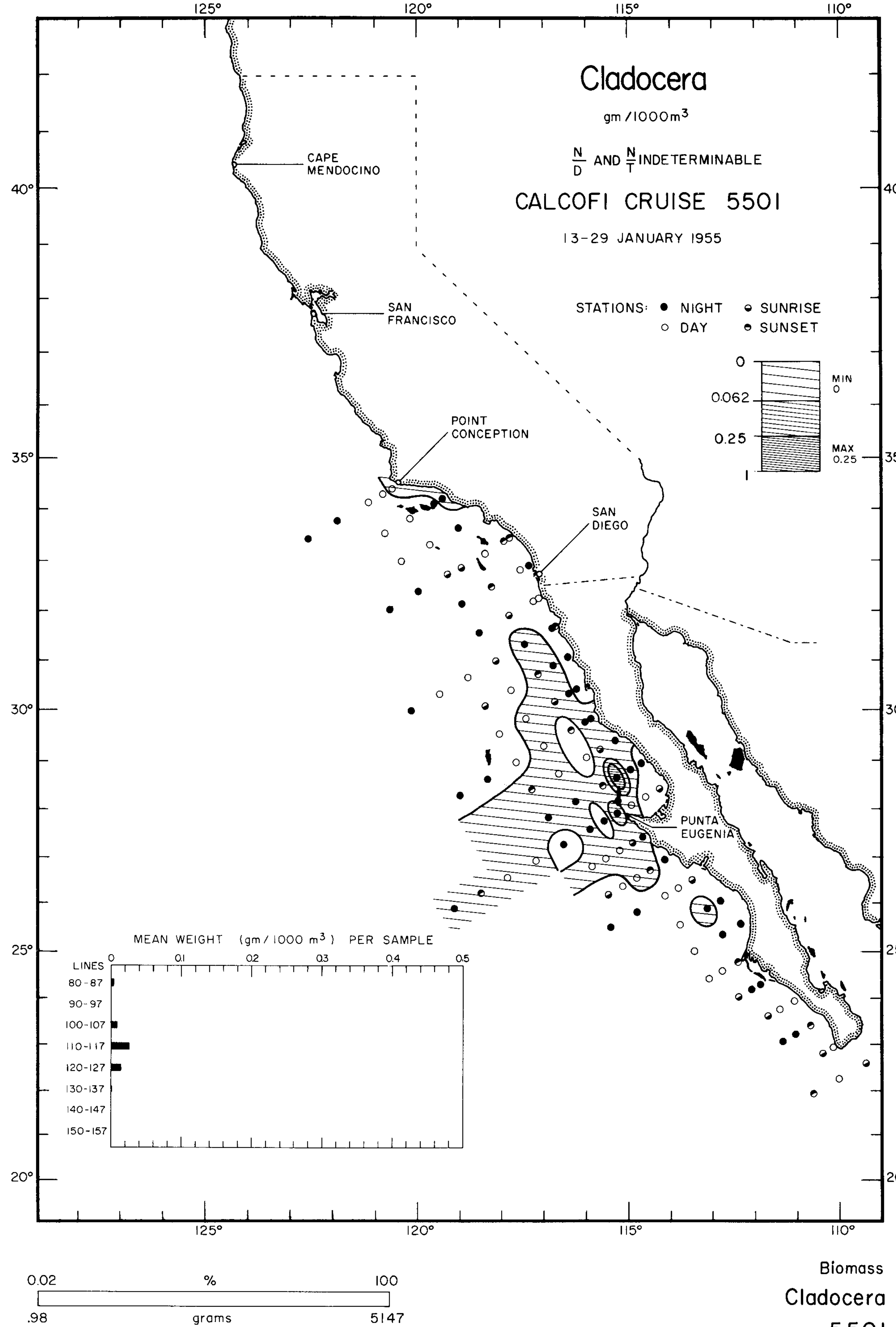




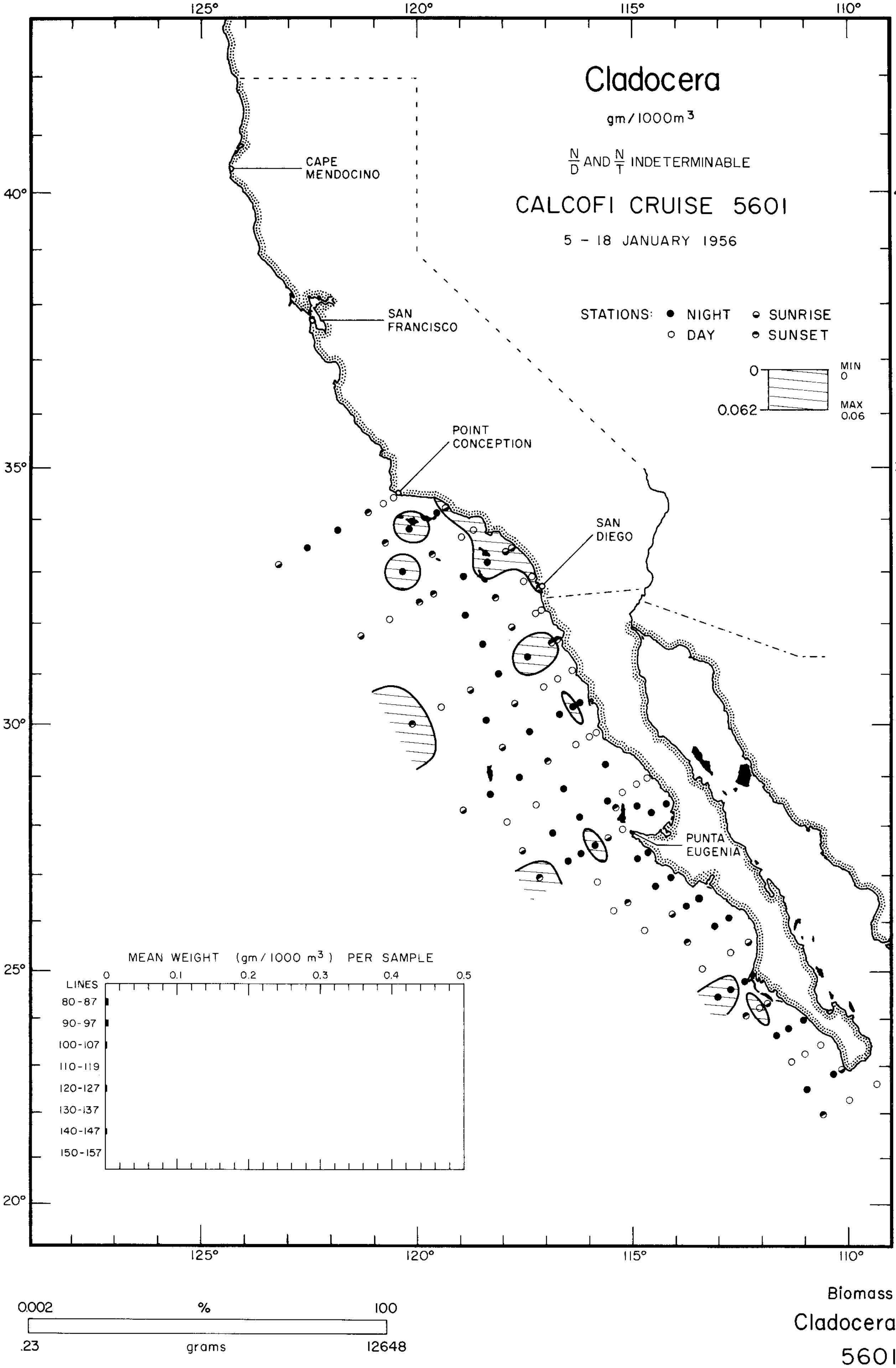
Biomass

Chaetognatha

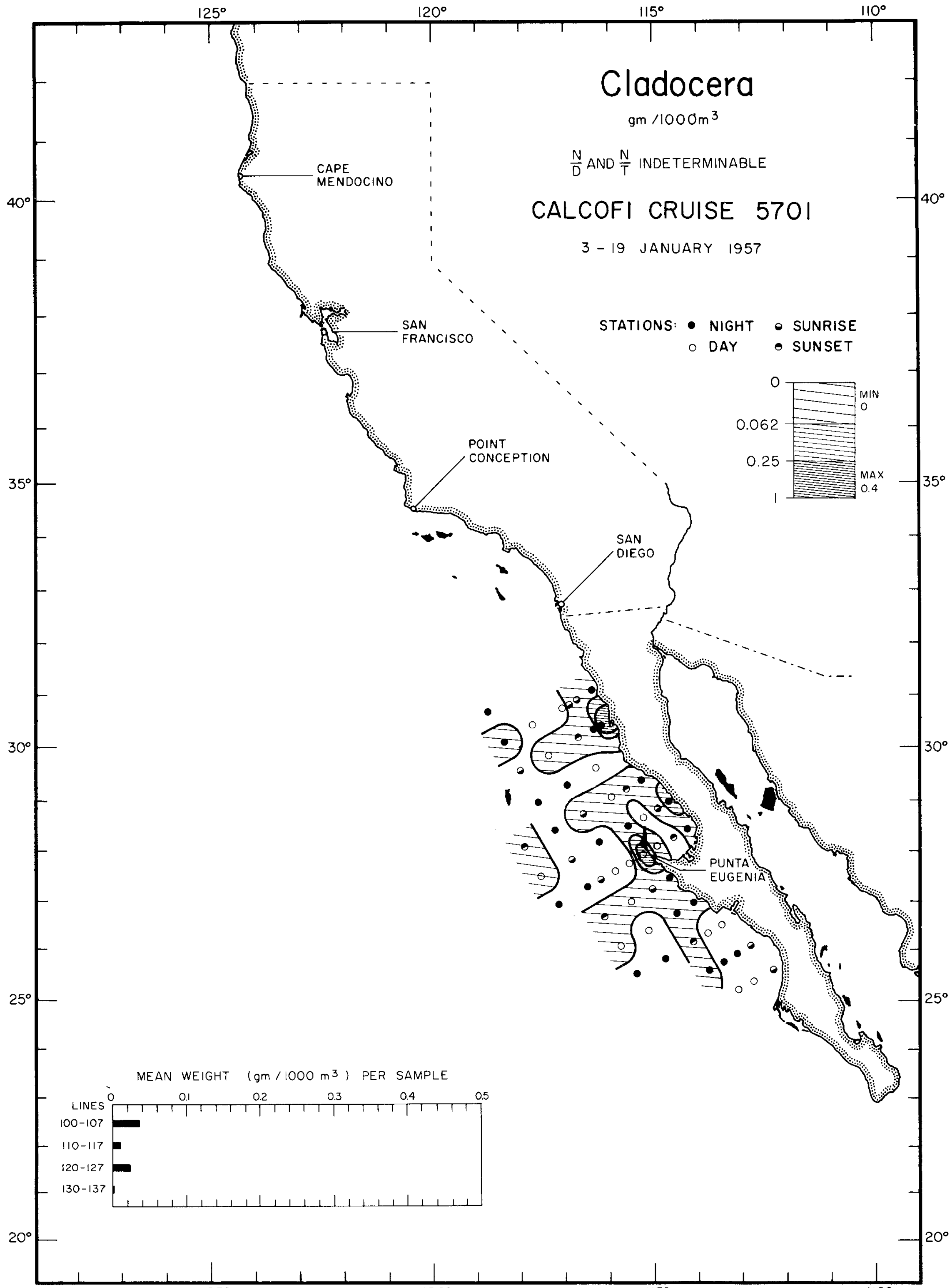
5901

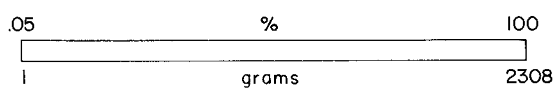


Biomass
Cladocera
5501



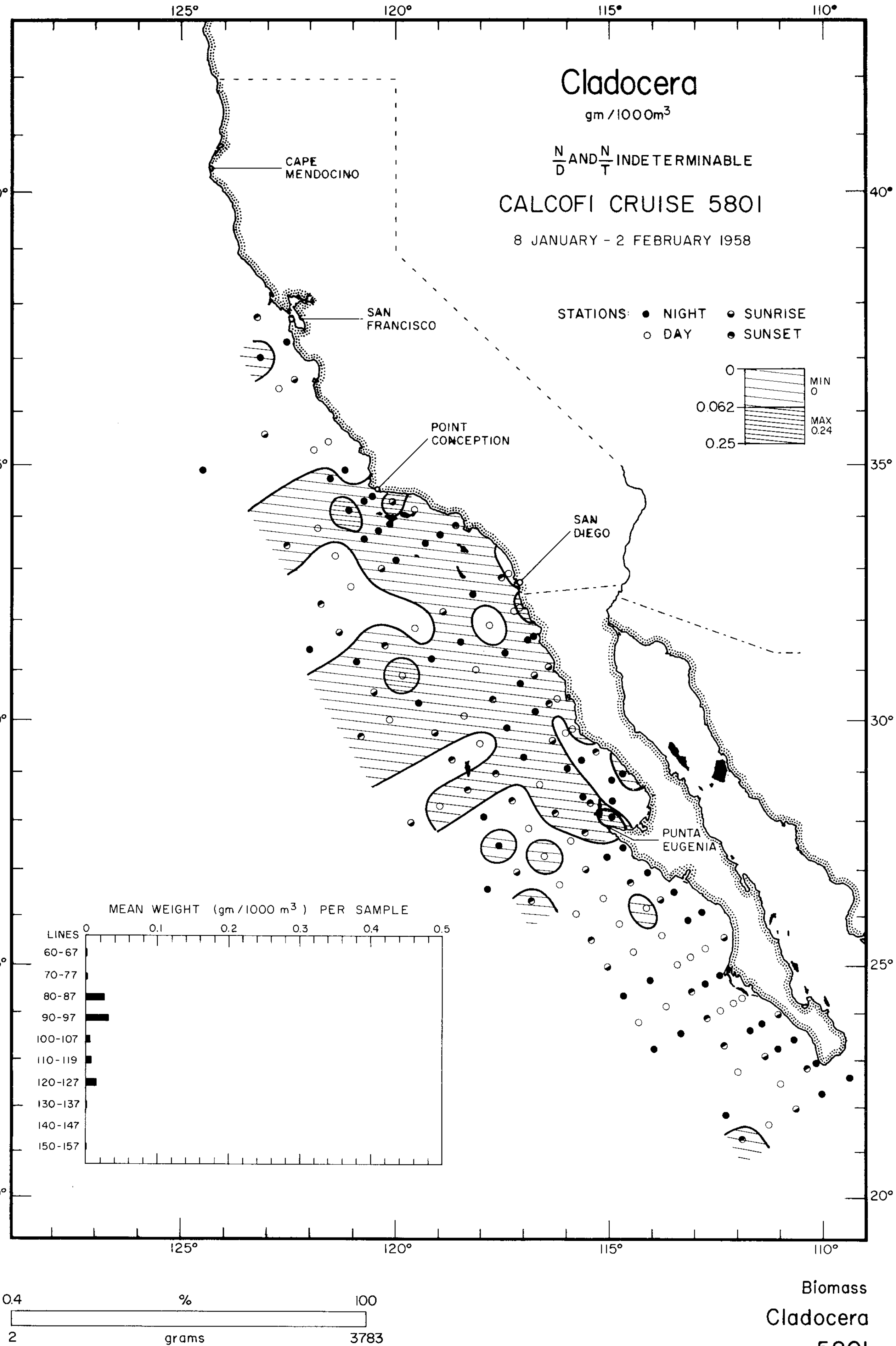
Biomass
Cladocera
5601



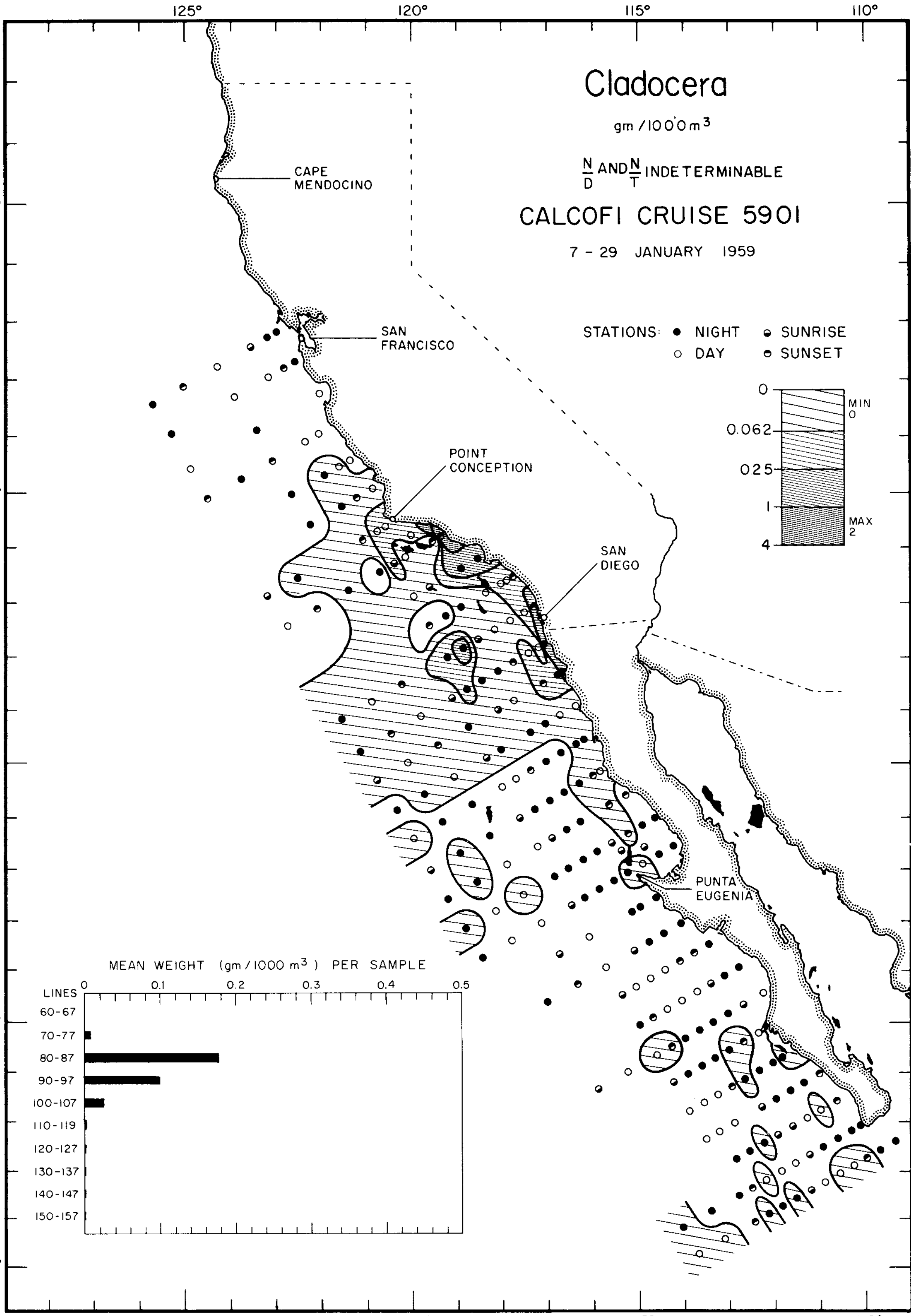


Biomass

Cladocera
5701



Biomass
Cladocera
5801



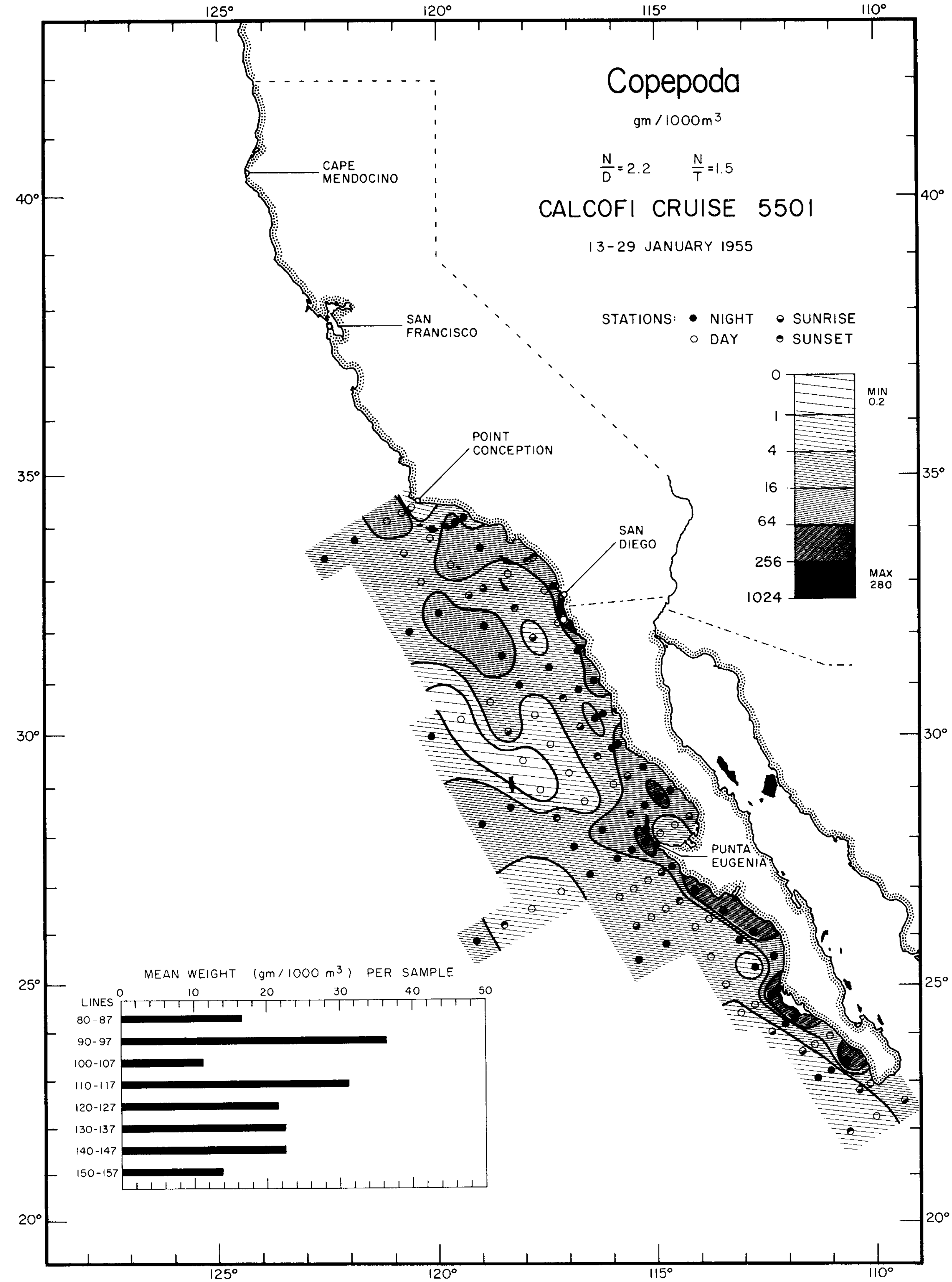
0.1 % 100

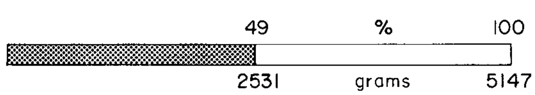
7 grams 4755

Biomass

Cladocera

5901

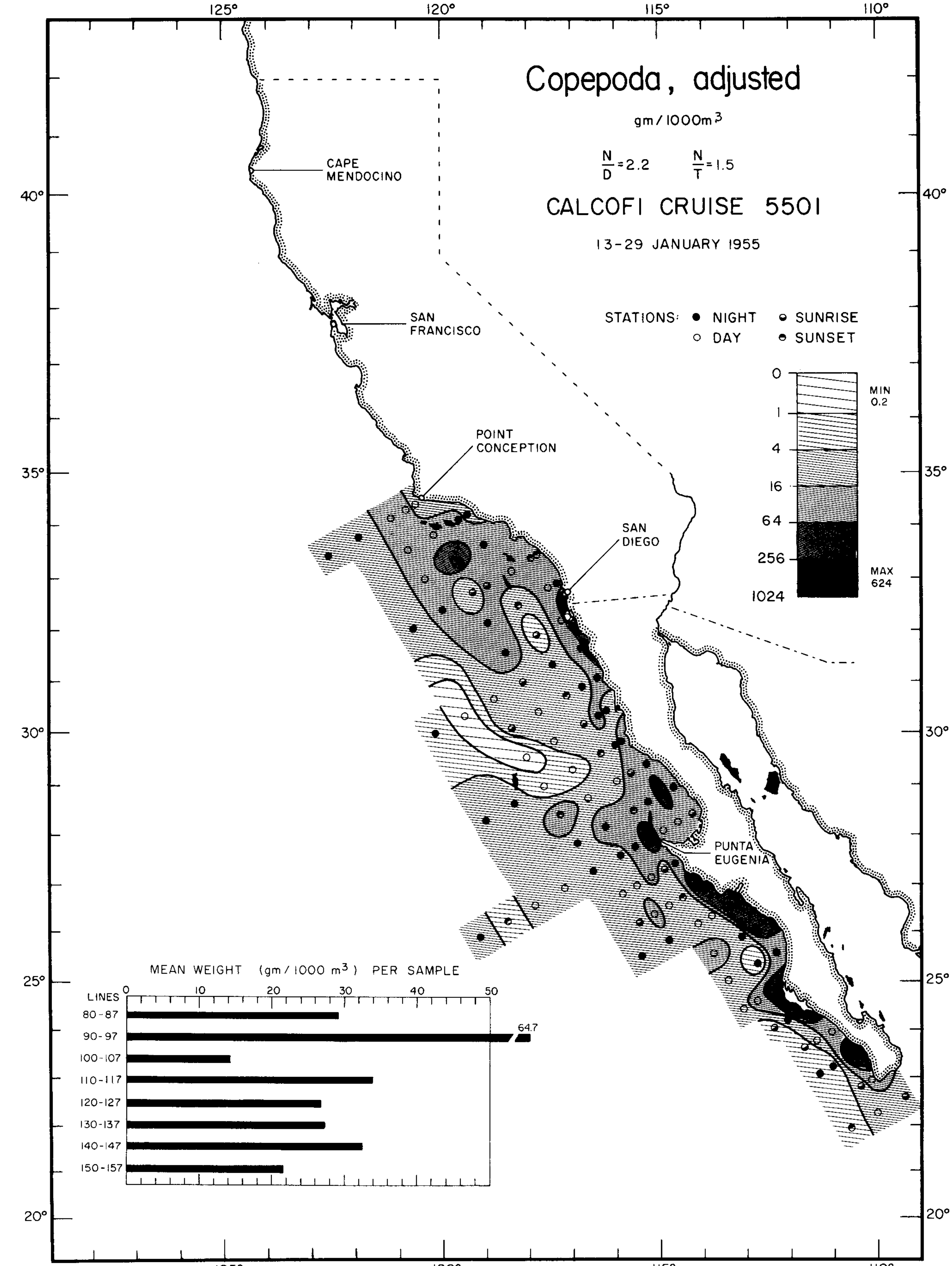




Biomass

Copepoda

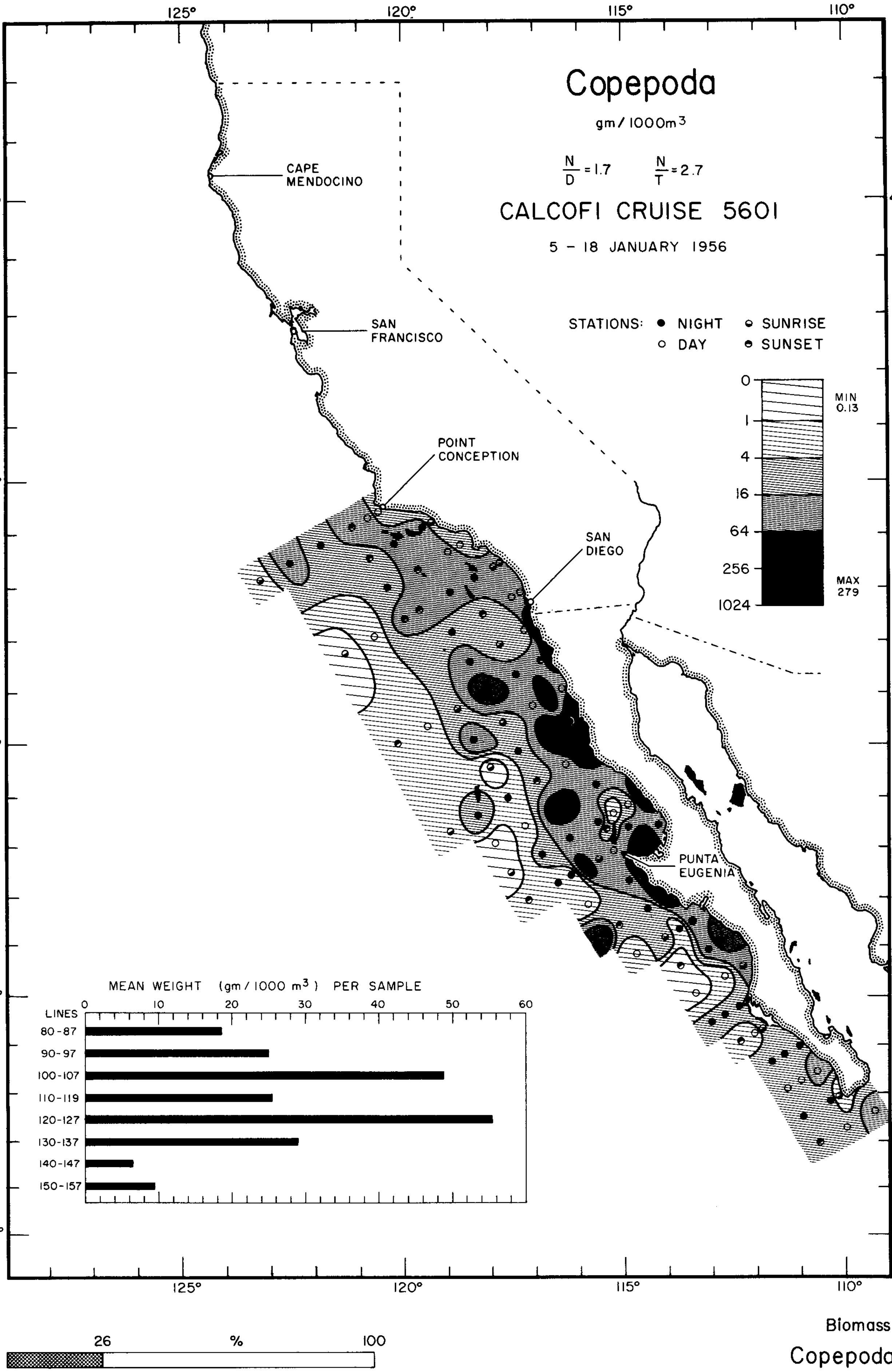
5501



Biomass

Copepoda, adjusted

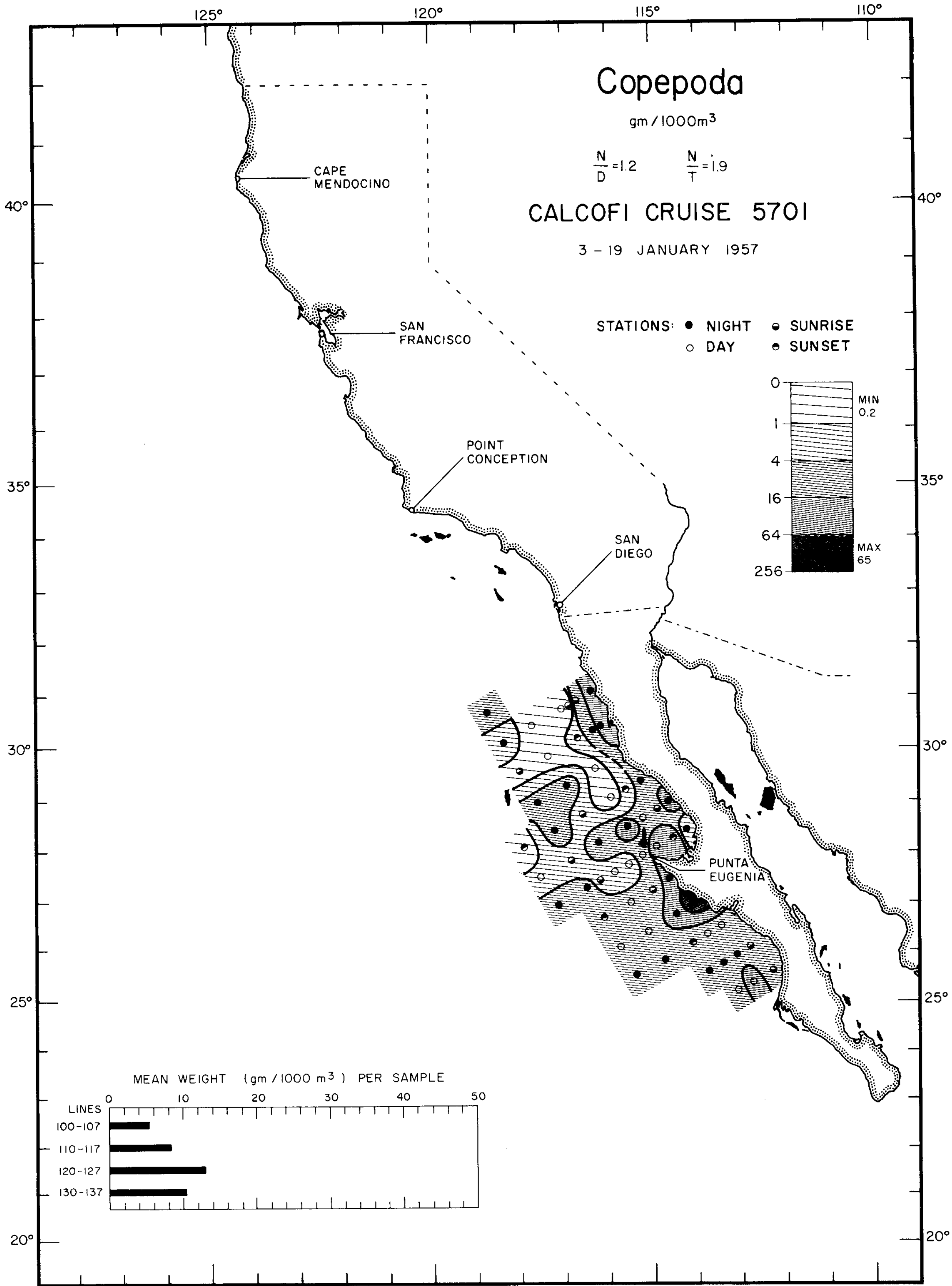
5501

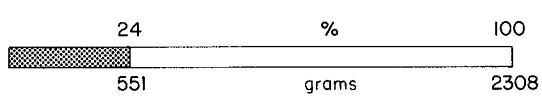


Biomass

Copepoda

5601

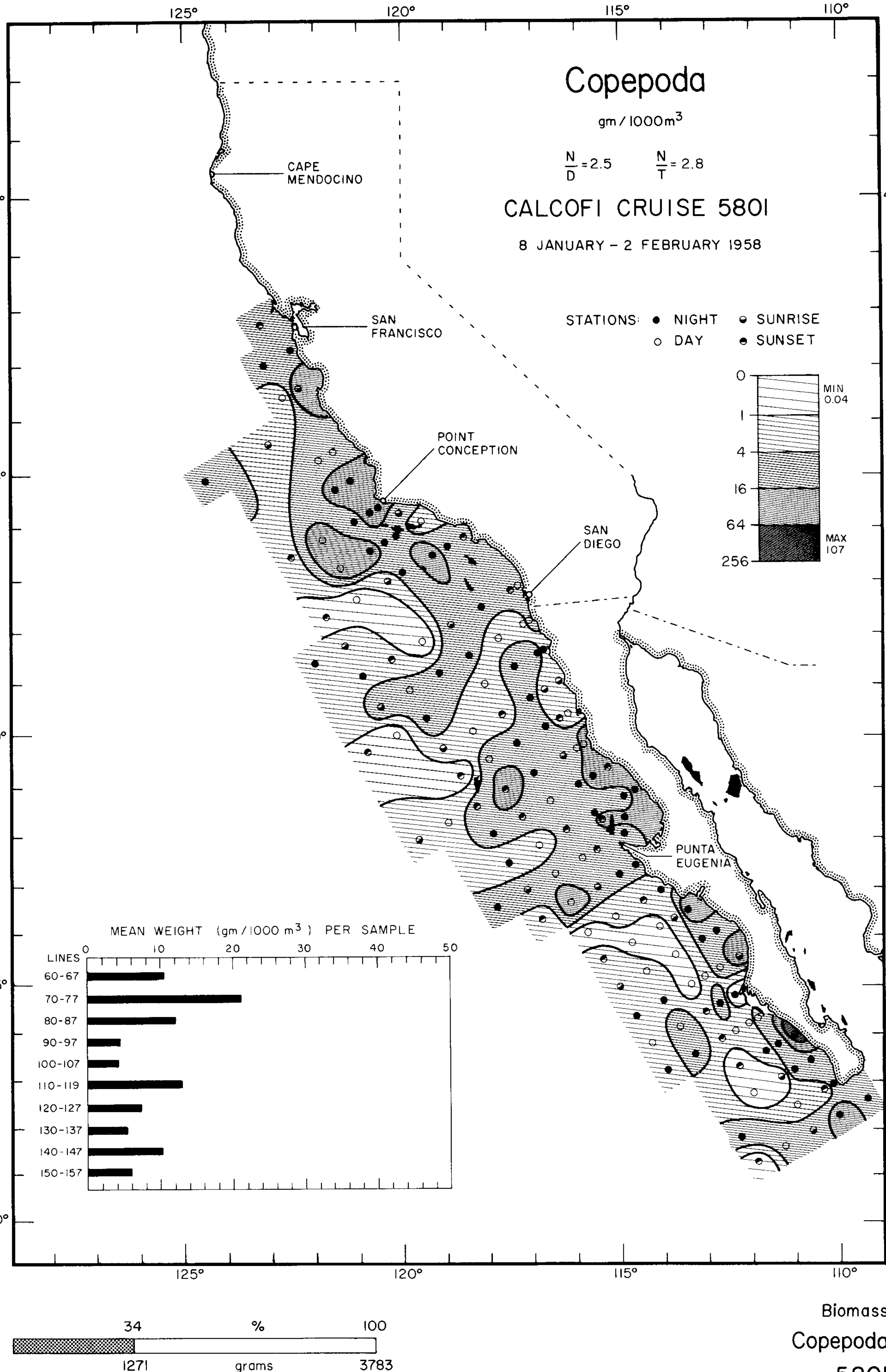




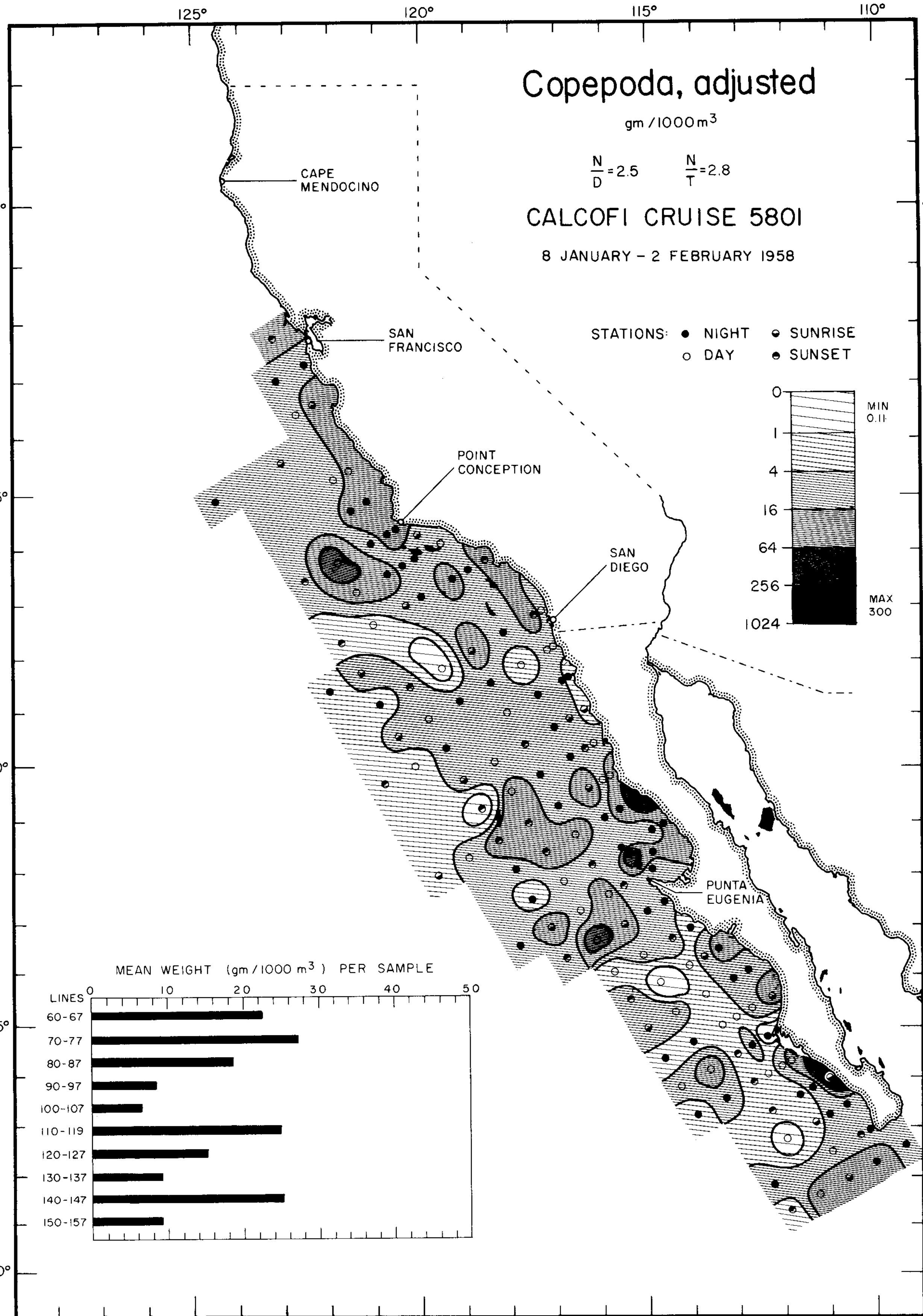
Biomass

Copepoda

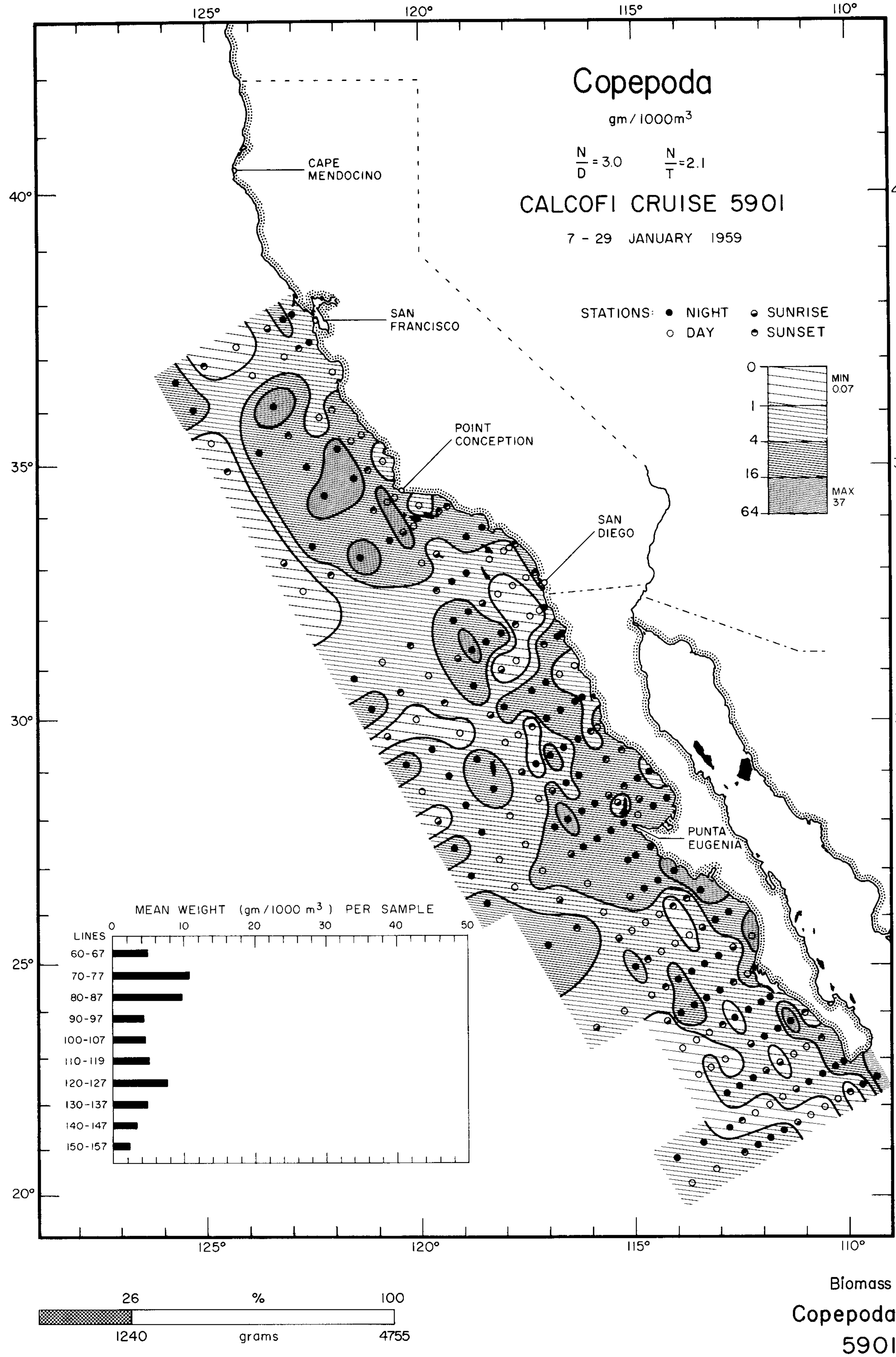
5701



Biomass
Copepoda
5801



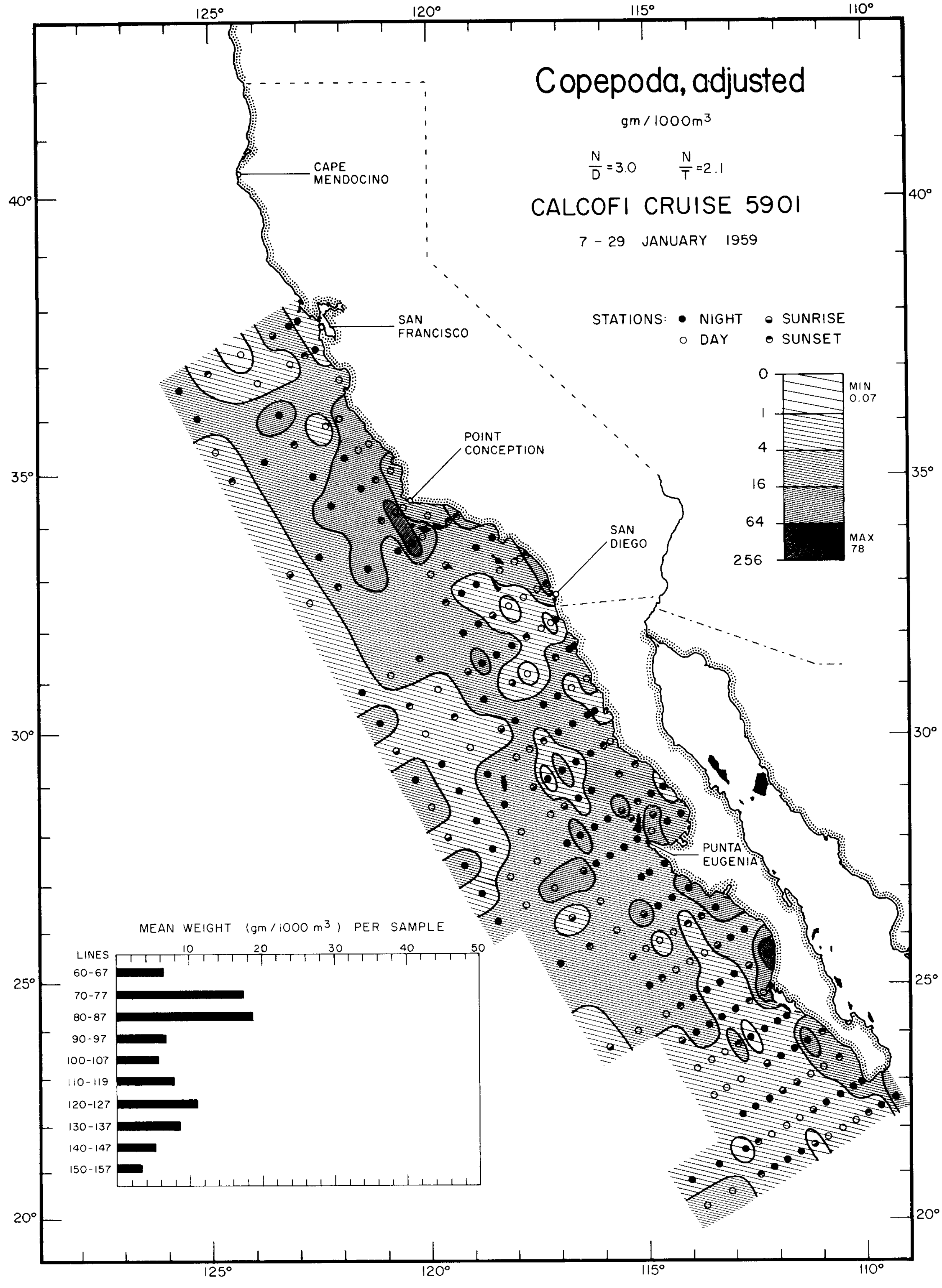
Biomass
Copepoda adjusted
5801



Biomass

Copepoda

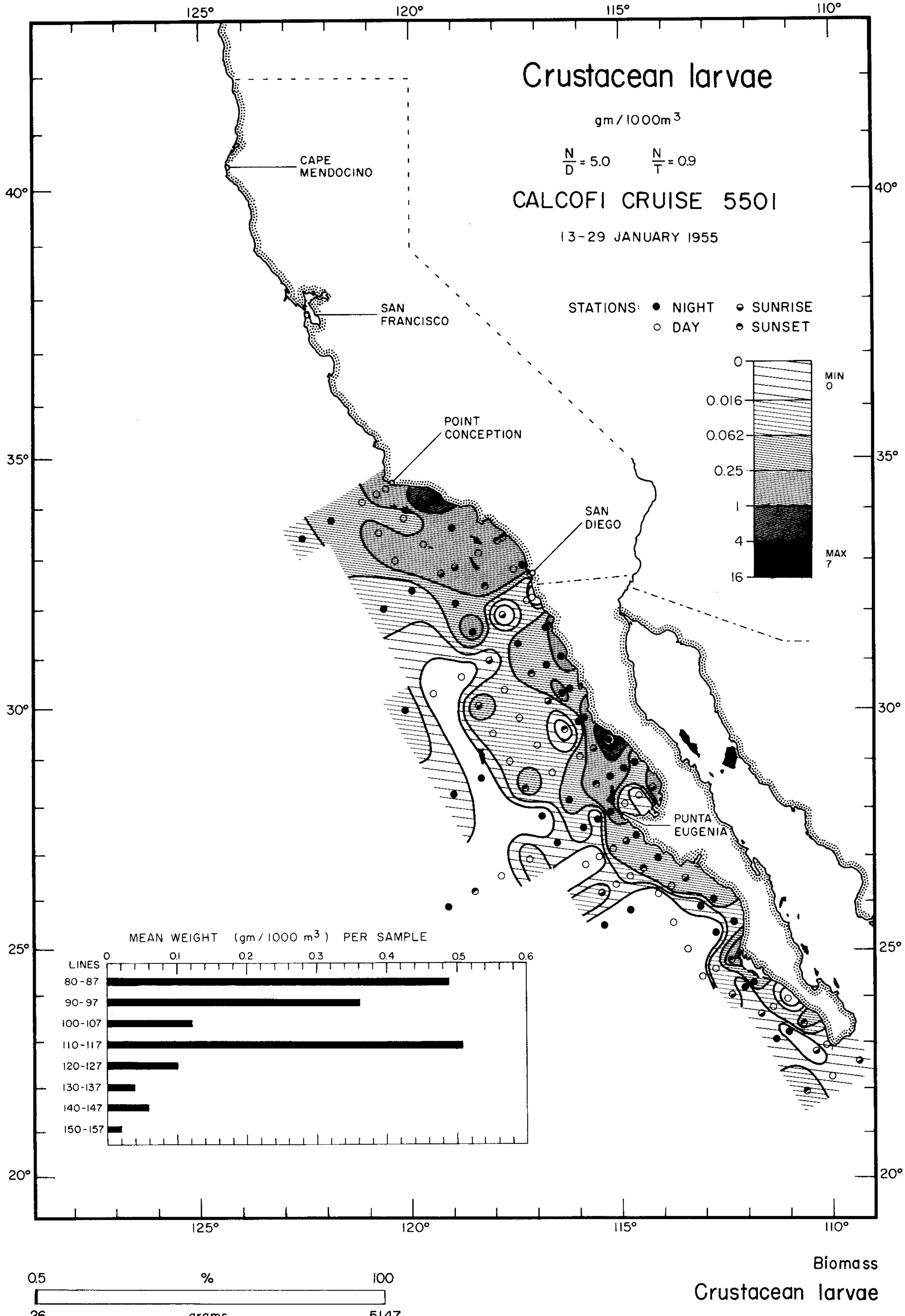
