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THE PHYSICAL OCEANOGRAPHY OFF THE CENTRAL CALIFORNIA COAST DURING FEBRUARY AND MAY-JUNE, 1991: A SUMMARY OF CTD DATA FROM LARVAL AND PELAGIC JUVENILE ROCKFISH SURVEYS

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

Hydrographic conditions during a 7-day period in February 1991 in the area bounded by Pt. Lobos (36°30'N) and Pt. Reyes (38°10'N), California, from the coast to approximately 135 km offshore are summarized in a series of horizontal maps and vertical transects. In addition, hydrographic conditions, during three periods of approximately ten days each from mid-May through mid-June 1991 in the coastal ocean bounded by Cypress Pt. (36°35'N) and Pt. Reyes, California (38°10'N), and from the coast to about 75 km offshore, are also summarized. A total of 69 conductivity-temperature-depth (CTD) casts were obtained during the *David Starr Jordan* cruise DSJ9102, while 240 standard casts were taken during cruise DSJ9105 over the course of three consecutive sweeps of the region. Data products contained in this report include (1) a master list of CTD stations during each cruise; (2) surface meteorological time series from the region's four National Data Buoy Center (NDBC) meteorological buoys; (3) horizontal maps of temperature, salinity, and density (sigma-theta [σ_θ]) at depths of 2 m, 10 m, 30 m, 100 m, 200 m, 300 m, and 500 m; and (4) temperature, salinity and σ_θ along four cross-shelf vertical transects in the survey region.

INTRODUCTION

In recent years, attempts have been made to integrate the studies of fisheries biologists investigating the recruitment problem (Sissenwine 1984; Rothschild 1986) with those of physical oceanographers studying coastal circulation patterns. This development is due to the widely held perception that spatial and temporal variations in hydrodynamics, on a wide range of scales, have a direct influence on the retention of young-of-the-year in areas favorable for their growth and survival (e.g., Sinclair 1988). This realization has fostered the development of interdisciplinary studies in the area of recruitment fisheries oceanography (Wooster 1988; Office of Oceanic and Atmospheric Research 1989[1]).

Along the central California coast, rockfishes of the genus *Sebastes* are a major component of the west coast groundfish fishery (Gunderson and Sample 1980), with annual landings from 1985-93 averaging 32,740 MT yr^{-1} (Pacific Fishery Management Council 1994). Current management of the rockfish fishery is based largely on analyses of catch-at-age data. Such models are usually poorly constrained in the absence of other information (Deriso et al. 1985). Auxiliary data, such as an independent recruitment index, have the potential to assist in the management of this fishery.

Research conducted at the Southwest Fisheries Science Center's (SWFSC) Tiburon Laboratory since 1983 has attempted to develop a recruitment index for rockfish. Data obtained during annual juvenile rockfish surveys have provided information regarding distributional and abundance patterns of young-of-the-year pelagic juveniles in the area between Monterey Bay and Pt. Reyes (latitude 36°30'-38°10'N) (Wyllie Echeverria et al. 1990). Results of this research show a complex pattern in the spatial distribution of pre-recruits of a variety of commercially significant species (e.g., widow rockfish, *S. entomelas*; chilipepper, *S. goodei*; yellowtail rockfish, *S. flavidus*; bocaccio, *S. paucispinis*; and shortbelly rockfish, *S. jordani*). Moreover, extreme interannual fluctuations in abundance have occurred, with combined stratified mean catches per haul ranging from 0.1-78.6 juvenile rockfish/tow (Eldridge 1994[2]).

Field studies have shown that the survey region is hydrodynamically complex. The California Current provides the backdrop for large-scale, seasonal circulation patterns (Hickey 1979). Coastal upwelling also occurs regionally for most of the year, especially from April to September (Huyer 1983). On the mesoscale (10-100 km), irregularities in the coastline interact with the wind stress field (Kelly 1985), resulting in turbulent jets, eddies and upwelling filaments, all of which are common features along the central California coast (Mooers and Robinson 1984; Flament et al. 1985; Njoku et al. 1985; Rosenfeld et al. 1994). Moreover, wind-driven fluctuations in coastal flow (Chelton et al. 1988) and freshwater discharge from San Francisco Bay (Applied Environmental Science Division[3]) add further complexity to the circulation regime.

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[1]Office of Oceanic and Atmospheric Research. 1989. Program Development Plan for the NOAA Recruitment Fisheries Oceanography Program. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Washington, D.C., 28 p.

[2]Eldridge, M. B. (editor). 1994. Progress in rockfish recruitment studies. SWFSC Admin. Rep. T-94-01, 55 p., unpublished report.

[3]Applied Environmental Science Division. Final Report, California Seabird Ecology Study. Volume II, Satellite Data Analysis. Science Applications International Corporation, Monterey, California.

Realizing that a basic description of the physical environment is necessary to better understand the distribution and abundance of young-of-the-year rockfish, collection of conductivity-temperature-depth (CTD) data was initiated in 1987 as part of the Tiburon Laboratory's annual juvenile rockfish surveys. In the spirit of Wooster (1988), the staff of the SWFSC Pacific Fisheries Environmental Group subsequently developed an interest in analyzing the CTD data and were enlisted in this recruitment fisheries oceanography study. Ultimately, it is our goal to determine and forecast the manner in which rockfish year-class strength is affected by variations in the physical environment.

This report summarizes results obtained from the CTD data collected in 1991. Due to the large quantity of data analyzed and the extensive array of results presented herein, we make little attempt to provide detailed interpretations of our findings. Reports covering the juvenile rockfish surveys of 1988 (DSJ8804 and DSJ8806), 1989 (DSJ8904), 1992 (DSJ9203 and DSJ9206), and 1993 (DSJ9304 and DSJ9307) have been published (Schwing et al. 1990; Johnson et al. 1992; Sakuma et al. 1994a; Sakuma et al. 1994b). A companion volume (Schwing and Ralston 1990[4]) contains individual traces of temperature, salinity, and sigma-t (σ_t, a representation of water density) plotted against depth for each CTD cast conducted in 1989. Further scientific analysis of these data, and their linkages to fisheries recruitment, will be compiled in future peer-reviewed scientific publications (e.g., Schwing et al. 1991).

MATERIALS AND METHODS

Meteorological Data

Meteorological data were obtained for selected sites in the juvenile rockfish survey region. These sites include the region's four National Data Buoy Center (NDBC) moored buoys: 46013 (Bodega Bay; 38.2°N, 123.3°W), 46026 (Farallones; 37.8°N, 122.7°W), 46012 (Half Moon Bay; 37.4°N, 122.7°W) and 46042 (Monterey Bay; 36.8°N, 122.4°W) (Appendix 2). Daily averages of several surface meteorological parameters, including air and sea temperature, east and north wind components, and barometric pressure, were calculated for the time period that includes the 1991 larval and juvenile rockfish surveys. Plots of several of these products are provided in this report to aid in the interpretation of results and to suggest possible atmospheric-oceanic interactions (Appendix 3).

Larval Rockfish Survey Design

In February of 1991 ichthyoplankton sampling was conducted aboard the NOAA Research Vessel (R/V) *David Starr Jordan* (DSJ) using bongo nets. Samples were collected from 150 stations within the region bounded by Pt. Lobos (36°30'N) and Pt. Reyes (38°10'N), California from the coast to approximately 135 km offshore. Bongo net sampling procedures generally followed the prescribed California Cooperative Fisheries Investigation (CalCOFI) guidelines (Kramer et al. 1972, Smith and Richardson 1977). CTD casts were done at certain bongo net stations, which encompassed the entire survey region (Appendix 2).