5901



Biomass

Copepoda, adjusted

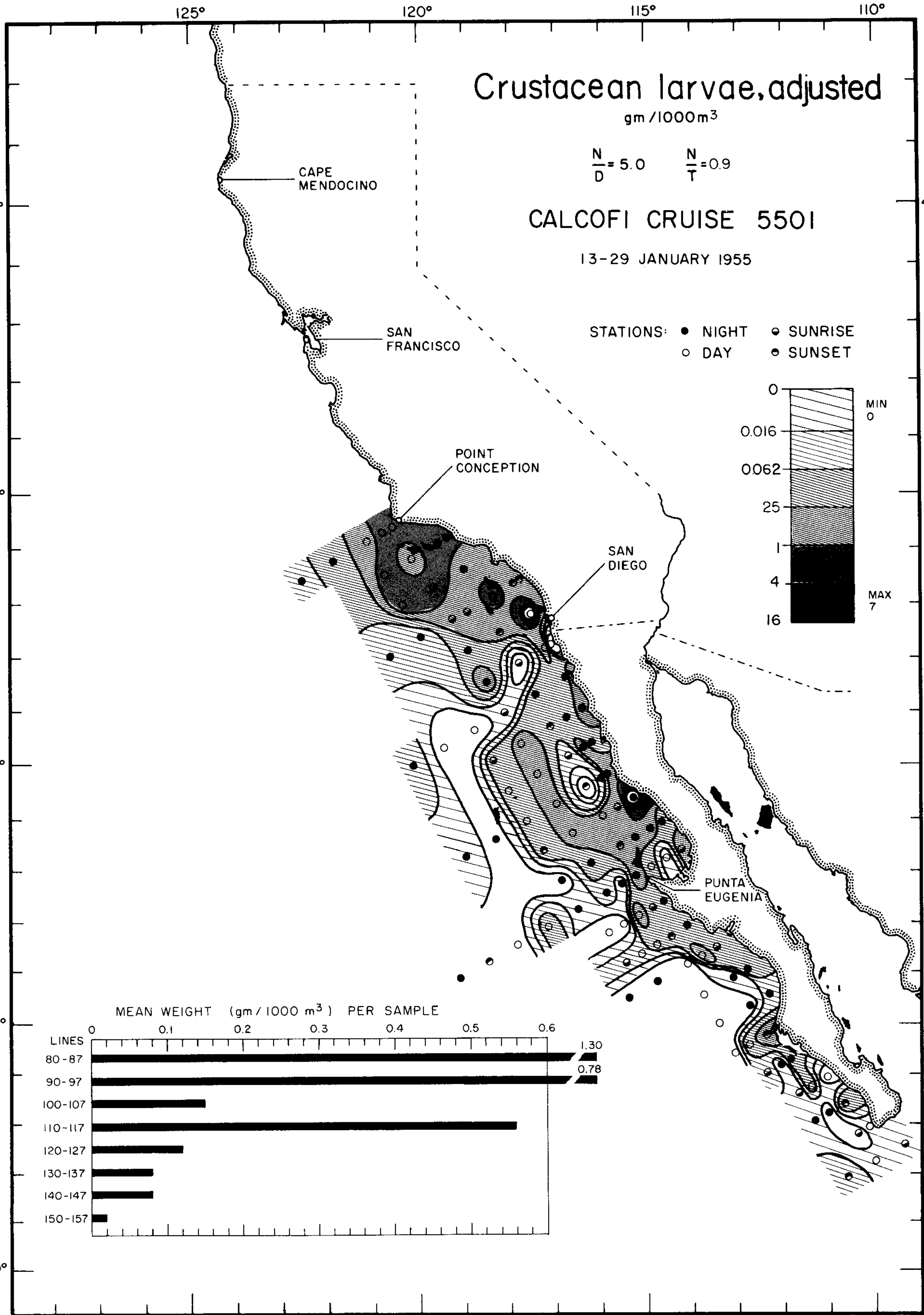
5901



Biomass

Crustacean larvae

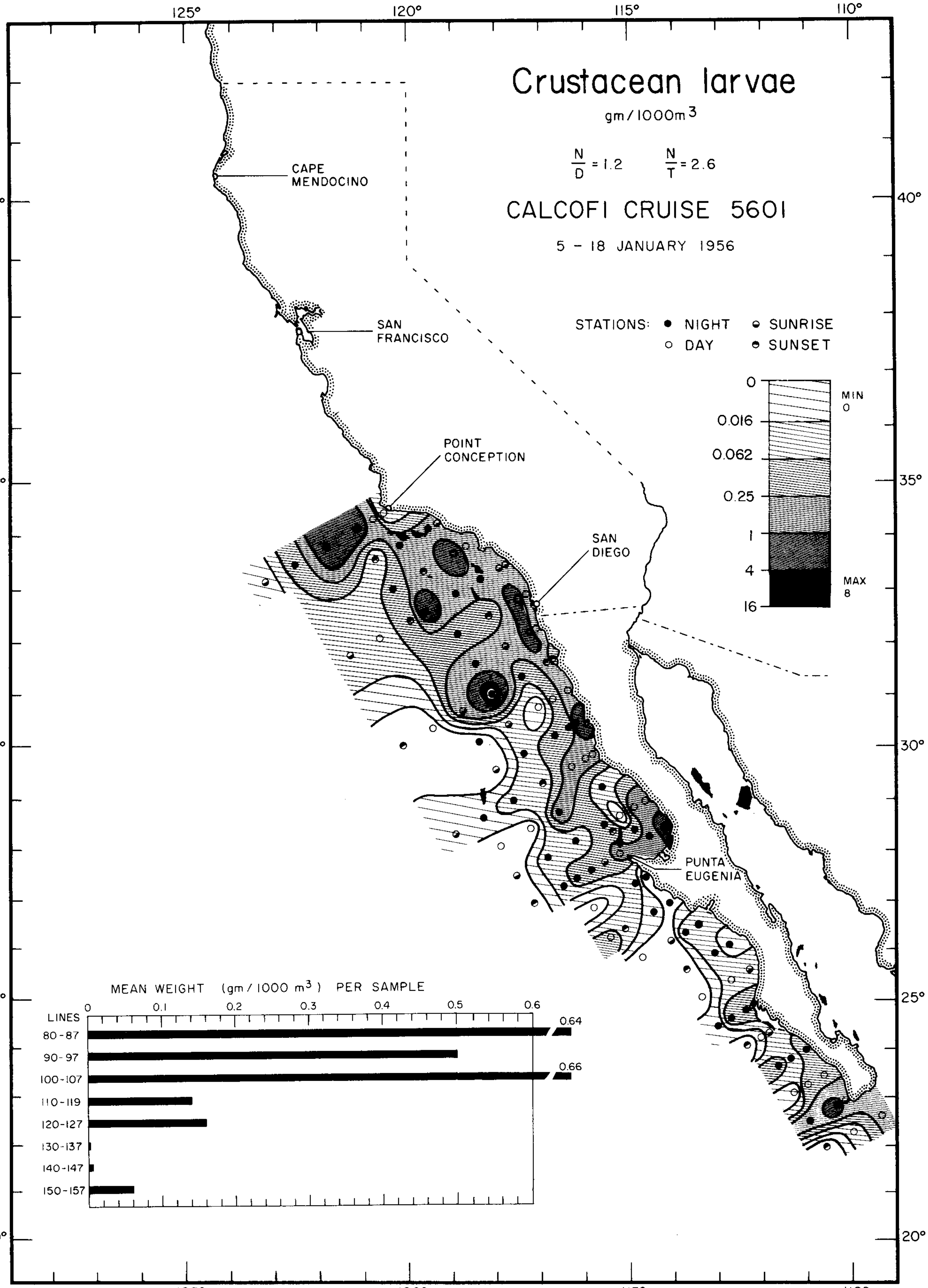
5501

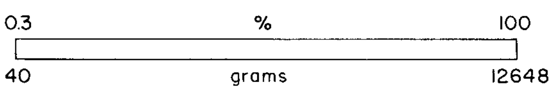


Biomass

Crustacean larvae, adjusted

5501

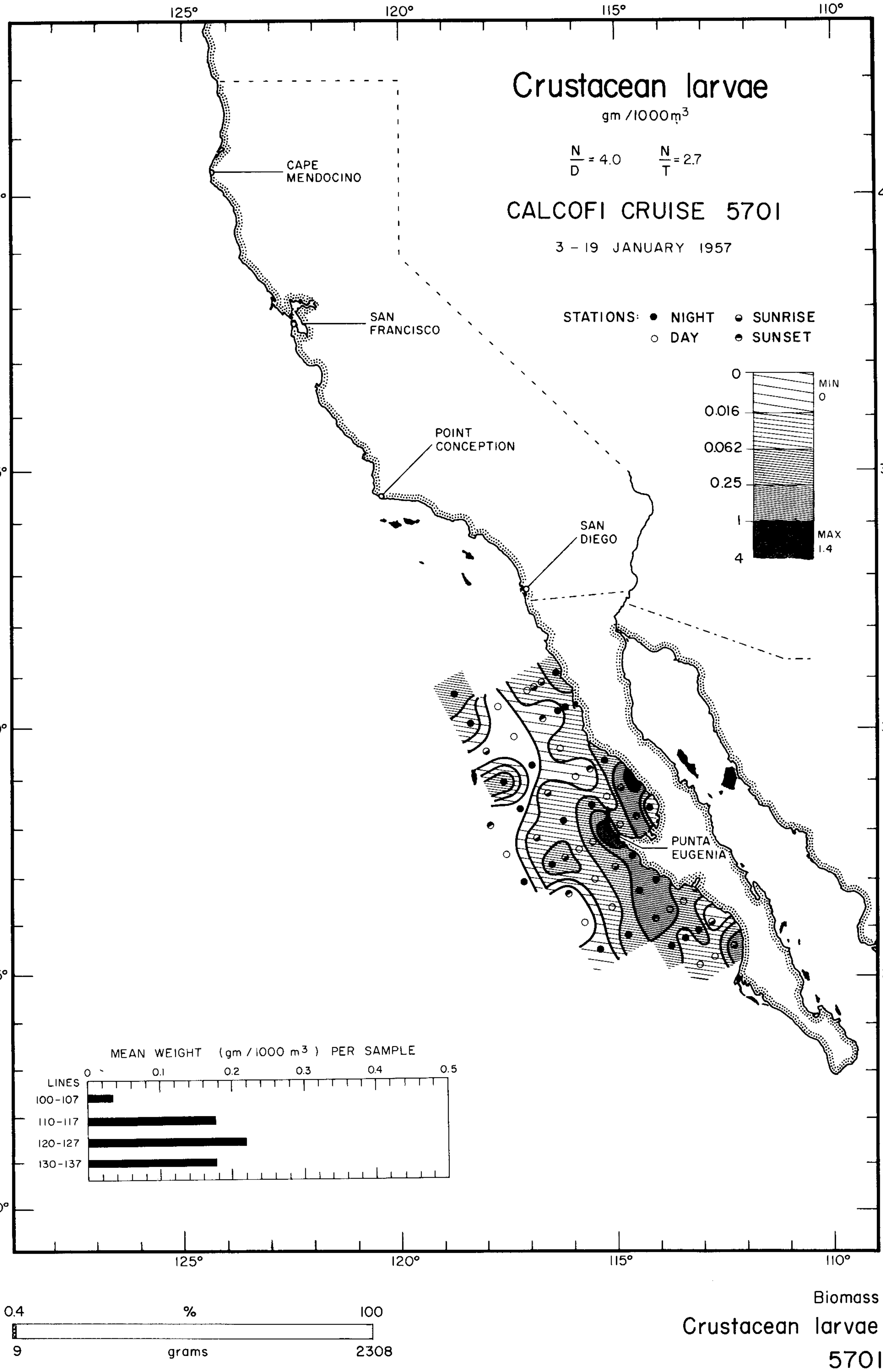




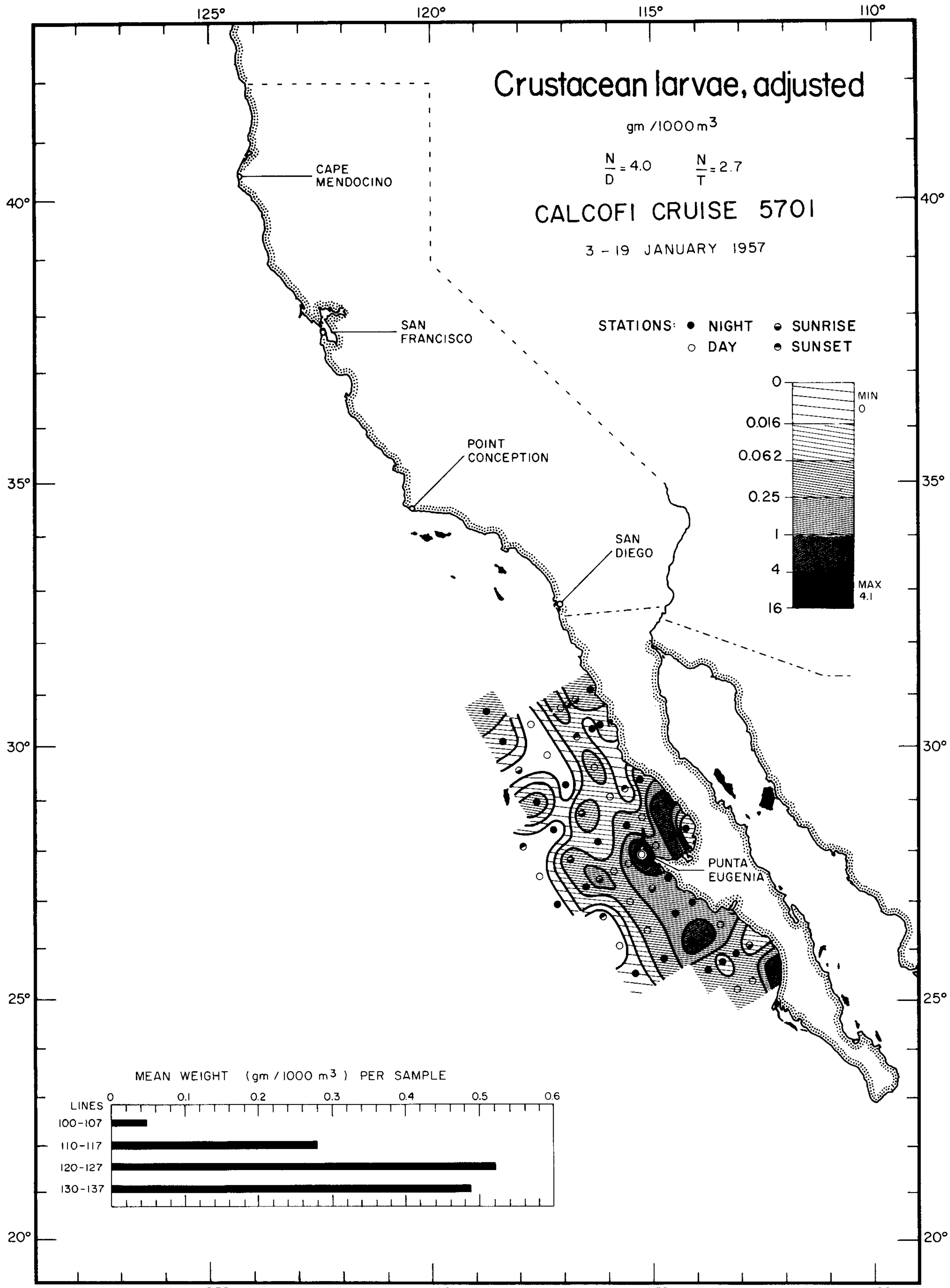
Biomass

Crustacean larvae

5601



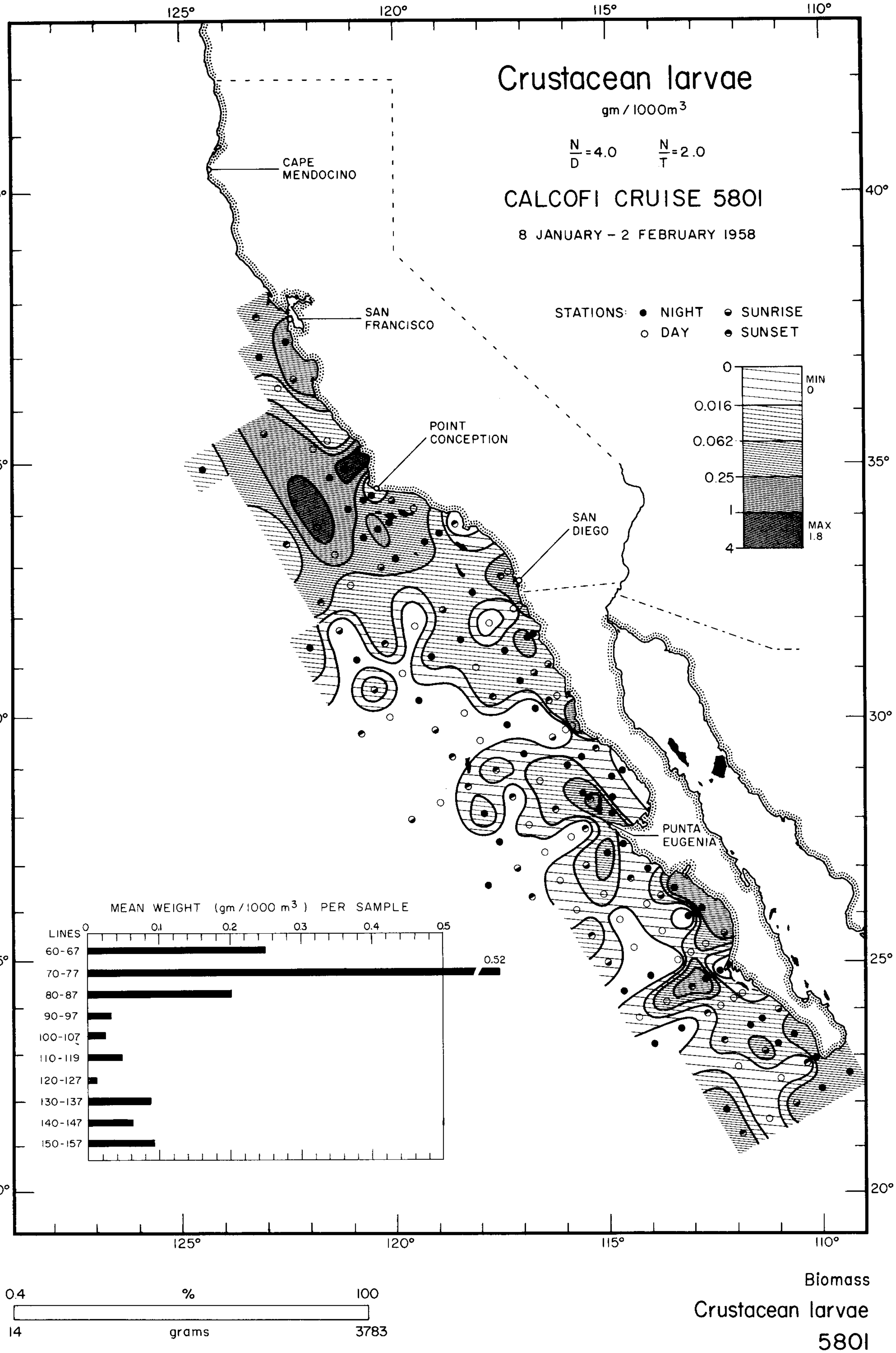
Biomass
Crustacean larvae
5701



Biomass

Crustacean larvae, adjusted

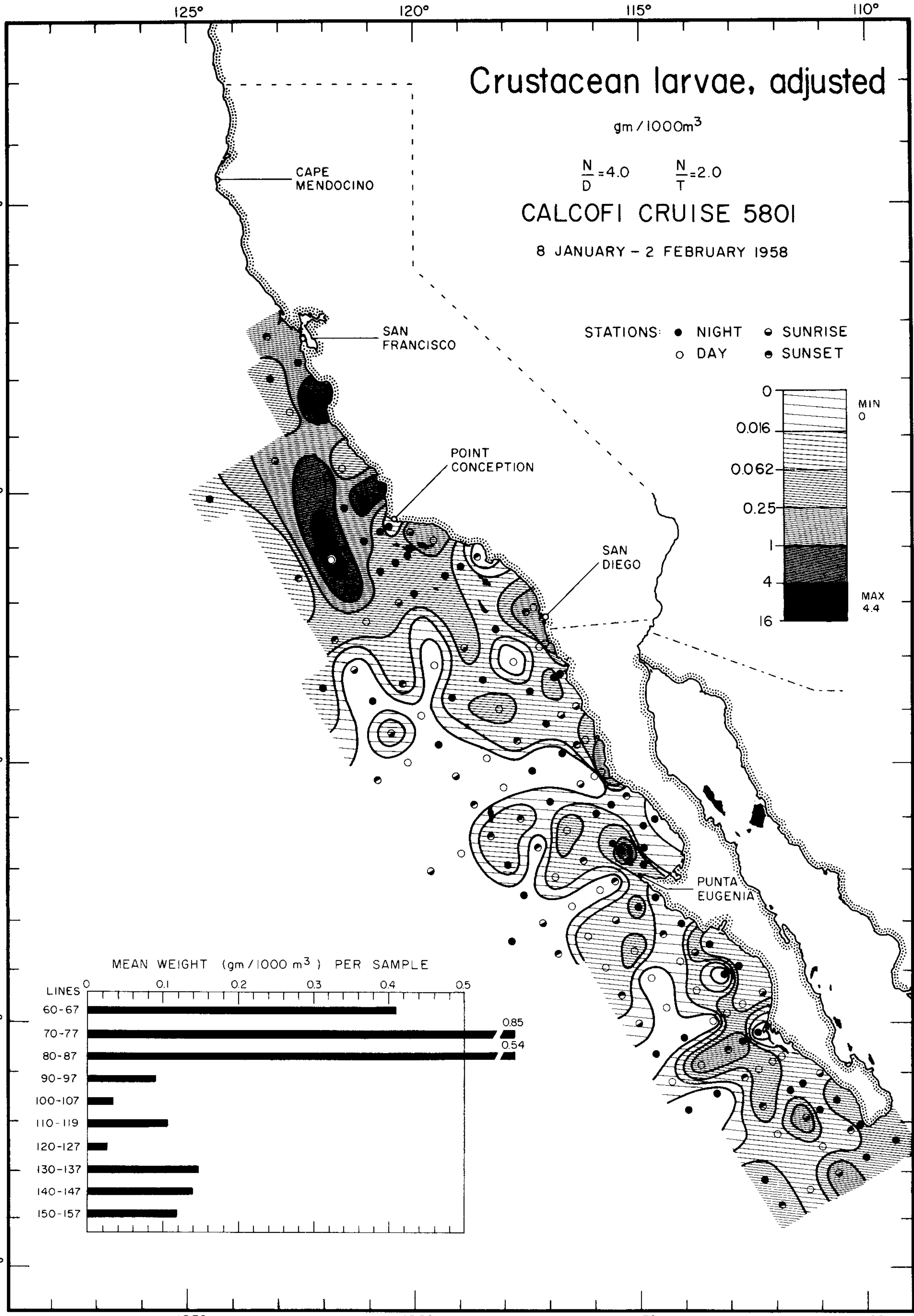
5701



Biomass

Crustacean larvae

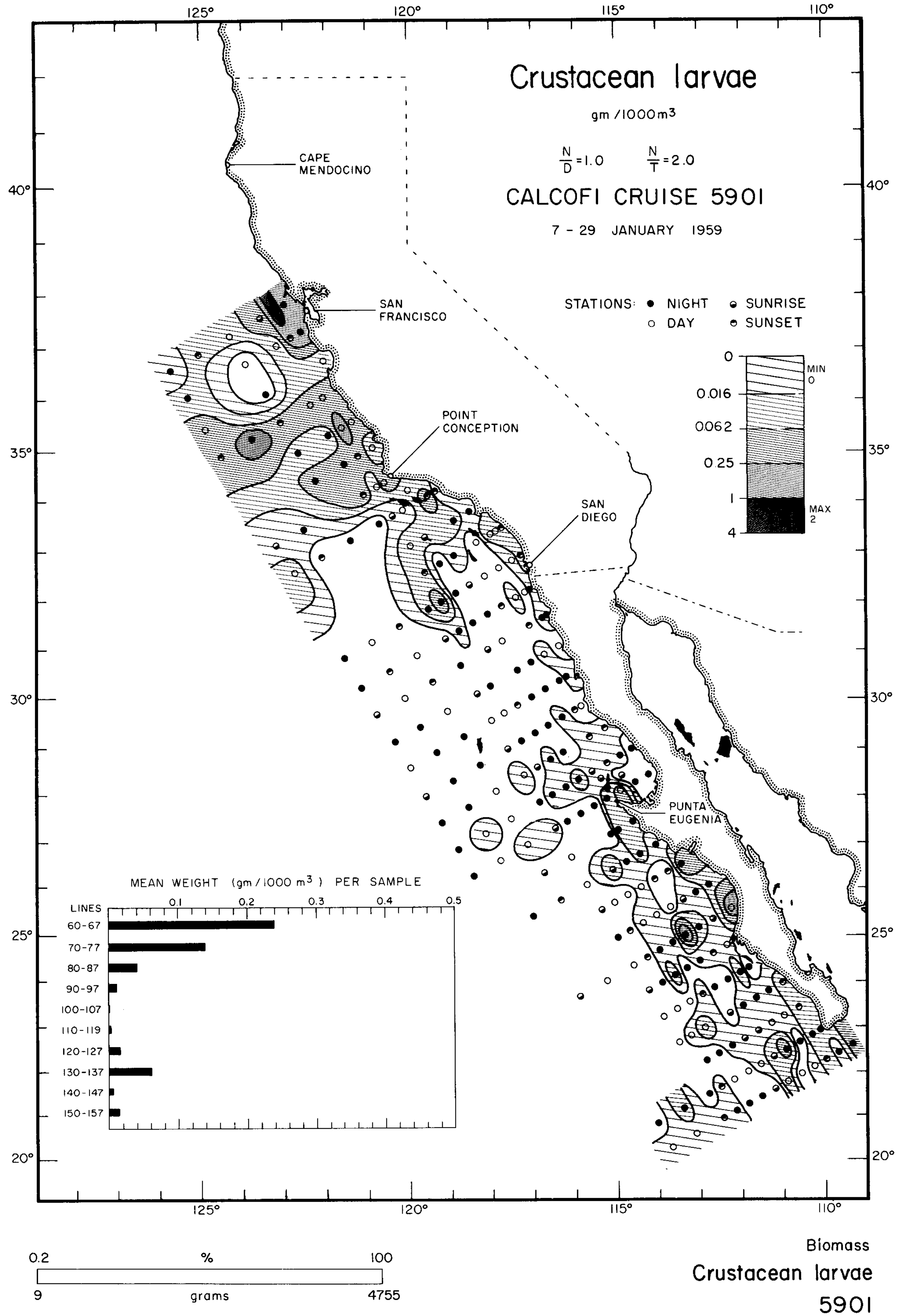
5801



Biomass

Crustacean larvae, adjusted

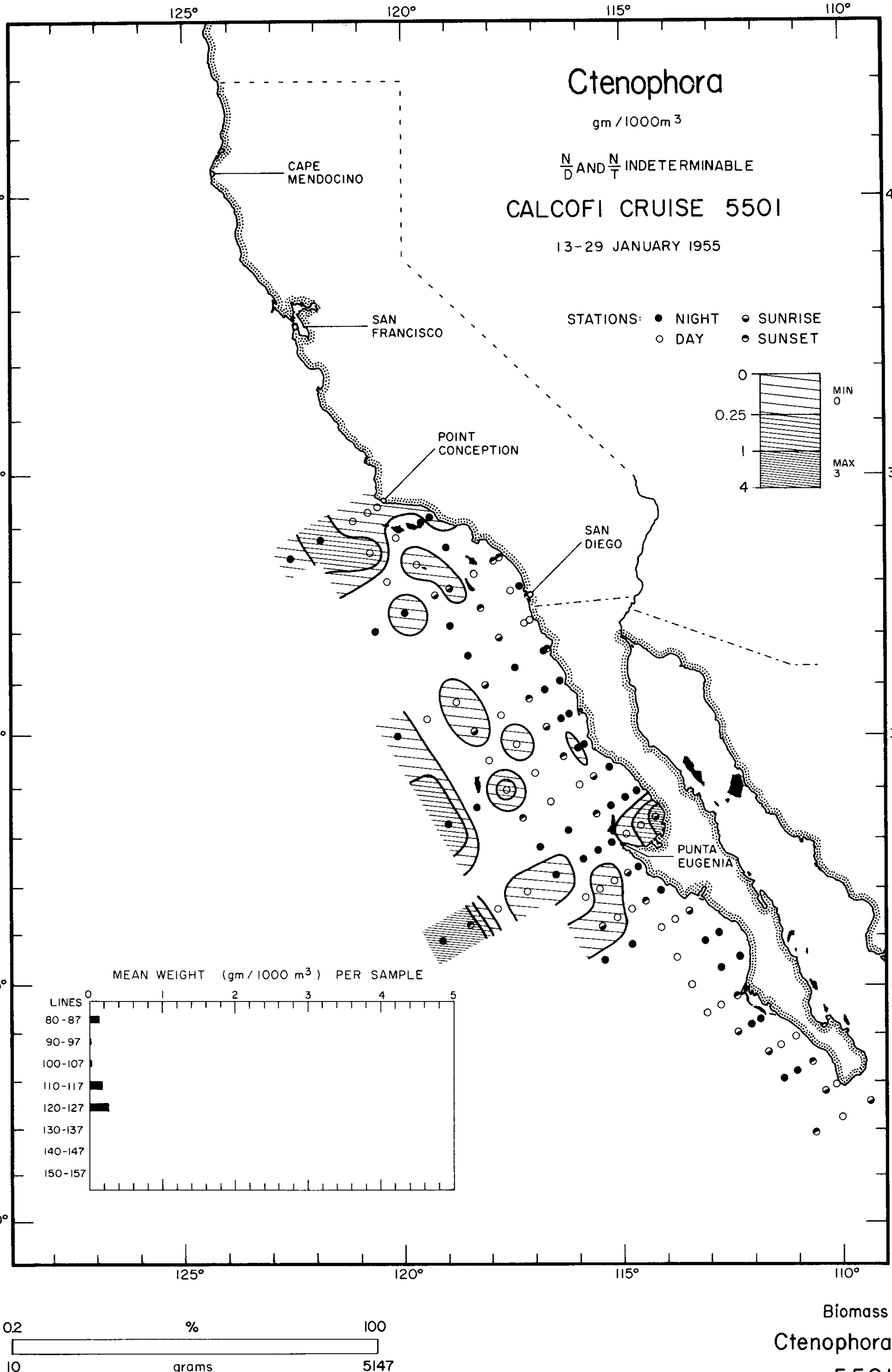
5801



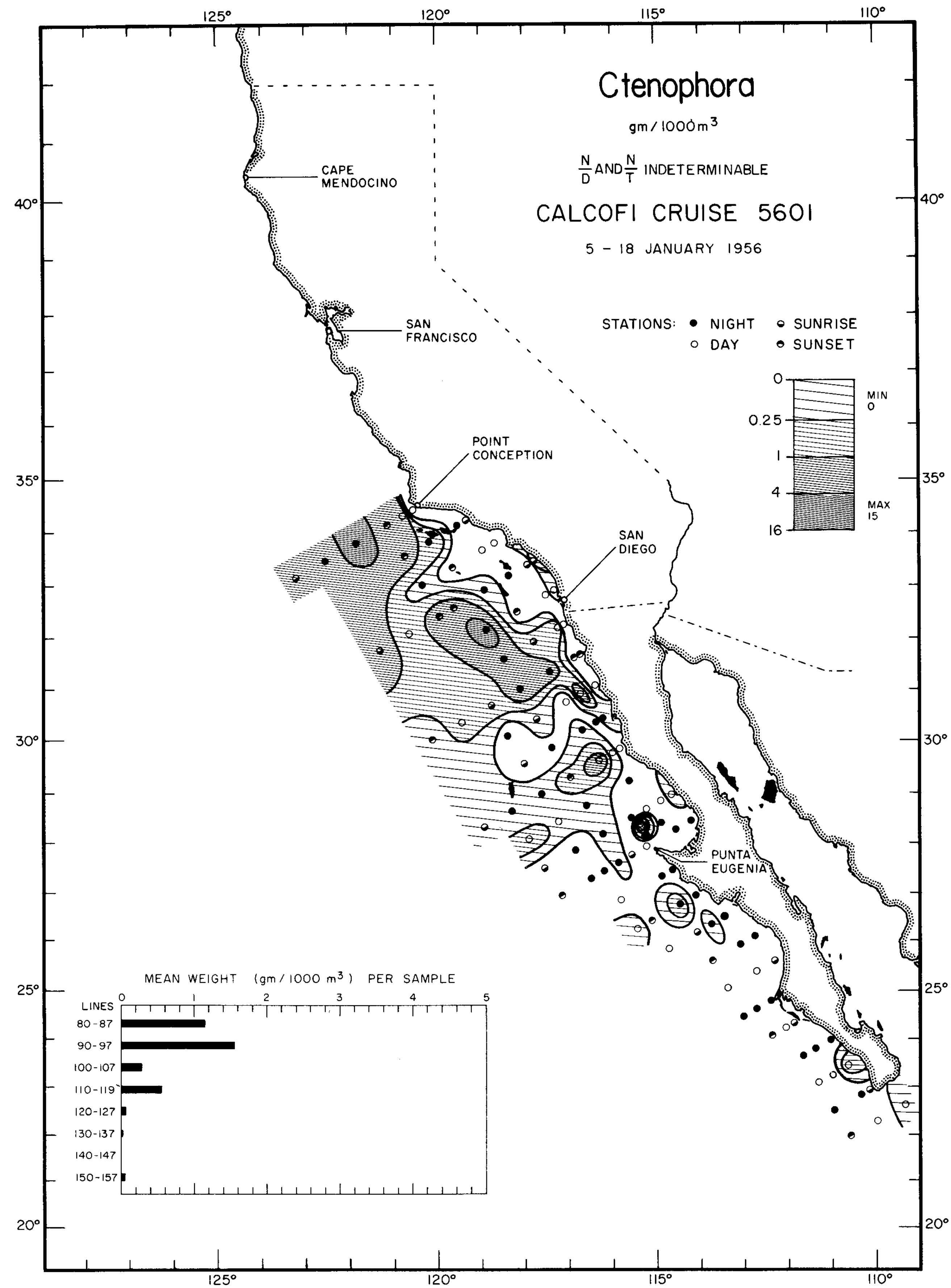
Biomass

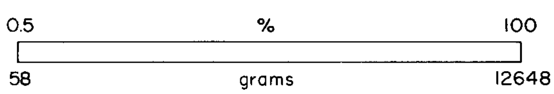
Crustacean larvae

5901



Biomass
Ctenophora
5501

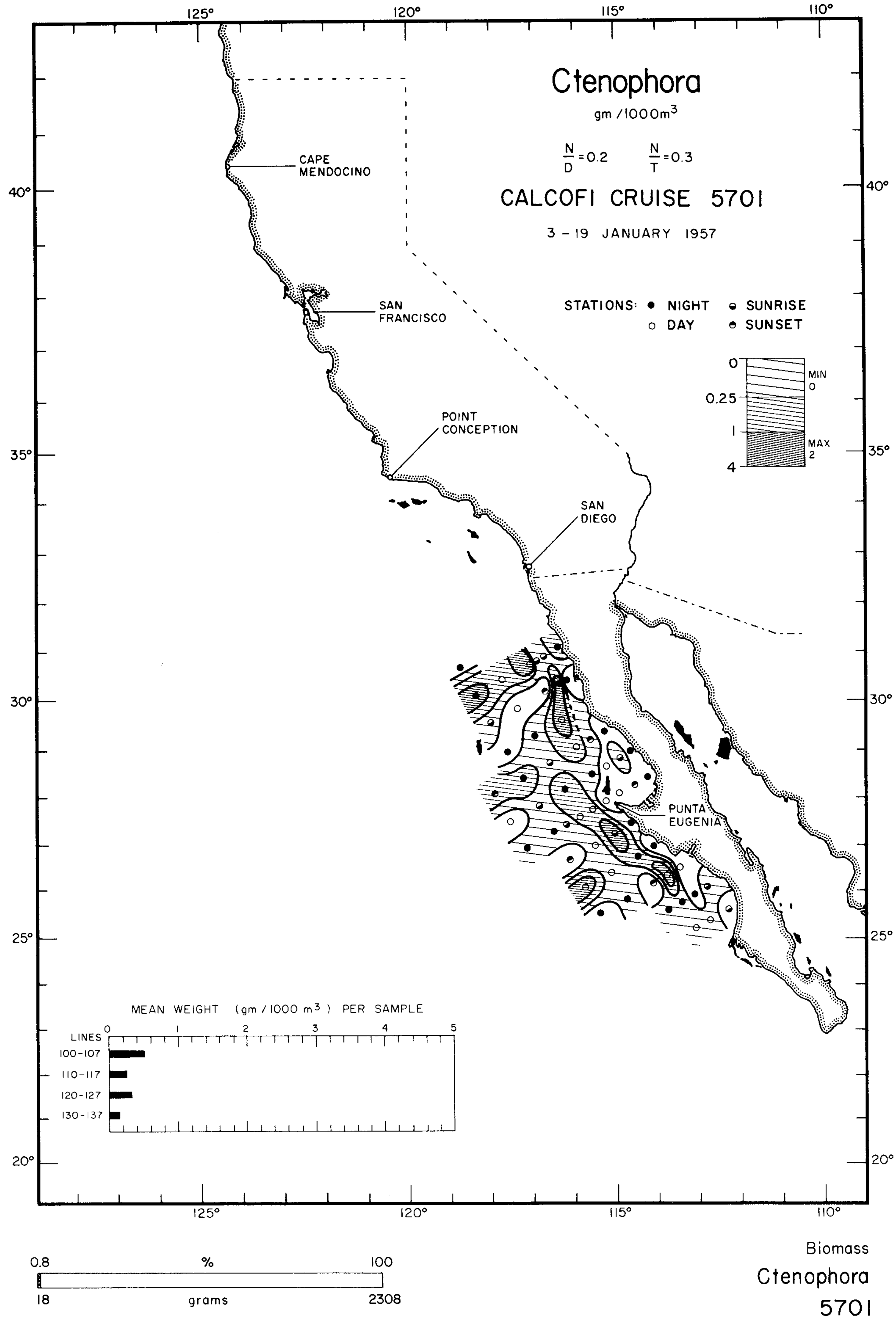




Biomass

Ctenophora

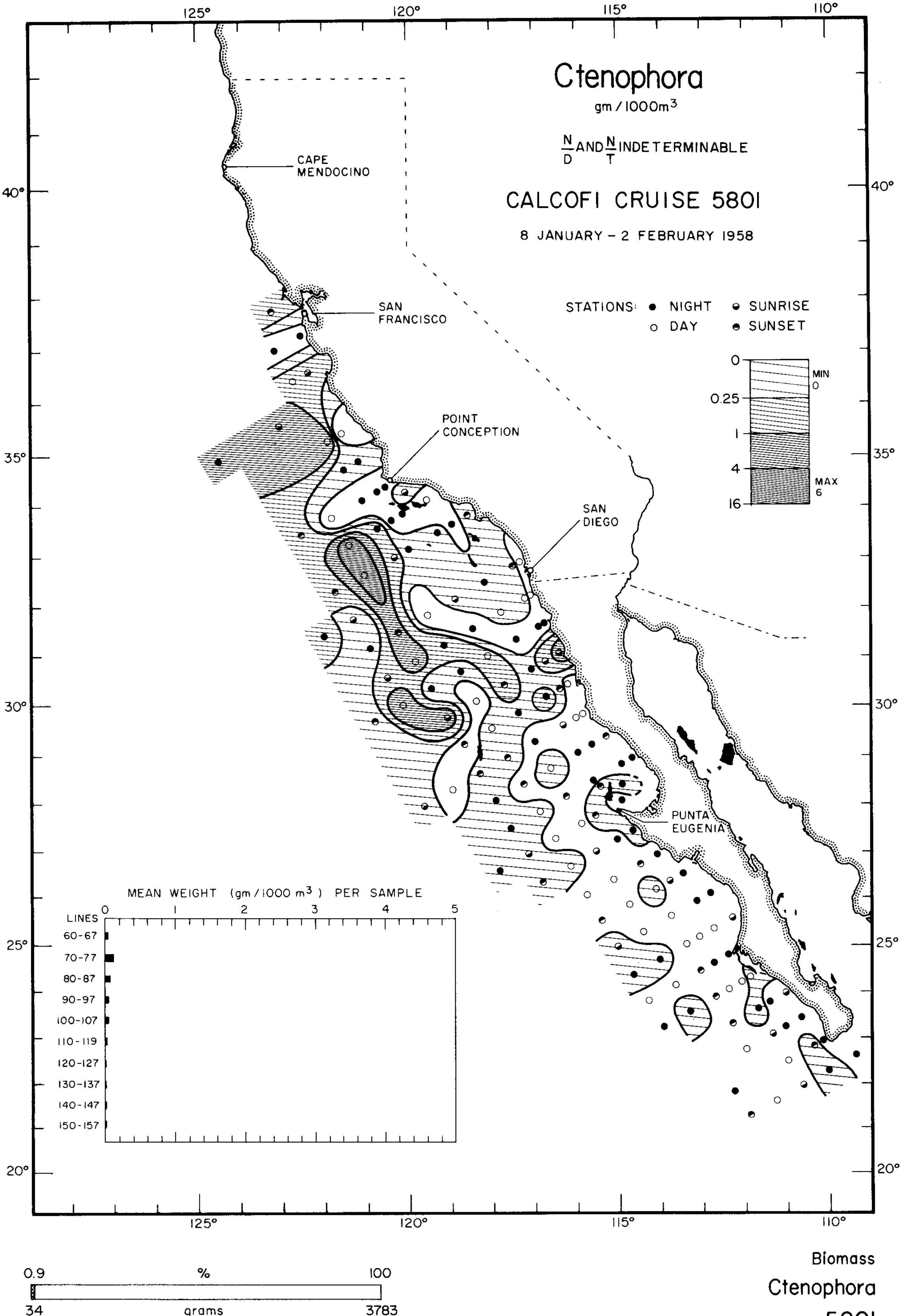
5601



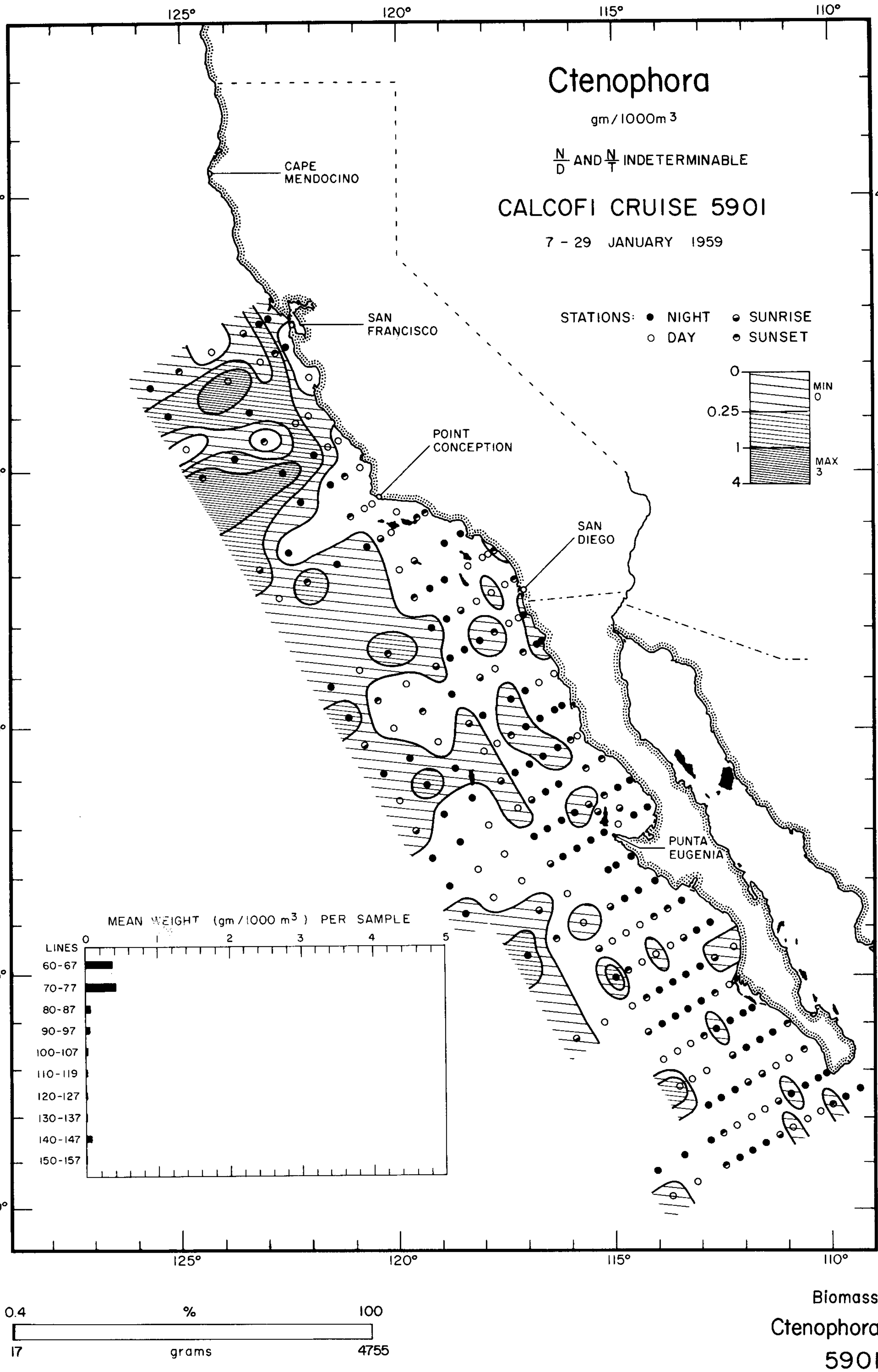
Biomass

Ctenophora

5701



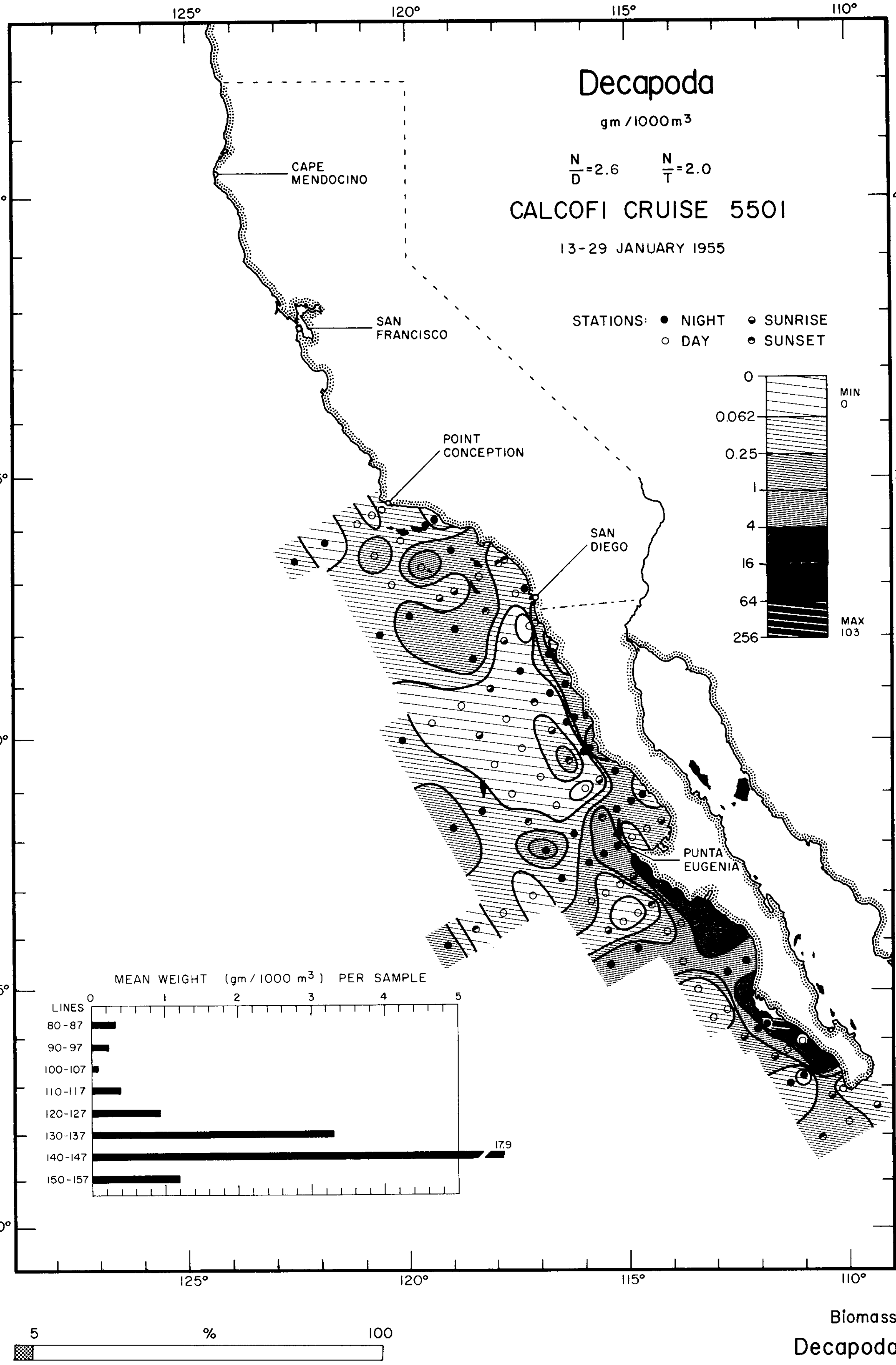
Biomass
Ctenophora
5801



Biomass

Ctenophora

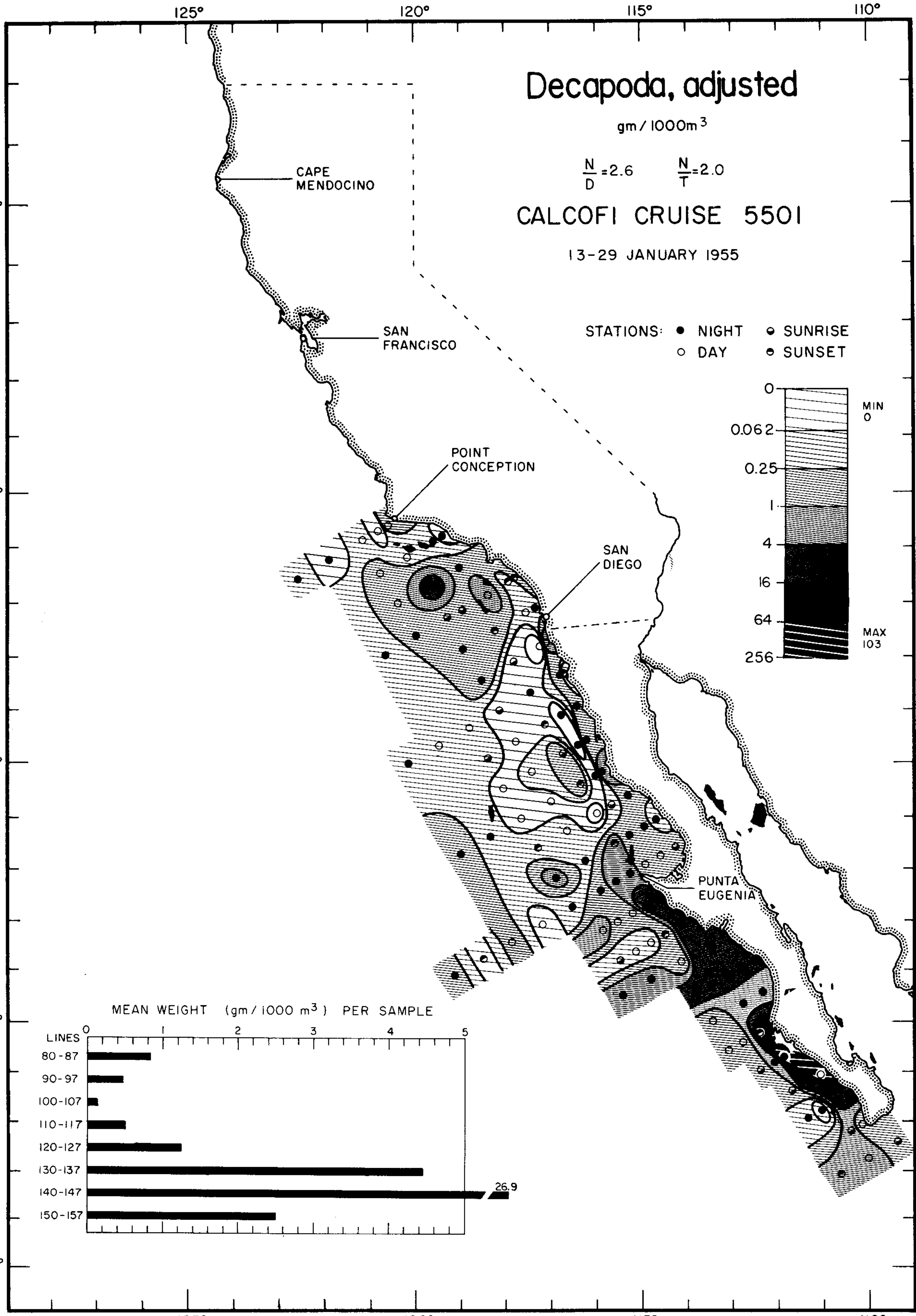
5901



Biomass

Decapoda

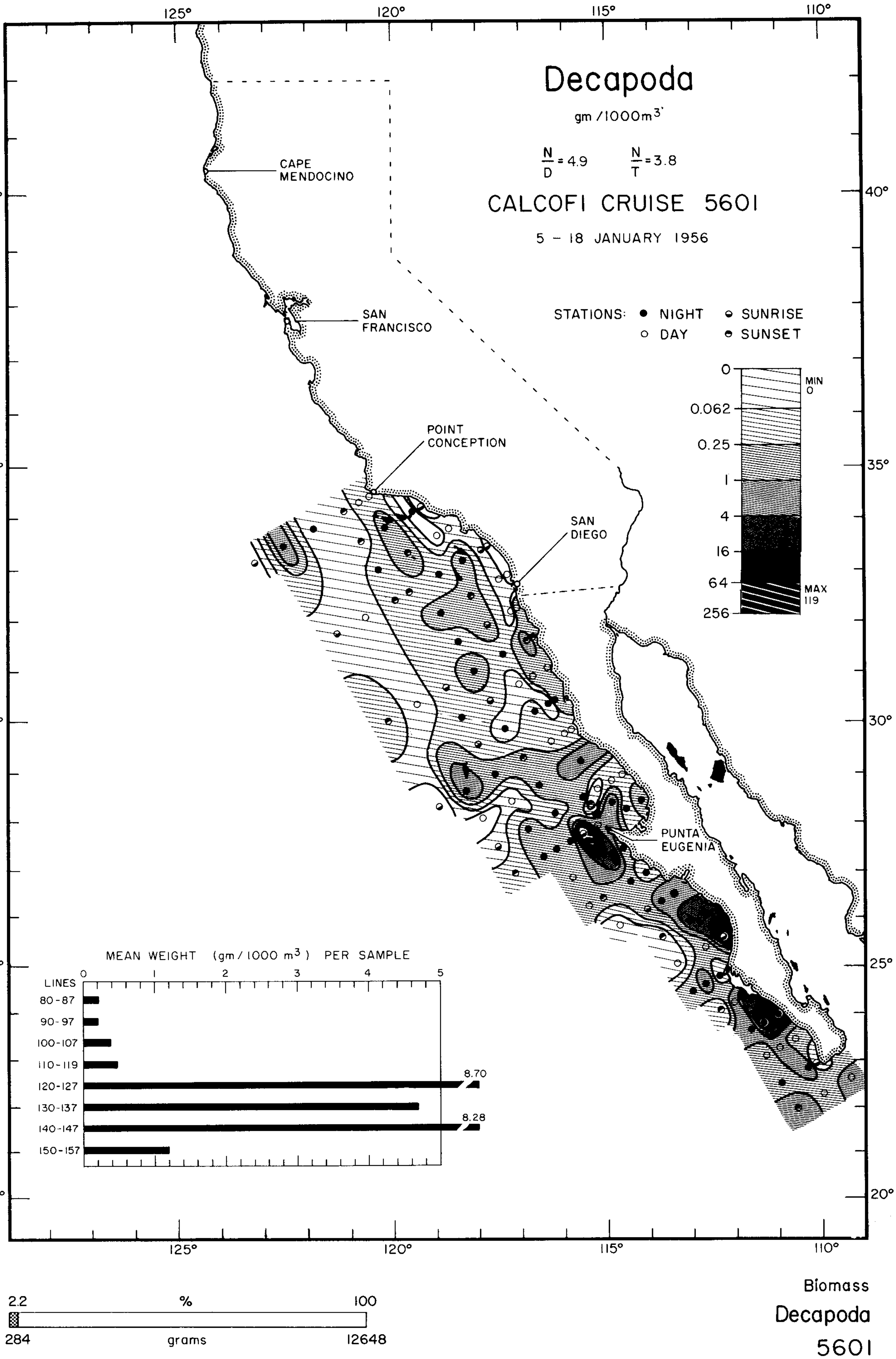
5501



Biomass

Decapoda, adjusted

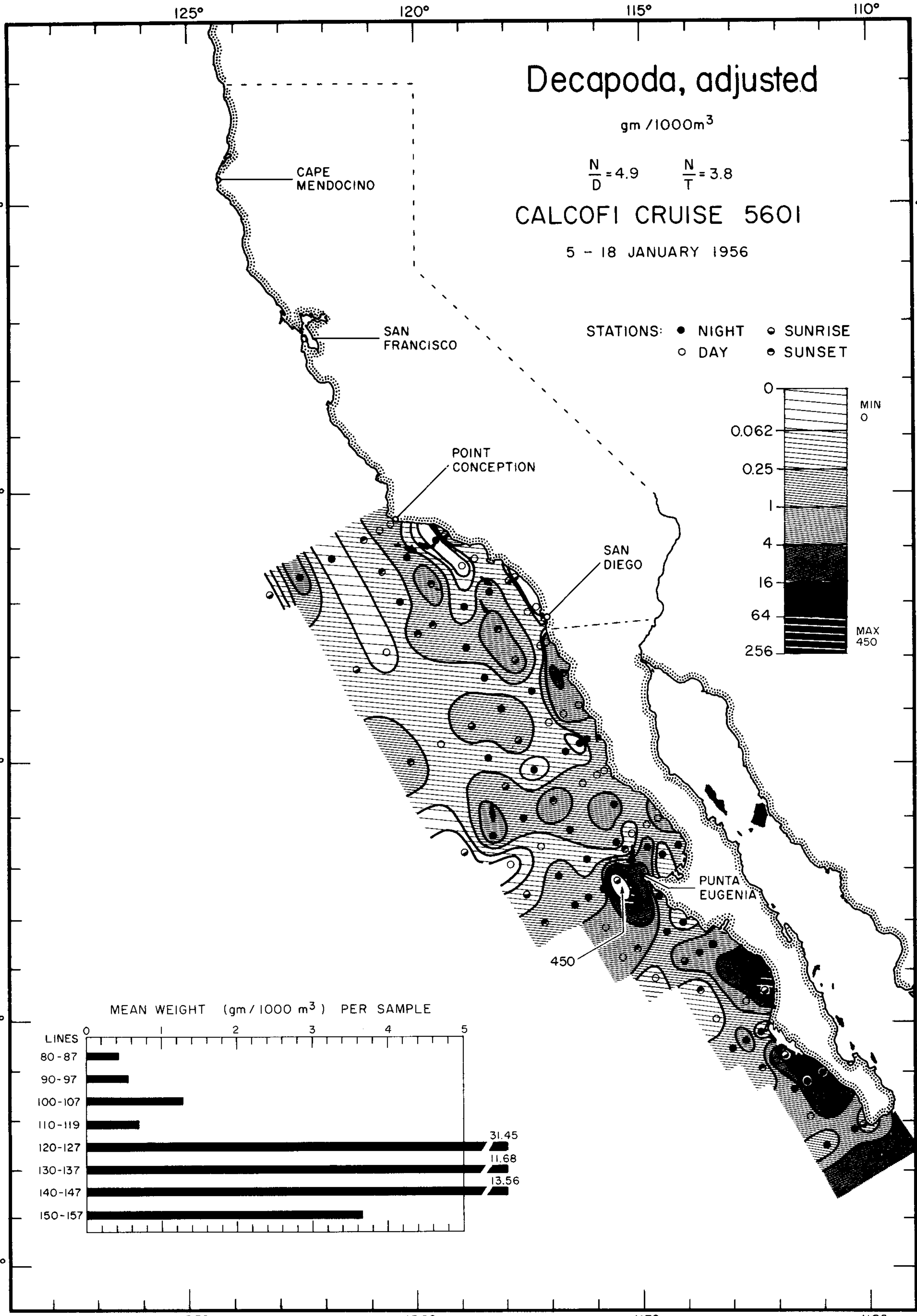
5501



Biomass

Decapoda

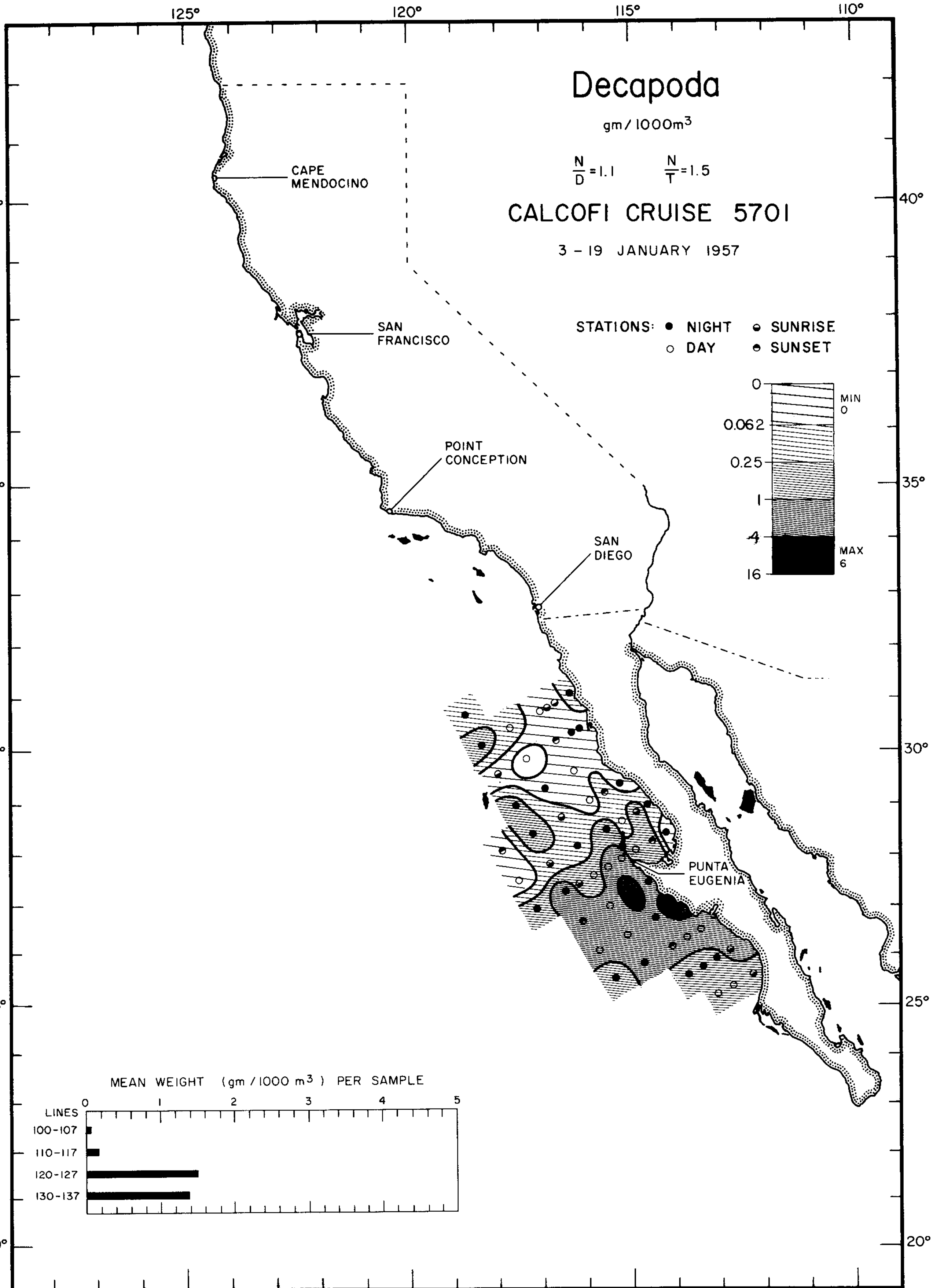
5601

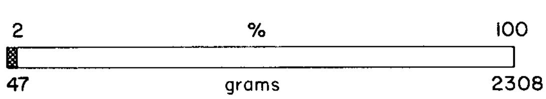


Biomass

Decapoda, adjusted

5601

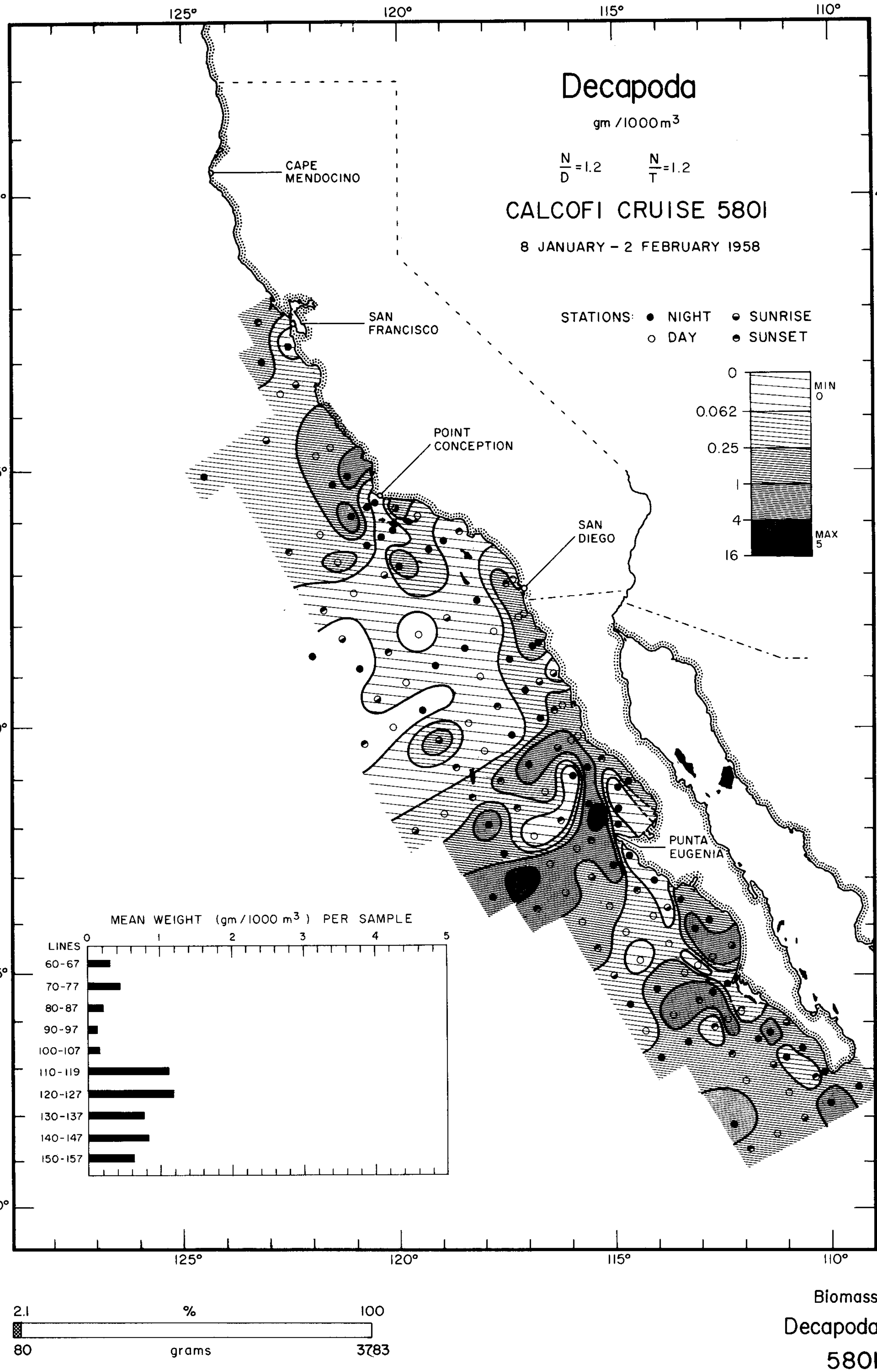




Biomass

Decapoda

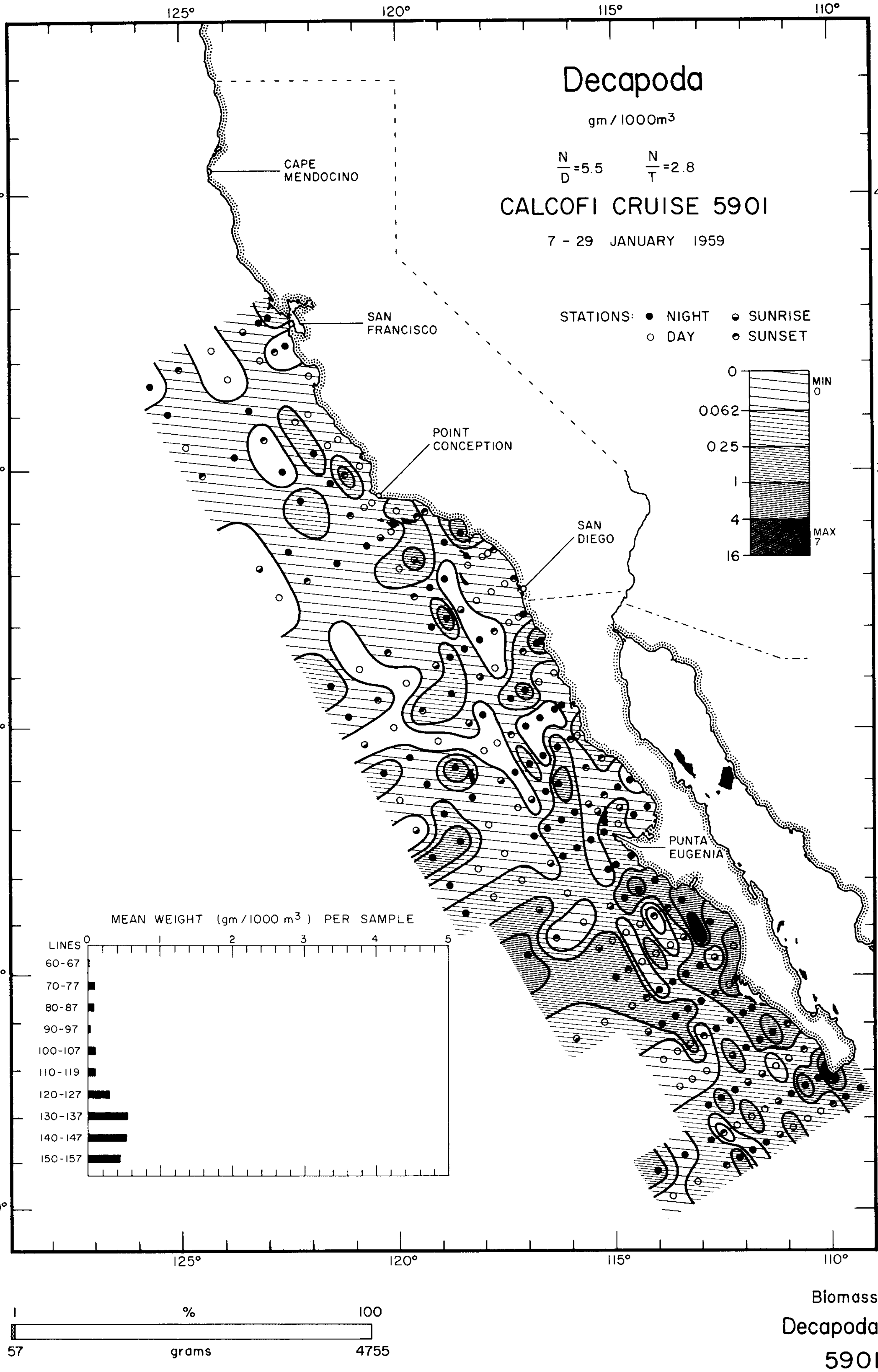
5701



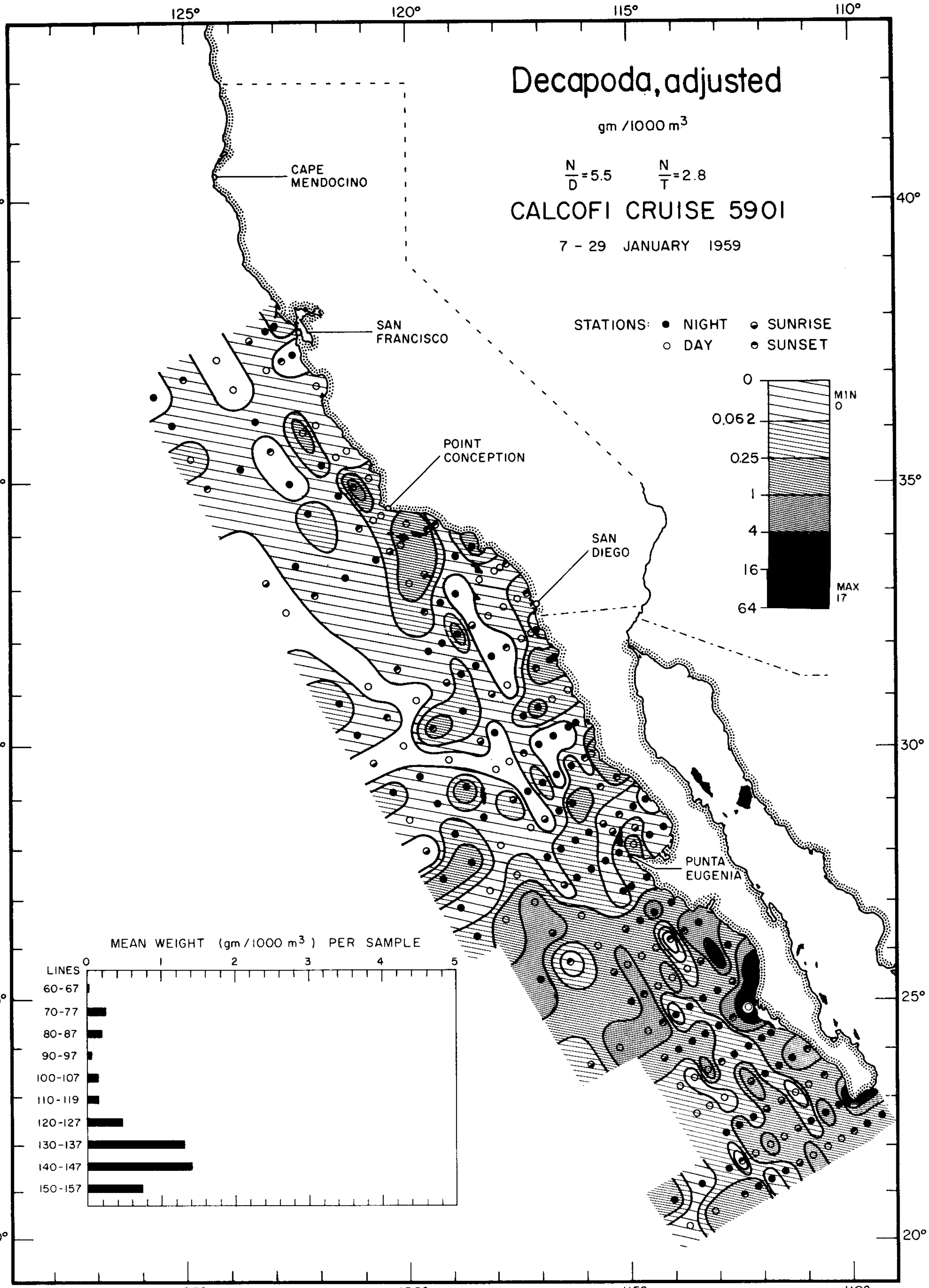
Biomass

Decapoda

5801



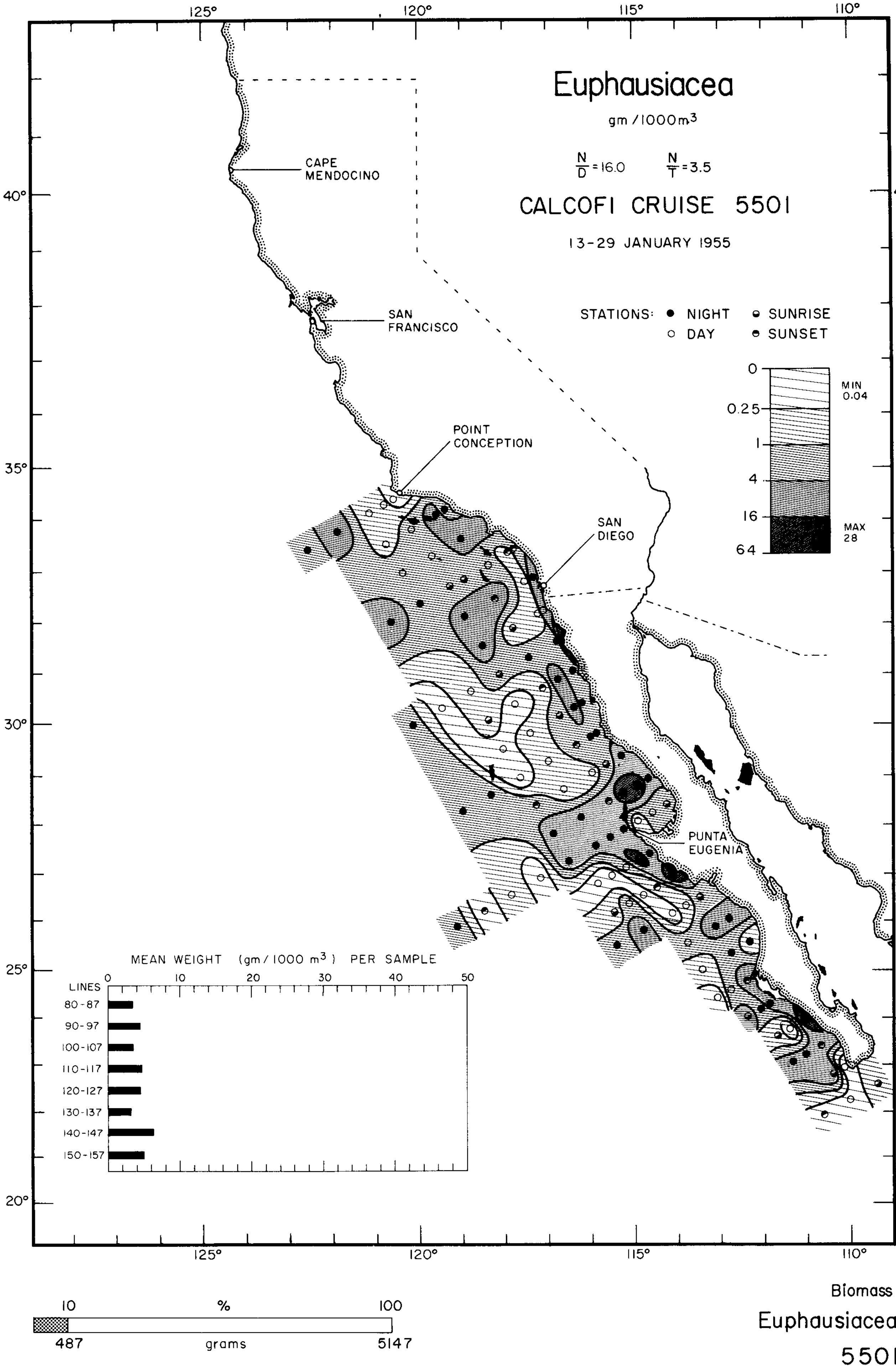
Biomass
Decapoda
5901



Biomass

Decapoda, adjusted

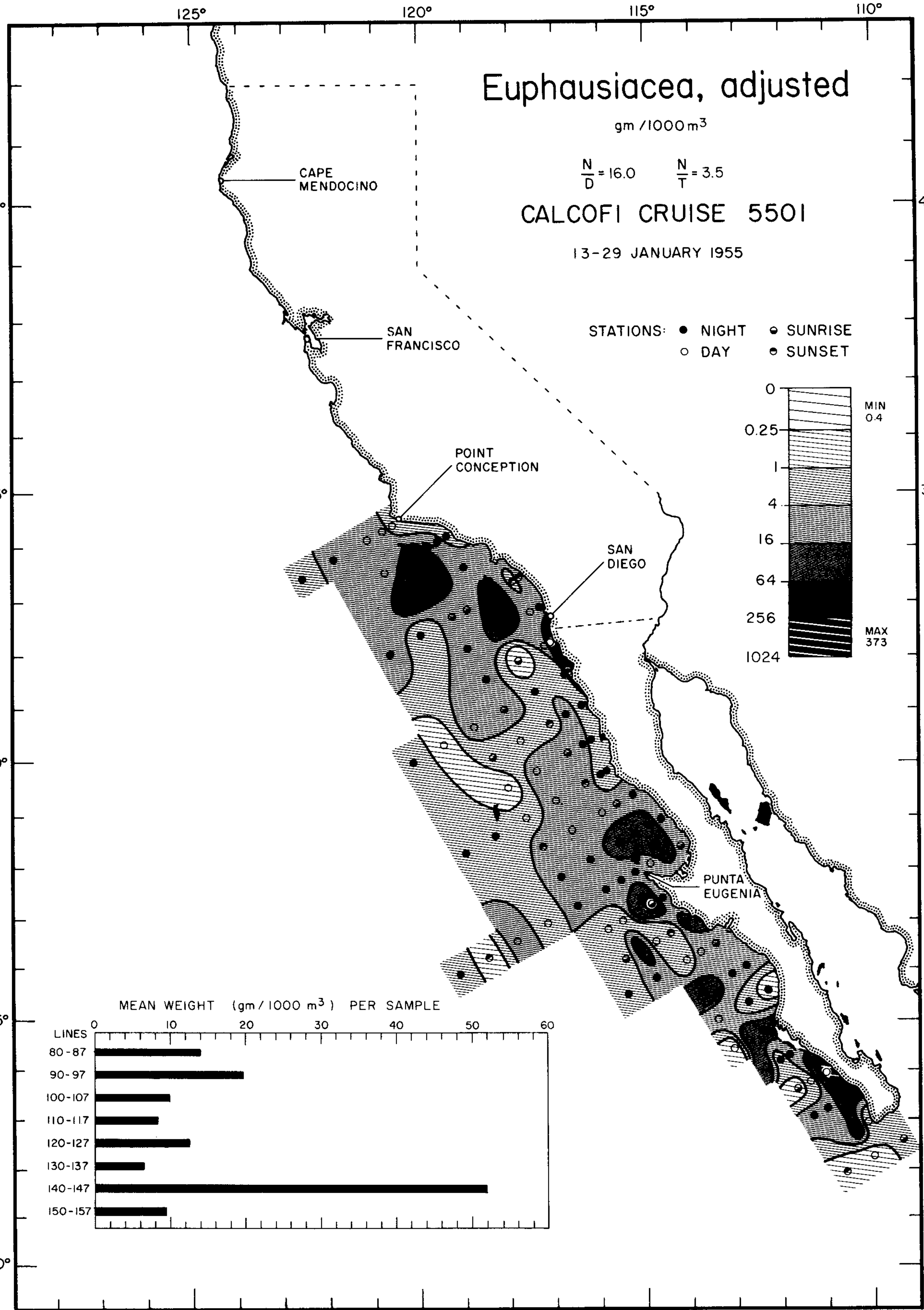
5901



Biomass

Euphausiacea

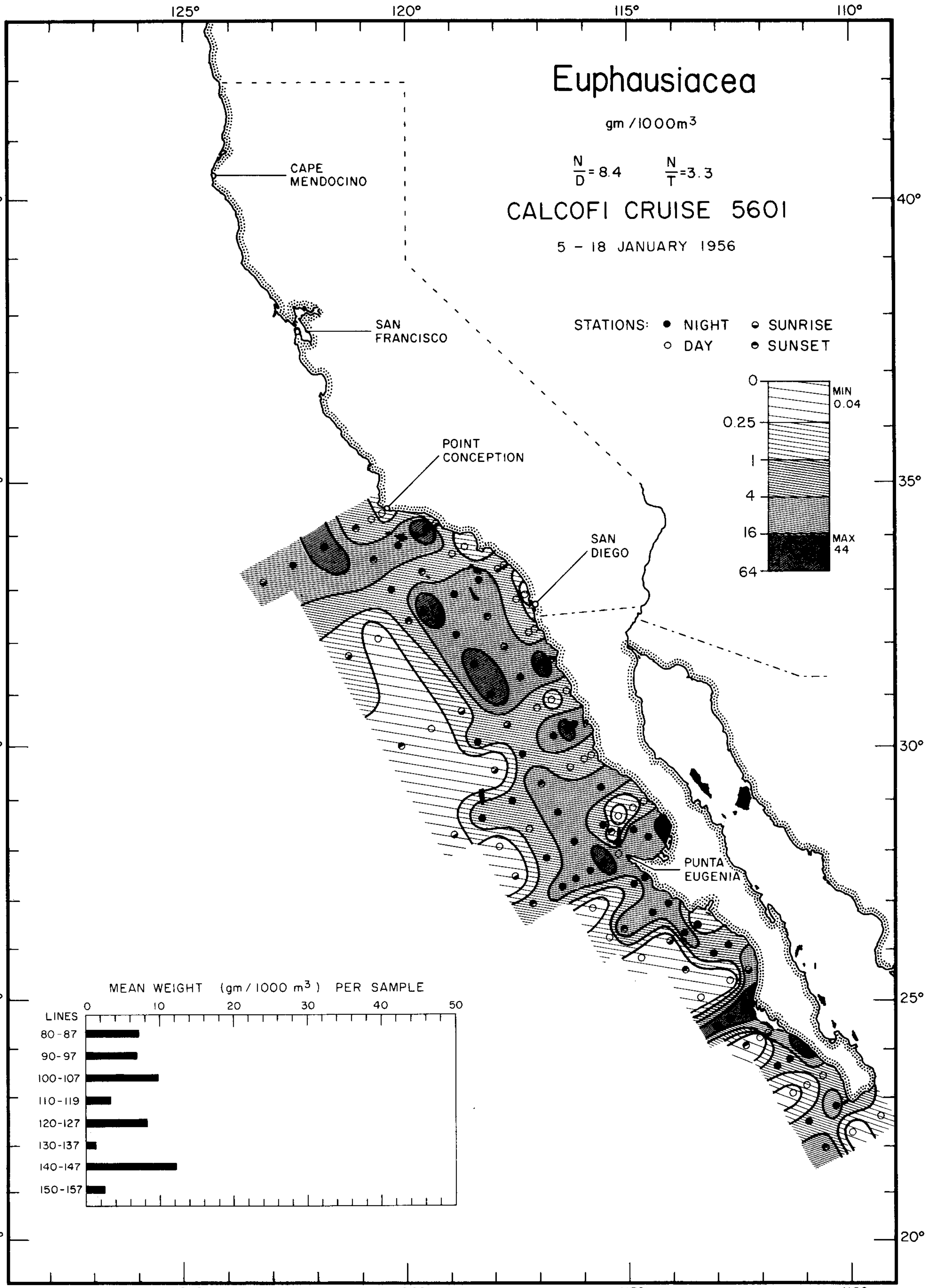
5501



Biomass

Euphausiacea, adjusted

5501



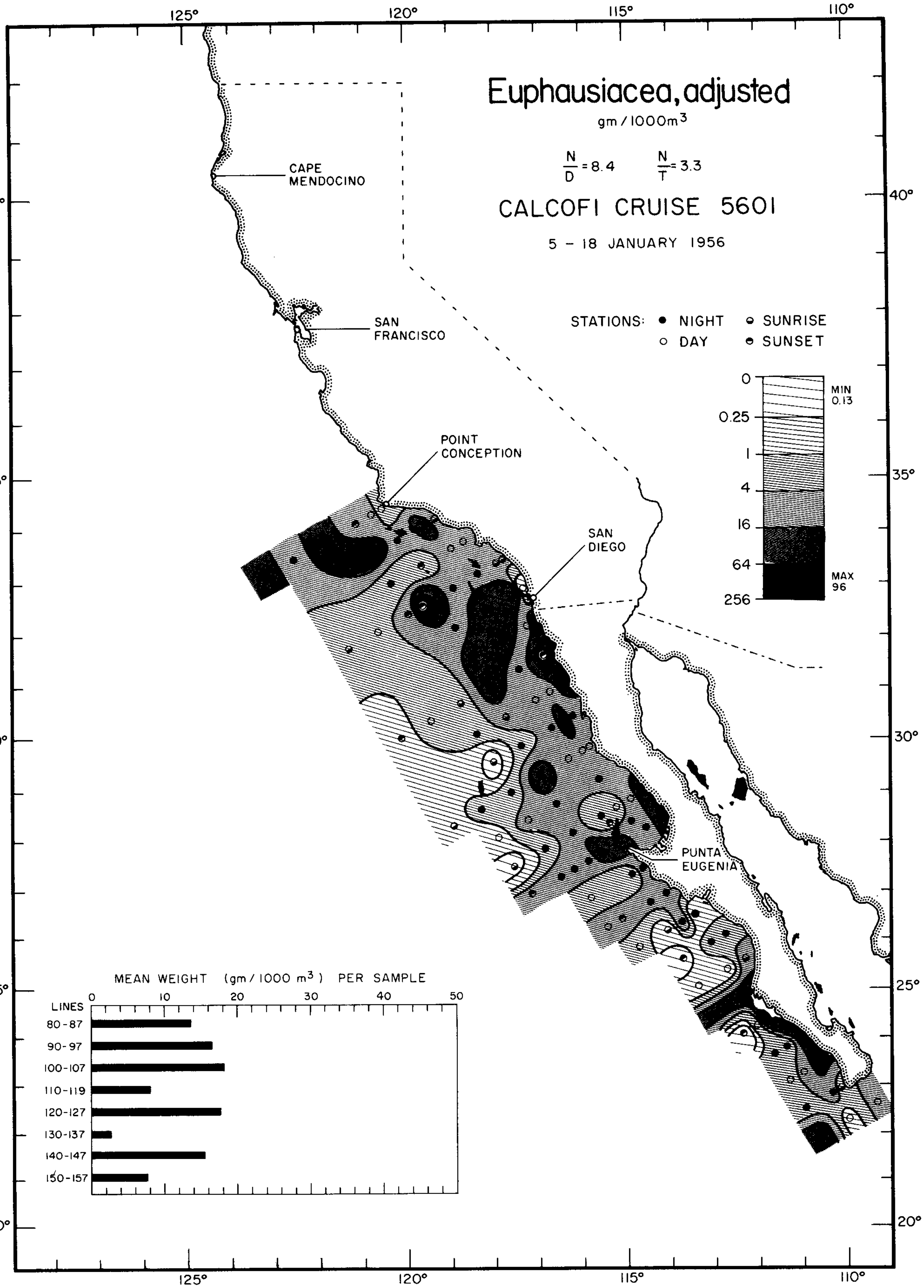
57 % 100

723 grams 12648

Biomass

Euphausiacea

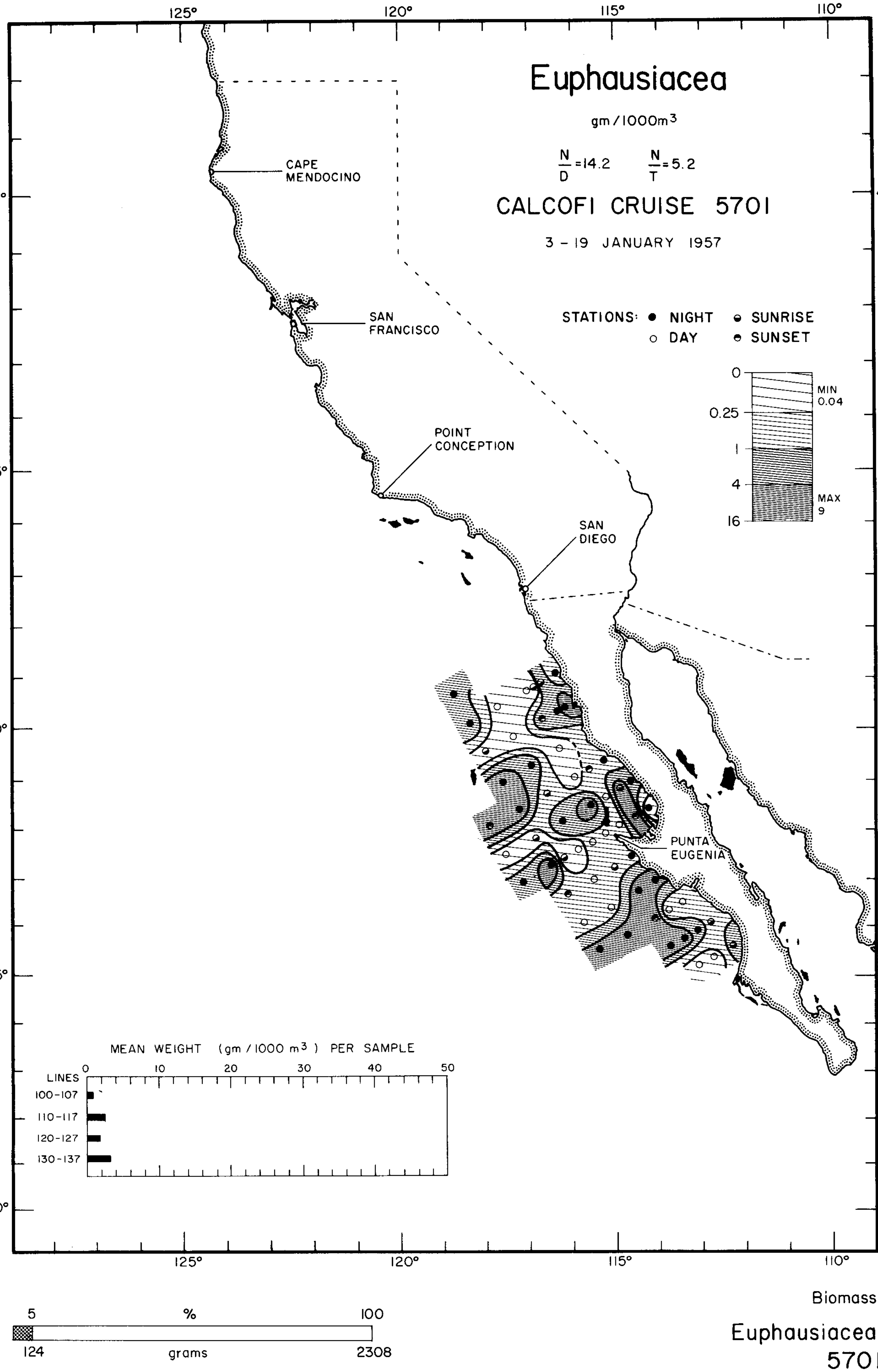
5601



Biomass

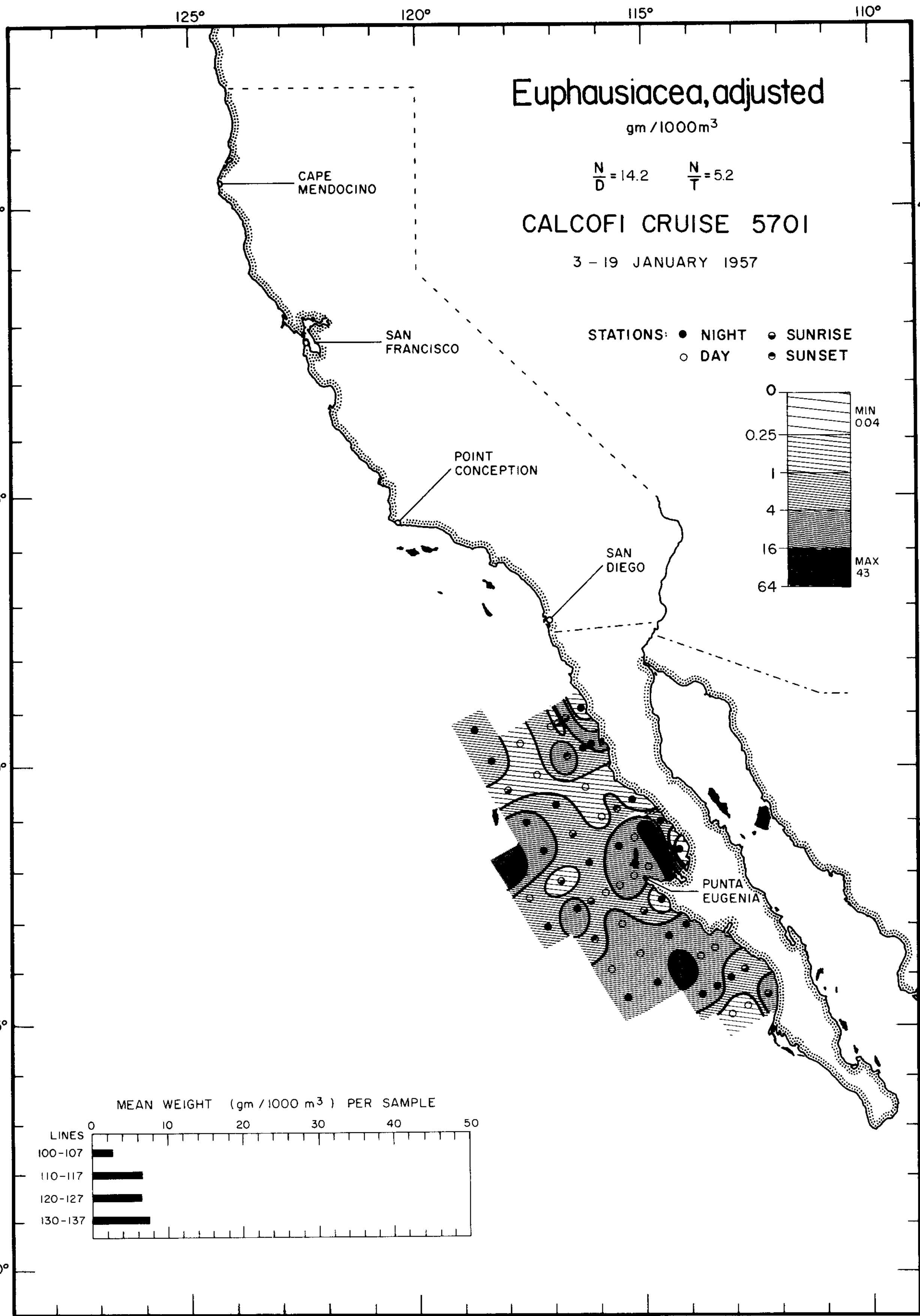
Euphausiacea, adjusted

5601



Biomass

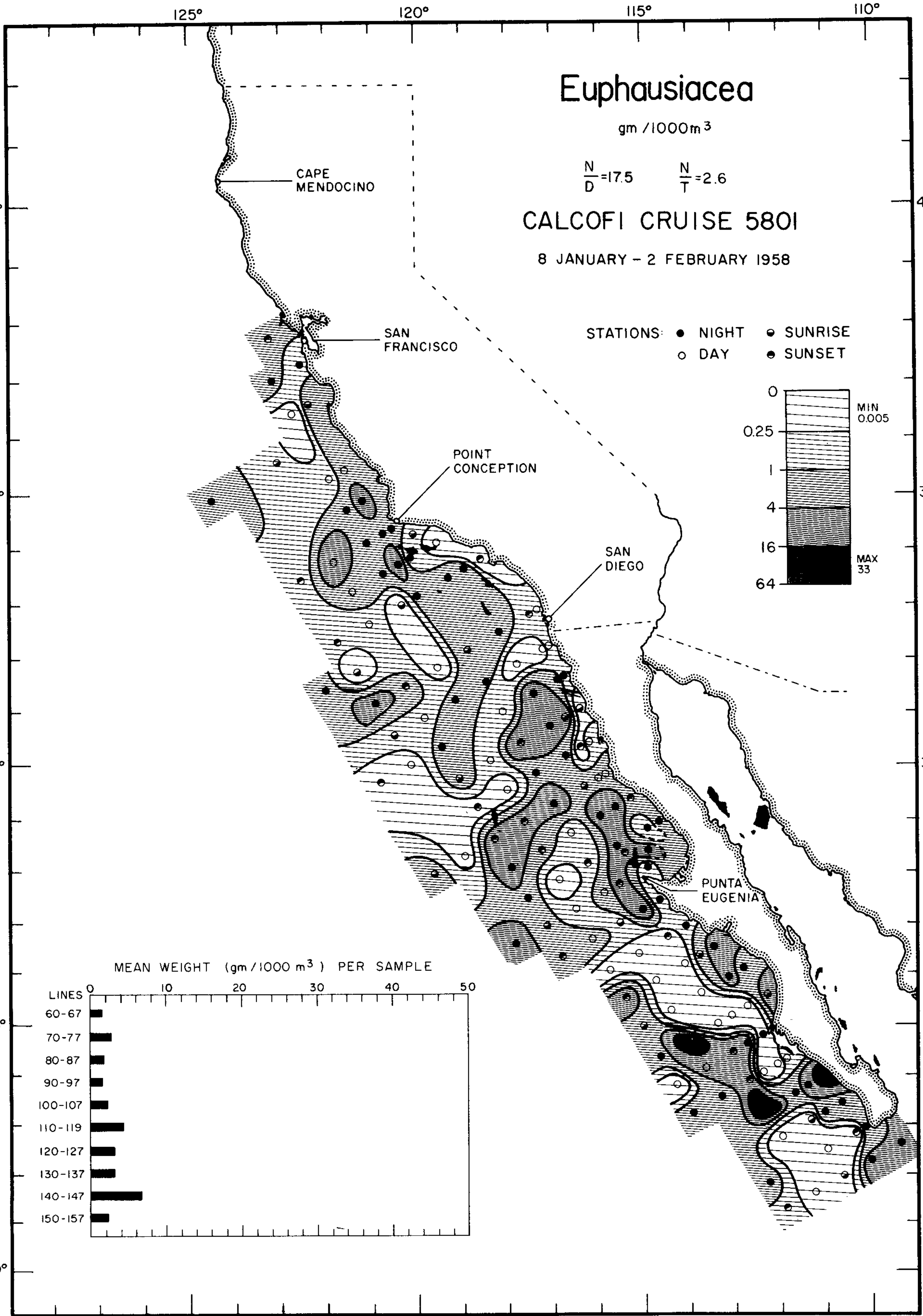
Euphausiacea
5701