Juvenile Rockfish Survey Design

Annual cruises aboard the NOAA R/V DSJ began in 1983 and have been conducted during late spring (April-June), a time when most pelagic-stage

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[4]Schwing, F. B., and S. Ralston. 1990. Individual cast data for CTD stations conducted during cruise DSJ8904 (May 14-June 13, 1989). SWFSC Admin. Rep. PFEG-91-01, 7 p. + figs., unpublished report.

juvenile rockfishes are identifiable as to species, but prior to their settling to nearshore and benthic habitats. Throughout this time, a standard haul consisted of a 15-minute nighttime tow of a large midwater trawl set to a depth of 30 m. Additional tows were made at other depths (i.e., 10 and 100 m) as allowed by constraints imposed by time and bottom bathymetry.

In 1986, the sampling design was altered to permit three consecutive "sweeps" through a study area bounded by Cypress Pt. (36°35'N) and Pt. Reyes (38°10'N), California, and from the coast to about 75 km offshore. Trawls are now conducted at five or six stations along a transect each night; each sweep is composed of seven transects. Starting in 1987, a CTD cast was conducted at each trawl station occupied. In addition, daytime activities were restructured to permit sampling of a new grid of standard CTD stations (Appendix 2). Standard CTD stations were specific locations where CTD casts were scheduled and repeated for each sweep of each cruise. CTD cast locations that were only specific to a particular sweep during a cruise were considered as additional CTD stations. Although each sweep typically lasts approximately ten days (seven nights of scheduled work plus 3 nights of additional discretionary sampling), adverse weather conditions can extend the completion date of a sweep. Logistical constraints can also restrict the number of casts completed. Discretionary sampling typically was focused on specific bathymetric features, such as Cordell Bank or Pioneer Canyon, or devoted to the intense study of oceanic features or processes that may be key to successful recruitment. CTD casts conducted during discretionary sampling were considered additional stations and not included in the grid of standard CTD stations.

Collection of CTD Data at Sea

All CTD data from the 1991 rockfish surveys presented in this report were collected with two Sea-Bird Electronics, Inc. SEACAT-SBE-19 profilers[5]. The first unit contained 64K of memory, while the second unit contained 256K. Both units were rated to a depth of 600 m. Four data channels were used to record pressure (0.05% of full scale range [50-5,000 psia]), temperature (0.01 °C from -5 to +35 °C), and conductivity (0.001 S/m from 0 to 7 S/m) at a baud rate of 9,600. The profilers were recalibrated annually by Sea-Bird Electronics, Inc. prior to their use at sea.

During deployment, the vessel was brought to a dead stop and the profiler was attached to a hydrographic winch cable. The profiler was then switched on and suspended underwater at the surface for a period of at least one minute to allow the conductivity and temperature sensors to equilibrate. The rate of descent was 60 m/minute to a depth 10 m off the bottom if water depths were less than 500 m. Otherwise the profiler was lowered to a maximum depth of 500 m. Only data collected on the downcast were ultimately preserved for analysis. During the cast, certain collection information was recorded on data sheets, including (1) the date, (2) time, (3) a profiler-assigned cast number, (4) a cruise-specific consecutive cast index number, (5) the trawl station number (when appropriate), (6) latitude, (7) longitude, (8) bucket temperature, and (9) bottom depth in meters. Position fixes were obtained using LORAN-C. Bucket temperatures were obtained from a continuous flow of surface water pumped into one of the vessel's laboratory sinks where a thermometer was submerged in a collection container. During DSJ9102, additional bucket temperatures were recorded at each bongo net station. All information recorded on the data sheets was eventually entered into a data file

[5]Sea-Bird Electronics, Inc., 1808 - 136th Place NE, Bellevue, Washington 98005, USA. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

(####.LST where #### is the four-digit cruise number) on a personal computer.

Data collected from a short series of casts (usually no more than 5-7) were periodically uploaded to a personal computer on board the vessel. During this step each cast was stored as a separate file and named using the convention C####&&&.HEX, where #### is the four-digit cruise number and &&& is the three-digit consecutive cast index number. After uploading, the profiler was reinitialized and the *.HEX files on the personal computer were backed-up on diskette.

An additional source of hydrographic data during DSJ9105 was the vessel's thermosalinometer (TS) unit, which provided a continuous data stream of surface temperature and salinity. These data were stored on diskette and transferred to a personal computer on board the vessel for further processing, analysis, and comparison with and verification of CTD observations. Position fixes for the TS unit were based on the SATNAV navigation system.

Data Processing

The first step in data processing was to convert the uploaded CTD *.HEX files to ASCII files. This was accomplished using the SEASCII program supplied by Sea-Bird Electronics, Inc. (SEASOFT Version 3.4[6]). The data were then analyzed with a FORTRAN program that performed the following functions: (1) removal of the equilibration phase from the data stream; (2) removal of the upcast or retrieval phase from the data stream; (3) removal of extreme outliers (i.e., data spikes); (4) correcting phase differences in sensor response by reverse-lagging temperature data

$$(\text{i.e., } T_i = T_i + 0.9[T_{i+1} - T_i])$$

(5) smoothing conductivity and temperature values using {1,4,6,4,1} weighting; (6) computing salinity and density for each scan using algorithms adapted from programs supplied by Sea-Bird Electronics, Inc. (SEASOFT, version 3.4[6]); (7) averaging temperature, salinity, and density values into one m depth bins, and ; (8) smoothing these using {1,2,3,2,1} weighting. A detailed discussion of the rationale behind these procedures may be found in the SEACAT-SBE-19 Conductivity, Temperature, Depth Recorder Operating and Repair Manual[7] [see also UNESCO (1988)]. Data were converted to their final ASCII format using a SAS[8] macro. All data were subsequently transferred to a SUN file server.

Each CTD ASCII file was manually edited to remove outliers (i.e. data spikes) in salinity and/or density, which had not been removed by the FORTRAN program. These outliers often occurred near the surface and at the thermocline. Comparisons were made between CTD temperature at the surface and bucket temperature at each CTD station using a simple regression to check for data outliers and any blatant calibration problems (Appendix 4). Although TS data was available for DSJ9105, the unit had not been properly calibrated. Therefore, direct comparison of the TS data

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[6]CTD Data Acquisition software, SEASOFT Version 3.4, September 1990, Sea-Bird Electronics, Inc., 1808 - 136th Place NE, Bellevue, Washington 98005, USA. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[7]SEACAT-SBE-19 Conductivity, Temperature, Depth Recorder Operating and Repair Manual, Serial Number 24, 30 March 1987, Sea-Bird Electronics, Inc., 1808 - 136th Place NE, Bellevue, Washington 98005, USA. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[8]SAS Institutes Inc., SAS Circle Box 8000, Cary, North Carolina 27512. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

with CTD data at the surface was not possible. The TS data were subsequently calibrated using the CTD data at the surface.

Processed hydrographic data were summarized, by cruise and sweep, in a series of horizontal maps and vertical transects, and are presented in this report. Although additional CTD casts were done during DSJ9105, only casts from the grid of standard CTD stations and only those casts which provided a relatively continuous sampling track within a specific sweep were included in the data summary for the horizontal maps (Appendix 5). This was done in an attempt to generate a relatively synoptic picture for each individual sweep and to allow for sweep to sweep comparisons of hydrographic features. The offshore extent of casts used in the vertical transects is shown in Appendix 6. Contouring of CTD data for horizontal maps and vertical transects was done using SURFER FOR WINDOWS graphics software[9], which estimates values throughout a specified region based on the available data. Kriging was selected as the optimal interpolation method used for the algorithm grid (cf., Cressie 1991).

Bucket temperatures taken at each bongo net station were contoured for DSJ9102 for comparison with the horizontal contour maps of CTD temperature at 2 m. TS raw data from DSJ9105 were edited to provide a nearly continuous sampling track for each sweep and then contoured. However, as the TS data were calibrated from the CTD data, only spatial differences due to the increased coverage of the TS data can be compared rather than the absolute temperature and salinity differences between the CTD and the TS. Bucket temperature and TS contour maps were generated using SURFER FOR WINDOWS graphics software[9].