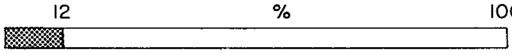


Biomass

Euphausiacea, adjusted

5701

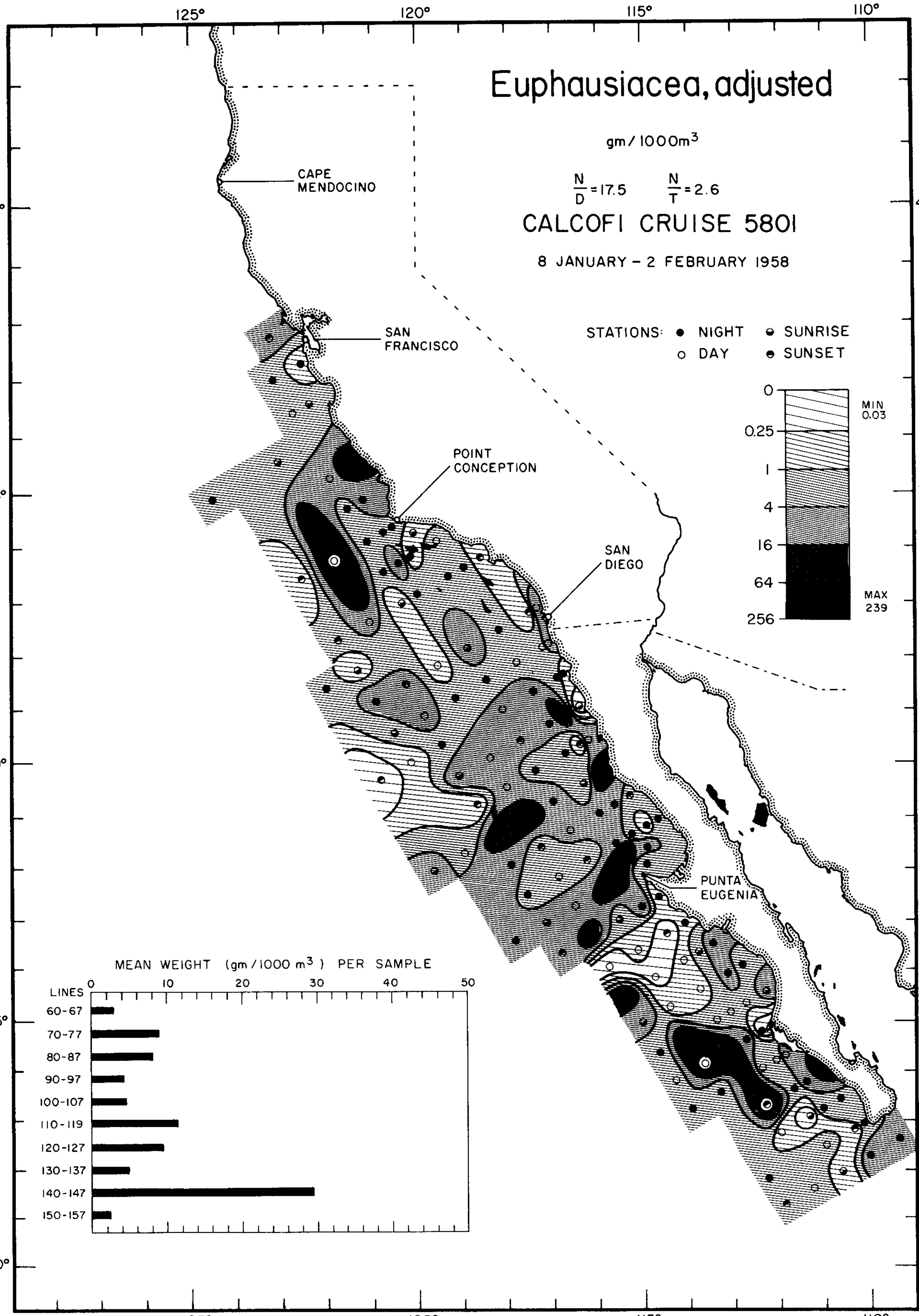




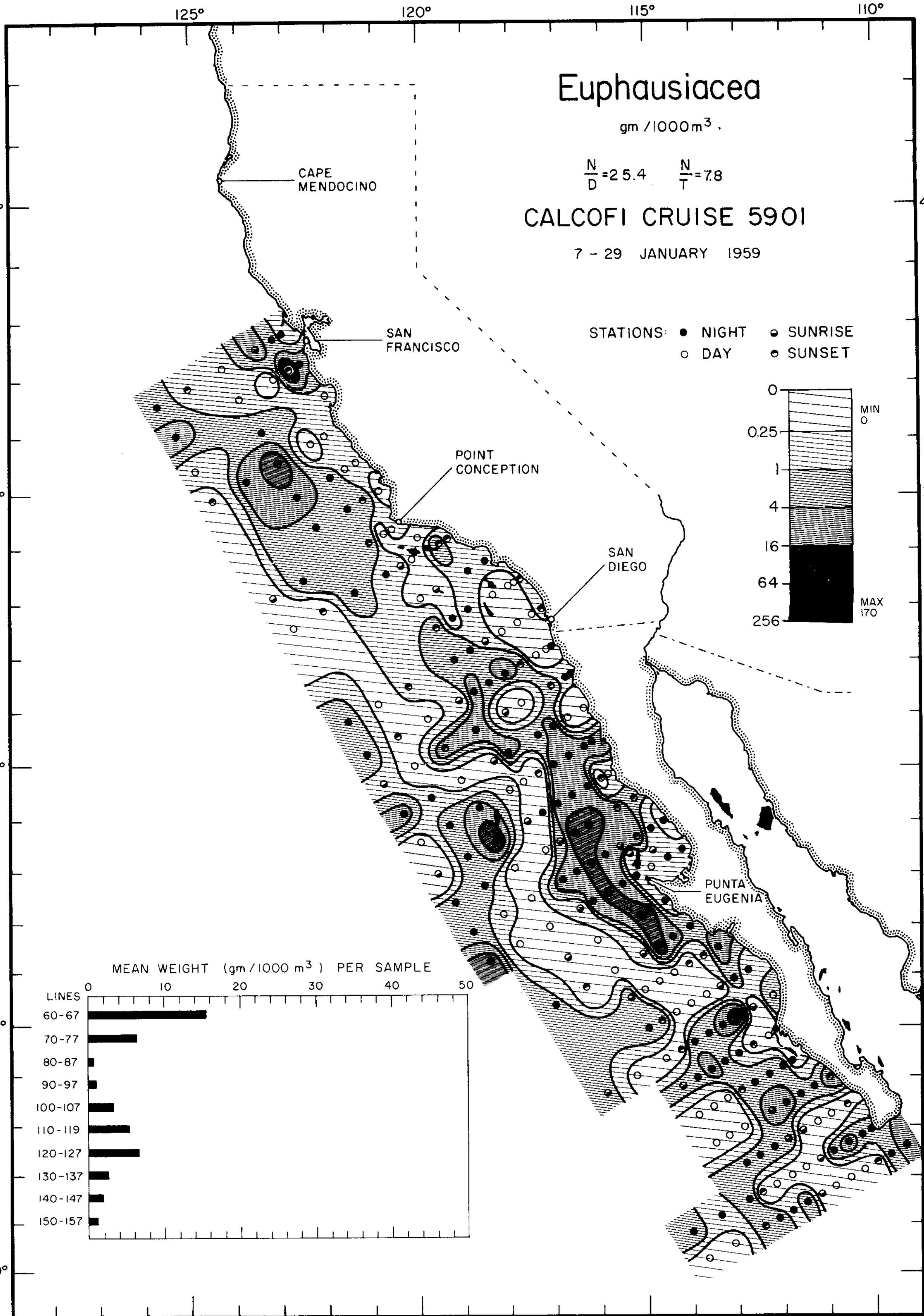
Biomass

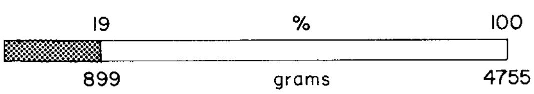
Euphausiacea

5801

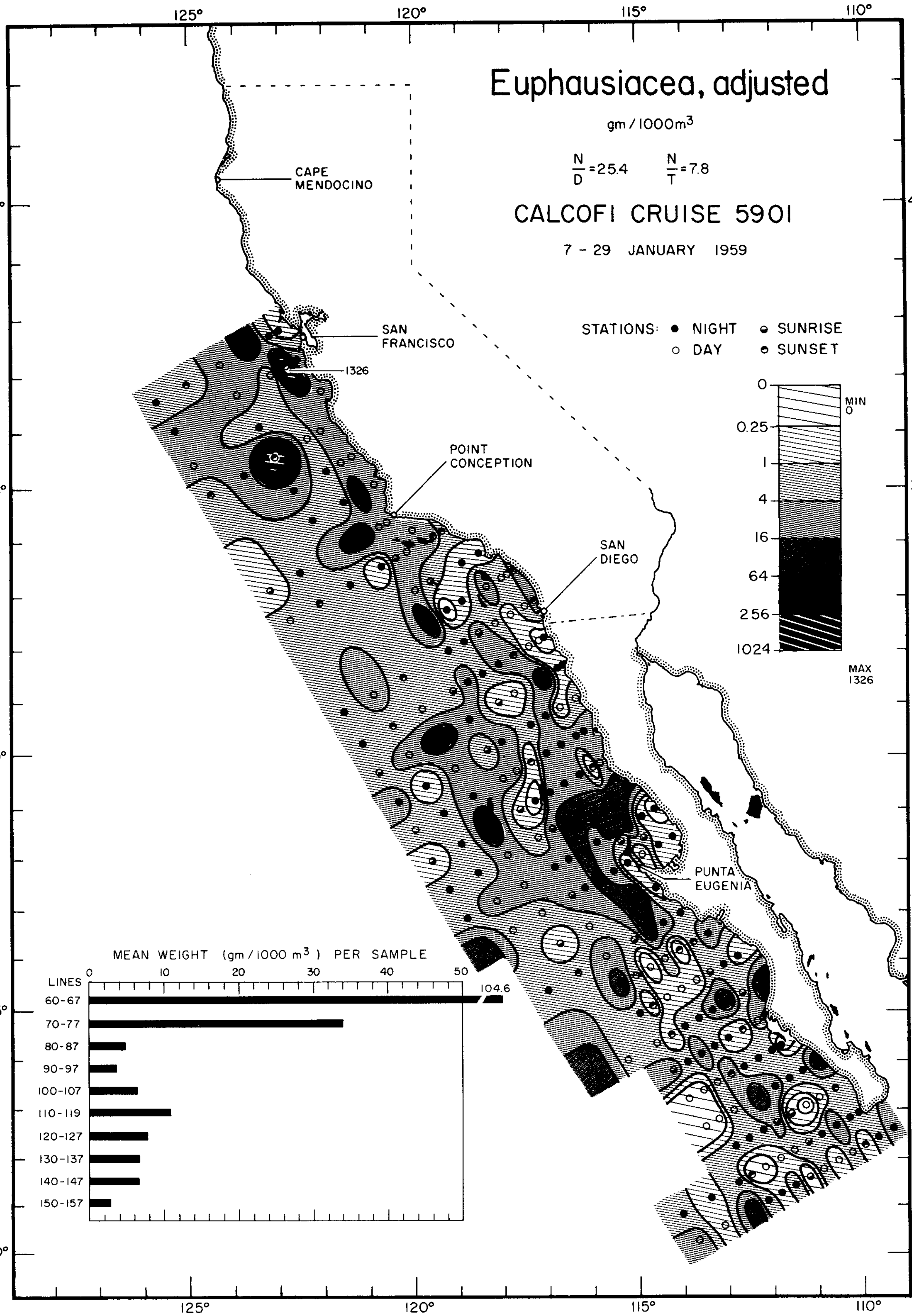


Biomass
Euphausiacea, adjusted
5801





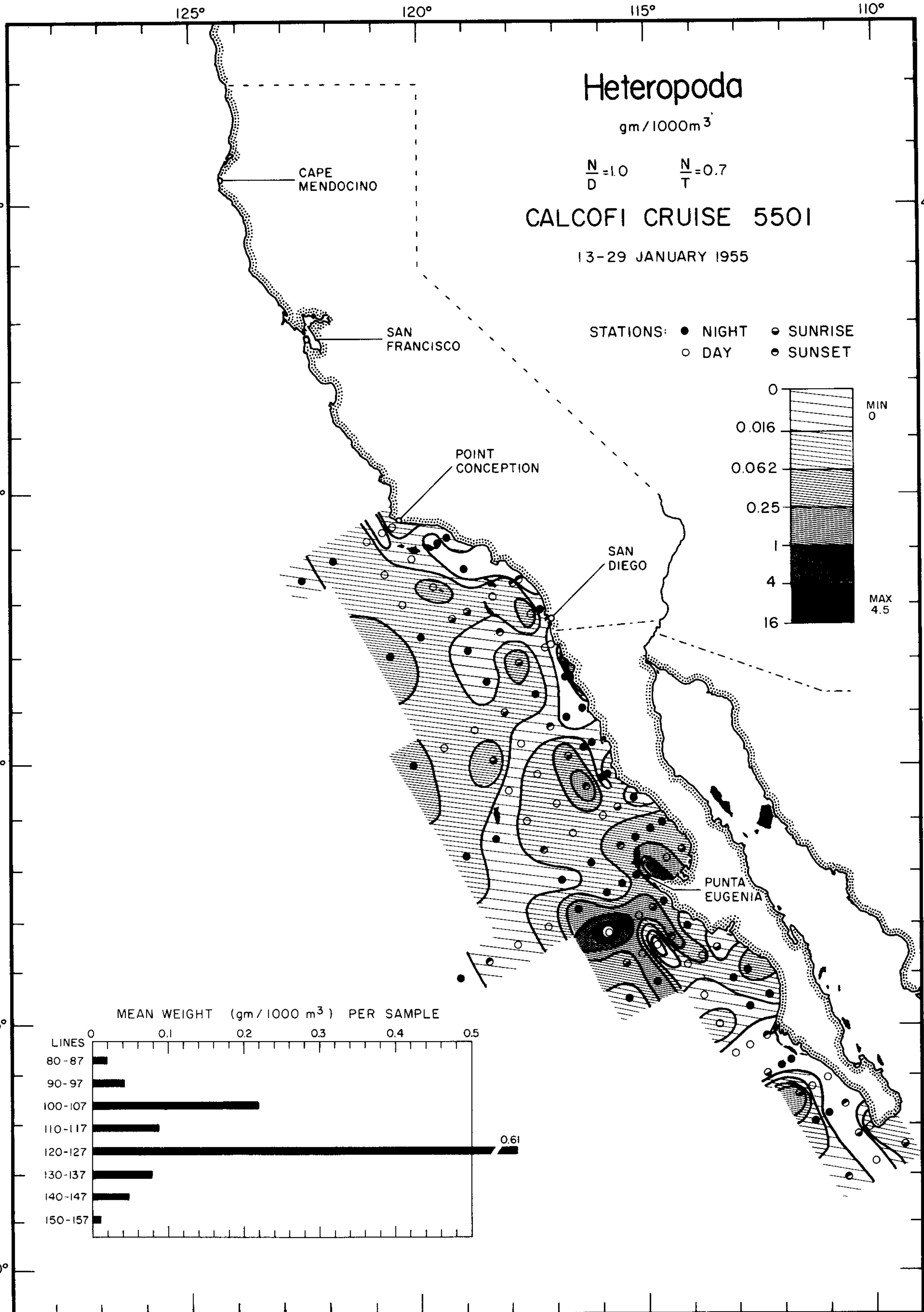
Biomass
Euphausiacea
5901



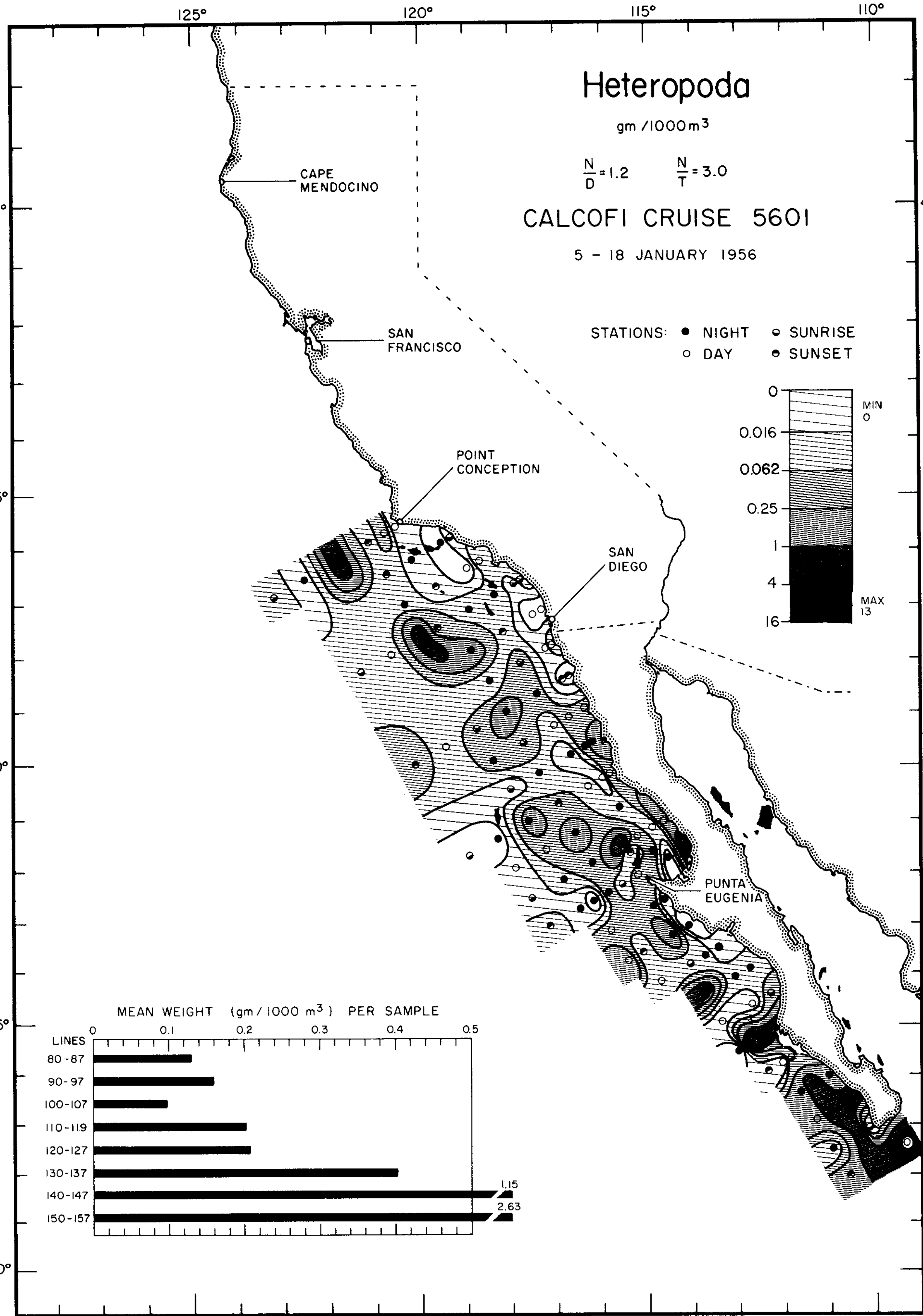
Biomass

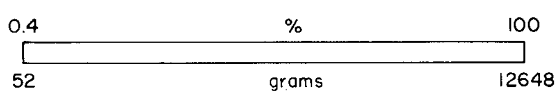
Euphausiacea, adjusted

5901



Biomass
Heteropoda
5501

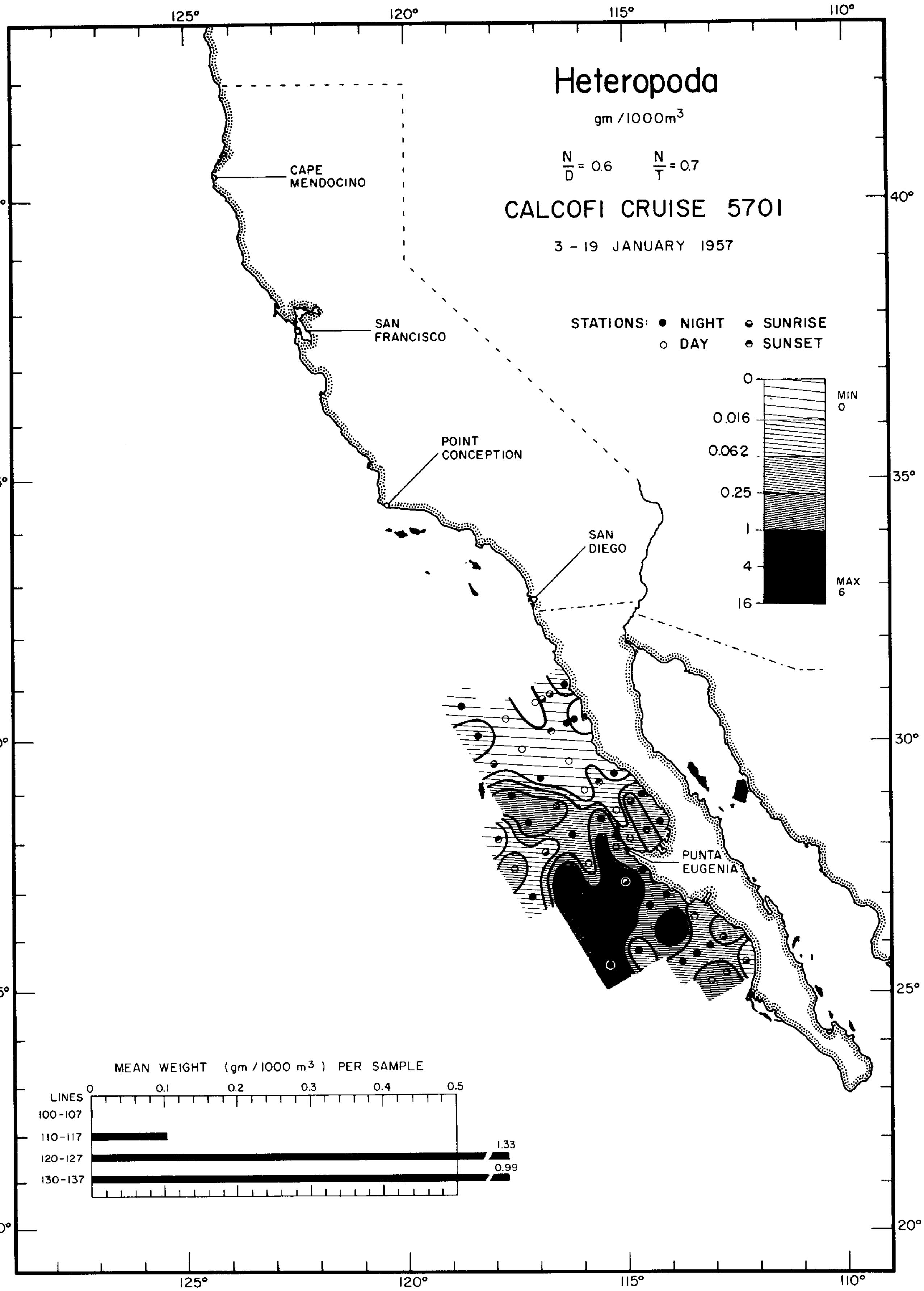


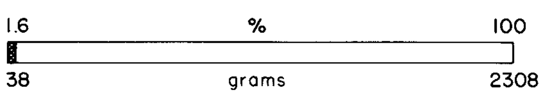


Biomass

Heteropoda

5601

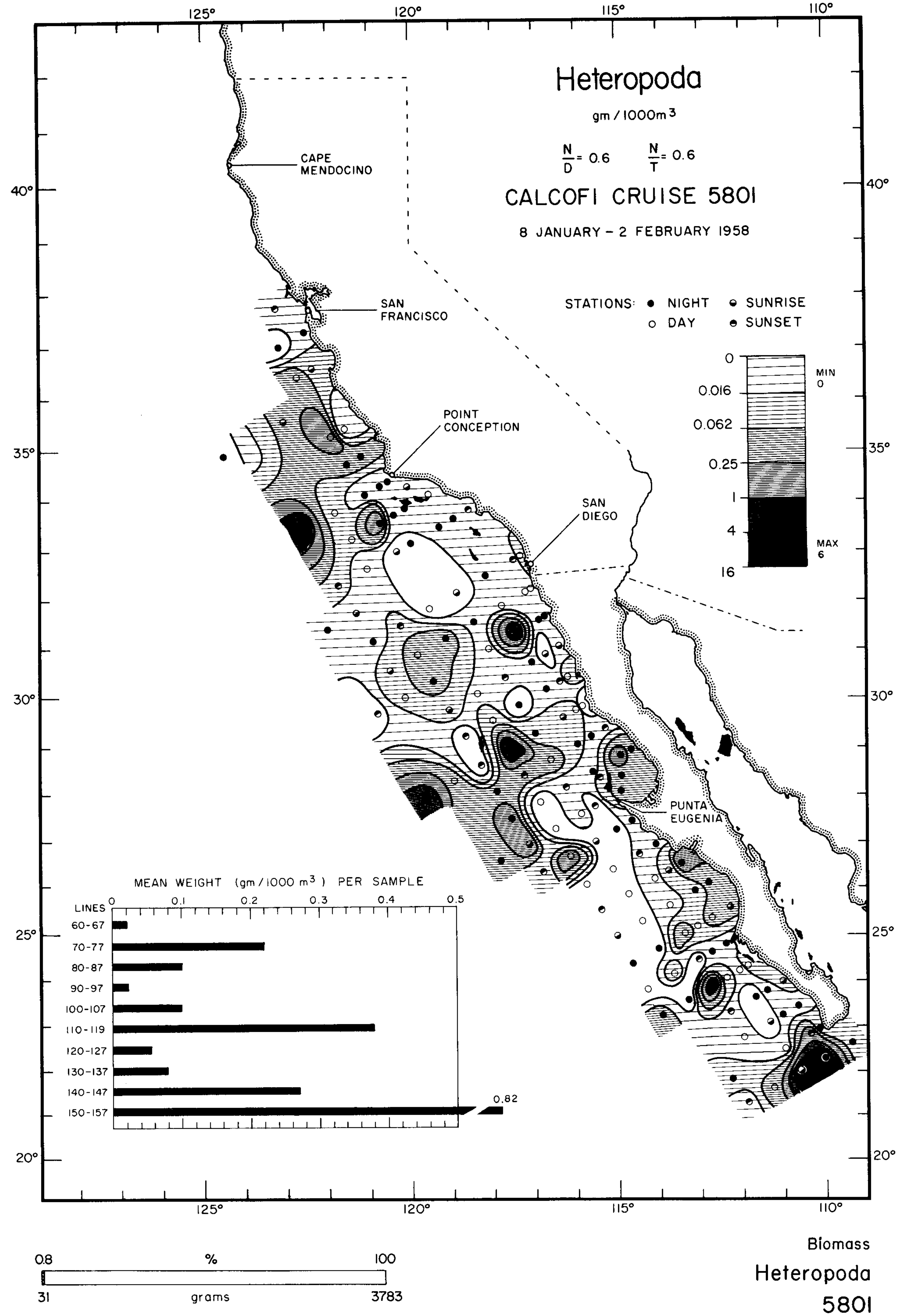




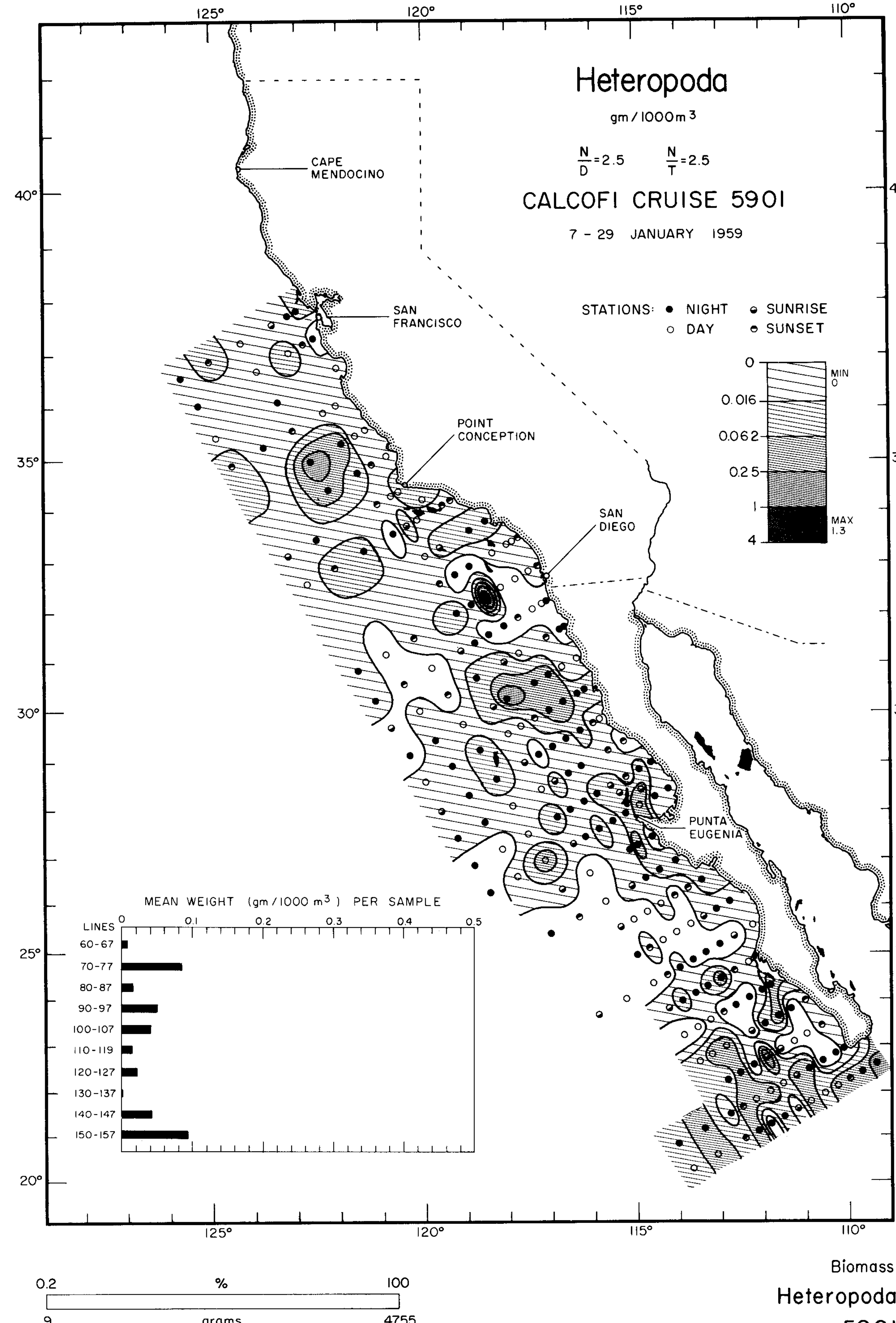
Biomass

Heteropoda

5701



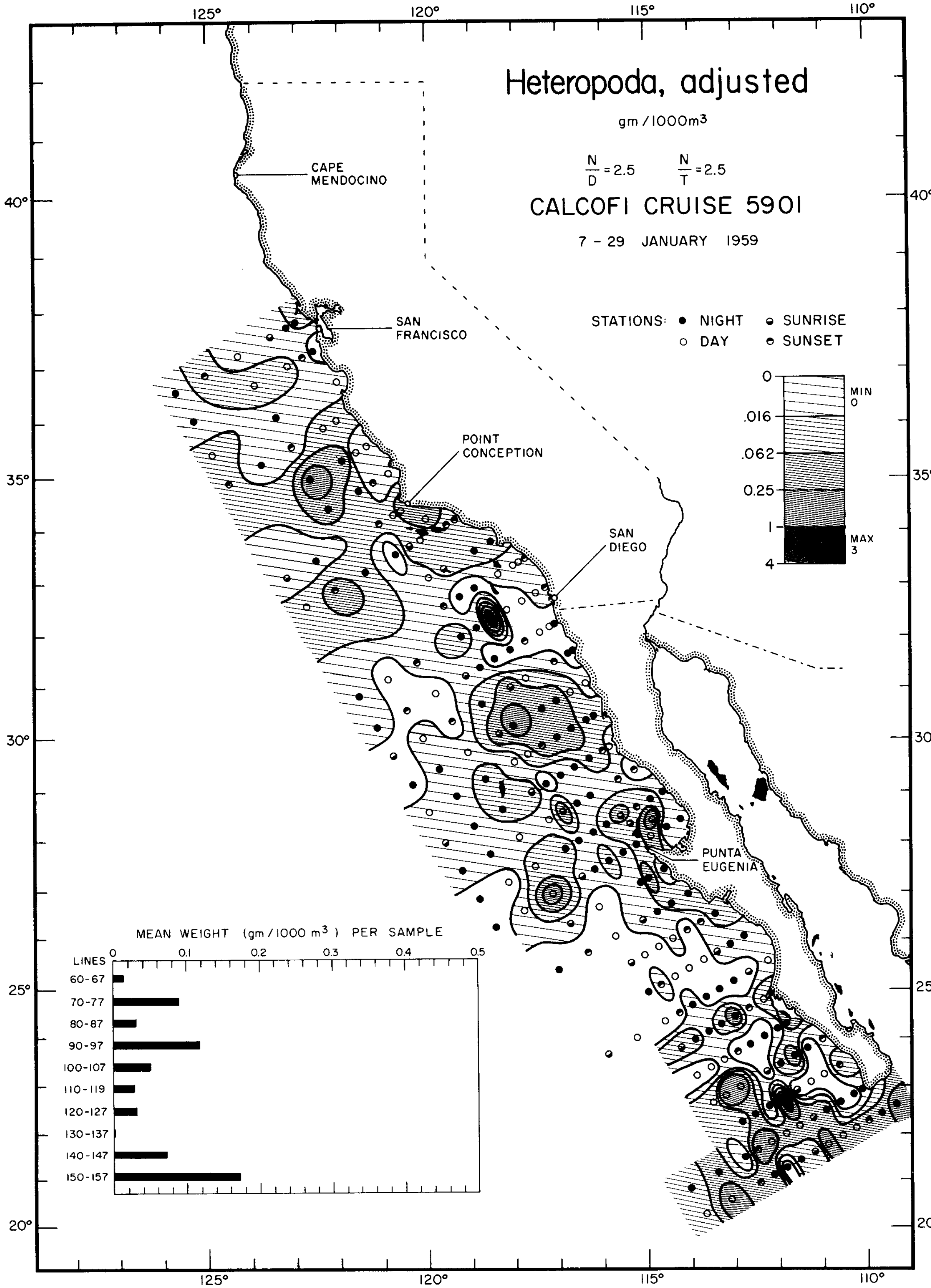
Biomass
Heteropoda
5801



Biomass

Heteropoda

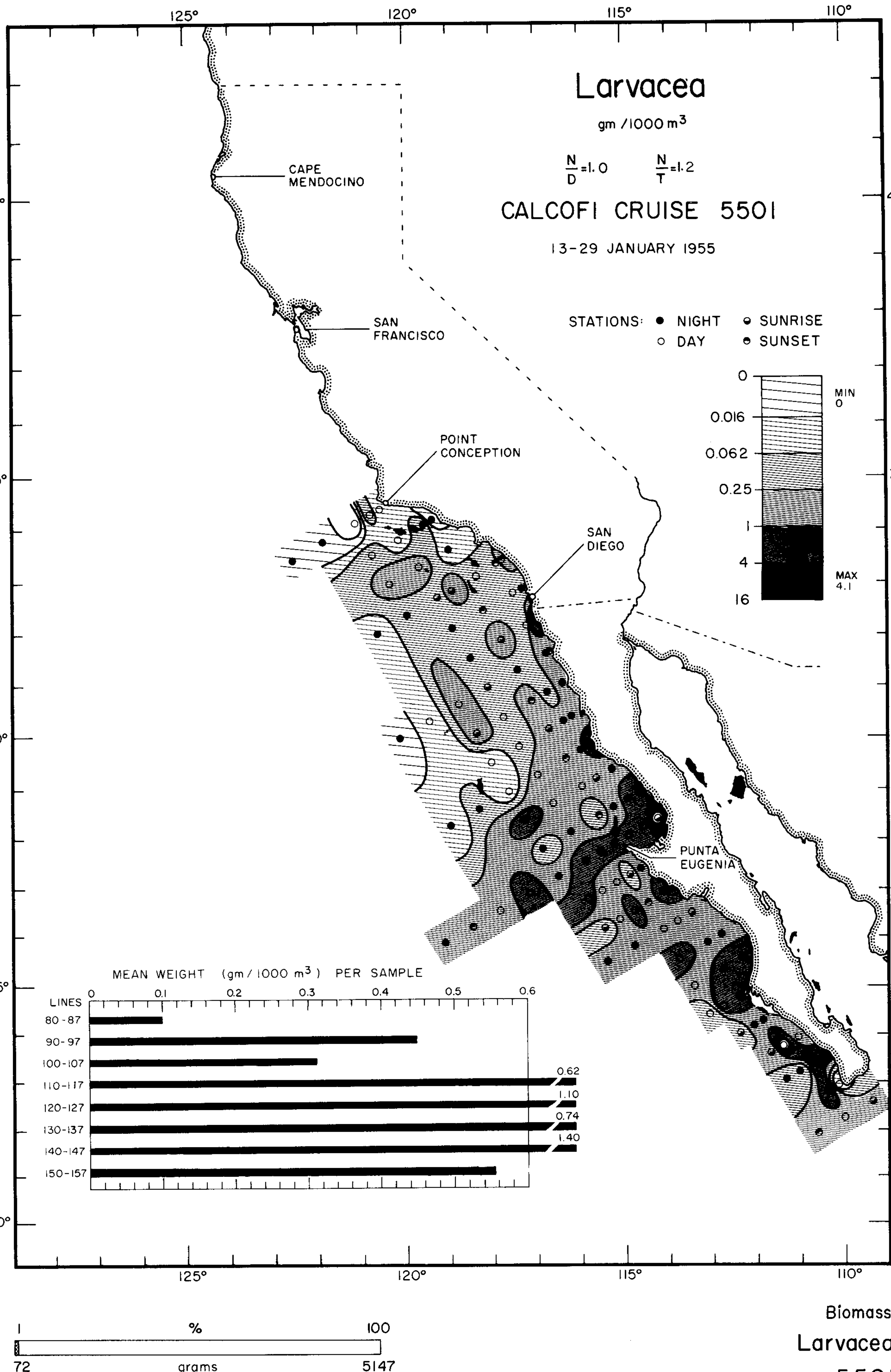
5901



Biomass

Heteropoda, adjusted

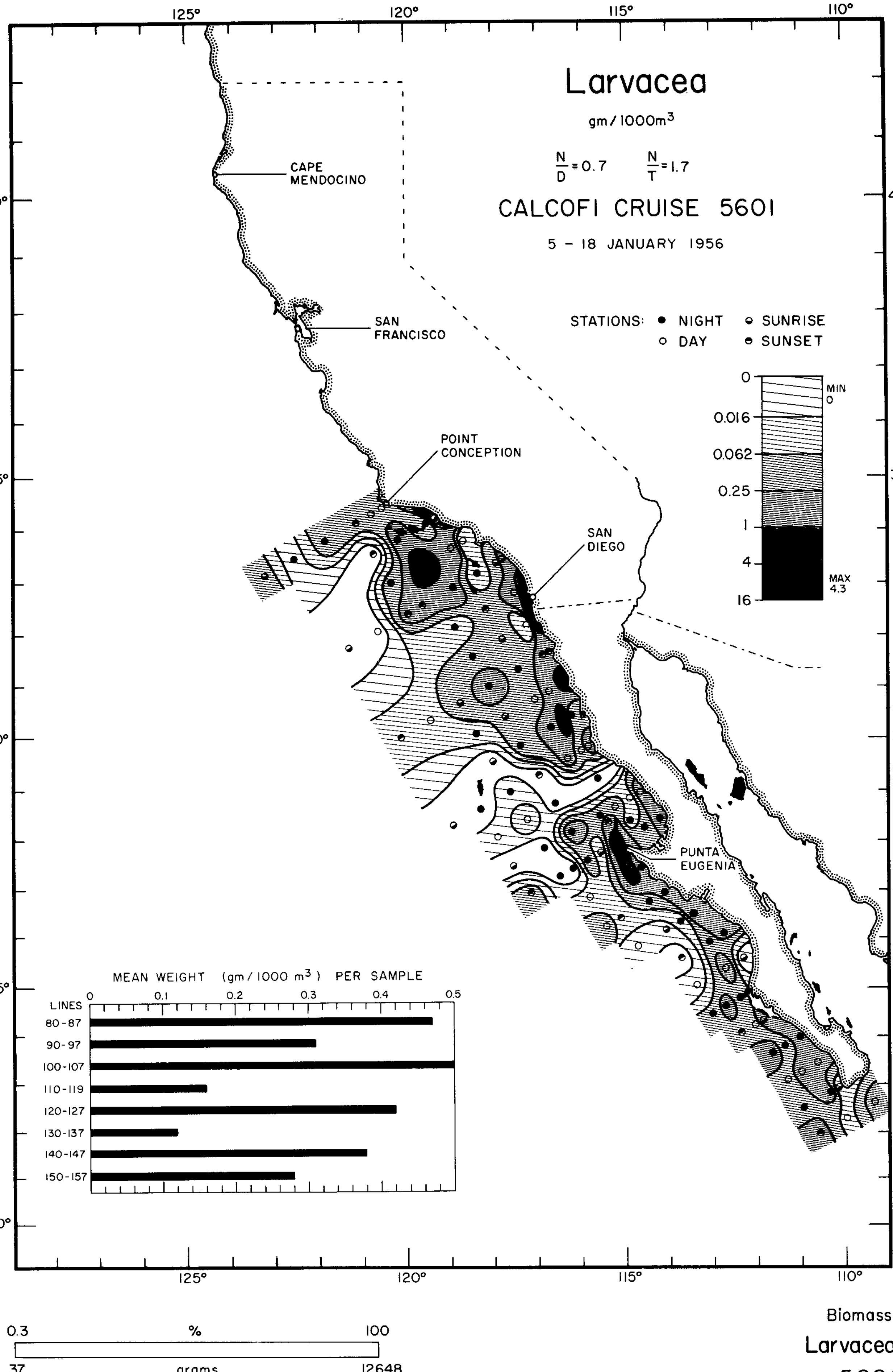
5901



Biomass

Larvacea

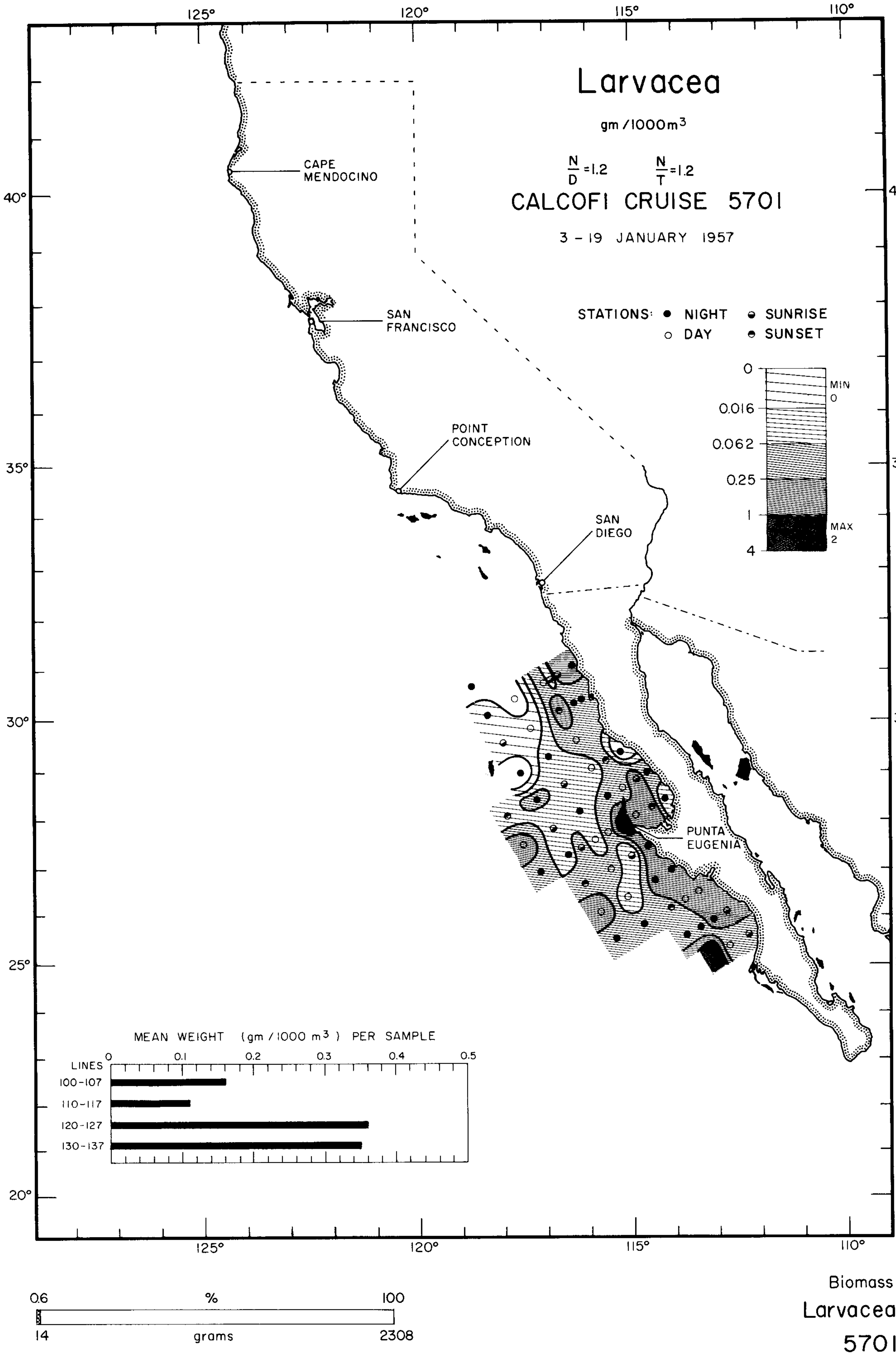
5501



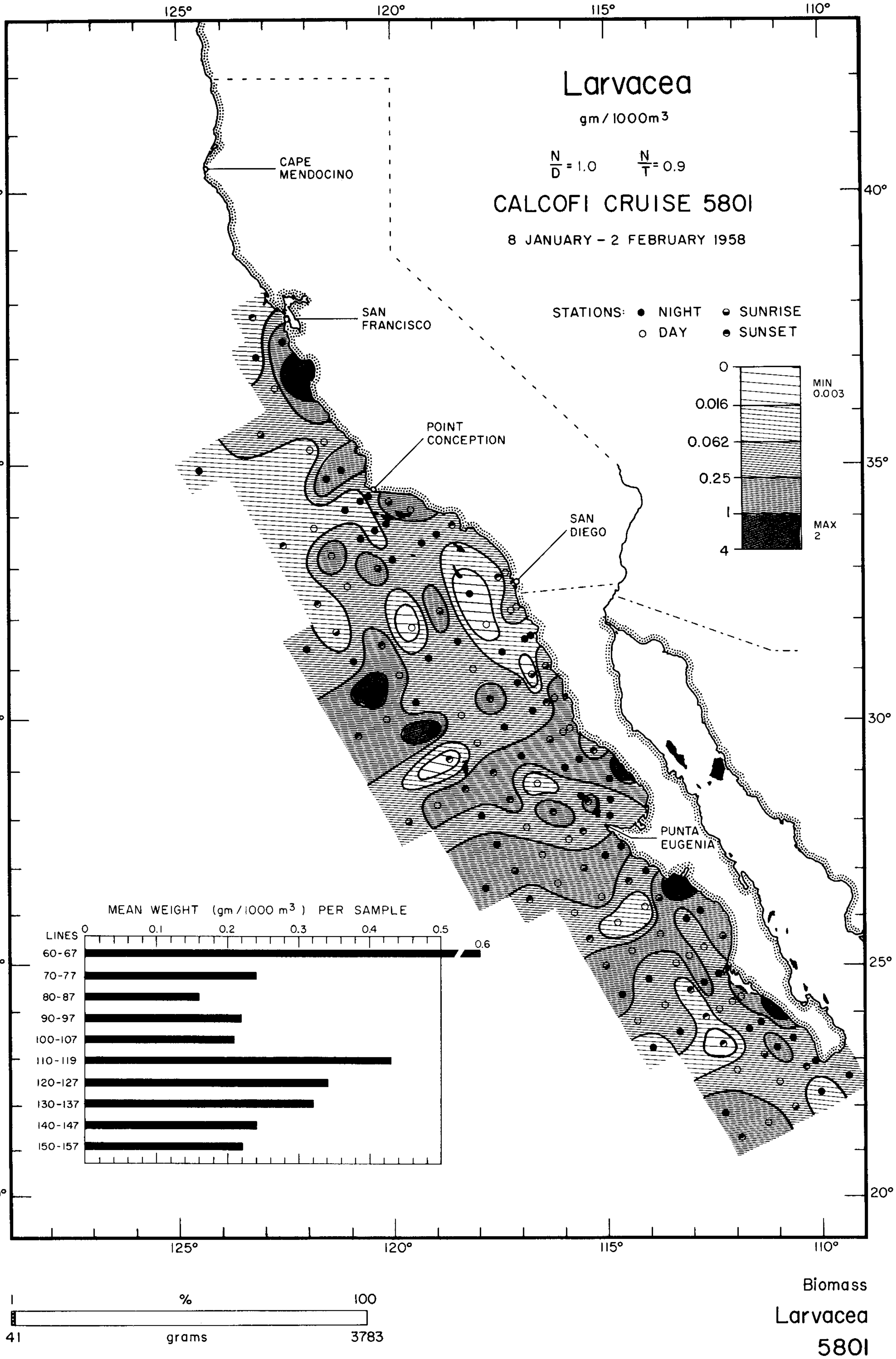
Biomass

Larvacea

5601



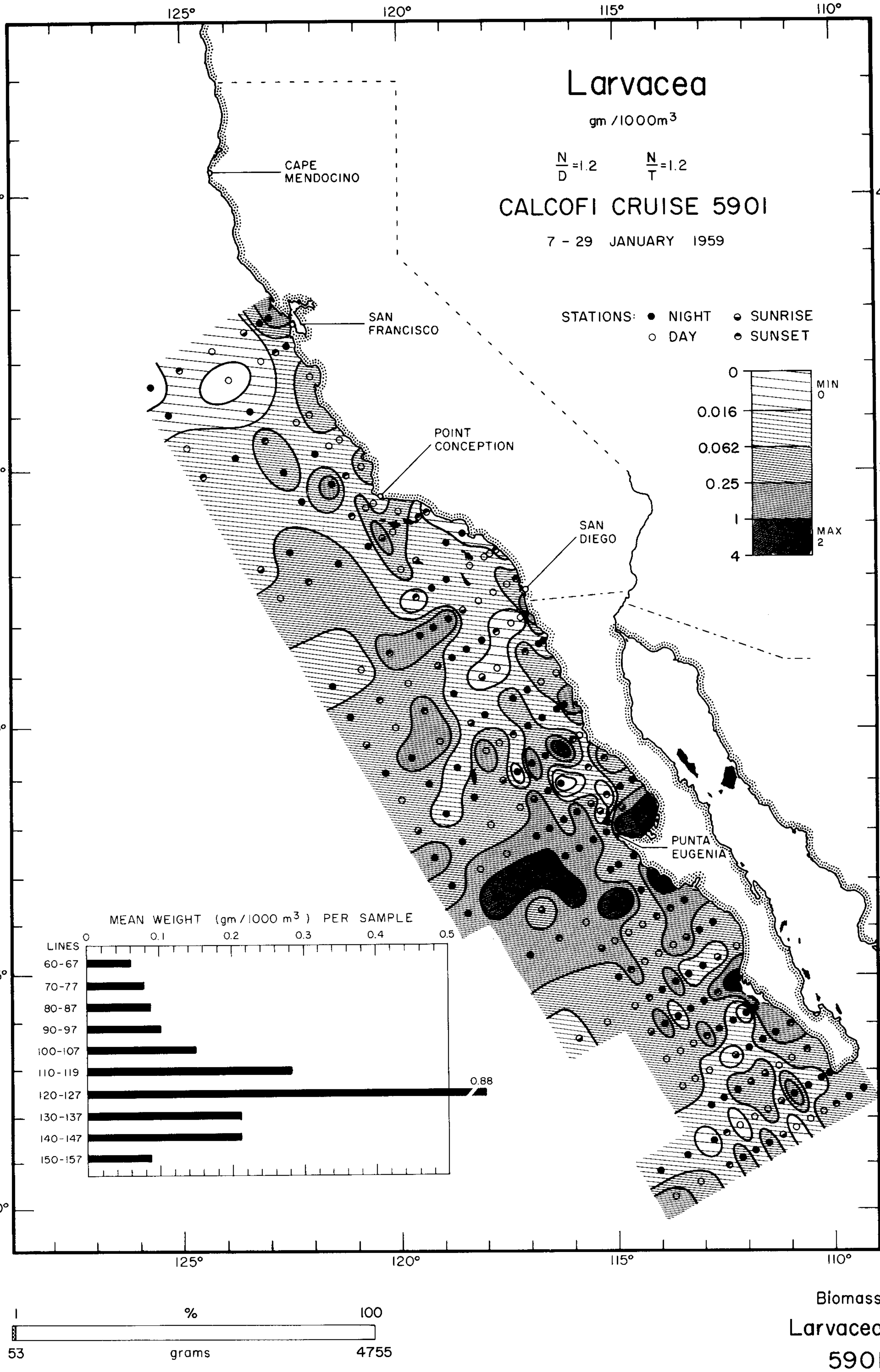
Biomass
Larvacea
5701



Biomass

Larvacea

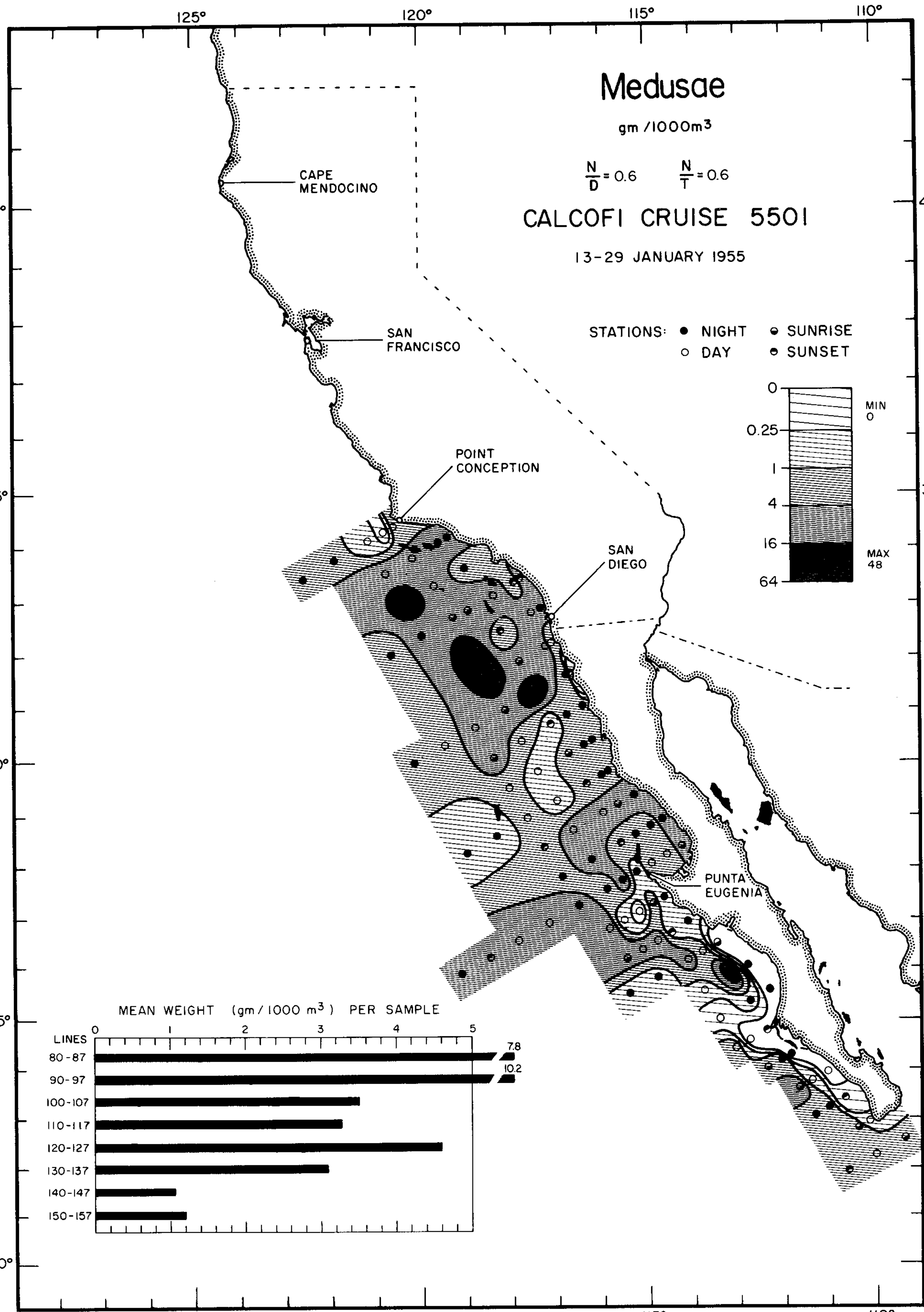
5801

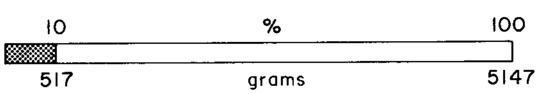


Biomass

Larvacea

5901

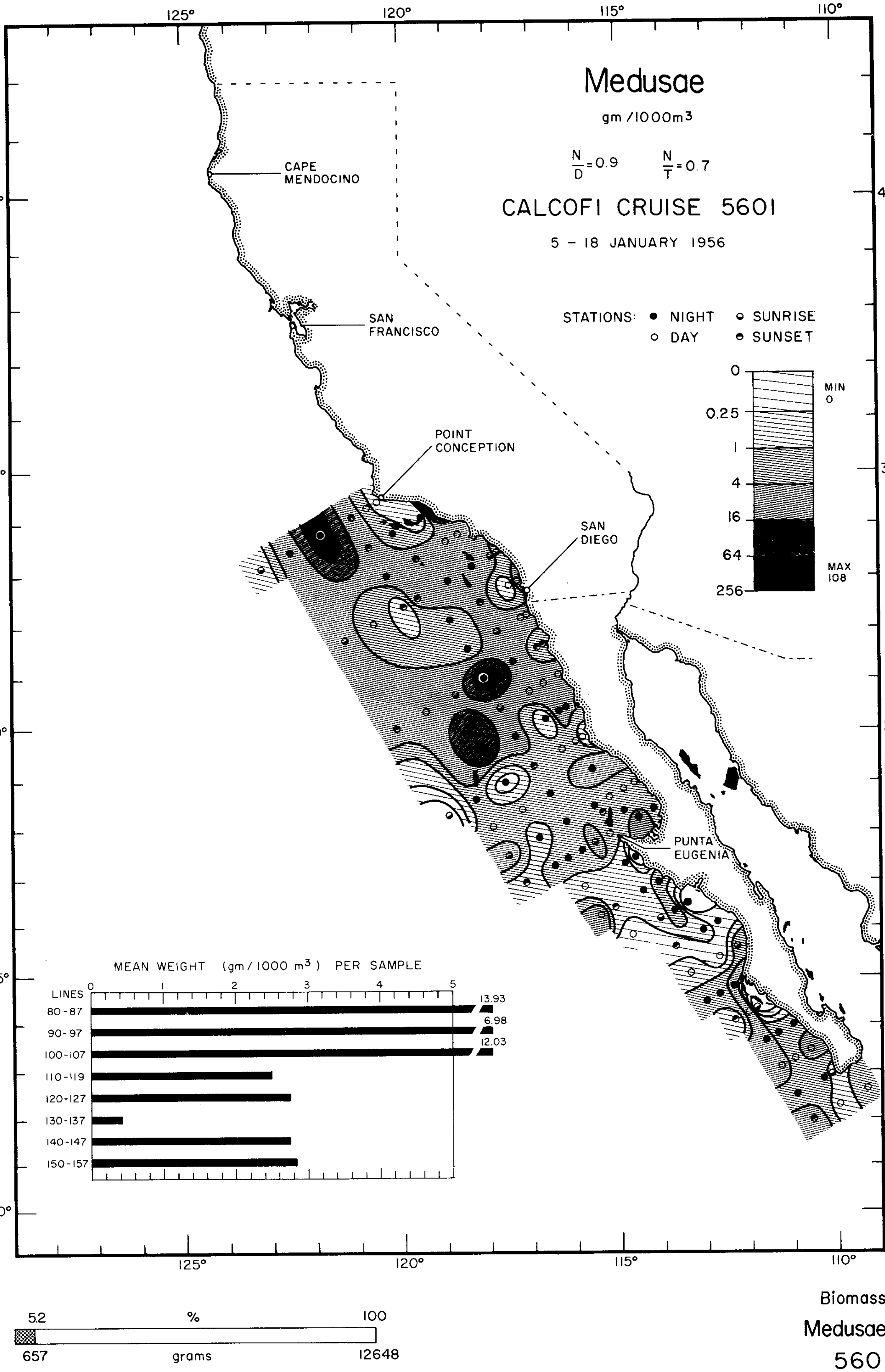




Biomass

Medusae

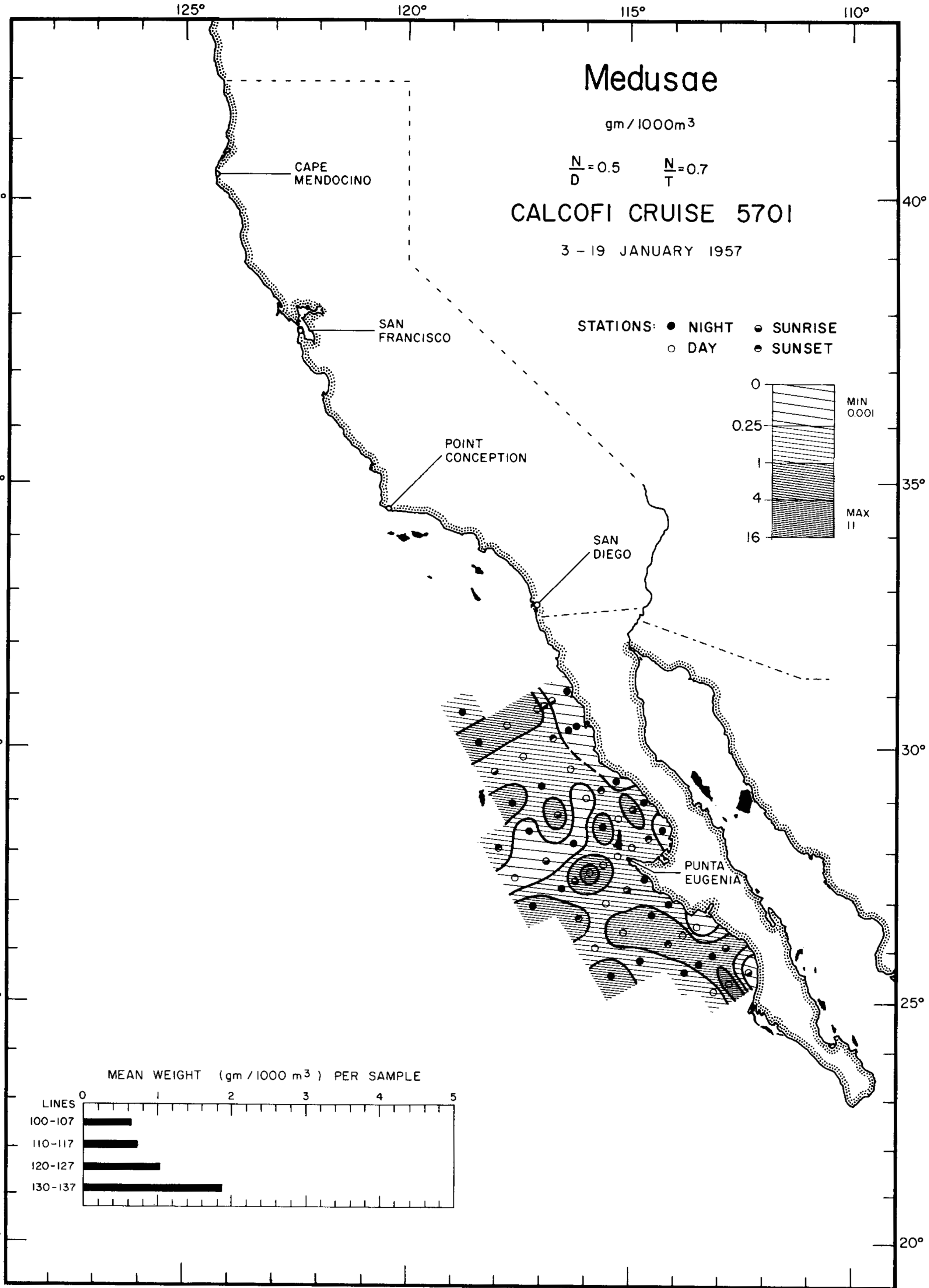
5501

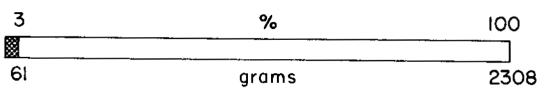


Biomass

Medusae

5601





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Medusae

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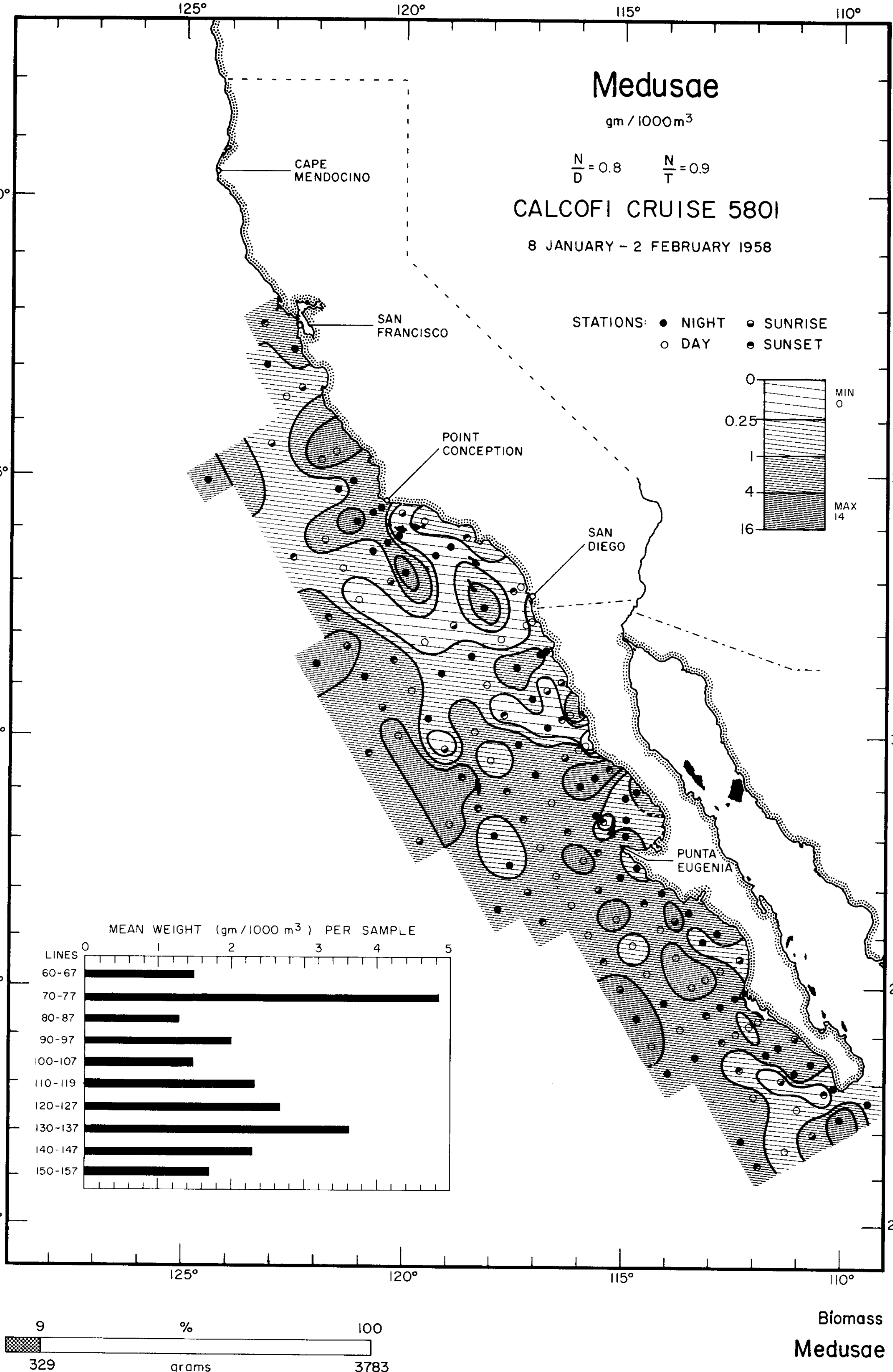

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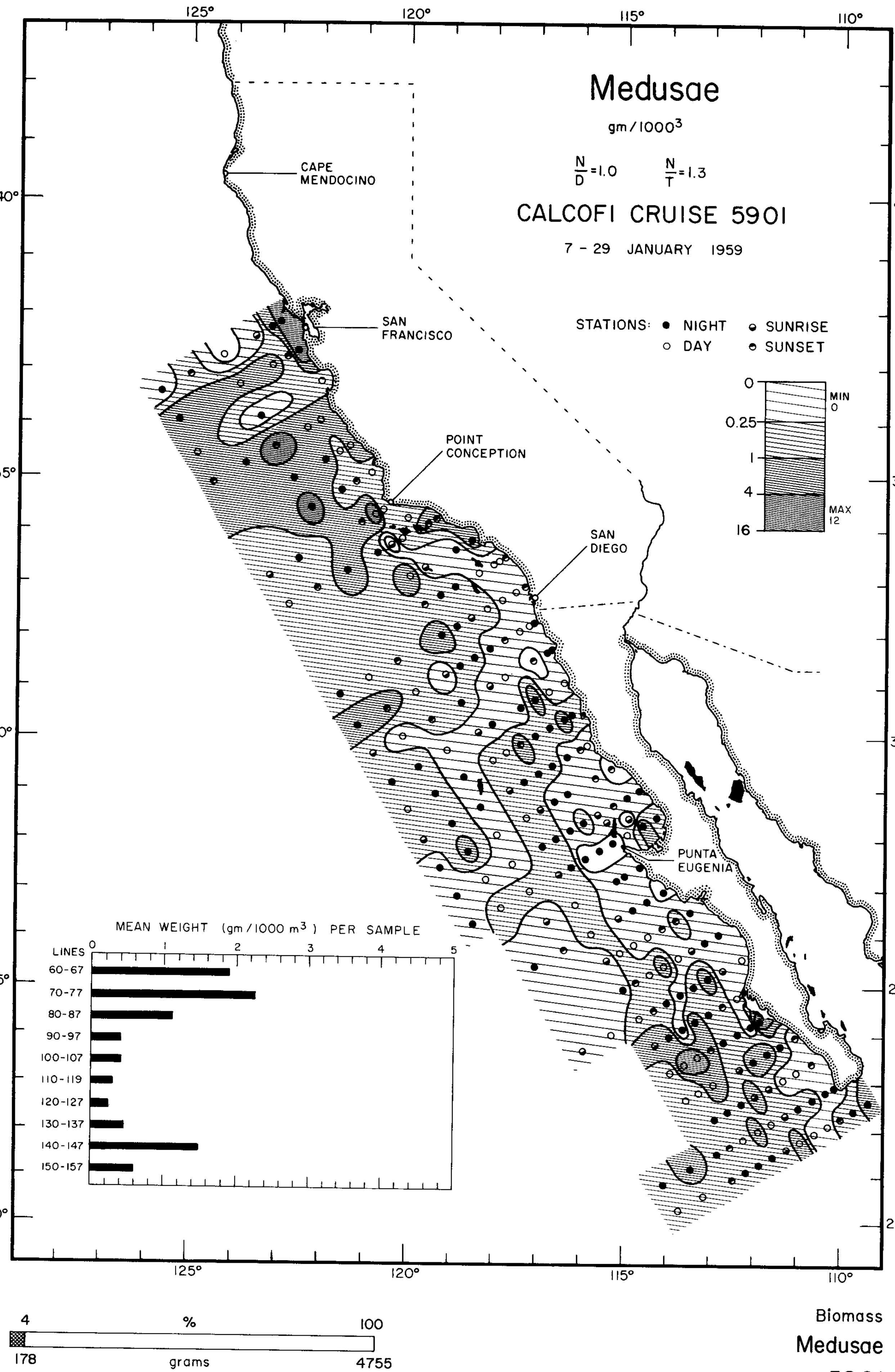
Medusae

5801



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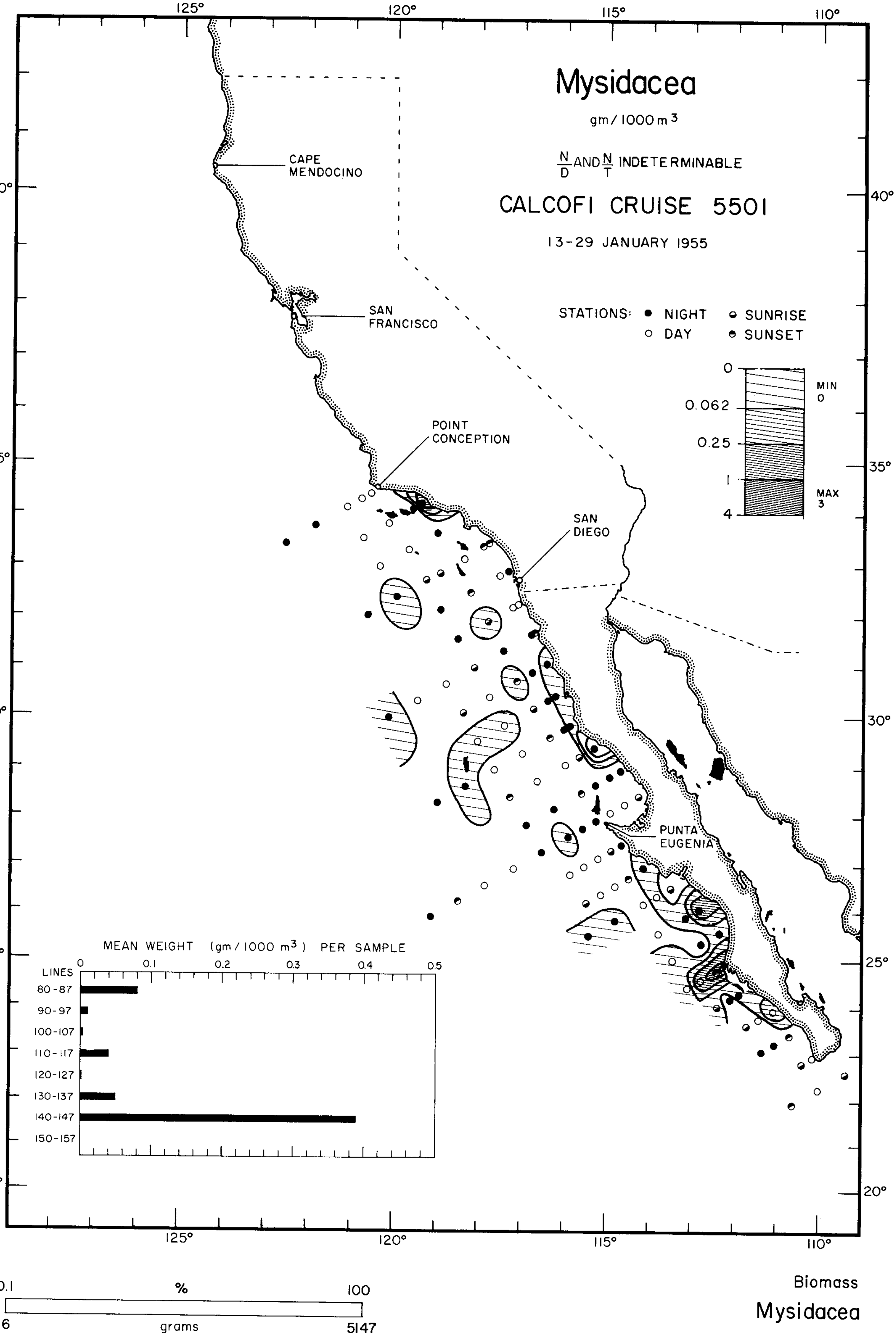
Medusae
5901



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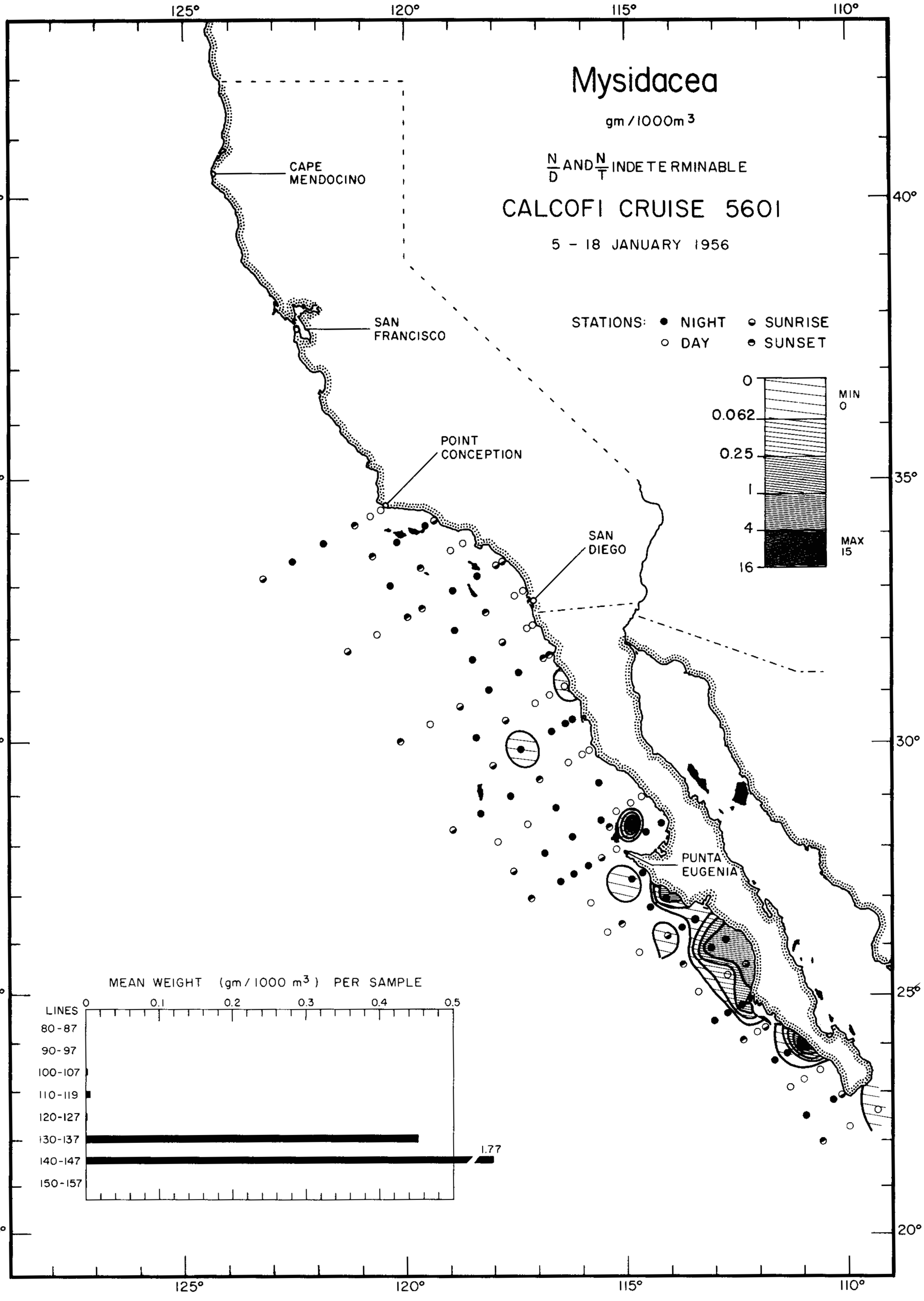
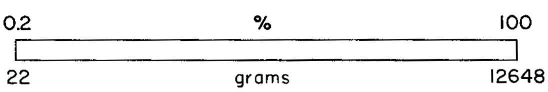
Mysidacea
5501





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Mysidacea
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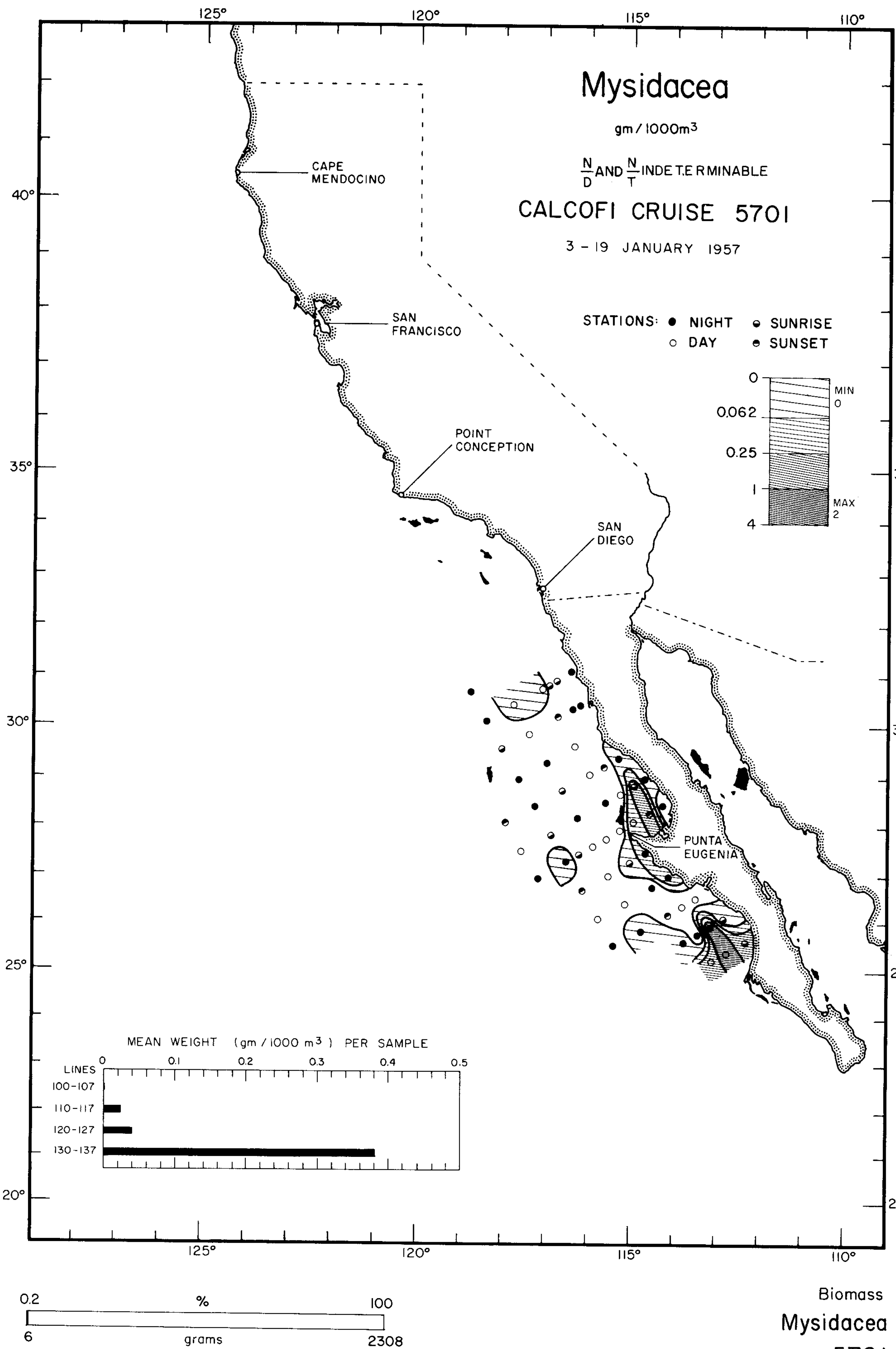