RESULTS

Data Products

Below are a few brief comments on each of the data products contained in this report in the order that they appear.

Appendix 1: Lists of CTD Stations Summarized from Cruises DSJ9102 and DSJ9105

The station lists include, from left to right, CTD cast number (only acceptable casts included), date, local military time, latitude and longitude (degrees, minutes), and station bottom depth. Cruise DSJ9102 (February 8-15) includes 69 stations (casts 1-78). Cruise DSJ9105, Sweep 1 (May 14-22) includes 83 standard stations (casts 1-84), Sweep 2 (May 27-June 3) includes 72 standard stations (casts 136-216), and Sweep 3 (June 3-10) includes 85 standard stations (casts 217-303).

Appendix 2: CTD Stations and Bathymetric Maps of Survey Region with Locations of the NDBC Buoys

The locations of the CTD stations for DSJ9102 and the standard CTD stations for DSJ9105 along with the locations of the NDBC buoys, the place names, and the bottom bathymetry of the survey areas are shown.

Appendix 3: Meteorological Time Series

Meteorological time series are presented for the four NDBC buoys as described above. The first figure in this section summarizes the daily average wind speed (m/s) and direction (relative to true north) at these

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[9]SURFER FOR WINDOWS, Golden Software, Inc., 809 14th Street, Golden, Colorado 80401. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

stations, in stick vector form, for the period January through June 1991. Vectors point in the direction toward which the wind was blowing; an arrow pointing toward the top of the page represents a northward-directed wind.

The following figures show scalar time series of sea surface temperature, or SST (°C); air temperature (°C); the north-south component of wind speed (m/s), a crude indicator of upwelling-favorable wind; and barometric pressure (millibars) at each meteorological station for the first 180 calendar days of 1991. A positive wind value denotes a northward-directed wind component. The survey periods for DSJ9102 and DSJ9105 (divided by sweep) are shaded in all time series plots.

Appendix 4: Regression Comparisons of CTD and Bucket Temperatures

The plots presented show comparisons between CTD temperature at 2 m and bucket temperature. The solid lines represent the lines of equality in order to show how the different data varied from each other. The regression statistics for each comparison were as follows:

DSJ9102: CTD temperature versus bucket temperature,
CTDtemp. = buckettemp. x 0.9803 + 0.0901
R^2 = 0.9523

DSJ9105: CTD temperature versus bucket temperature,
CTDtemp. = buckettemp. x 1.0309 - 0.7771
R^2 = 0.9615

The offset between the CTD temperature at 2 m and the bucket temperature observed for both cruises could have been due to the fact that the bucket temperatures were taken in water that had been pumped into the ships interior, which may have lead to some residual heating.

Appendix 5: Horizontal Maps of CTD and TS

a) Maps of TS temperature and salinity and bucket temperature

A map of bucket temperature for DSJ9102 is presented in front of the corresponding horizontal map for the CTD Temperature at 2 m. Maps of surface temperature (°C) and salinity (ppt) obtained from the vessel's TS continuous profiling unit are presented for each sweep of DSJ9105. The TS maps are located in front of the corresponding horizontal map for the CTD at 2 m. The contour intervals are 0.2°C for temperature and 0.05 ppt for salinity. They are included to provide some verification of hydrographic spatial patterns inferred from the CTD data. The 2-m CTD, surface TS, and bucket temperature maps display good quantitative agreement, despite the fact that the data used to generate each were collected by different instruments.

b) Maps of CTD temperature, salinity and density, by depth

Horizontal maps of temperature (°C), salinity (ppt) and density (sigma-theta [σ_θ]) (kg/m^3) are presented at depths of 2 m, 10 m, 30 m, 100 m, 200 m, 300 m, and 500 m. The locations of the CTD casts used in generating the horizontal contours are shown by a + symbol. The 2-m depth was selected to represent surface conditions. The 10-m depth was selected to represent near-surface conditions because (1) the quality of data in the first few meters below the surface was not acceptable at some stations, and (2) localized, ephemeral conditions, related to factors such as strong surface heating and low vertical mixing that did not reflect the realistic, longer-term conditions of the region, were generally confined to the upper 5 m (refer to footnote 4). The 30-m depth was contoured to coincide with the standard midwater trawl depth during the surveys. The contour intervals are 0.2°C, 0.05 ppt and 0.05 kg/m^3, respectively for depths 2-100 m. For the 200- to 500-m depths, the contour intervals were lowered to 0.1°C, 0.02 ppt, and 0.02 kg/m^3.

Appendix 6: Vertical Transects

Vertical transects of temperature, salinity and density are presented for four cross-shelf transects off the Farallones, Pacifica, Pescadero, and Davenport for DSJ9102 and off Pt. Reyes, the Farallones, Pescadero, and Davenport for DSJ9105. Station maps denote the location of each transect and the offshore extent of stations used to generate plots for each sweep. The locations of CTD casts used in generating the vertical transects are shown by an ◆. The contour intervals are 0.5°C for temperature, 0.1 ppt for salinity, and 0.2 kg/m^3 for density.

Synopsis of Hydrographic Conditions

The 1991 young-of-the-year surveys stand out as having much cooler temperatures and higher salinities than typical for the central California coastal region. This is illustrated by comparing the temperature/salinity (T/S) relationship at several depths, based on an average of all CTD casts during the 1991 May-June survey, to the mean T/S characteristics for all May-June surveys during 1987-1993 (Figure 1). 1991 also contrasts strongly with conditions during 1992, an El Niño year characterized by extremely warm temperatures, lower than normal salinities, and poleward transport (Sakuma et al. 1994a; Lynn et al. 1995). The averaged near-surface temperature and salinity for the May-June 1991 survey were about 1.3°C cooler and 0.1 ppt higher, respectively, than the 1987-1993 means (Table 1). They deviate even more from the long-term April-June temperature and salinity averages for the region 36-38°N, 121-126°W (Churgin and Halminski 1974).

Near-surface values in the region's two major upwelling centers, near Pt. Reyes and Pt. Año Nuevo (37°07'N, between Pescadero and Davenport), for May-June 1991 were 8.5-9.5°C and 33.8-33.9 ppt. More typical near-surface values for these sites, from young-of-the-year surveys in other years, are 10-12°C and 33.7-33.8 ppt, respectively. The 1991 observations represent extreme upwelling conditions; temperatures in the upwelling centers were 0.25-0.75°C below the coolest measurements in the Churgin and Halminski (1974) data set for this region, and maximum salinities in the upper 30 m were up to 0.1 ppt higher than their maximum historical observations. Near-surface values in 1991 for the outer portion of the survey region were 10.5-11.5°C and 33.0-33.3 ppt, compared to long-term averages of 12-13°C and 33.2-33.3 ppt (Lynn 1967). The characteristics of the upwelling centers during 1991 are similar to those measured in 1989 (Schwing et al. 1991), another relatively cool, saline year that featured what can be described as sustained upwelling-favorable wind stress. However near-surface water in the offshore portion of the 1991 surveys was substantially cooler and slightly less saline than conditions in 1989. This implies a greater transport of subarctic water by the California Current.