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Mysidacea
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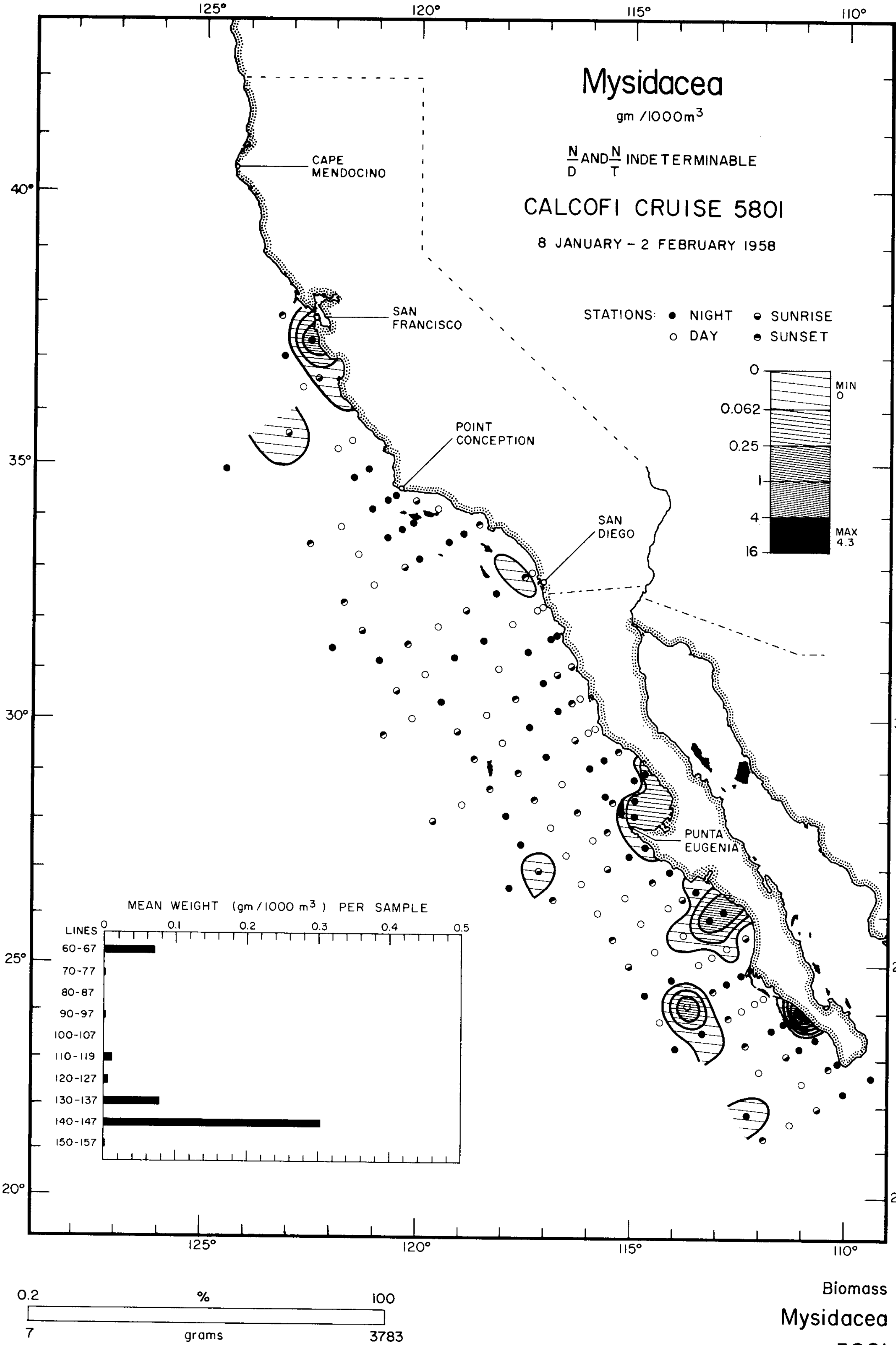
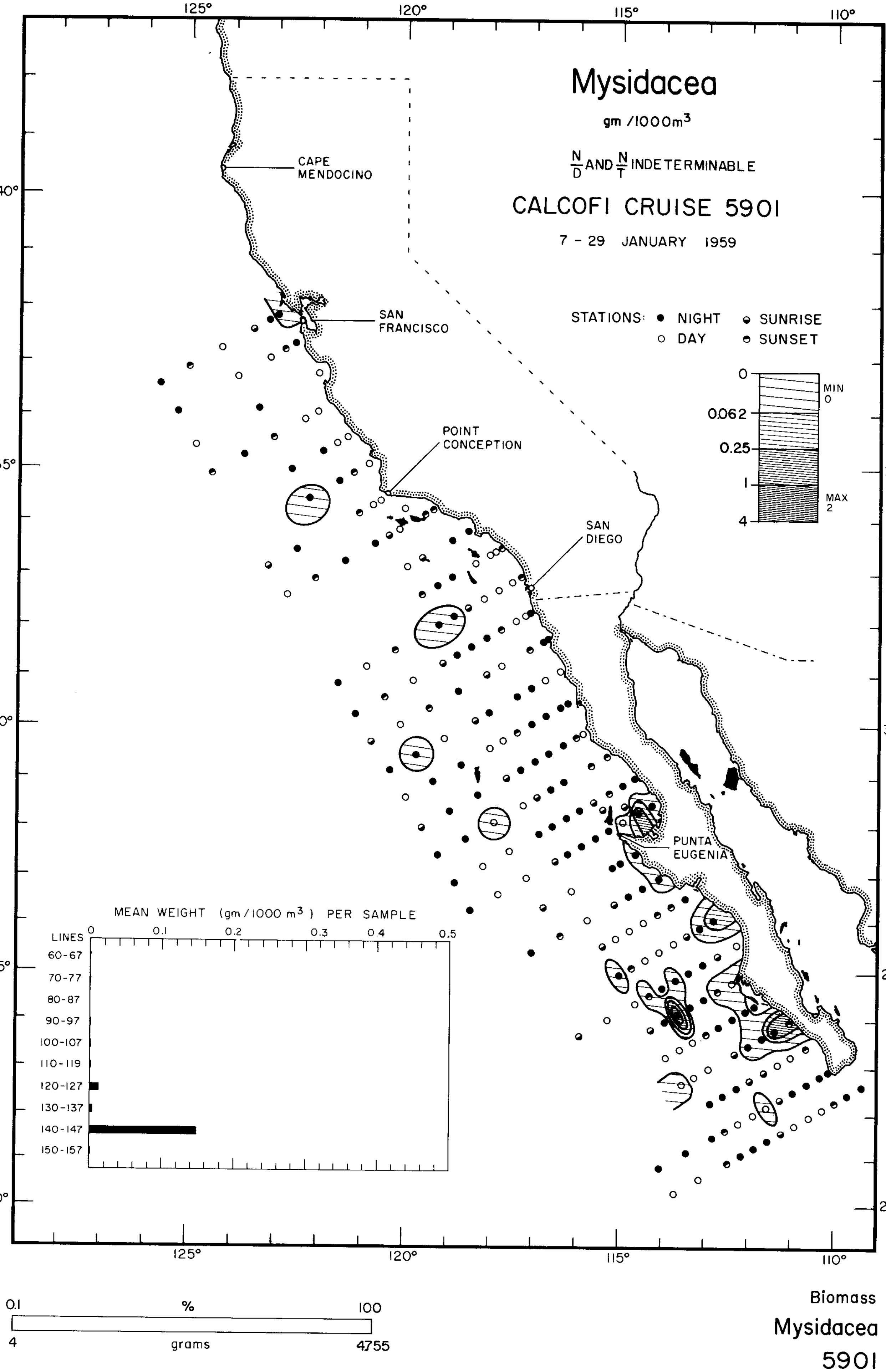
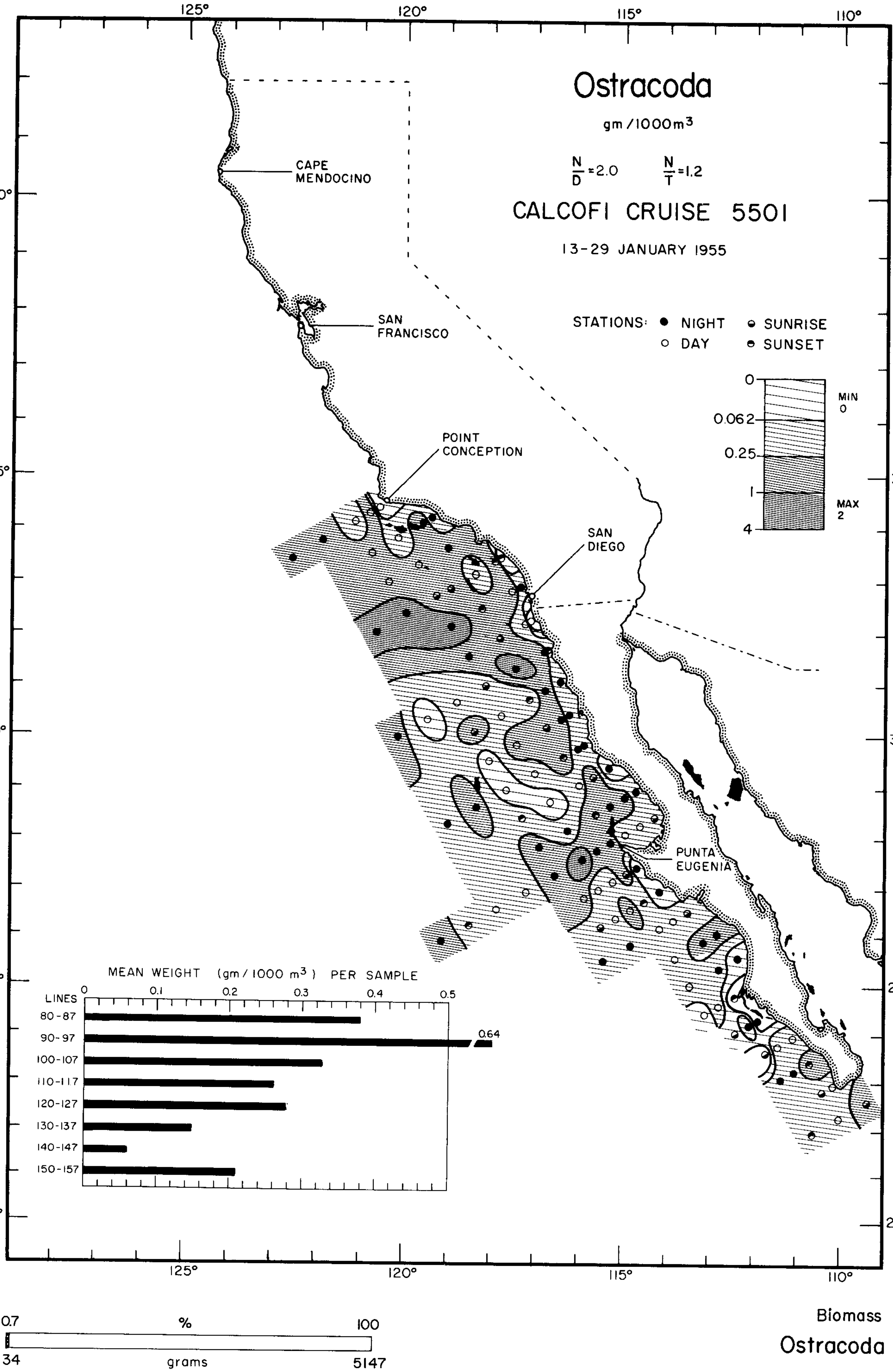
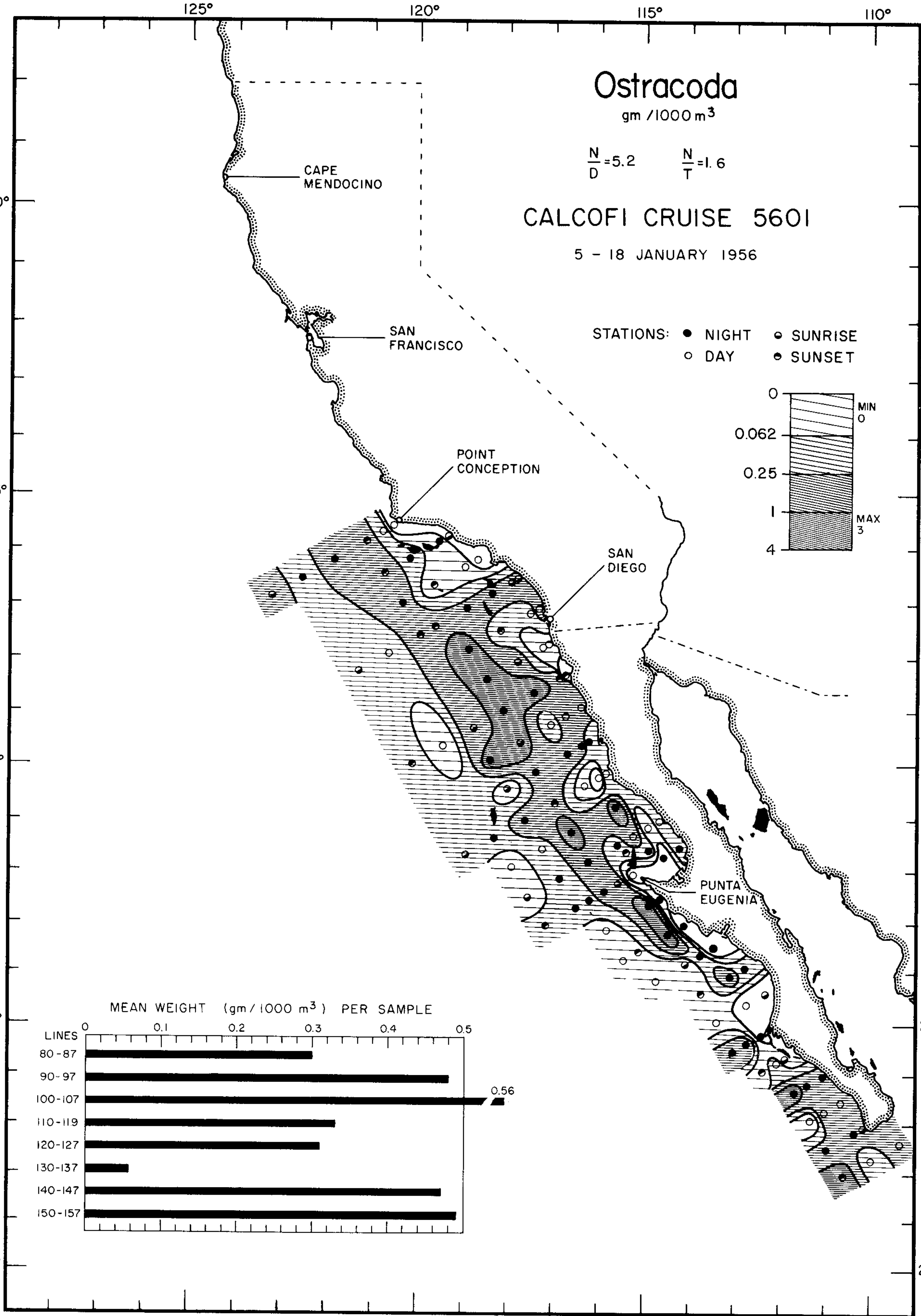


Biomass
Mysidacea
5801


Mysidacea
gm /1000m3
N/D AND N/T INDETERMINABLE
CALCOFI CRUISE 5901
7 - 29 JANUARY 1959
STATIONS: NIGHT SUNRISE DAY SUNSET
0
0.062
0.25
1
4
MIN 0
MAX 2
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
MEAN WEIGHT (gm / 1000 m3) PER SAMPLE
LINES
0
0.1
0.2
0.3
0.4
0.5
60-67
70-77
80-87
90-97
100-107
110-119
120-127
130-137
140-147
150-157
0.1
%
100
4
grams
4755
Biomass
Mysidacea
5901