A comparison of the averaged vertical structure from 1987-1992 to conditions in 1991 further demonstrates the upper water column during May-June was anomalously cool and fresh (Figure 2). Anomalies were greatest near the coast, where the effects of upwelling are most notable, and offshore, where they increased and deepened to the west. The latter implies a reduced contribution of warm, low saline (relative to upwelled water) California Current water that typically is found in the outer portion of the survey area (Schwing et al. 1991). The anomalies also show that the surface layer was less stratified during 1991, possibly because of greater turbulent wind mixing. An exception to this pattern is the negative salinity anomalies over the continental slope off Davenport during sweep 2 of DSJ9105 (Figure 2). Examination of the horizontal maps in this report reveal an unusual intrusion of offshore water from the south off Monterey Bay, not seen in the other sweeps nor in other years. The contrast of this water type to the nearby upwelled water near Pt. Año

Nuevo produced an extremely intense front in the upper water column. Positive temperature and negative salinity anomalies over the slope below 50 m depth may be associated with this intrusion. This structure implies an extremely strong southward geostrophic transport.

Coolest surface temperatures during the February 1991 survey (11.5-12.0°C) were measured in the upwelling centers. Surface salinities also were relatively high (>33.3 ppt) in these areas. Lowest salinities (<33.0 ppt) were associated with the San Francisco Bay plume, located slightly south of the Golden Gate. Low salinities suggesting dilution by Bay outflow were noted at 10 and 30 m in the outer Gulf of the Farallones. Offshore near-surface waters were about 12.0-12.5°C and 33.1-33.2 ppt. Near-surface water during February 1991 also was cooler and more saline than historical observations from the region (Lynn 1967; Lynn et al. 1982; Chelton and Kosro 1987), particularly in the area adjacent to Point Reyes. Ramp et al. (1995) suggest this was probably due to a combination of lower than average freshwater inflow from San Francisco Bay, stronger wind stress which resulted in deeper mixing of surface water, and a greater inflow of cool, salty water from an upwelling site north of Point Reyes. The core of the relatively warm Davidson Current may have been either further offshore or weaker than normal in February 1991 as well.

The four NDBC buoys in the survey region exhibited sustained upwelling-favorable winds, except for a reversal to northward stress at the beginning of sweep 3. Coastal upwelling indices (Bakun 1973; Mason and Bakun 1986) during the first half of 1991 were anomalously high, indicating stronger than normal upwelling during the time of these surveys (Figure 3). Relative to long-term conditions, wind stress along the California coast was more strongly equatorward throughout 1991 (Climate Diagnostics Bulletin 1991). This was due to an Aleutian Low (AL) that was very weak and displaced to the north in early 1991, and the development and maintenance of a very intense, northward-shifted Northeast Pacific High (NPH) in the spring and summer. Thus 1991 winds off the west coast can be categorized as more favorable for upwelling than usual. In contrast, 1992-1994 winds were equatorward but generally less favorable for upwelling (Figure 3).

The 1991 wind and SST anomalies in the northeast Pacific were similar in several respects to those seen during La Niña, or anti-El Niño, events (Murphree and Reynolds 1995). However, atmospheric and oceanic anomalies throughout the Pacific region, especially in the tropical Pacific, show that a La Niña event did not occur in 1991, and 1991 is not classified as a La Niña period (Tom Murphree, Naval Postgraduate School, pers. comm.). By late summer 1991, the NPH had weakened below its seasonal mean, leading to the establishment of an anomalously deep AL in late 1991. Upwelling anomalies became negative in the latter part of 1991 as well. The AL continued to intensify and expanded southward during that winter, resulting in the unusual atmospheric circulation patterns in early 1992 typical of the mature phase of El Niño events (Murphree and Reynolds 1995).

Wind conditions such as those seen in most of 1991 could lead to an increase in California Current transport, hence lower than normal temperature and salinity values on density surfaces. This is implied by Figure 1. A comparison of individual CTD casts from 1991 to the long-term mean at selected repeated stations supports this. The idea of greater equatorward transport in 1991 (cf. 1989) is consistent with the cool temperature, but lower salinity relative to 1989, in the outer portion of the survey area. In an analysis of CalCOFI data, Chelton (1981) and Chelton et al. (1982) show a close positive correlation between higher southward transport, cooler temperature and lower salinity in the California Current, and weaker than normal cyclonic wind forcing in the northeast Pacific, all features of 1991. Because cross-shelf gradients in temperature and salinity in the California Current System are much greater than alongshore gradients (Lynn et al. 1982), an increase in coastal upwelling contributes relatively high salinities into the upper water column of the survey area, which compensates for a greater volume of less saline water being transported from the north. However the effect of upwelling complements any impact of increased equatorward transport on reducing temperature.

In summary, the cool and saline conditions observed during 1991 appear to be due to a combination of greater than normal coastal upwelling, associated with unusually strong and sustained equatorward wind stress and increased southward transport by the California Current. Such anomalies are typical along the west coast of North America during La Niña events. However, atmospheric and oceanic indicators in the greater Pacific region show that there was no La Niña event in 1991. The stronger California Current, whose signal was seen throughout the upper 200 m of the water column (Figure 1), contributed more relatively cool, low saline water to the survey area. This greater transport of subarctic water combined with locally upwelled water, resulting in very cool surface waters but lessened the high salinity signal of upwelling. The 1991 pattern is the opposite of that seen in the summers of 1981 and 1984, when water off central California was relatively saline, but warmer than would be associated with stronger upwelling (Chelton 1988). An unusual northward surface current was noted at these times as well (Chelton 1988).

Chelton (1981) and Chelton et al. (1982) also link interannual zooplankton variability with increased southward transport and the other anomalies observed off central California in 1991. Under this scenario, 1991 may have been a year of high zooplankton biomass. The relatively high numbers of juveniles caught during the 1991 surveys (Eldridge 1994[2]) could have benefited from a higher than usual concentration of prey. Higher southward transport may have enhanced recruitment from the north as well, leading to the relatively higher proportion young-of-the-year of northerly distributed species, such as *S. entomelas* and *S. flavidus*, found in 1991 (Eldridge 1994[2]), as well as total recruitment. Clearly the anomalous ocean conditions during 1991 and similar years appear to be related to unusual biological distributions and abundances. This is the basis of a series of hypotheses, which are being examined as a part of this project, relating interannual environmental variability linkages to groundfish recruitment success.

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Table 1. Mean temperature and salinity on selected depths, from all CTD casts during May-June 1991 young-of-the-year survey, compared to means of all CTD casts from 1987-1993 surveys (1991-1993 only for depths greater than 200m), and Churgin and Halminski (1974) averages for the region 36-38°N, 121-126°W for April-June.

	1991		1987-93 MEANS		CHURGIN & HALMINSKI	
	T	S	T	S	T	S
5m	10.56	33.55	11.91	33.45	11.90	33.17(10m)
30m	9.63	33.63	10.49	33.57	11.01	33.29
50m	9.09	33.70	9.74	33.64	10.28	33.40
100m	8.47	33.87	8.88	33.84	9.03	33.68
200m	7.66	34.04	7.93	34.03	7.82	34.01
300m	7.00	34.04	7.09	34.09	6.89	34.10
400m	6.27	34.16	6.34	34.14	6.19	34.15
500m	5.75	34.21	5.72	34.19	5.57	34.21

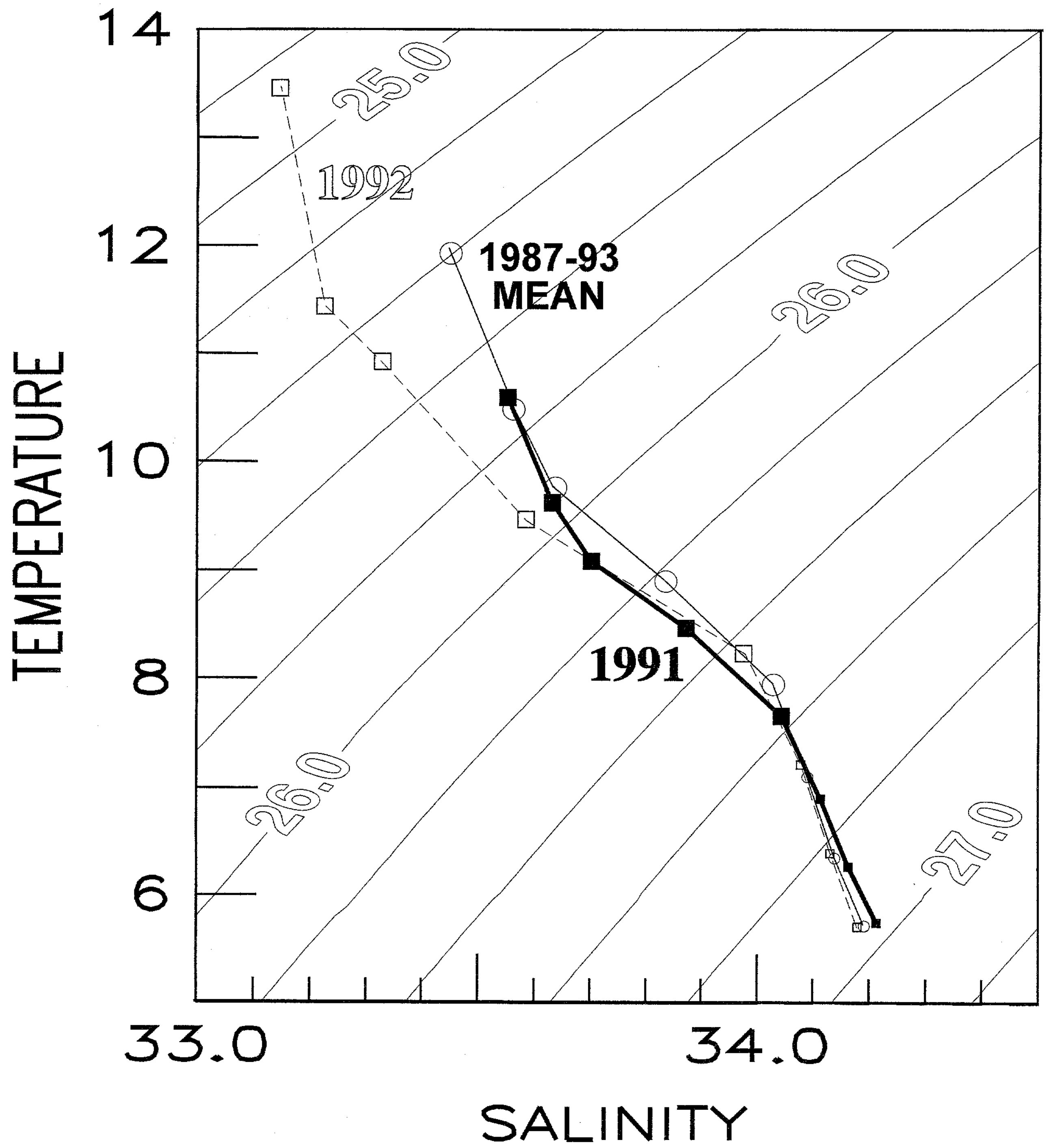


Figure 1. Temperature/salinity relationship at 5, 30, 50, 100, 200, 300, 400, and 500 m, comparing means from May-June 1987-93 surveys to DS9105 surveys. Means for depths greater than 200 m derived from 1991-93 data only.

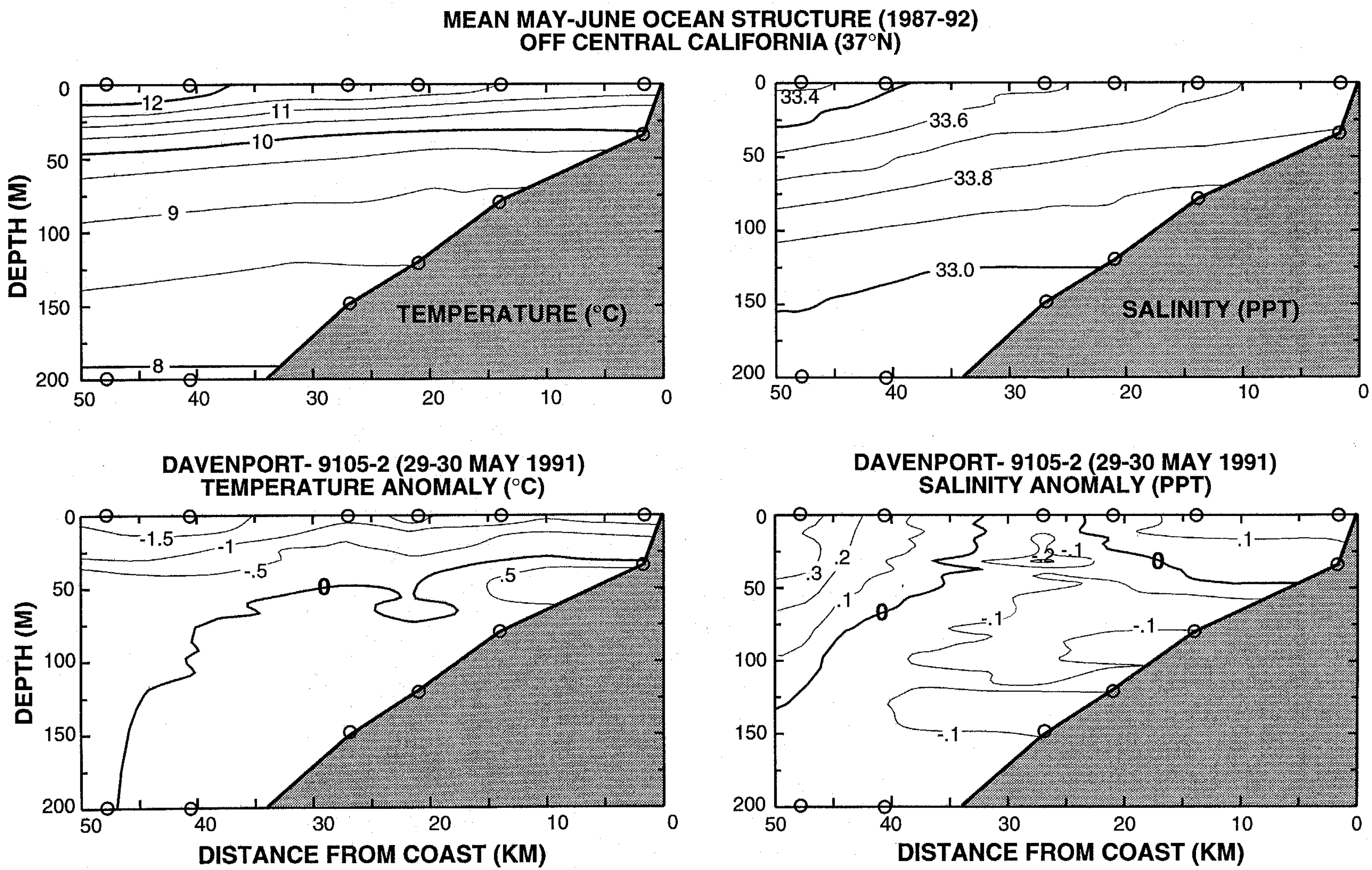


Figure 2. Vertical sections of temperature and salinity off Davenport (37°N). Upper figures show mean temperature and salinity fields from all May-June sweeps during 1987-92 (n=18). Lower figures show temperature and salinity anomalies during cruise DS9105, sweep 2, relative to the 1987-92 means.