Biomass
Ostracoda
5501



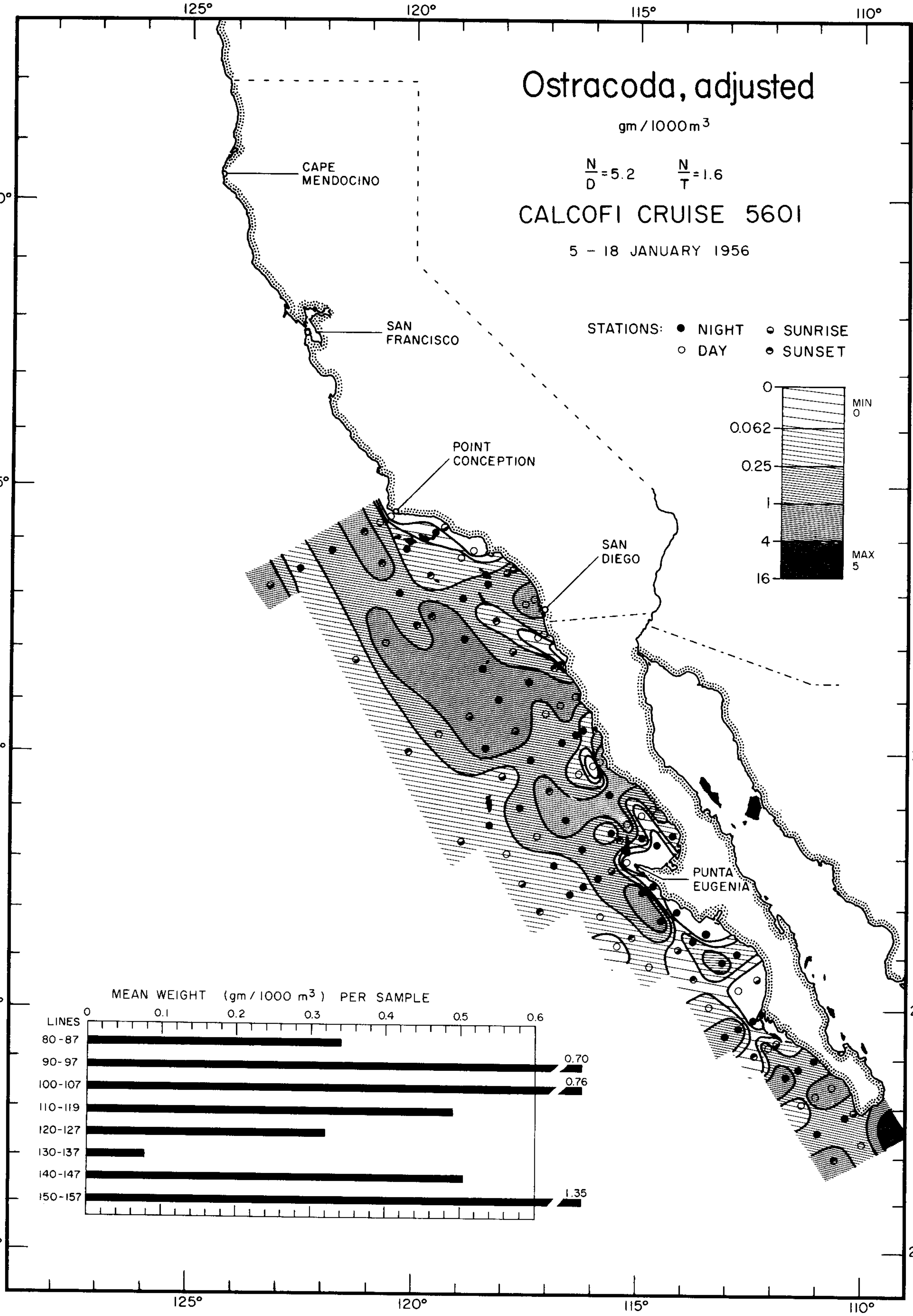
0.3 % 100

42 grams 12648

Biomass

Ostracoda

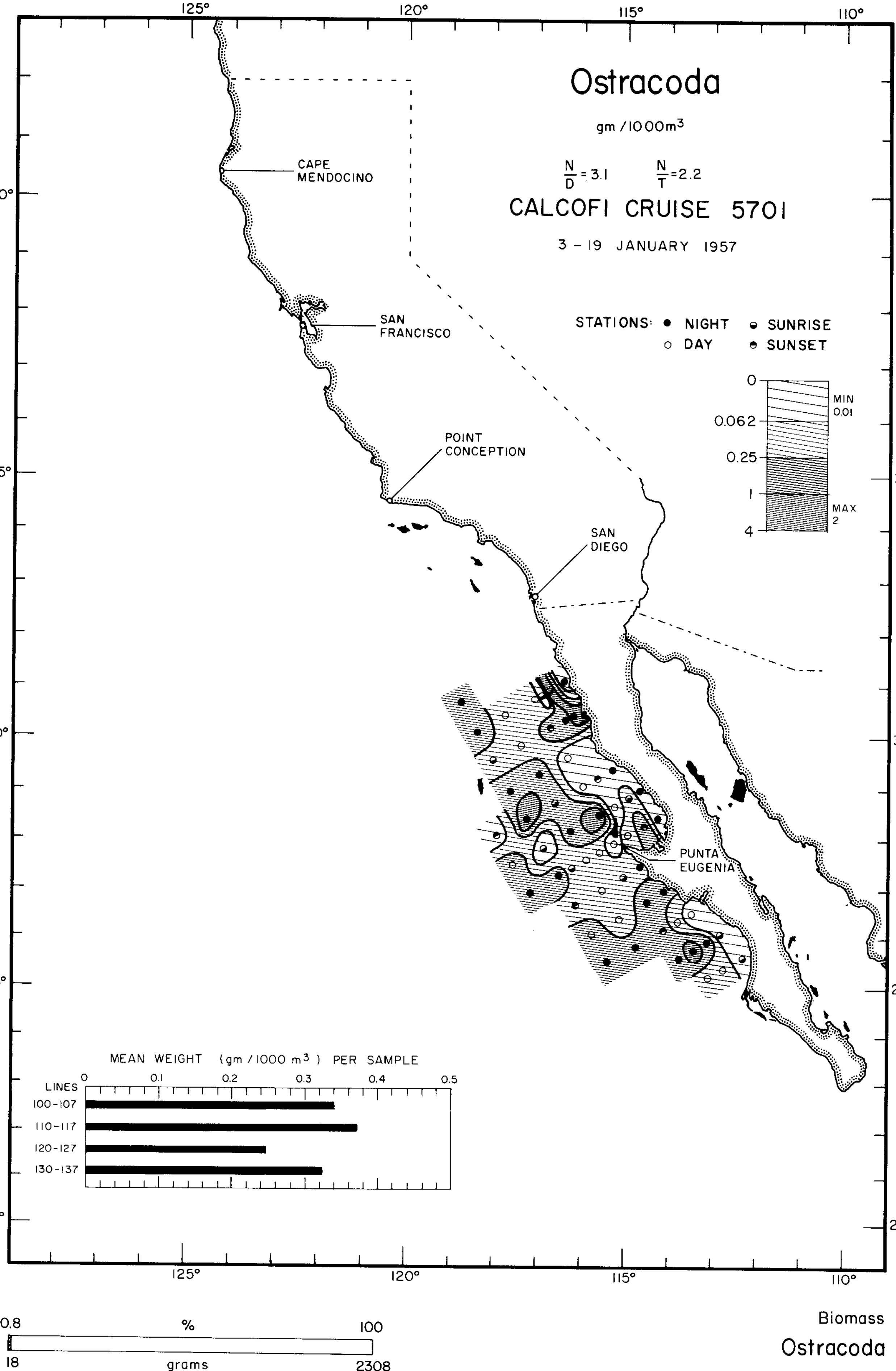
5601



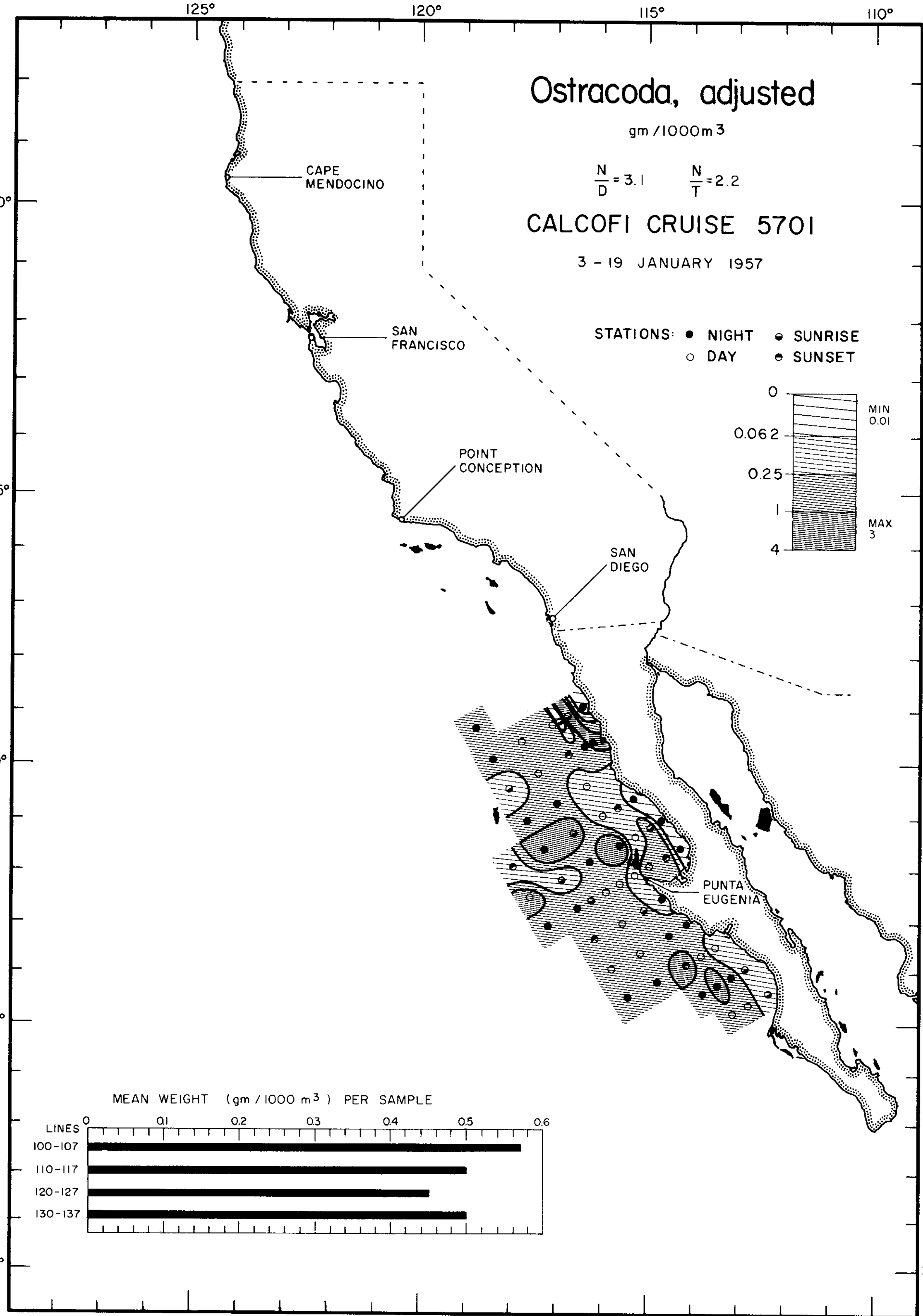
Biomass

Ostracoda, adjusted

5601



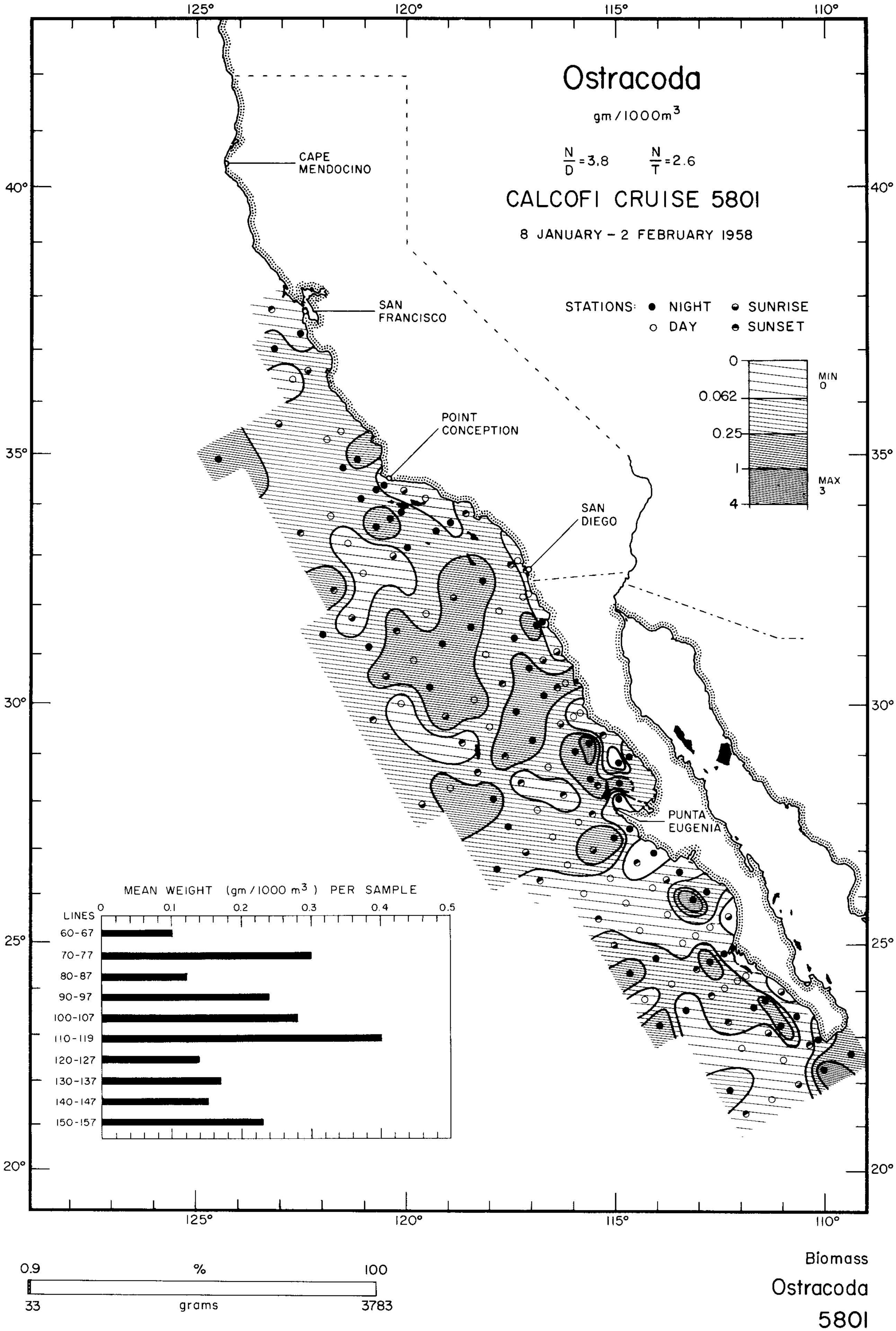
Biomass
Ostracoda
5701



Biomass

Ostracoda, adjusted

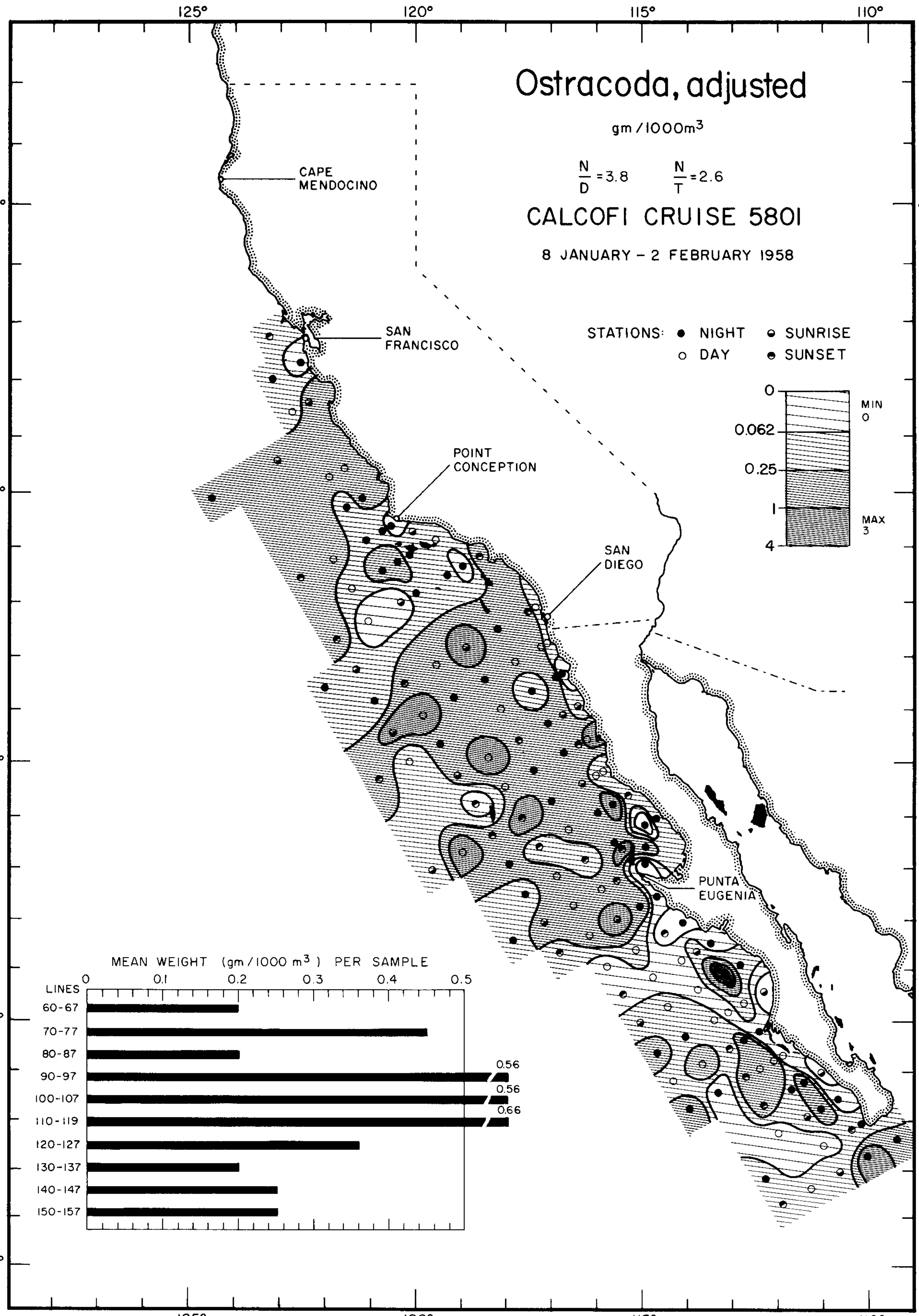
5701



Biomass

Ostracoda

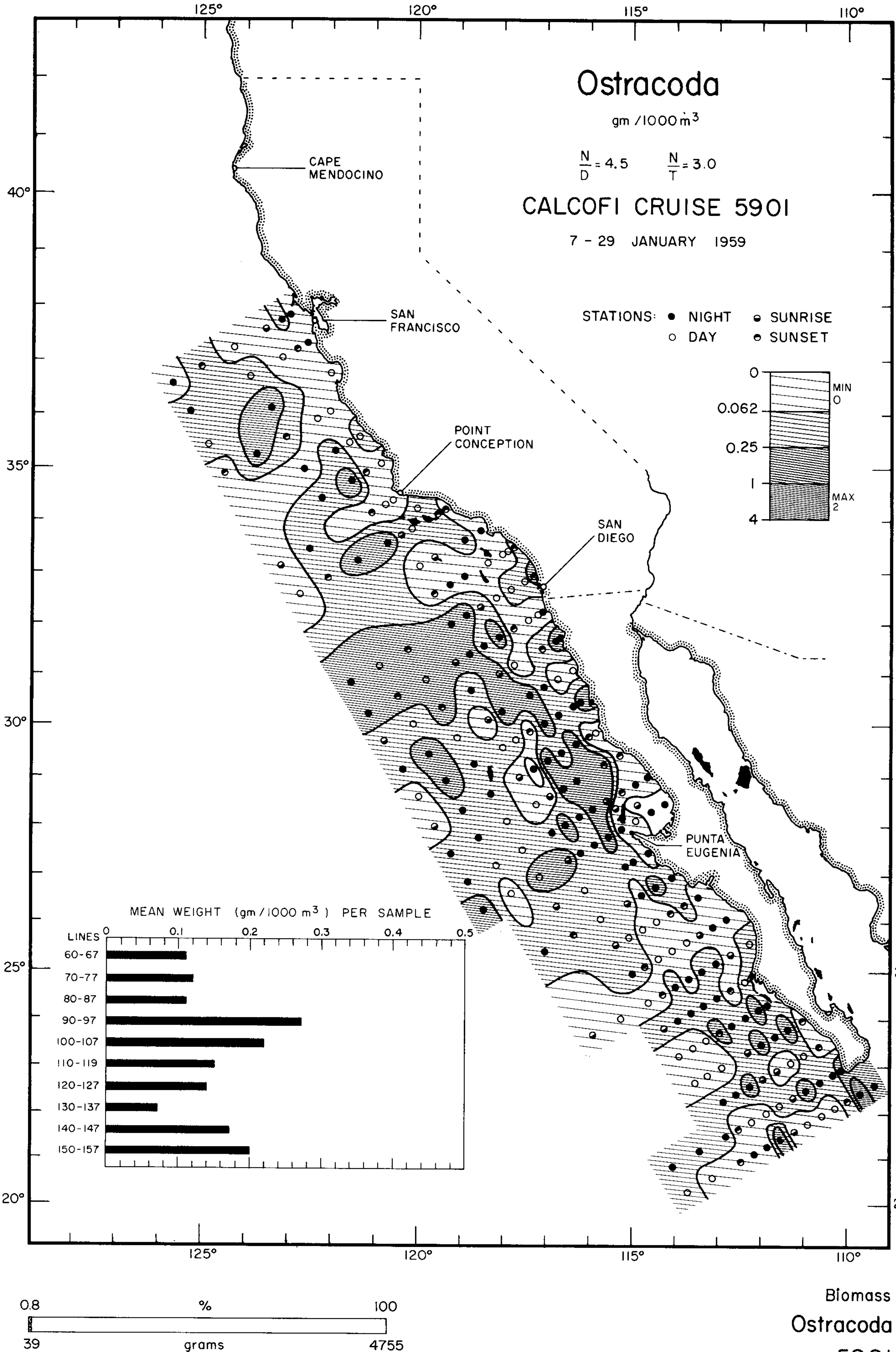
5801



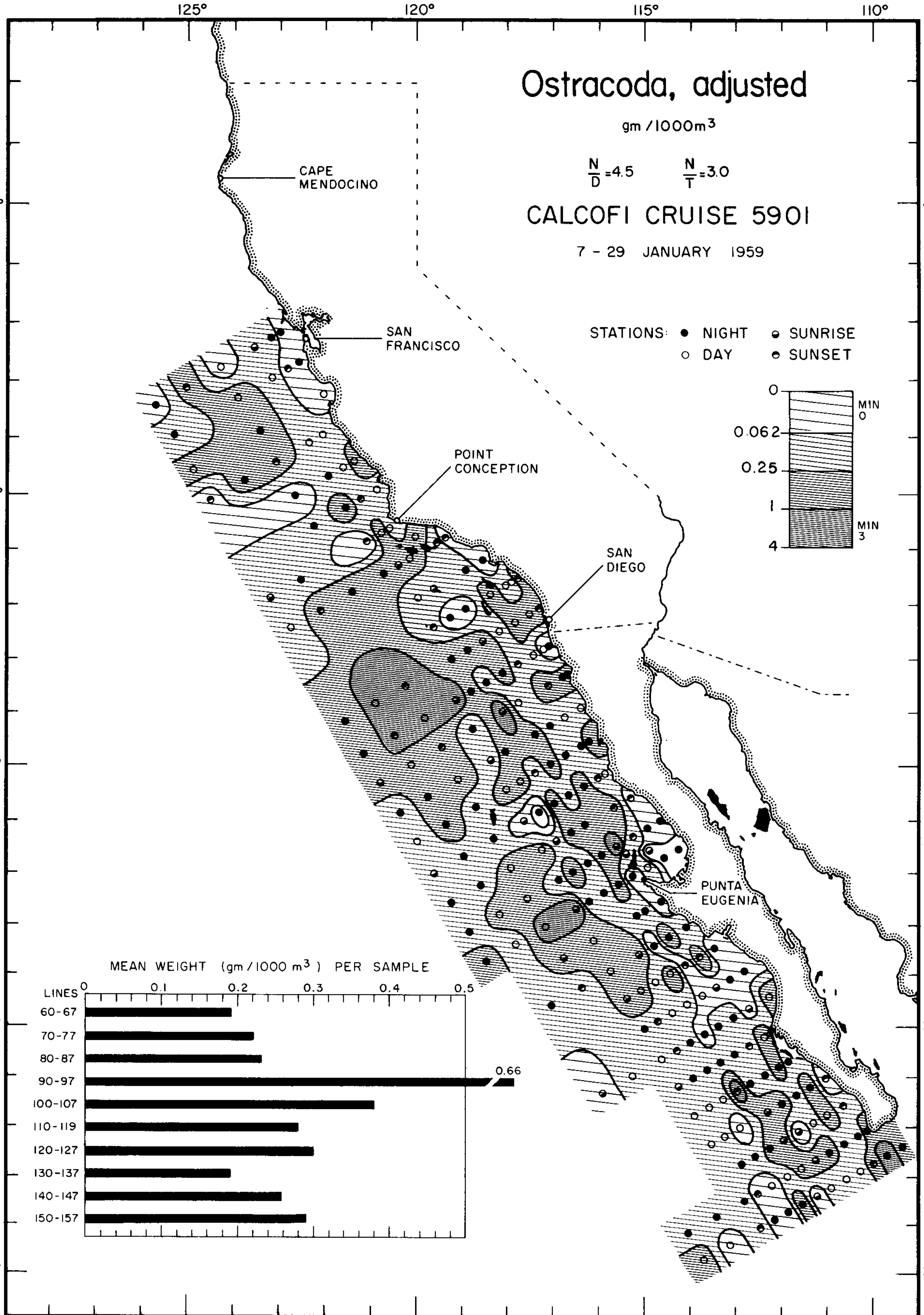
Biomass

Ostracoda, adjusted

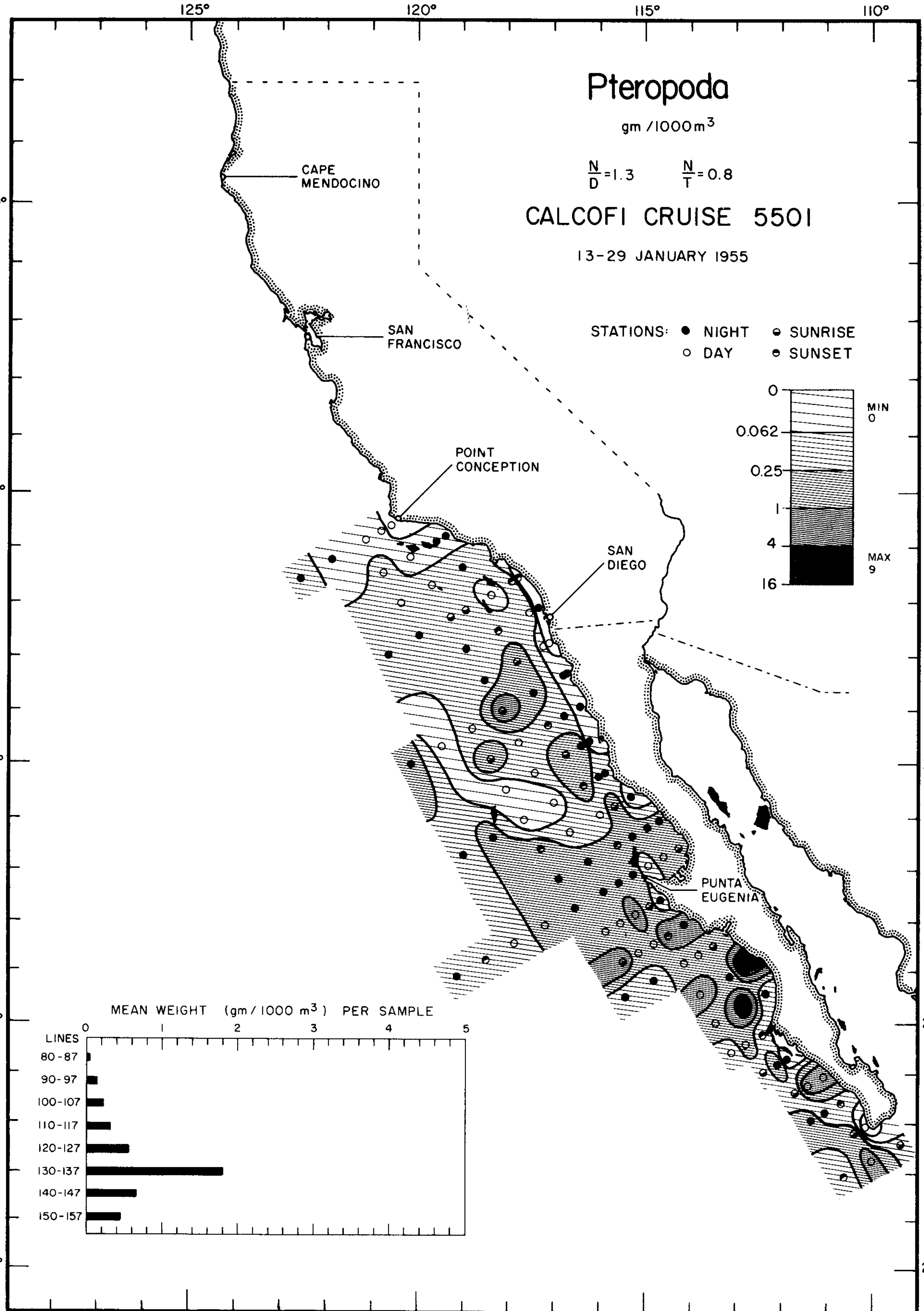
5801

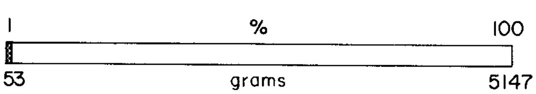


Biomass
Ostracoda
5901

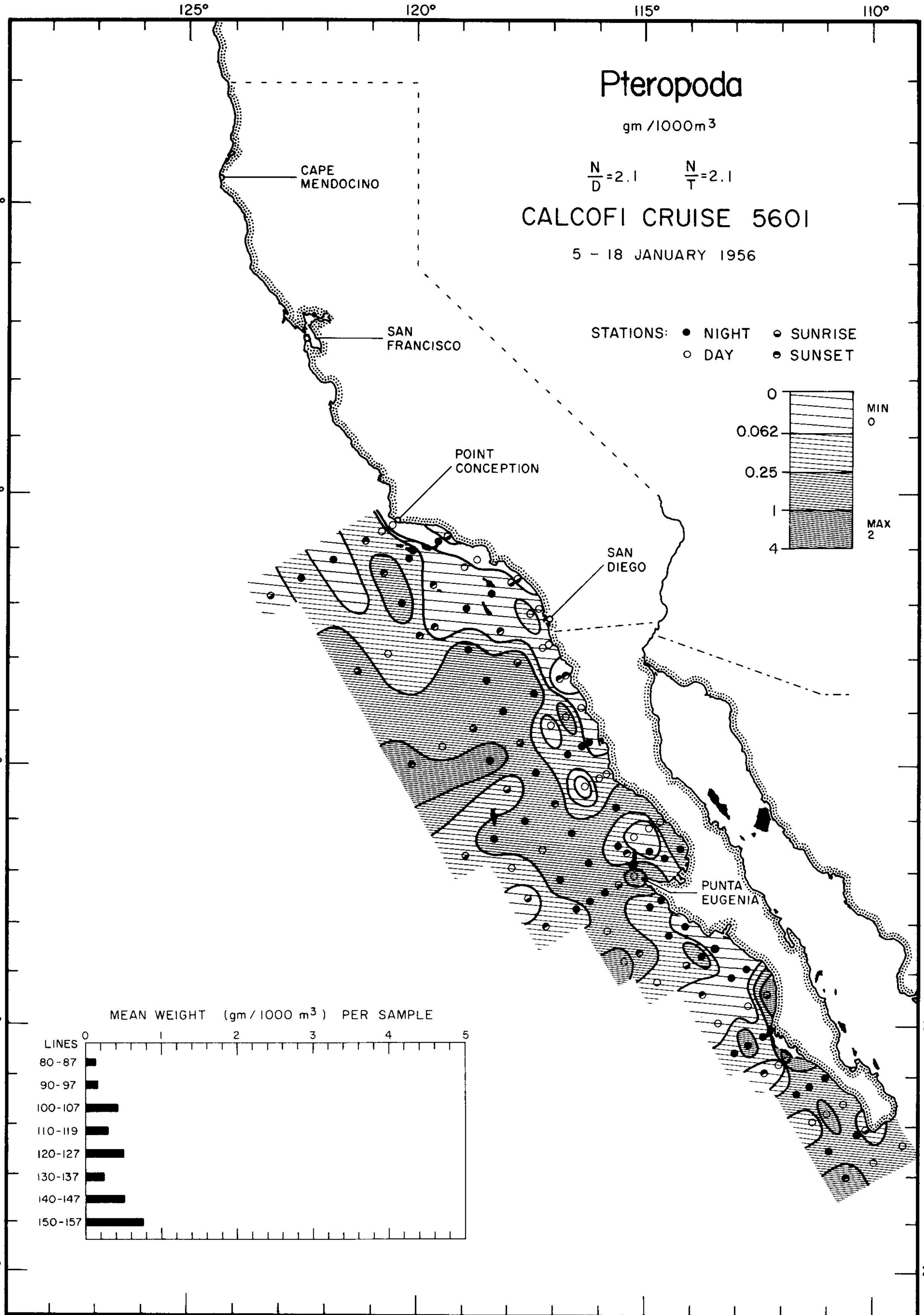


Biomass
Ostracoda, adjusted
5901





Biomass
Pteropoda
5501



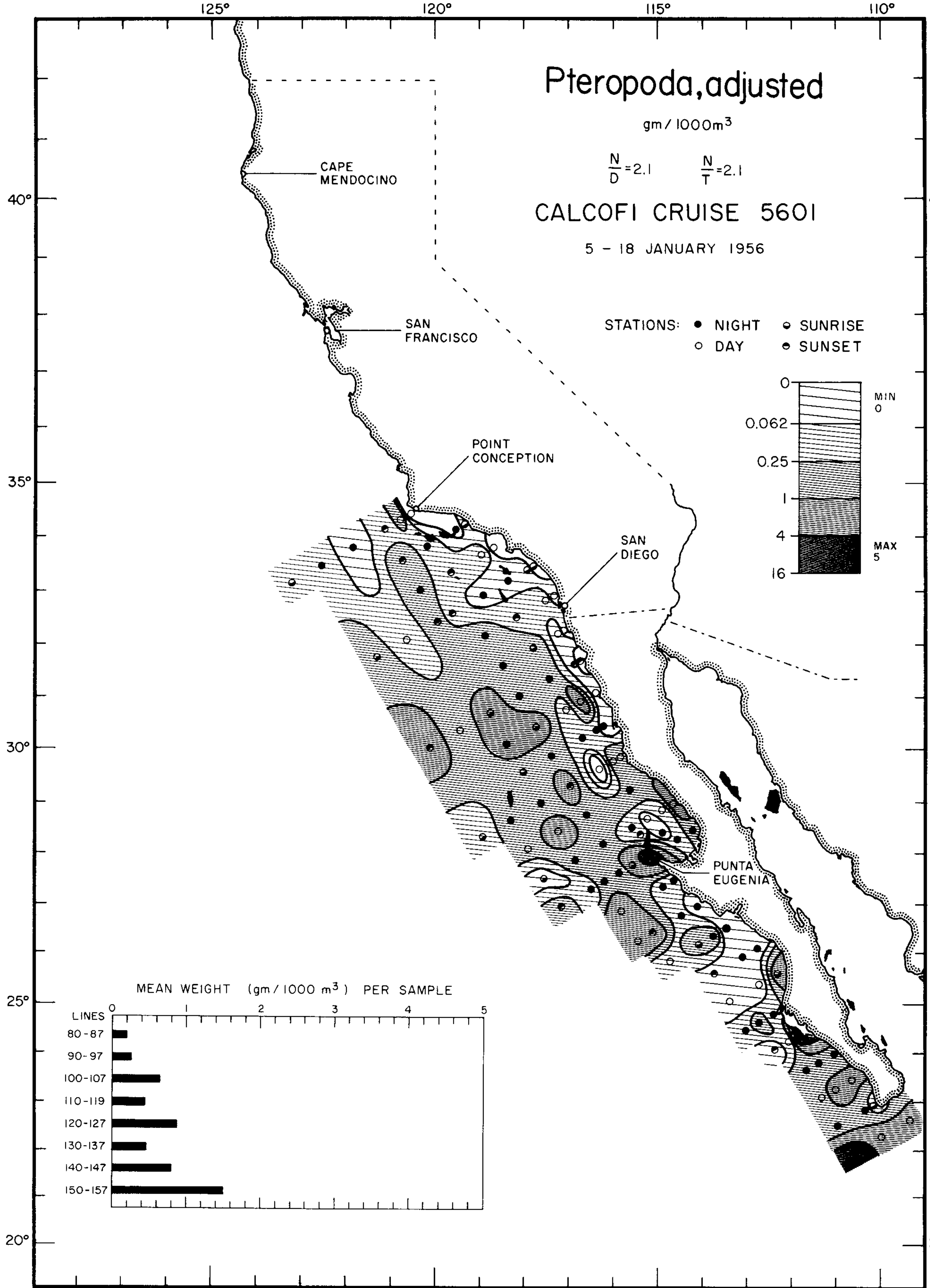
0.3 % 100

39 grams 12648

Biomass

Pteropoda

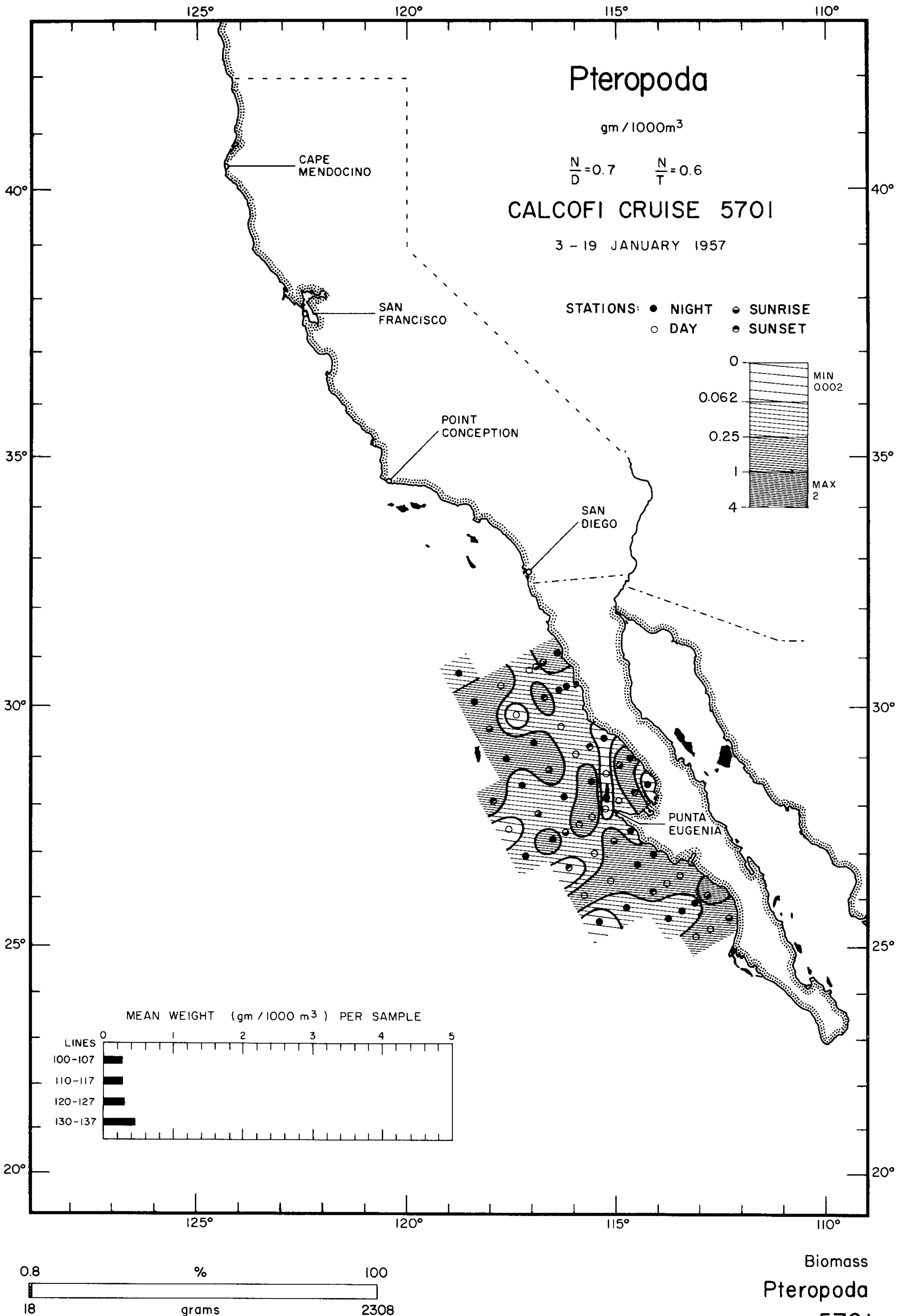
5601



Biomass

Pteropoda, adjusted

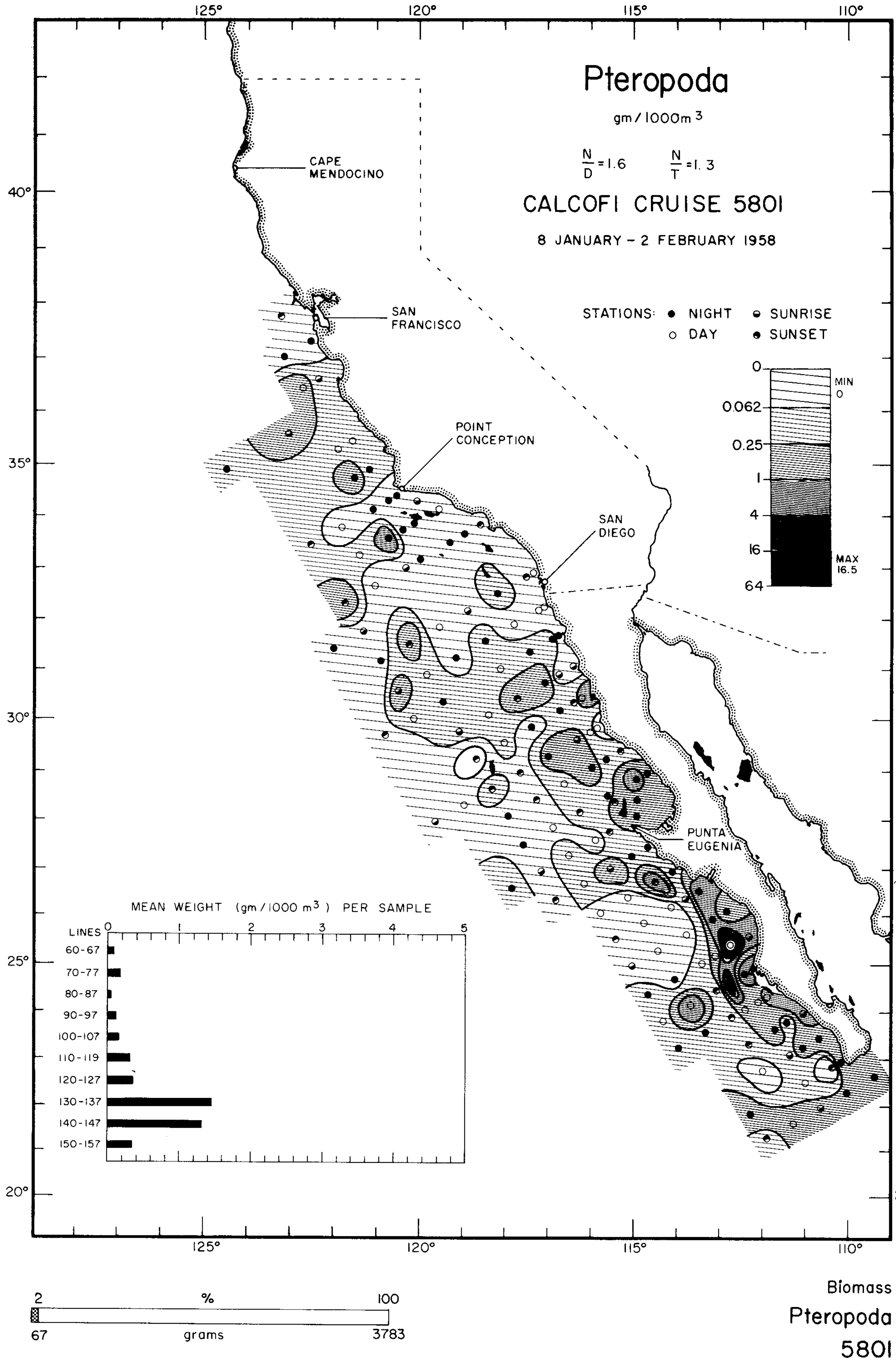
5601



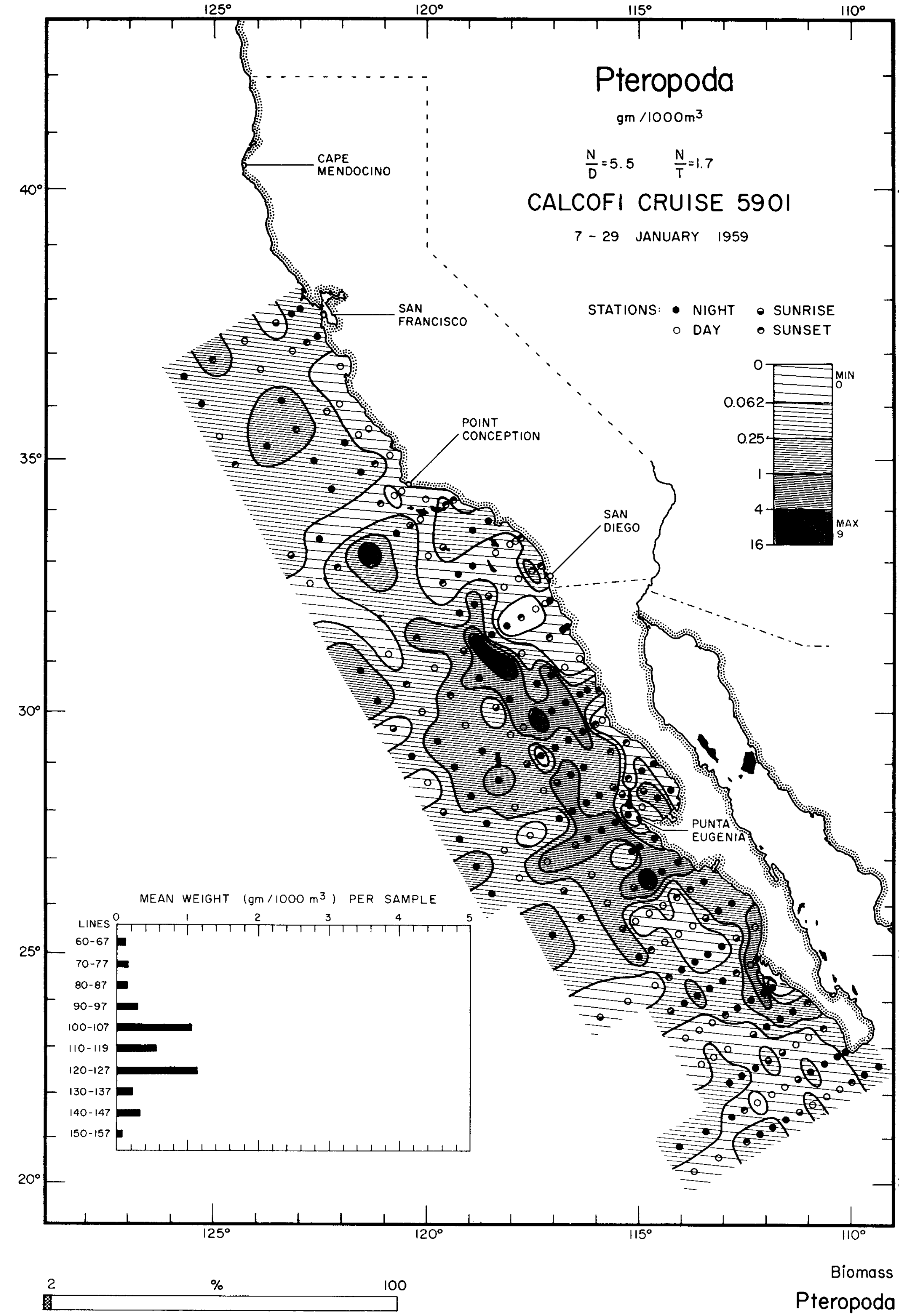
Biomass

Pteropoda

5701



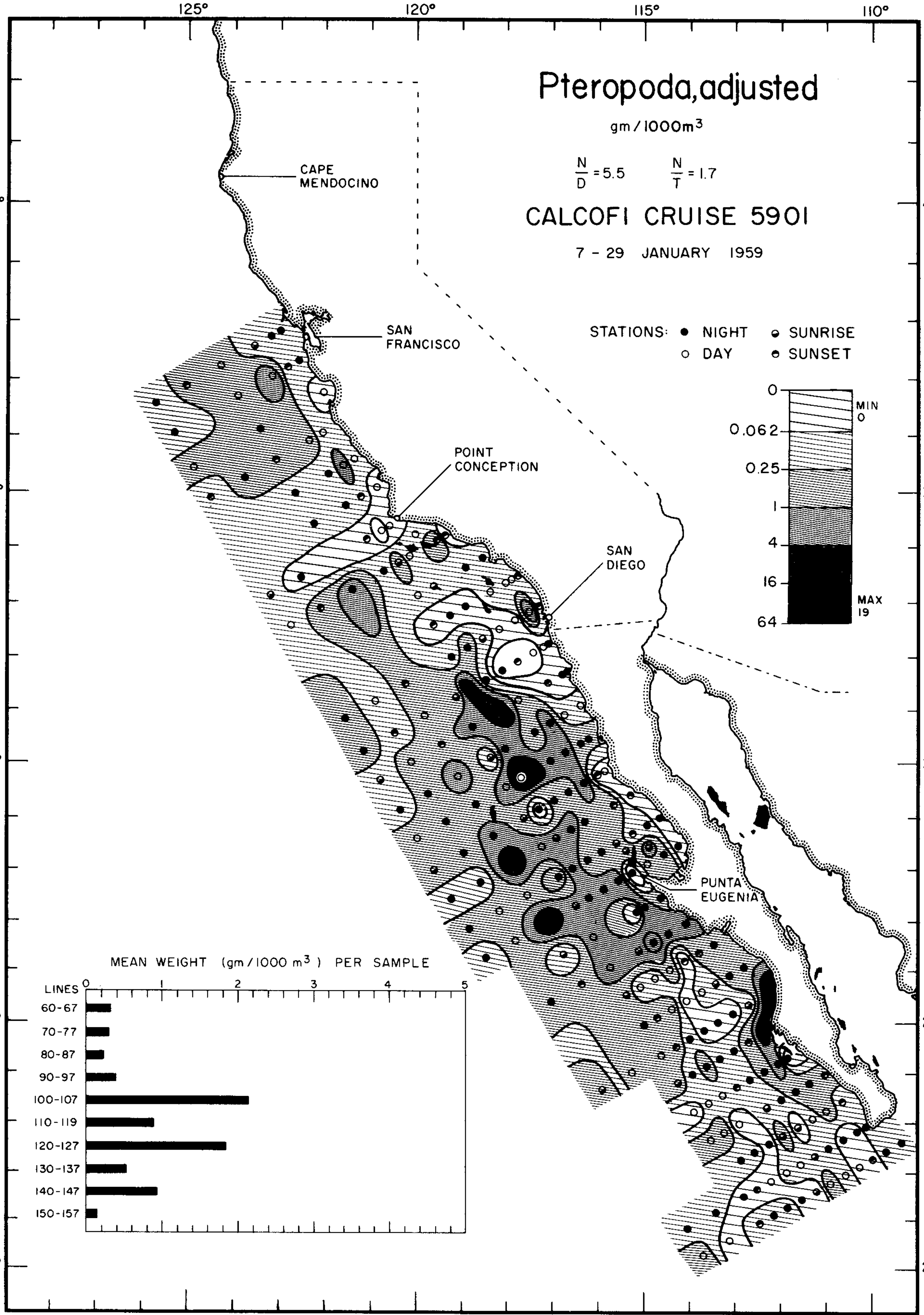
Biomass
Pteropoda
5801



Biomass

Pteropoda

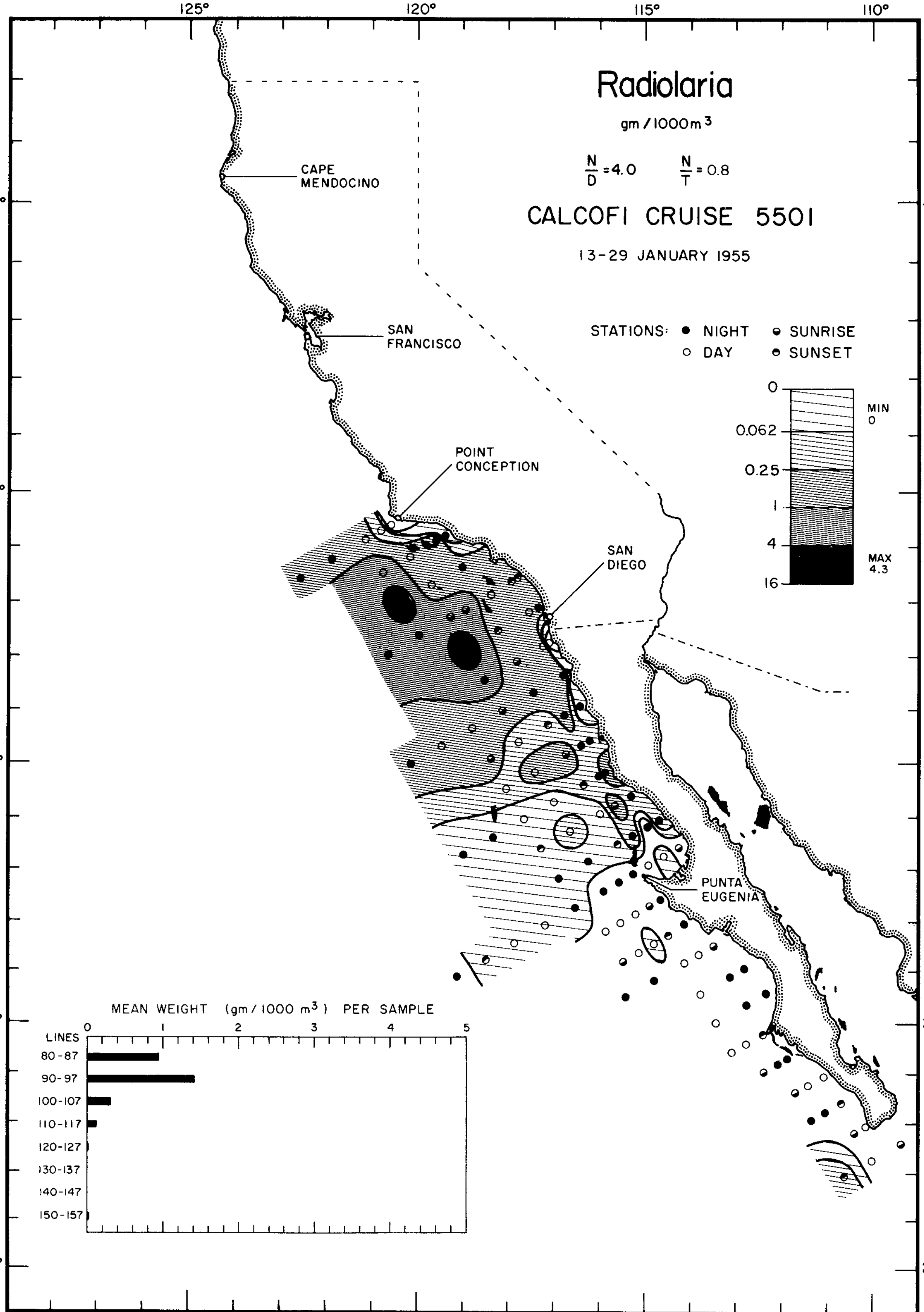
5901

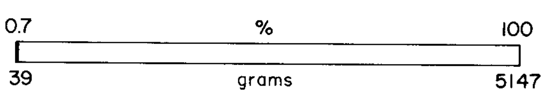


Biomass

Pteropoda, adjusted

5901

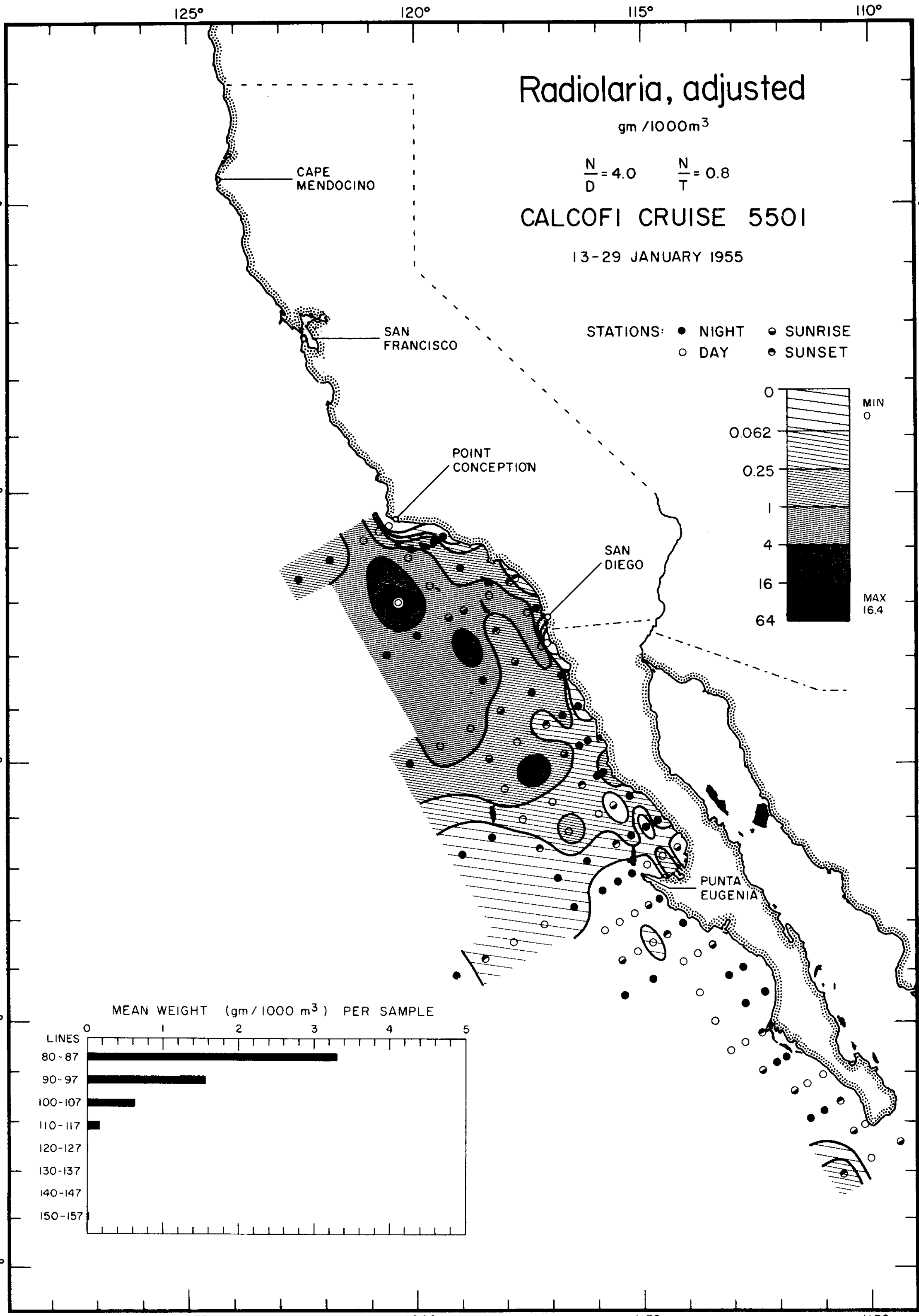




Biomass

Radiolaria

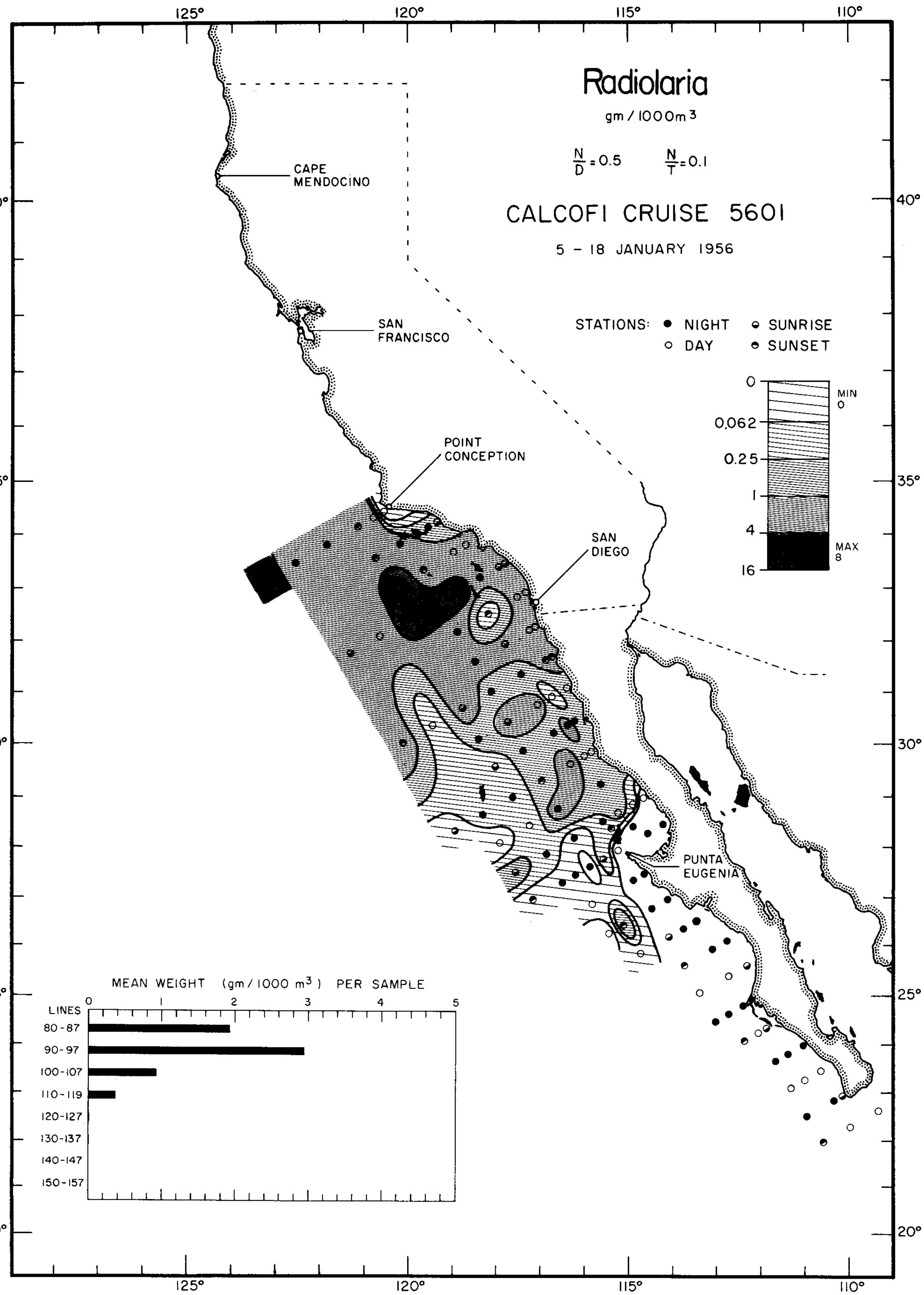
5501



Biomass

Radiolaria, adjusted

5501



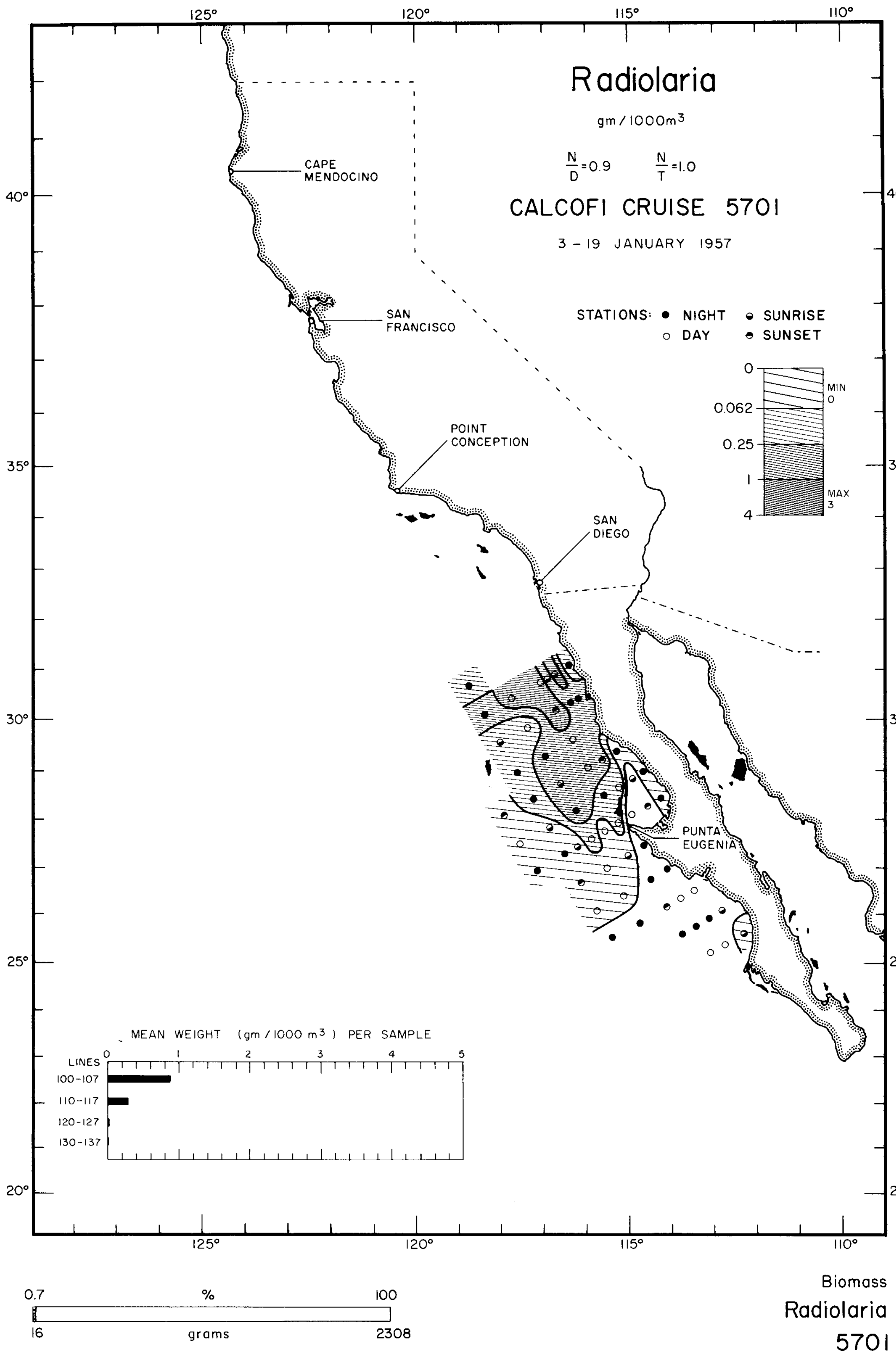
0.8 % 100

98 grams 12684

Biomass

Radiolaria

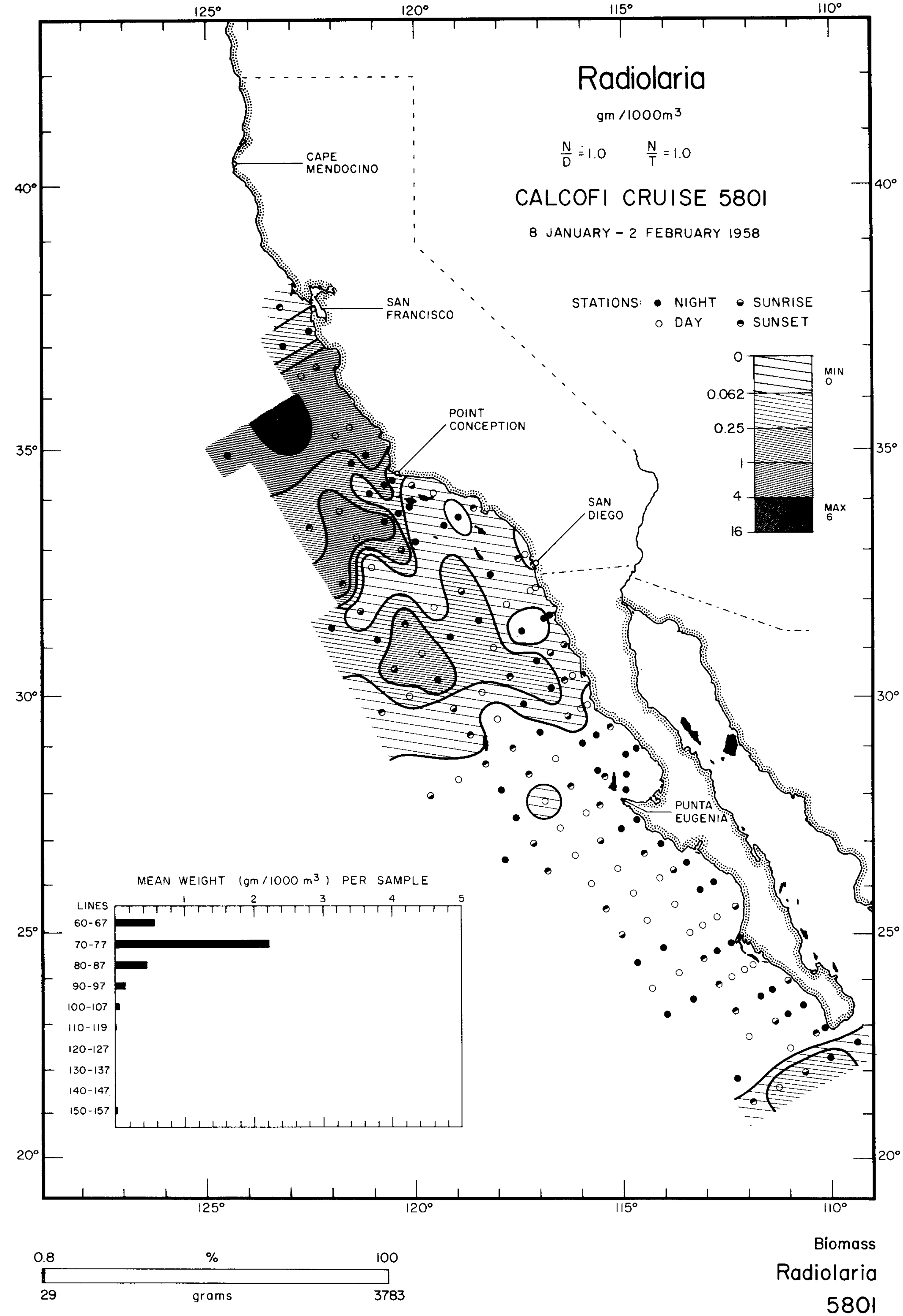
5601



Biomass

Radiolaria

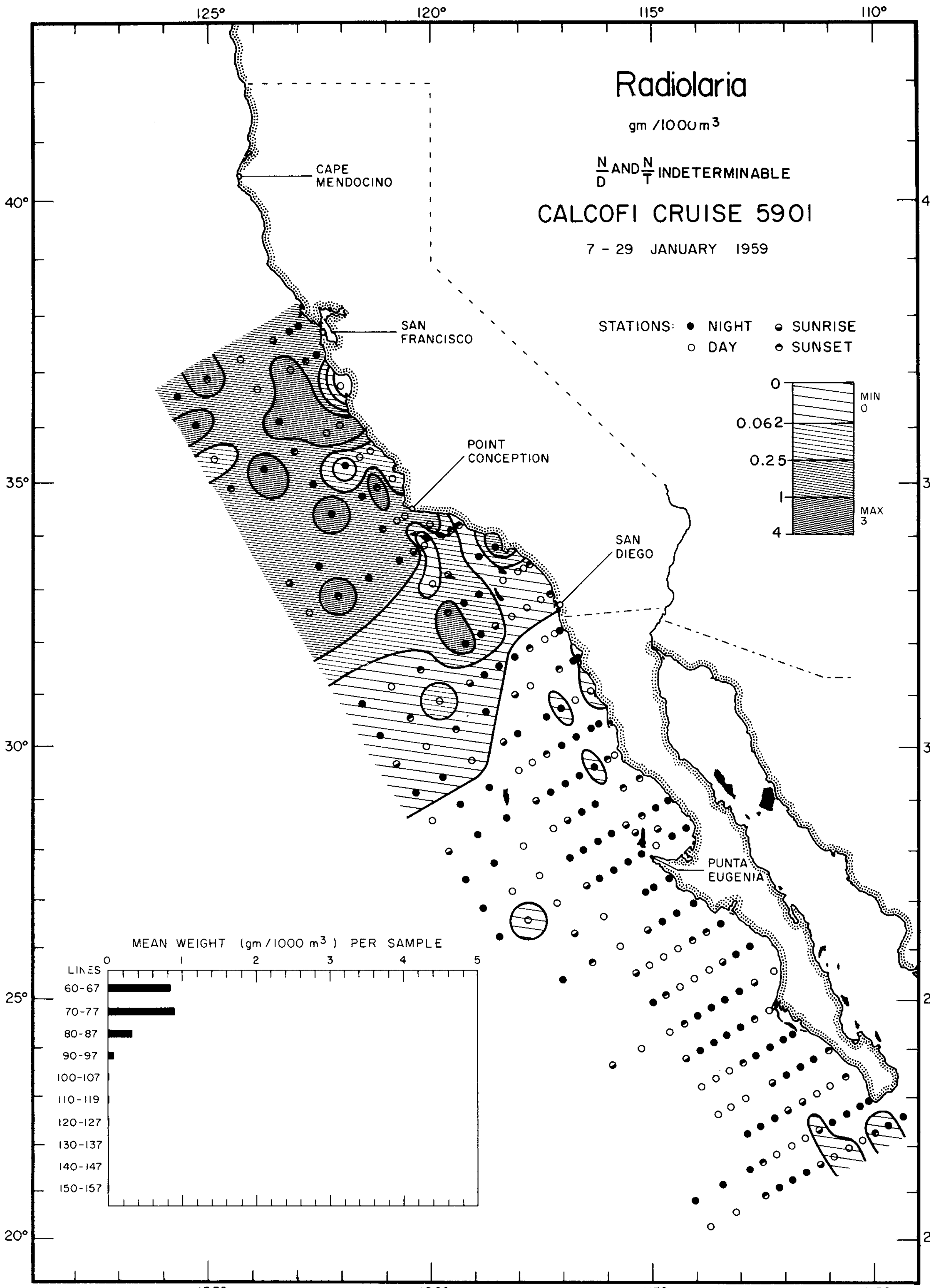