UPWELLING INDEX ANOMALIES (m^3/s/100m coastline)
RELATIVE TO 1946-1994 MEAN

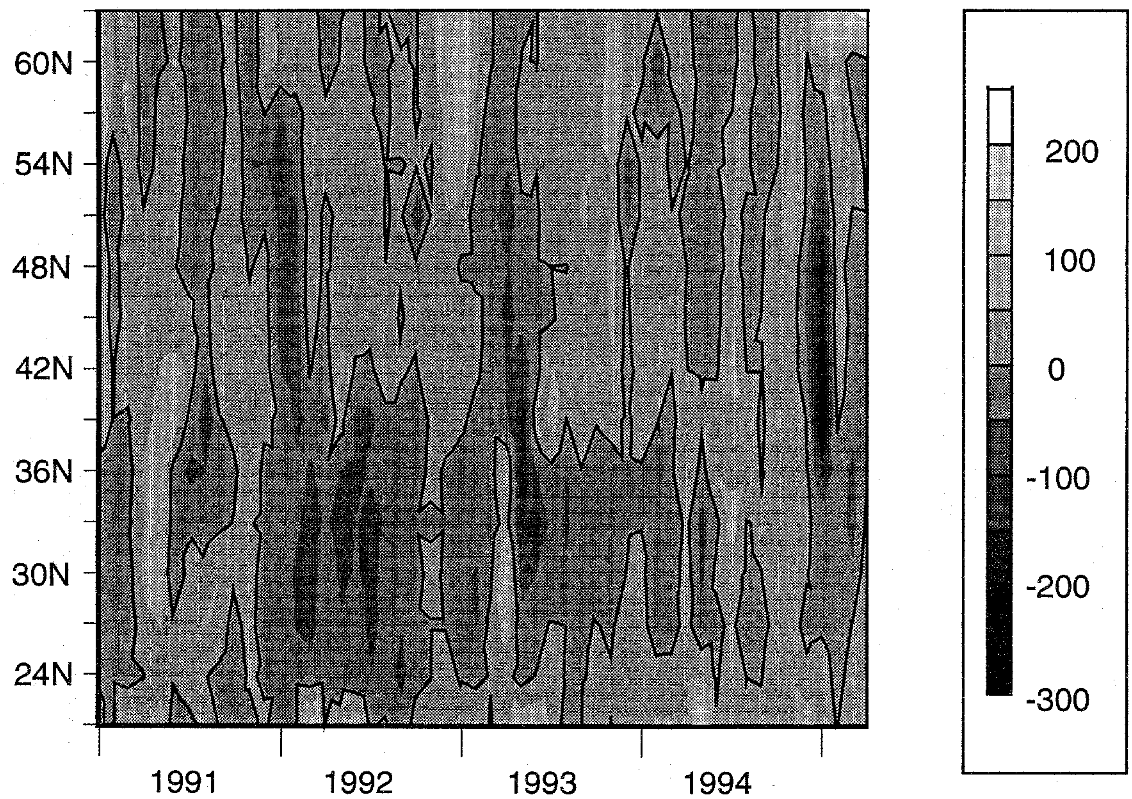


Figure 3. Monthly anomalies in upwelling index along the North American west coast for January 1991-April 1995. The monthly anomalies are deviations from the 1946-94 period. Positive anomalies denote greater than normal upwelling (less than normal downwelling where monthly index is negative).

APPENDIX 1.1: LIST OF CTD STATIONS SUMMARIZED FROM CRUISE DSJ9102

DSJ9102

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
1	08FEB91	1345	36 30.0	121 58.0	91
2	08FEB91	1601	36 30.0	122 10.5	1463
3	08FEB91	1802	36 30.0	122 22.8	1609
5	08FEB91	1950	36 40.0	122 30.7	2158
6	08FEB91	2232	36 40.0	122 18.2	1463
7	09FEB91	0050	36 40.0	122 5.8	1920
8	09FEB91	0400	36 40.0	121 53.4	71
9	09FEB91	0530	36 45.0	122 2.8	695
10	09FEB91	0730	36 45.0	121 50.4	27
11	09FEB91	0847	36 50.0	121 54.1	66
12	09FEB91	0945	36 55.0	121 57.5	26
13	09FEB91	1030	36 50.0	122 0.2	84
14	09FEB91	1215	36 50.0	122 6.4	640
15	09FEB91	1450	36 50.0	122 12.6	1737
16	09FEB91	1657	36 49.6	122 37.4	2012
17	09FEB91	1900	36 50.0	122 50.1	2377
18	09FEB91	2031	36 55.0	122 43.4	1737
19	09FEB91	2243	36 55.0	122 31.1	914
20	10FEB91	0205	36 55.1	122 18.2	238
21	10FEB91	0400	36 55.4	122 6.4	51
22	10FEB91	1045	37 0.0	122 50.0	1280
23	10FEB91	1303	37 0.1	122 37.4	384
24	10FEB91	1547	37 0.0	122 25.0	293
25	10FEB91	1812	36 59.8	122 13.1	22
26	10FEB91	2241	37 5.0	122 43.5	512
27	11FEB91	0055	37 5.0	122 31.3	106
28	11FEB91	0320	37 5.0	122 18.8	27
29	11FEB91	0440	37 10.1	122 25.2	38
30	11FEB91	0625	37 10.1	122 37.8	104
31	11FEB91	0815	37 10.0	122 50.2	375
33	11FEB91	1035	37 10.0	123 2.5	680
34	11FEB91	1215	37 10.1	123 15.2	1975
35	11FEB91	1354	37 10.0	123 27.7	3255
36	11FEB91	1542	37 10.1	123 40.0	3658
37	11FEB91	1737	37 15.1	123 52.9	3658
38	11FEB91	1936	37 20.2	123 39.5	3658
39	11FEB91	2203	37 20.1	123 27.3	1372
40	11FEB91	2350	37 20.0	123 14.9	1525
41	12FEB91	0145	37 20.1	123 2.4	768
42	12FEB91	0415	37 20.0	122 50.1	146
43	12FEB91	0635	37 20.1	122 37.7	82
44	12FEB91	0748	37 20.1	122 31.7	64
45	12FEB91	0855	37 14.9	122 31.6	77
46	12FEB91	1038	37 15.0	122 43.9	113
47	12FEB91	1335	37 15.0	122 56.3	384
48	12FEB91	1448	37 15.1	123 2.5	677
49	12FEB91	2318	37 25.0	123 2.3	622
50	13FEB91	0030	37 25.0	122 56.2	347
51	13FEB91	0335	37 25.1	122 43.8	82
52	13FEB91	0525	37 25.1	122 31.0	44
53	13FEB91	0620	37 30.1	122 33.9	46
55	13FEB91	0910	37 30.0	122 52.7	101
56	13FEB91	1059	37 30.0	123 5.4	777
57	13FEB91	1305	37 30.0	123 17.8	1737
58	13FEB91	1431	37 35.1	123 14.0	1554
59	13FEB91	1658	37 35.0	123 1.3	274
60	13FEB91	1924	37 35.0	122 48.6	69
61	13FEB91	2111	37 35.2	122 35.7	35

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (M)
62	13FEB91	2154	37 39.0	122 36.8	27
63	13FEB91	2348	37 43.3	122 49.2	55
64	14FEB91	0155	37 40.1	123 2.4	93
65	14FEB91	0404	37 39.9	123 14.7	1463
66	14FEB91	0601	37 38.4	123 26.6	2377
67	14FEB91	0731	37 45.2	123 21.8	1426
68	14FEB91	0942	37 45.1	123 9.3	104
69	14FEB91	1125	37 45.9	122 58.6	64
70	14FEB91	1322	37 50.0	122 47.0	44
71	14FEB91	1450	37 53.2	122 53.1	57
72	14FEB91	1651	37 50.0	123 4.4	82
73	14FEB91	1841	37 50.0	123 17.3	104
74	14FEB91	2045	37 50.1	123 29.3	1646
75	14FEB91	2202	37 55.1	123 26.7	183
76	15FEB91	0002	37 55.0	123 14.0	97
77	15FEB91	0224	37 56.4	122 58.4	59
78	15FEB91	0608	37 35.0	123 20.0	1463