5701

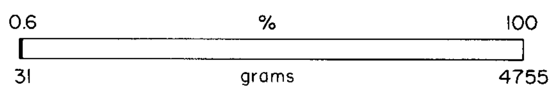


Biomass

Radiolaria

5801

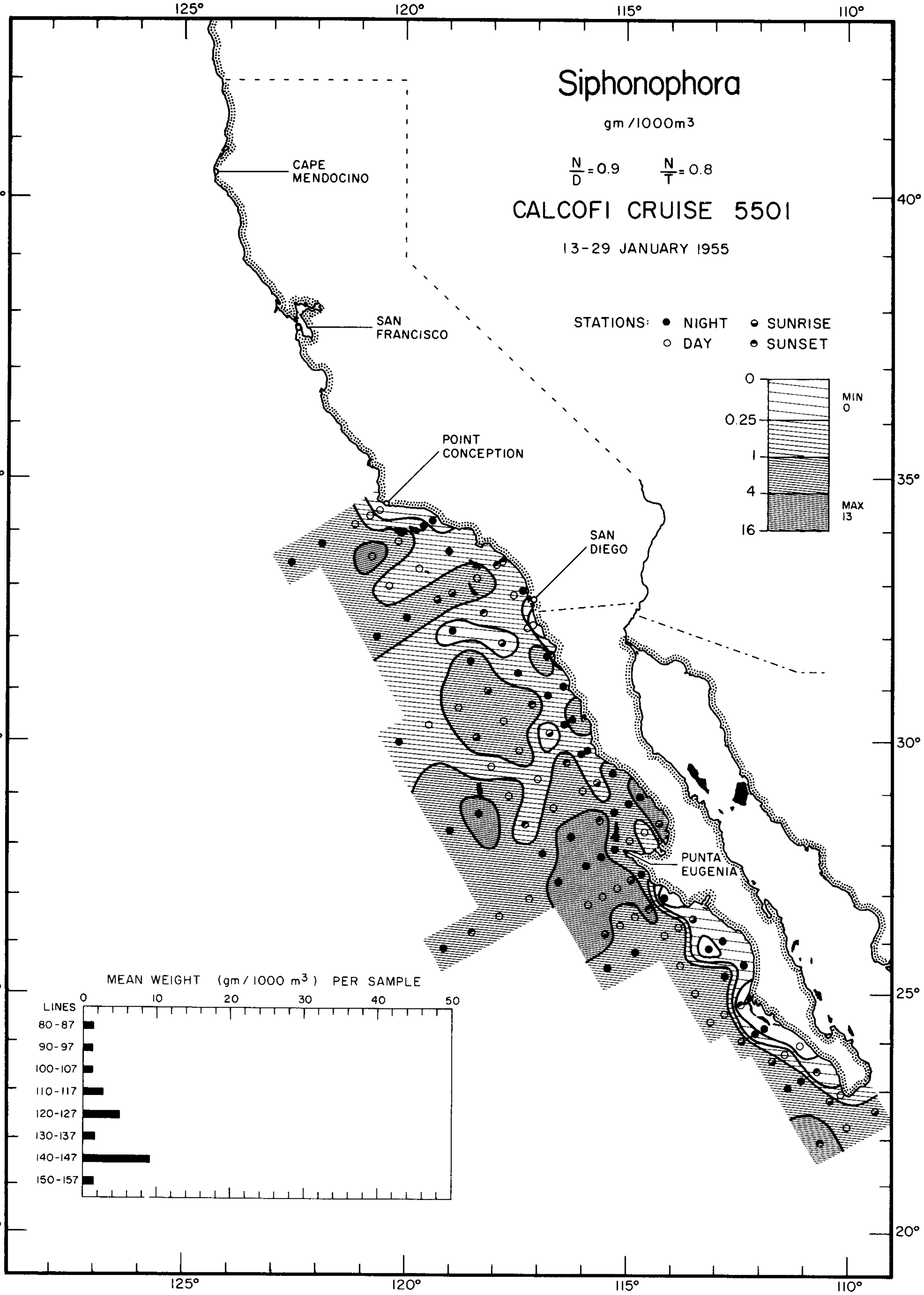




Biomass

Radiolaria

5901



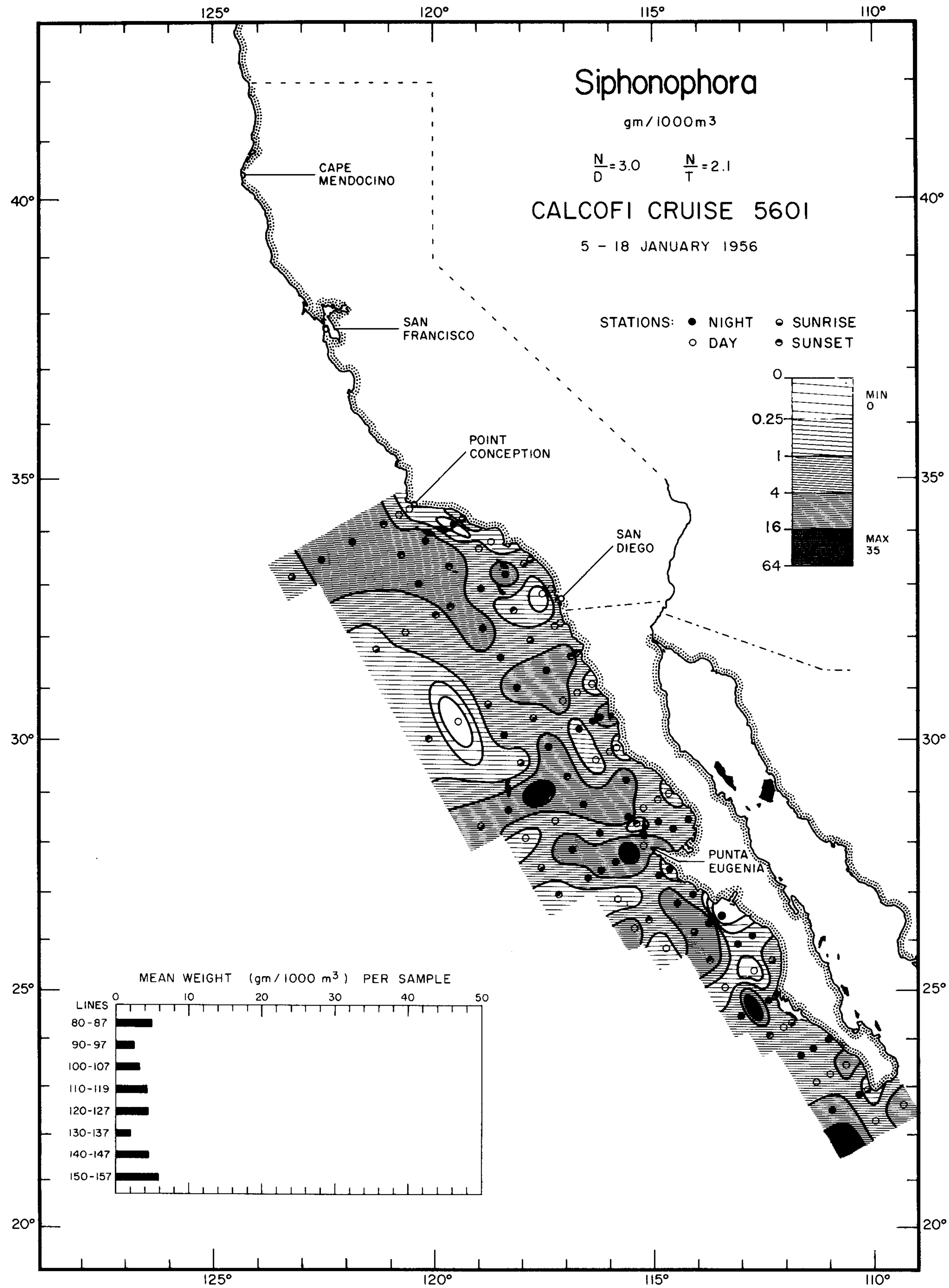
4.7 % 100

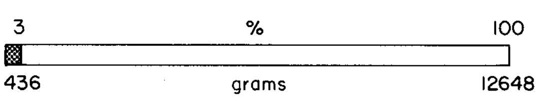
244 grams 5147

Biomass

Siphonophora

5501





Biomass

Siphonophora

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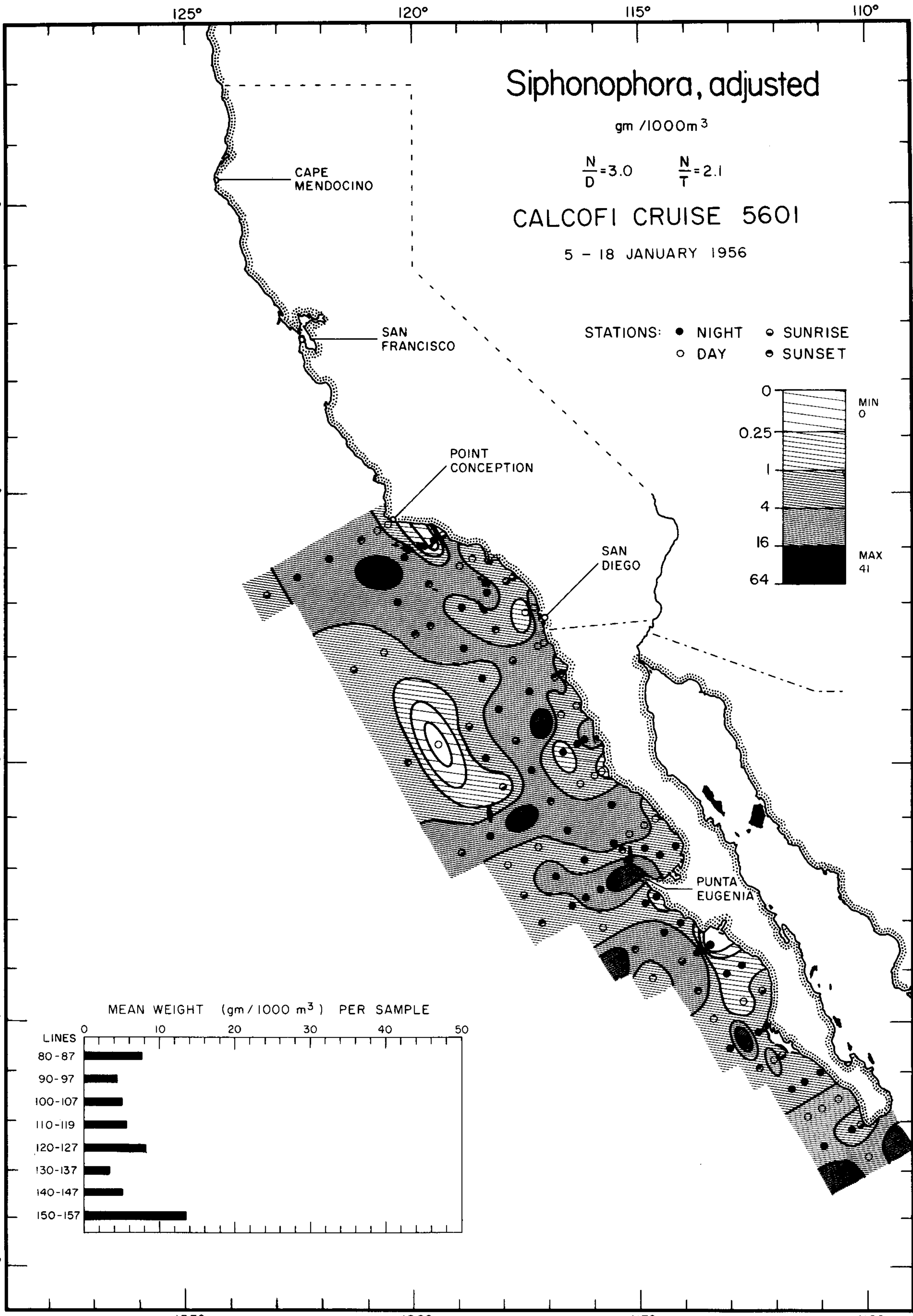
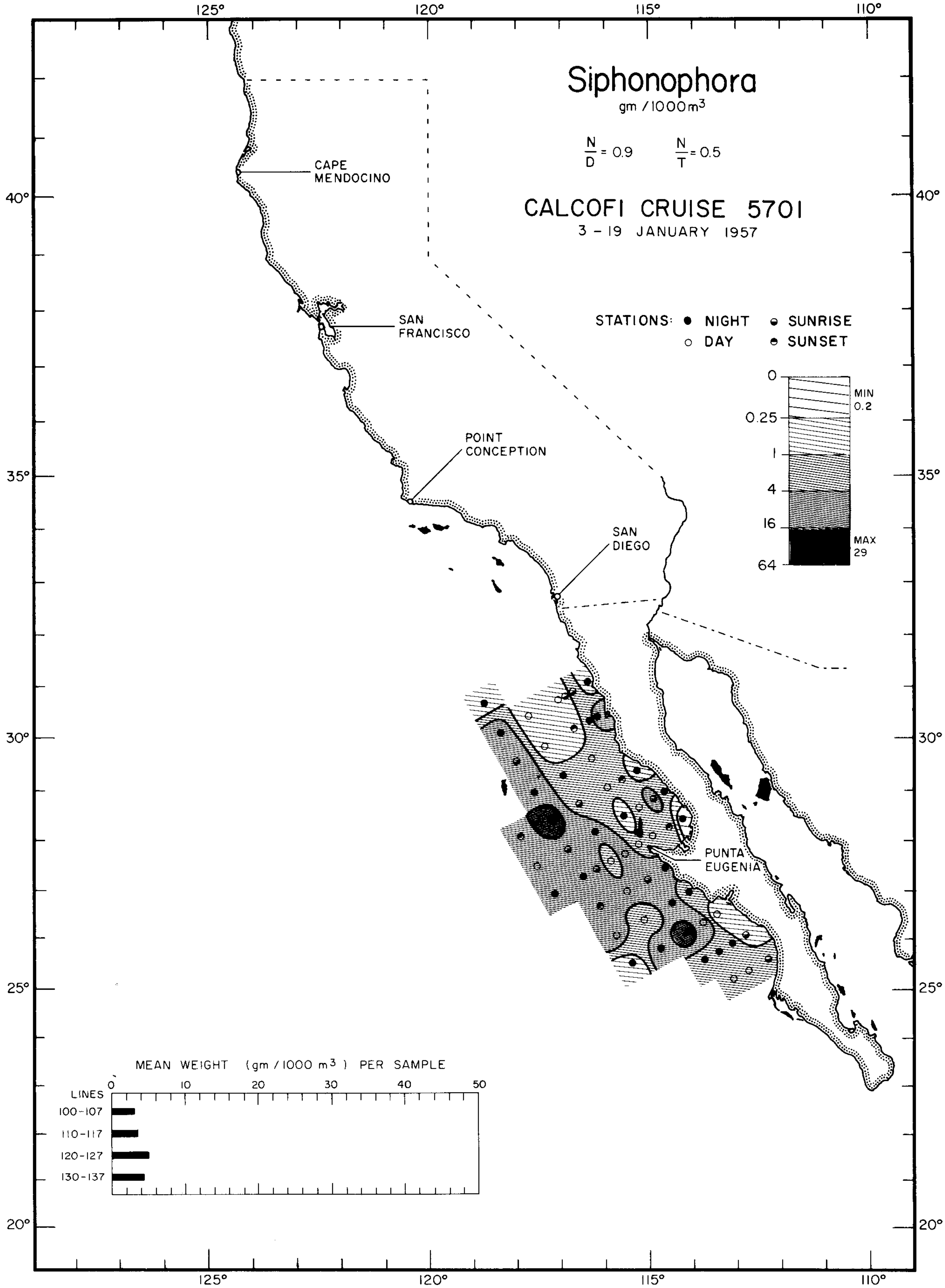
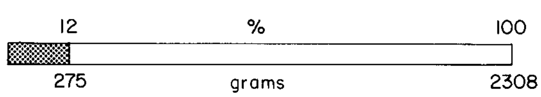


Biomass
Siphonophora, adjusted
5601

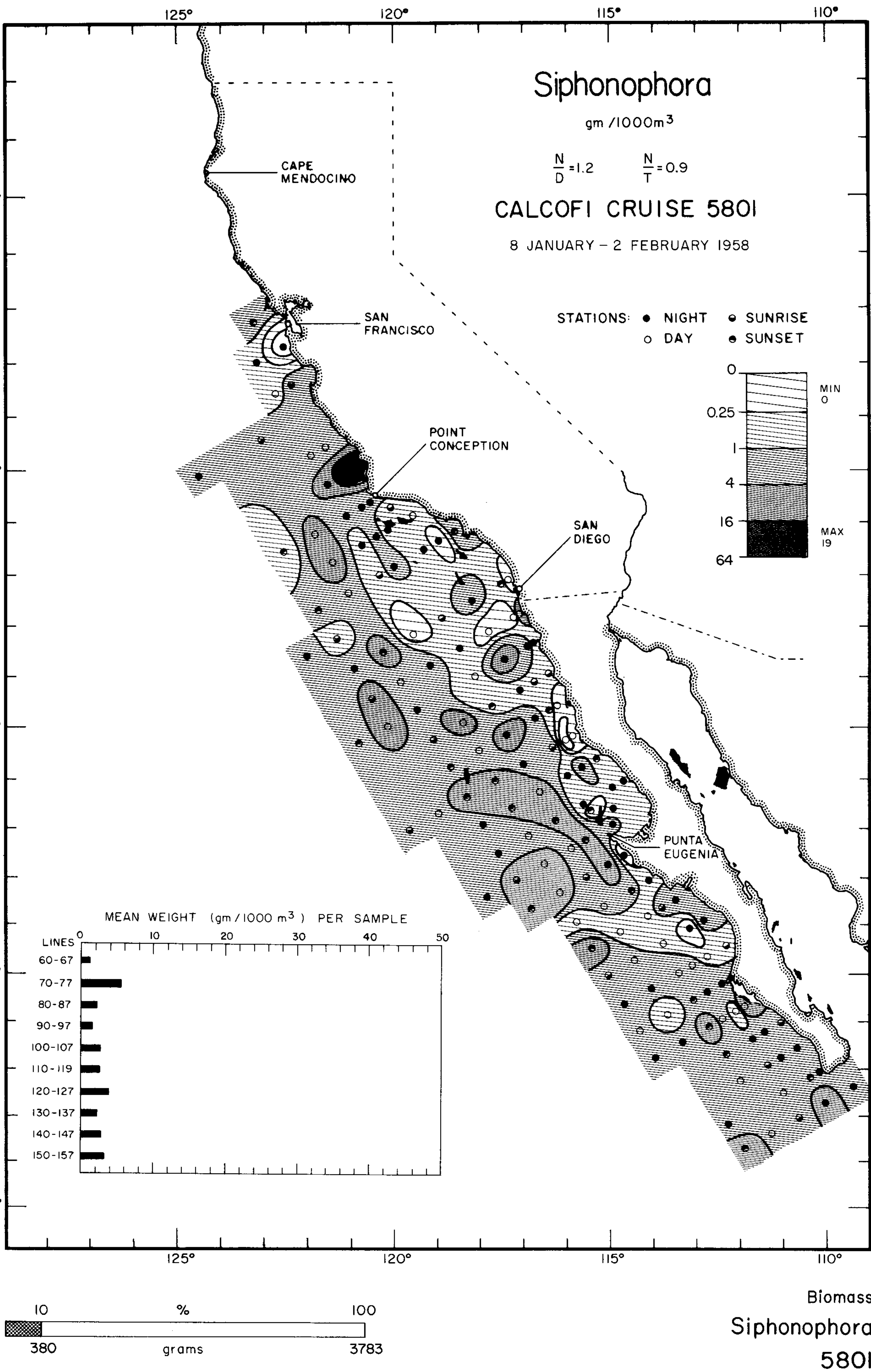




Biomass

Siphonophora

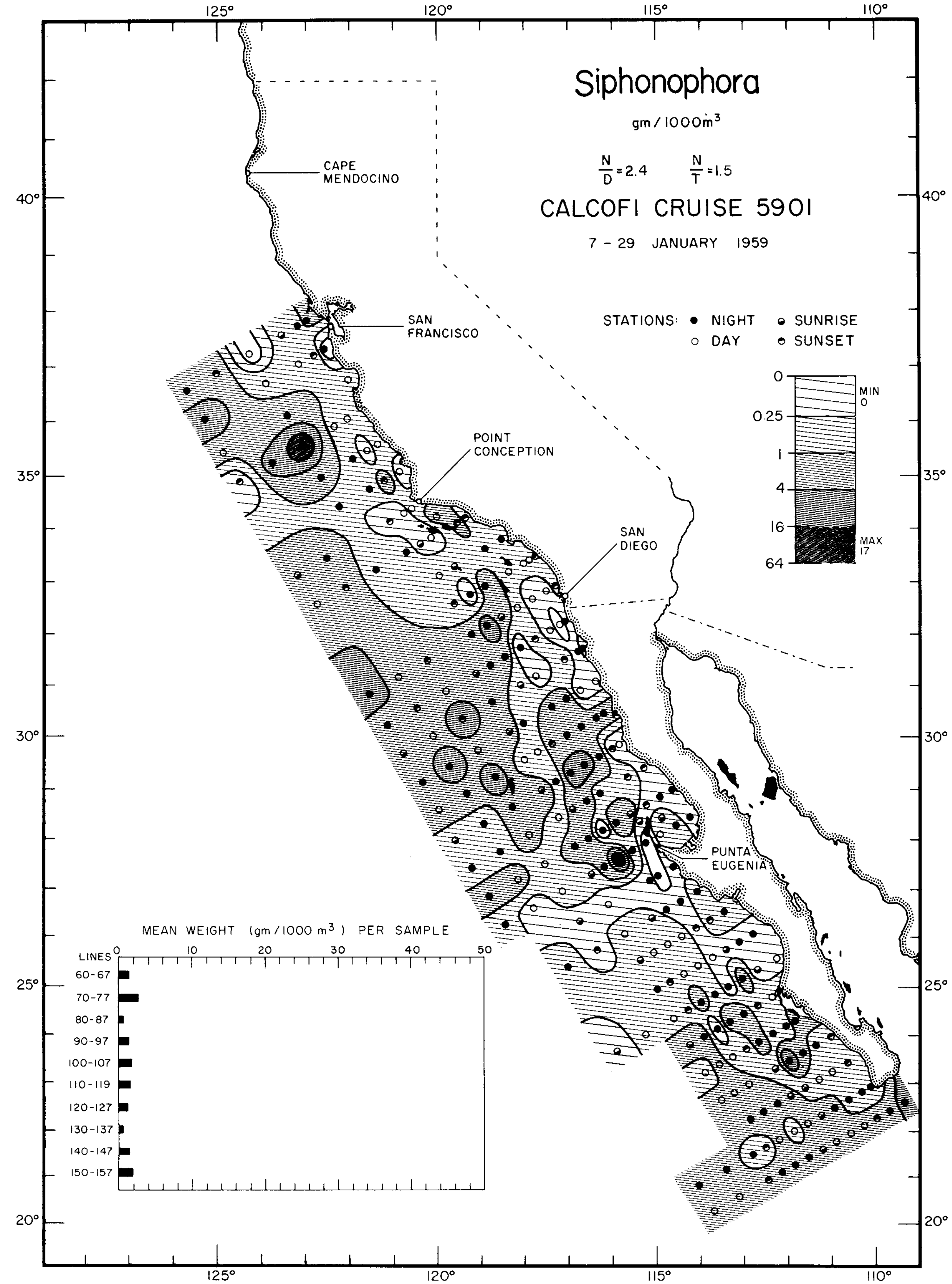
5701

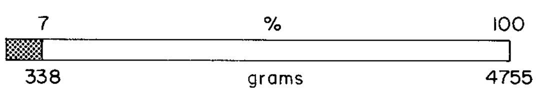


Biomass

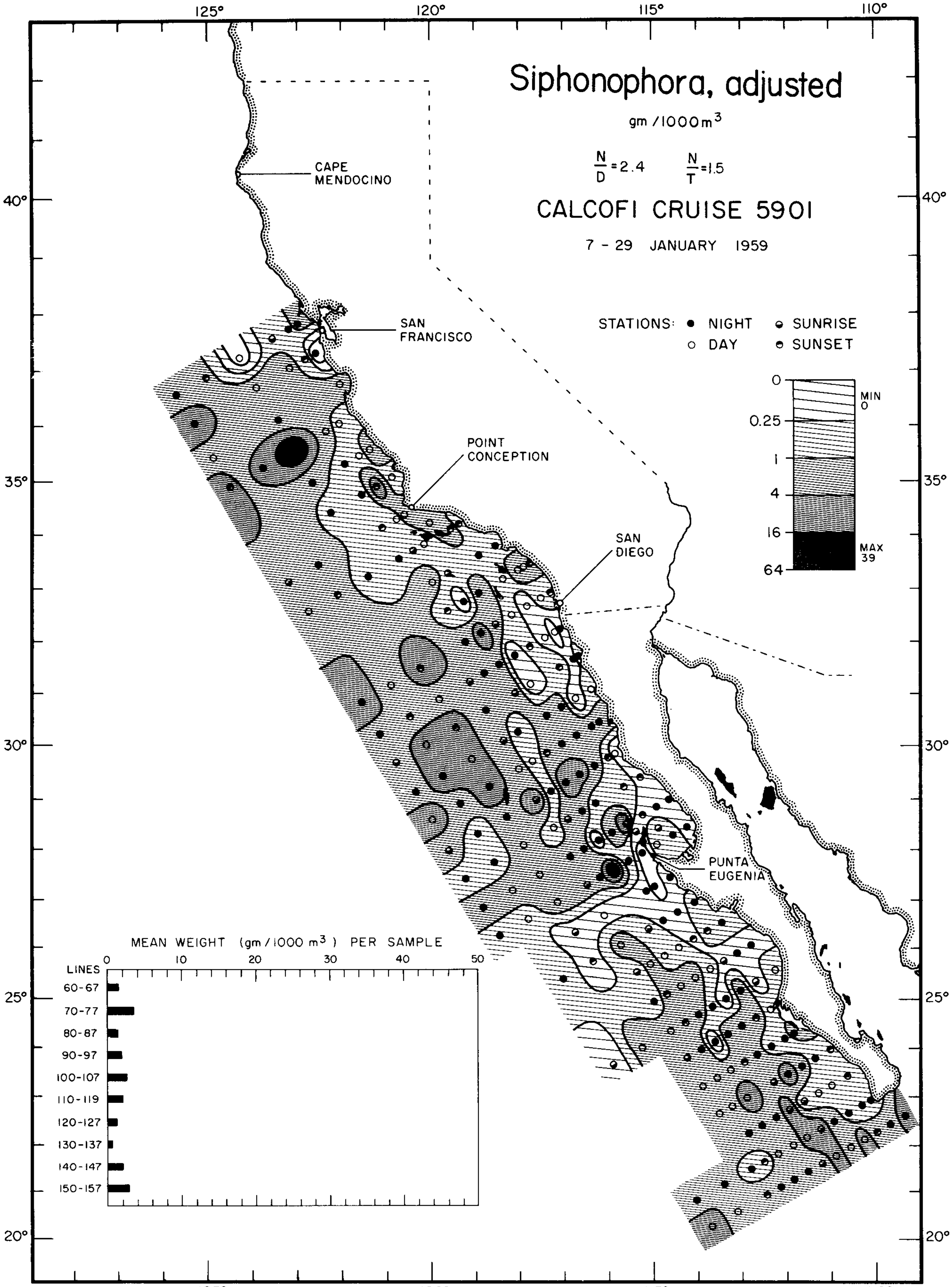
Siphonophora

5801





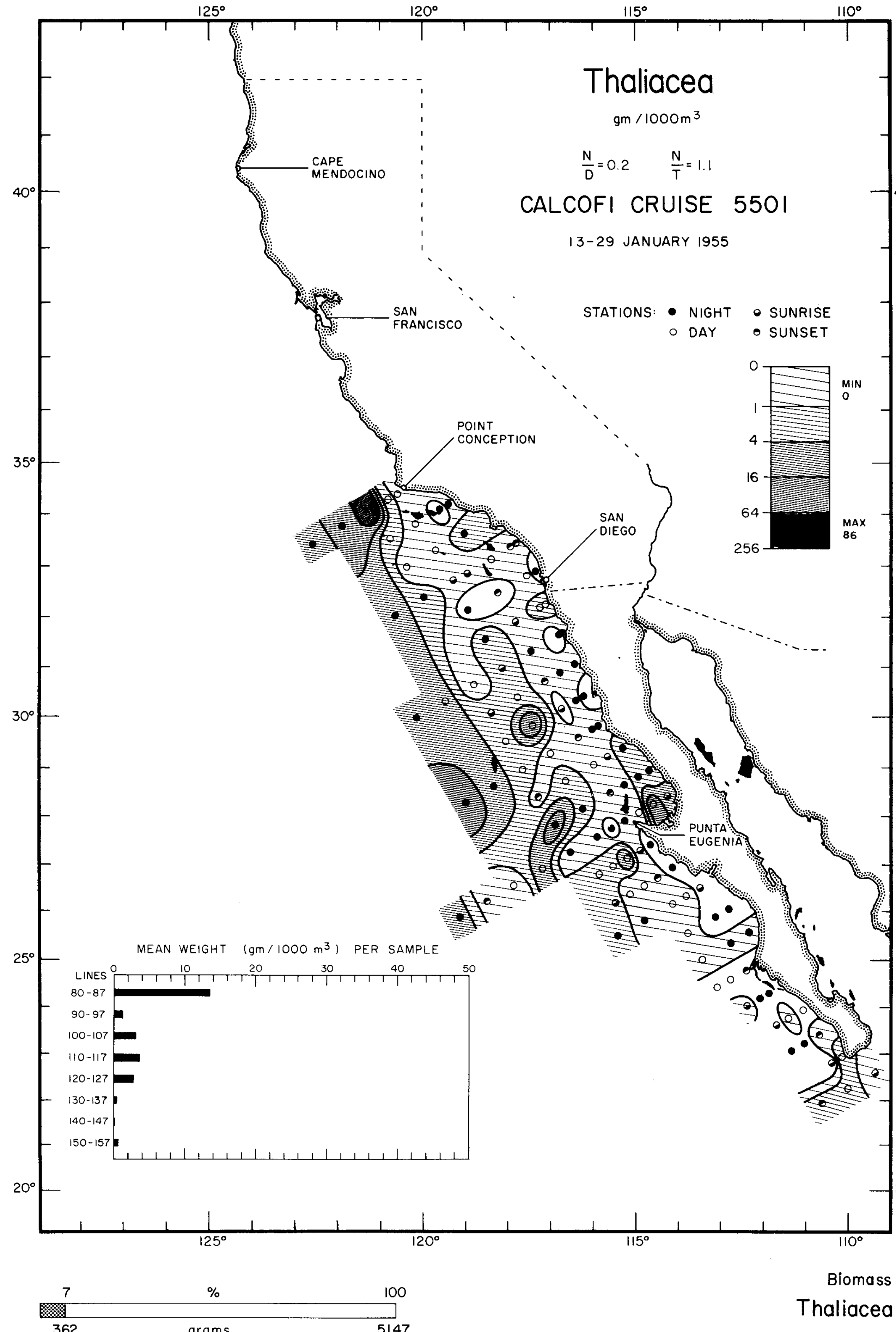
Biomass
Siphonophora
5901



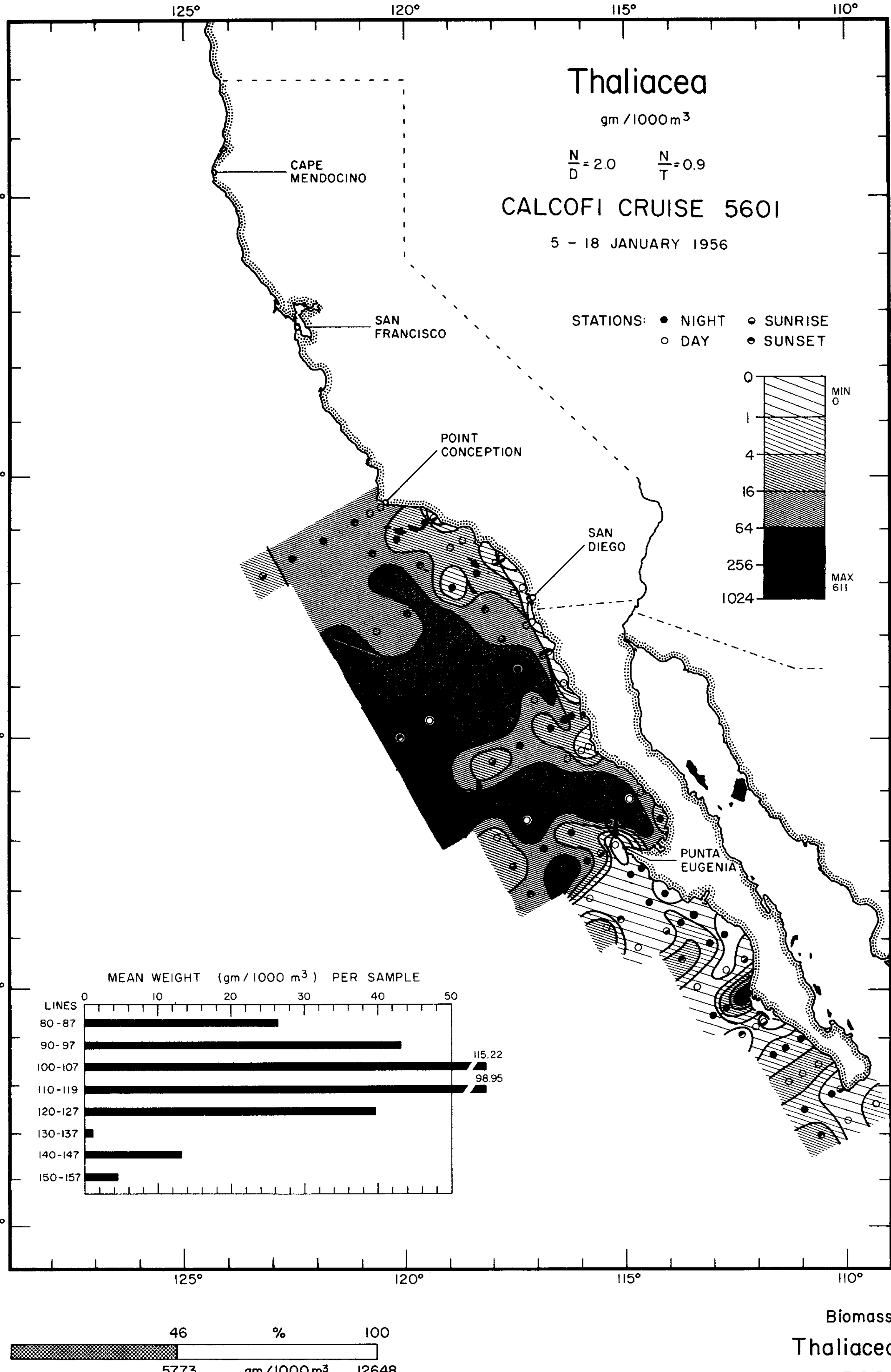
Biomass

Siphonophora, adjusted

5901



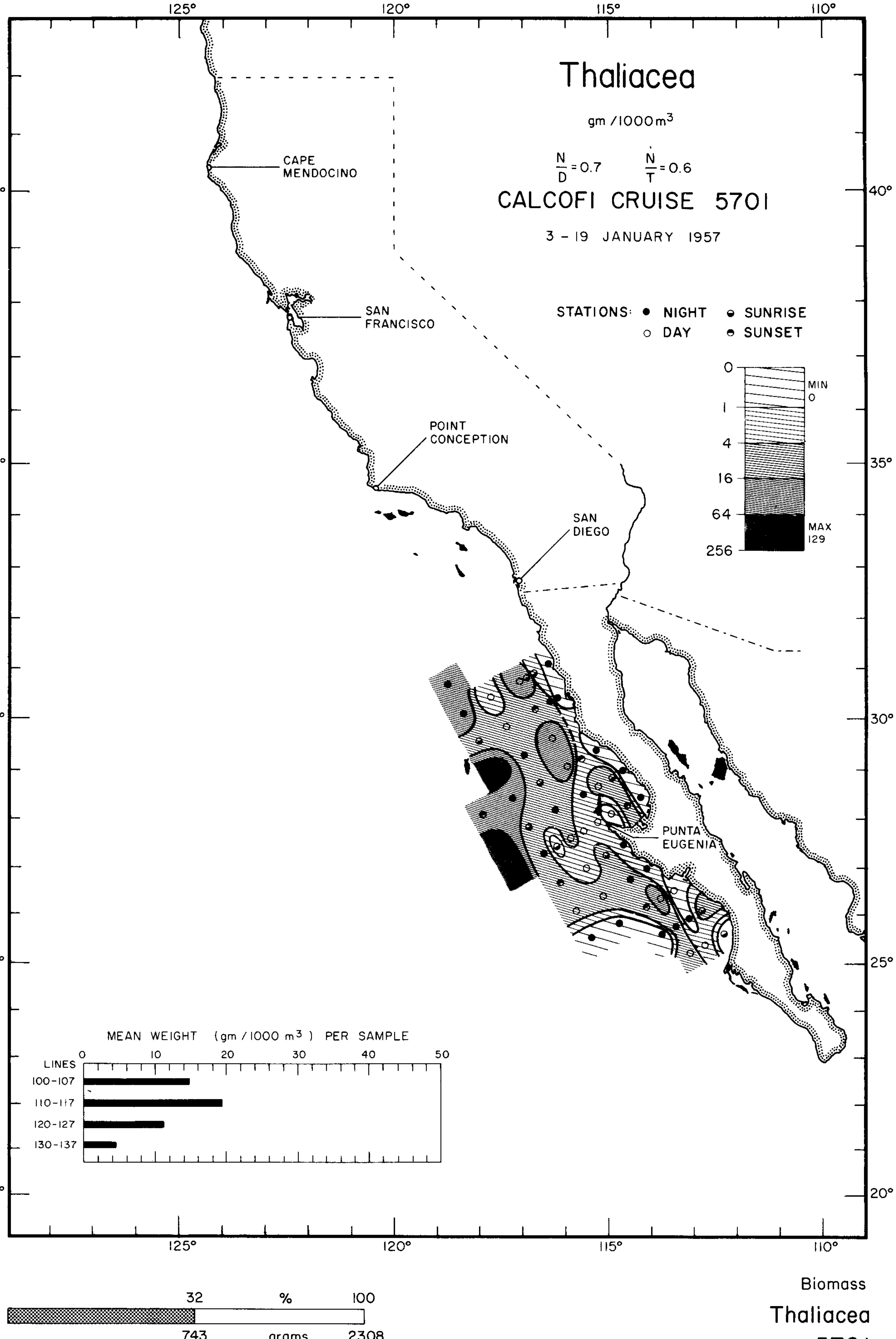
Biomass
Thaliacea
5501



Biomass

Thaliacea

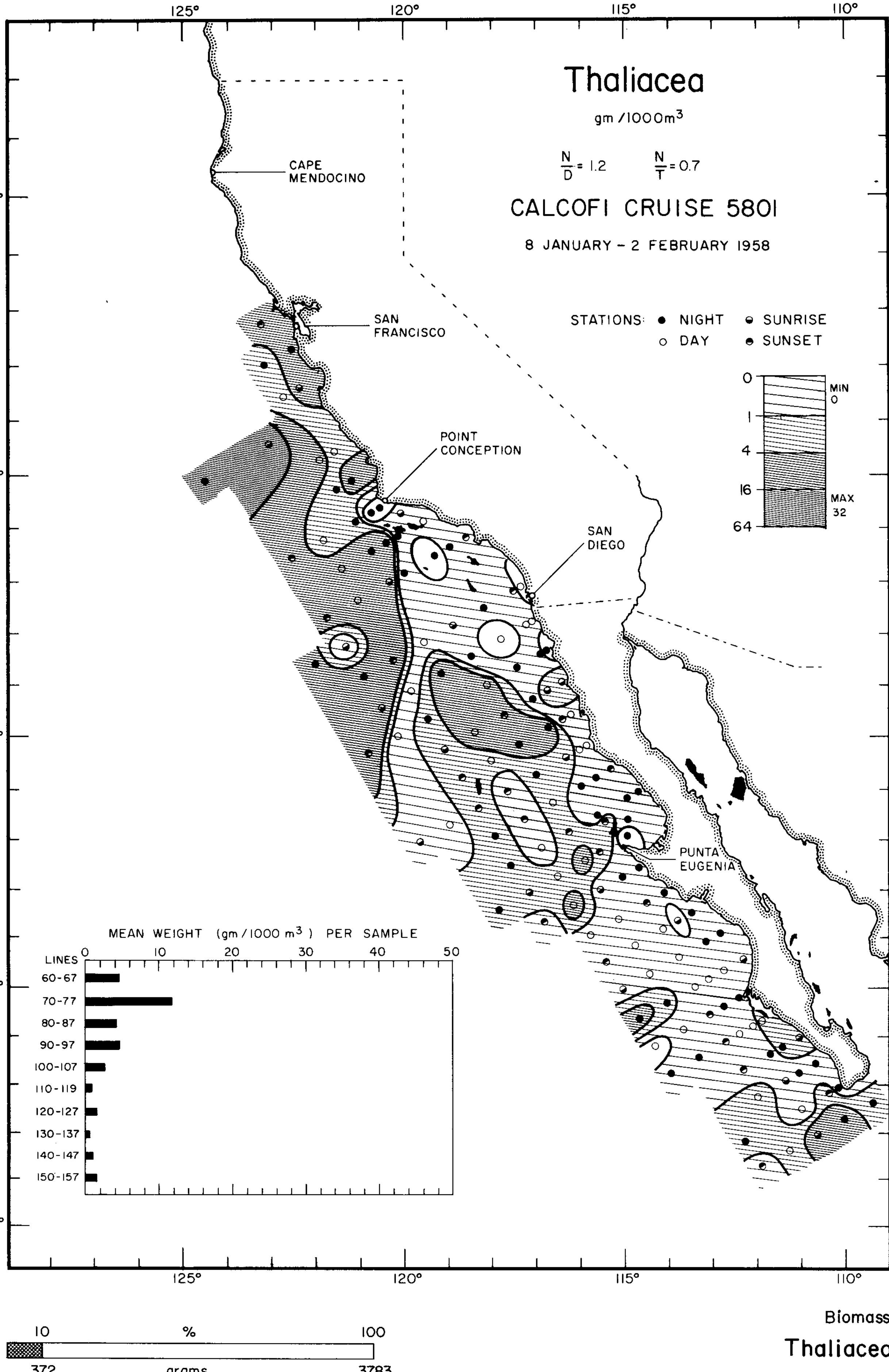
5601



Biomass

Thaliacea

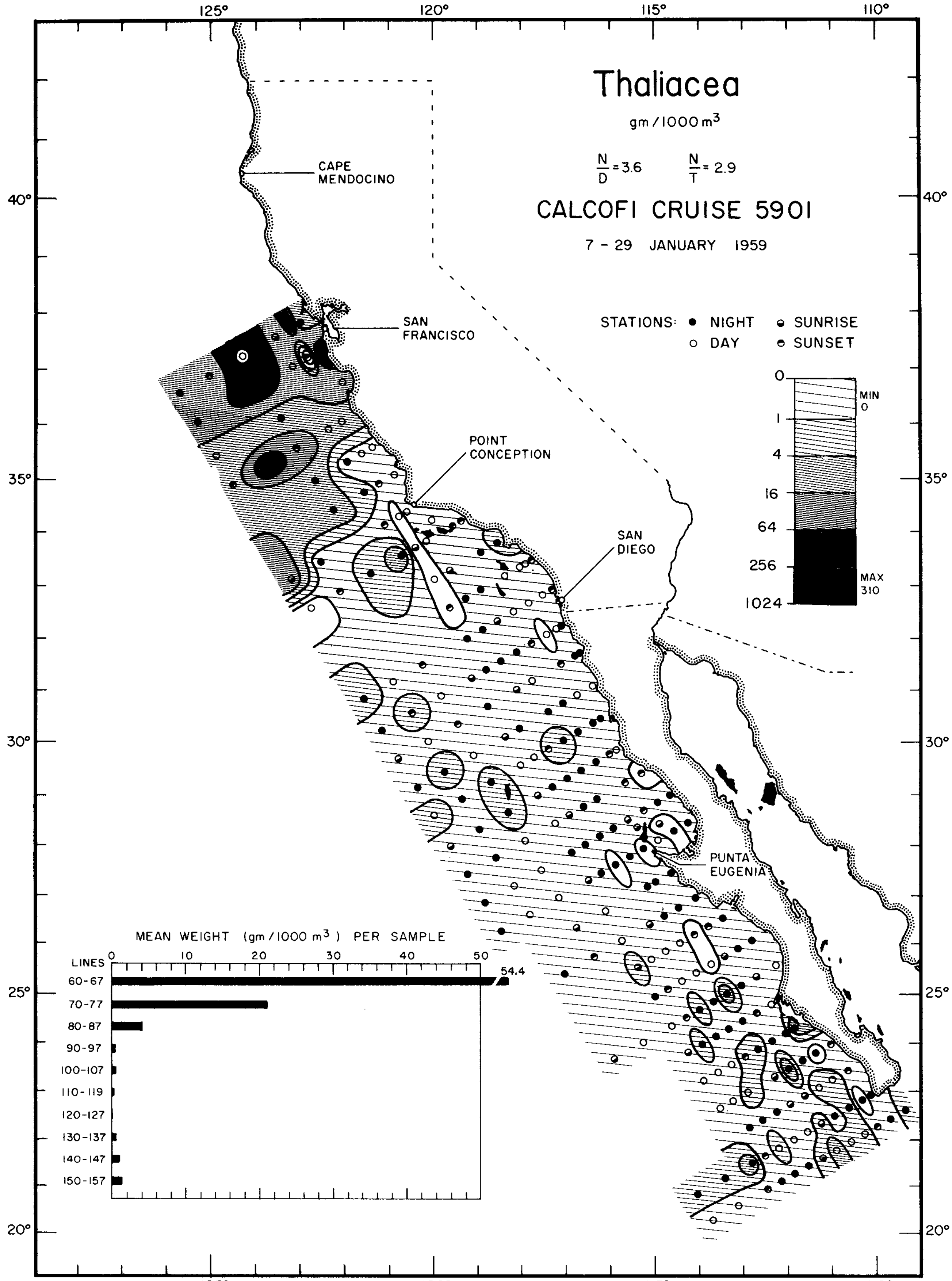
5701

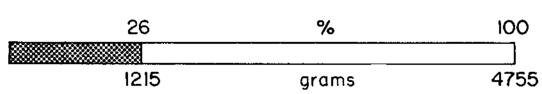


Biomass

Thaliacea

5801

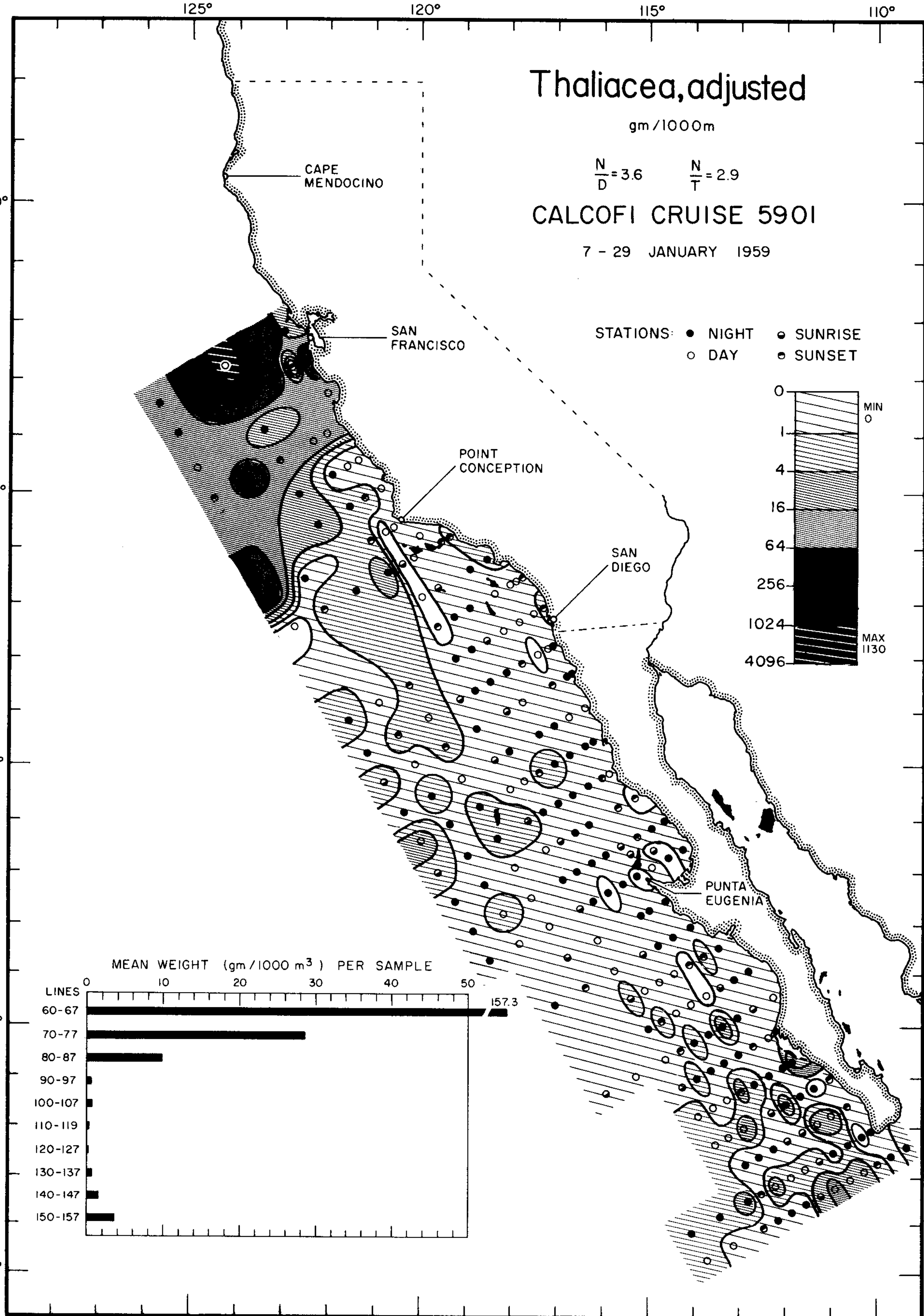




Biomass

Thaliacea

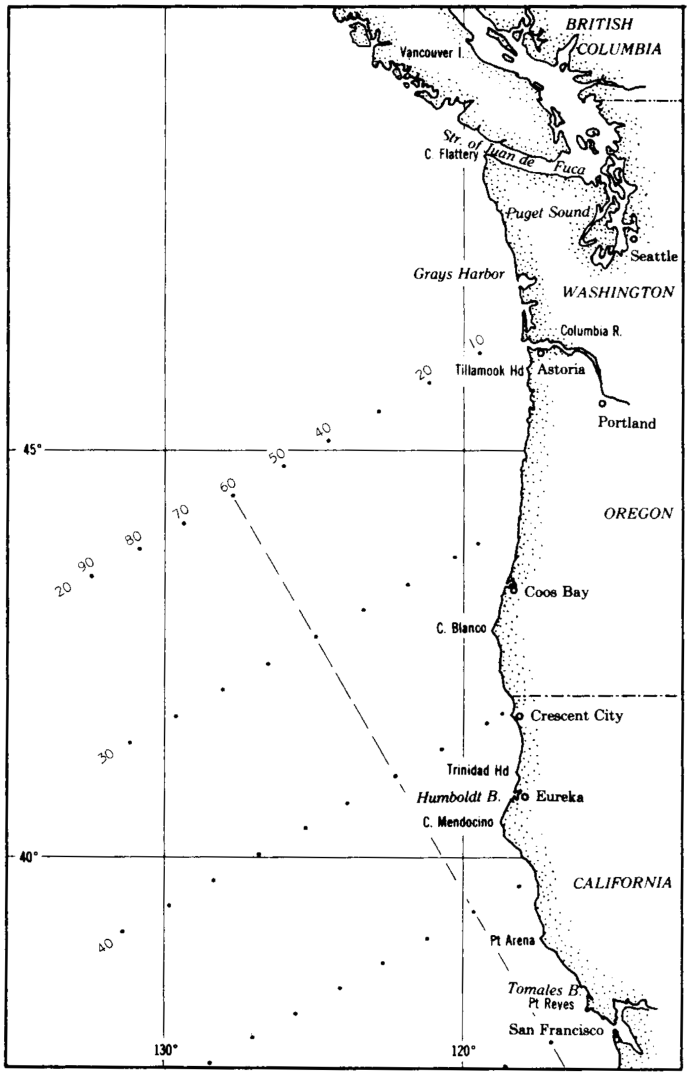
5901

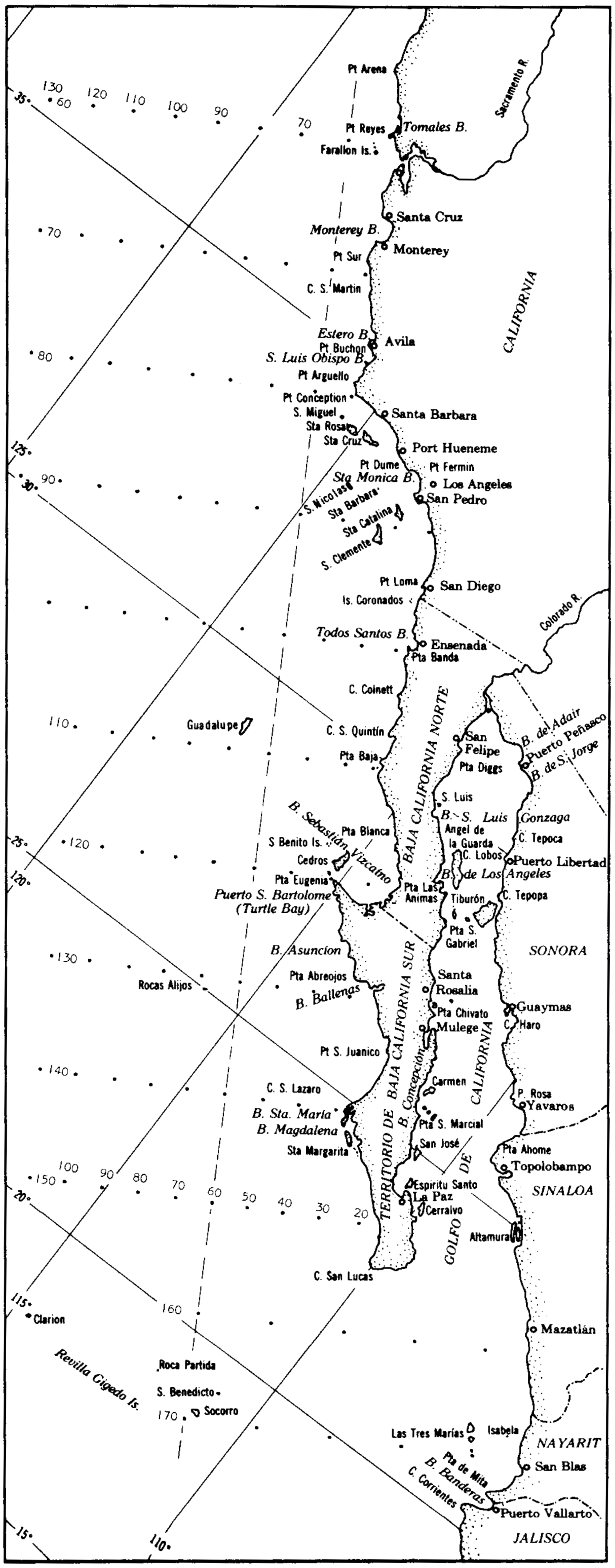


Biomass

Thaliacea, adjusted

5901





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.

CONTENTS

J. D. Isaacs, A. Fleminger and J. K. Miller
Distributional atlas of zooplankton biomass in the California Current region: Winter 1955 - 1959 v
Charts 1-122