APPENDIX 1.2: LIST OF CTD STATIONS SUMMARIZED FROM CRUISE DSJ9105

DSJ9105 Sweep 1

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
1	14MAY91	1812	36 49.0	122 5.0	102
2	14MAY91	1902	36 54.0	122 4.5	60
3	14MAY91	1954	36 53.0	121 56.0	38
4	14MAY91	2024	36 50.8	121 59.0	86
5	14MAY91	2327	36 46.5	121 53.5	210
6	15MAY91	0020	36 44.4	121 58.6	326
7	15MAY91	0239	36 43.5	121 55.3	93
8	15MAY91	0329	36 38.5	121 51.5	37
9	15MAY91	0543	36 39.4	121 57.1	86
10	15MAY91	0900	36 40.0	122 10.0	1189
11	15MAY91	1018	36 46.3	122 26.1	823
12	15MAY91	1131	36 40.0	122 22.3	1737
13	15MAY91	1252	36 46.3	122 28.4	2103
14	15MAY91	1407	36 40.0	122 34.7	2377
15	15MAY91	1522	36 33.7	122 40.7	2743
16	15MAY91	1647	36 33.7	122 28.4	2743
17	15MAY91	1815	36 33.7	122 16.1	2560
18	15MAY91	2007	36 35.0	122 10.6	2195
20	16MAY91	0132	36 38.8	122 3.0	914
21	16MAY91	0353	36 41.4	122 5.0	1829
22	16MAY91	0532	36 45.1	122 8.0	914
23	16MAY91	0630	36 52.6	122 10.0	97
24	16MAY91	0752	36 52.6	122 22.3	823
25	16MAY91	0914	36 52.6	122 34.7	1600
26	16MAY91	1107	36 52.6	122 47.0	2286
27	16MAY91	1232	36 52.6	122 59.3	2697
28	16MAY91	1350	36 59.0	123 5.3	2743
29	16MAY91	1501	37 5.0	122 59.3	914
30	16MAY91	1628	37 5.0	122 47.0	686
31	16MAY91	1750	37 5.0	122 34.6	113
32	16MAY91	1902	37 5.0	122 22.3	53
33	16MAY91	2011	36 59.0	122 12.5	48
34	16MAY91	2321	36 57.4	122 16.5	86
35	17MAY91	0013	36 59.0	122 22.5	119
36	17MAY91	0255	36 57.5	122 24.6	210
37	17MAY91	0420	36 59.0	122 35.5	402
38	17MAY91	0647	37 10.7	122 28.4	68
39	17MAY91	0802	37 10.7	122 40.7	112
40	17MAY91	0920	37 10.7	122 53.0	421
41	17MAY91	1050	37 10.7	123 5.3	869
42	17MAY91	1237	37 10.7	123 17.6	1966
43	17MAY91	1418	37 22.3	123 17.6	1646
44	17MAY91	1550	37 22.3	123 5.3	823
45	17MAY91	1714	37 22.3	122 53.0	196
46	17MAY91	1828	37 22.3	122 40.7	84
47	18MAY91	2030	37 38.0	122 46.0	51
48	18MAY91	2330	37 41.3	122 53.3	57
49	19MAY91	0025	37 47.5	122 52.0	55
50	19MAY91	0228	37 50.3	122 44.9	37
51	19MAY91	0354	37 58.1	122 56.1	90
52	19MAY91	0637	37 38.2	123 6.3	823
53	19MAY91	1339	37 22.3	123 17.6	1646
54	19MAY91	1503	37 22.3	123 5.3	823
55	19MAY91	1627	37 22.3	122 53.0	183
56	19MAY91	1733	37 22.3	122 40.7	86
57	19MAY91	1840	37 22.3	122 28.4	33
58	19MAY91	2030	37 16.5	122 29.0	51
59	19MAY91	2248	37 16.5	122 35.1	91

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (M)
60	19MAY91	2327	37 16.6	122 39.0	95
61	20MAY91	0259	37 15.5	122 49.4	210
62	20MAY91	0405	37 16.5	122 59.1	549
63	20MAY91	0641	37 30.8	122 47.0	80
64	20MAY91	0755	37 30.9	122 59.4	223
65	20MAY91	0912	37 30.8	123 11.6	1280
66	20MAY91	1037	37 30.8	123 24.1	2377
67	20MAY91	1158	37 30.7	123 36.4	2743
68	20MAY91	1332	37 38.4	123 42.4	3338
69	20MAY91	1500	37 46.2	123 48.6	3429
70	20MAY91	1624	37 46.2	123 36.3	2697
71	20MAY91	1750	37 46.2	123 24.0	1509
72	20MAY91	1911	37 46.2	123 11.6	110
73	20MAY91	2022	37 39.5	123 2.5	106
74	20MAY91	2307	37 38.2	123 11.3	1244
75	21MAY91	0013	37 44.6	123 8.3	68
76	21MAY91	0312	37 52.1	123 17.8	108
77	21MAY91	0514	37 52.2	123 29.4	1097
78	21MAY91	0649	38 1.6	123 30.0	146
79	21MAY91	0808	38 1.6	123 42.4	2560
80	21MAY91	2030	38 10.0	123 0.0	53
81	21MAY91	2251	38 9.1	123 3.8	73
82	21MAY91	2343	38 10.0	123 10.1	91
83	22MAY91	0210	38 10.6	123 16.6	119
84	22MAY91	0335	38 8.7	123 21.4	172

DSJ9105 Sweep 2

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (M)
136	27MAY91	2030	37 37.9	122 47.9	60
137	27MAY91	2340	37 41.7	122 53.8	60
138	28MAY91	0040	37 47.5	122 52.2	57
139	28MAY91	0249	37 49.8	122 44.4	37
140	28MAY91	0415	37 58.0	122 56.0	51
141	28MAY91	1820	37 22.2	122 40.7	86
142	28MAY91	1930	37 22.3	122 28.6	31
143	28MAY91	2015	37 16.5	122 29.0	51
144	28MAY91	2245	37 15.2	122 33.0	86
145	28MAY91	2330	37 16.5	122 39.2	104
146	29MAY91	0235	37 14.7	122 47.8	187
147	29MAY91	0445	37 16.5	122 59.0	549
148	29MAY91	0630	37 22.3	122 53.0	331
149	29MAY91	0823	37 22.3	123 5.3	823
150	29MAY91	1012	37 22.3	123 17.2	1646
151	29MAY91	1122	37 16.5	123 11.4	1097
152	29MAY91	1235	37 10.7	123 17.7	1829
153	29MAY91	1405	37 10.8	123 5.2	823
154	29MAY91	1529	37 10.8	122 53.0	424
155	29MAY91	1650	37 10.6	122 40.7	112
156	29MAY91	1800	37 10.7	122 28.4	68
157	29MAY91	1950	37 5.0	122 22.3	49
158	29MAY91	2020	36 59.0	122 12.6	37
159	29MAY91	2246	36 58.8	122 18.5	88
160	29MAY91	2325	36 59.0	122 22.5	119
161	30MAY91	0200	36 59.4	122 26.8	137
162	30MAY91	0345	36 58.5	122 34.4	384

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
163	30MAY91	0450	37 5.0	122 34.6	112
164	30MAY91	0605	37 5.0	122 47.0	622
165	30MAY91	0721	37 5.0	122 59.4	914
166	30MAY91	0829	36 59.0	123 5.4	2743
167	30MAY91	0942	36 52.5	122 59.3	2697
168	30MAY91	1100	36 59.0	122 53.0	1372
169	30MAY91	1210	36 52.5	122 46.9	2286
170	30MAY91	1340	36 52.6	122 34.7	1234
171	30MAY91	1512	36 52.6	122 22.4	823
172	30MAY91	1642	36 52.5	122 10.0	95
173	30MAY91	2101	36 50.7	121 59.0	86
174	30MAY91	2250	36 46.0	121 52.0	69
175	30MAY91	2340	36 44.4	121 58.6	283
176	31MAY91	0122	36 42.4	121 53.9	80
177	31MAY91	0202	36 38.6	121 51.5	37
178	31MAY91	0427	36 39.0	121 55.8	64
179	31MAY91	0804	36 40.0	122 10.0	1134
180	31MAY91	0928	36 46.3	122 16.1	823
181	31MAY91	1115	36 46.3	122 28.4	1829
182	31MAY91	1302	36 46.3	122 40.6	2103
183	31MAY91	1453	36 46.3	122 52.9	2560
185	31MAY91	1825	36 33.7	122 28.4	2743
186	31MAY91	1949	36 33.7	122 16.1	2560
187	31MAY91	2050	36 35.0	122 10.5	2323
188	31MAY91	2330	36 34.0	122 1.2	384
189	01JUN91	0021	36 38.9	122 3.1	914
190	01JUN91	0227	36 41.4	122 5.0	1920
191	01JUN91	0511	36 46.1	122 5.9	914
192	01JUN91	1210	37 30.8	122 59.4	219
193	01JUN91	1330	37 30.8	123 11.8	1280
194	01JUN91	1458	37 30.9	123 24.0	2469
195	01JUN91	1615	37 31.5	123 35.2	2240
196	01JUN91	2040	37 40.1	123 2.5	91
197	01JUN91	2330	37 39.0	123 11.3	1189
198	02JUN91	0027	37 44.7	123 8.6	66
199	02JUN91	0308	37 53.2	123 17.8	110
200	02JUN91	0455	37 53.5	123 31.4	1463
201	02JUN91	0612	38 1.6	123 30.1	150
202	02JUN91	0725	38 1.6	123 42.4	2560
203	02JUN91	0847	38 1.6	123 54.7	3475
212	02JUN91	2105	38 10.0	123 0.0	55
213	02JUN91	2220	38 10.8	123 5.3	75
214	02JUN91	2316	38 10.0	123 10.0	91
215	03JUN91	0103	38 9.3	123 16.2	115
216	03JUN91	0420	38 9.1	123 21.3	163

DSJ9105 Sweep 3

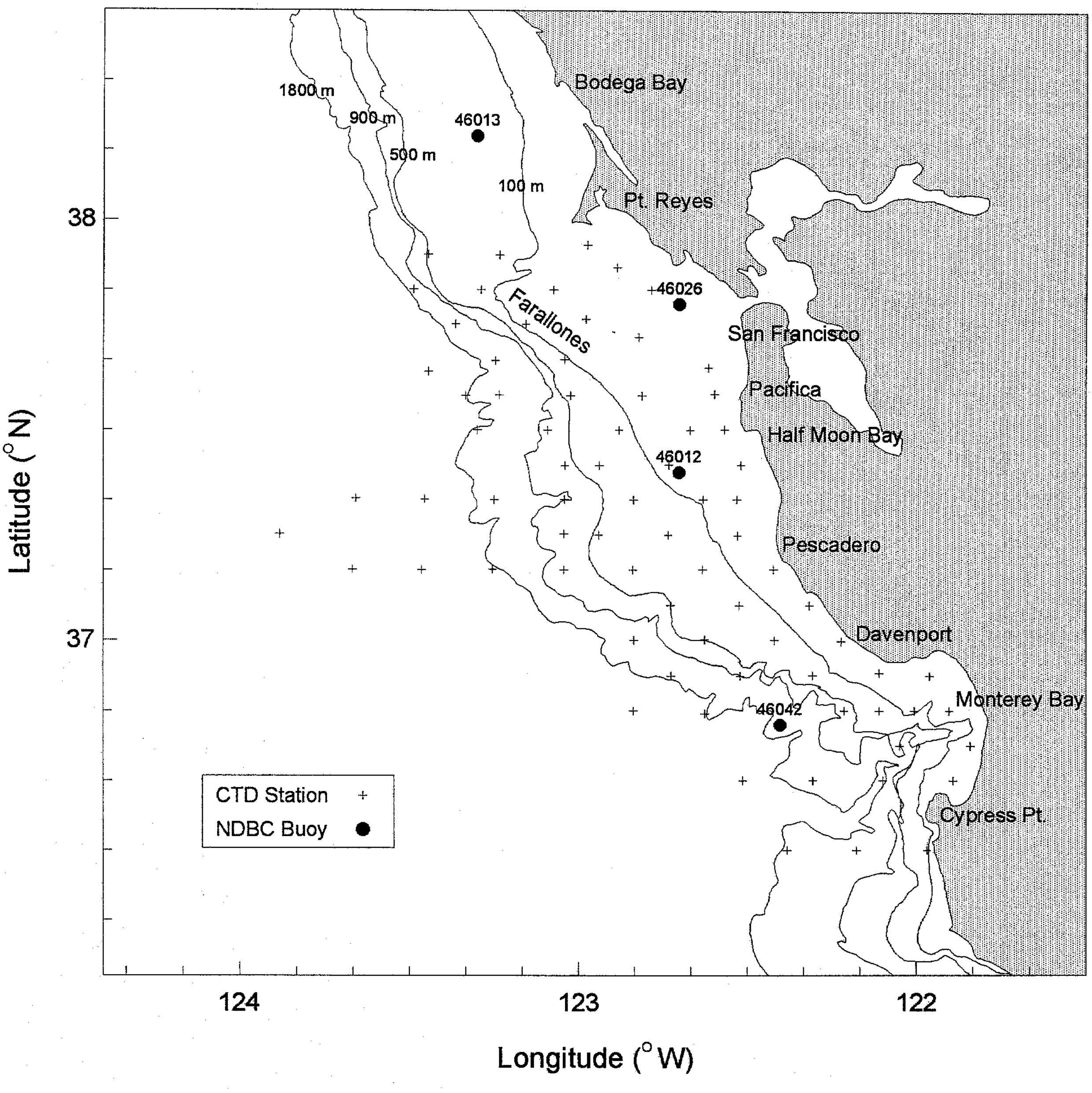
CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
217	03JUN91	1945	36 46.4	122 9.0	914
218	03JUN91	2252	36 40.8	122 5.6	1920
219	03JUN91	2325	36 38.9	122 3.0	914
220	04JUN91	0114	36 34.3	122 1.2	428
221	04JUN91	0419	36 34.5	122 9.3	0
222	04JUN91	0620	36 33.7	122 28.4	2743
224	04JUN91	0909	36 40.0	122 46.9	2743

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
225	04JUN91	1025	36 46.3	122 53.0	2743
226	04JUN91	1200	36 46.4	122 40.7	2377
227	04JUN91	1318	36 40.1	122 34.5	2377
228	04JUN91	1454	36 46.5	122 28.5	2103
229	04JUN91	1614	36 40.0	122 22.3	1737
230	04JUN91	1800	36 46.2	122 16.1	1737
231	04JUN91	2032	36 59.0	122 12.5	48
232	04JUN91	2244	36 59.0	122 18.8	86
233	04JUN91	2316	36 59.0	122 22.5	121
234	05JUN91	0155	36 58.8	122 27.5	141
235	05JUN91	0328	36 58.8	122 34.5	369
236	05JUN91	0504	37 5.0	122 22.2	51
237	05JUN91	0612	37 5.0	122 34.6	113
238	05JUN91	0723	37 5.0	122 47.0	613
239	05JUN91	0844	37 5.1	122 59.3	914
240	05JUN91	0957	36 59.0	123 5.3	2743
241	05JUN91	1111	36 52.6	122 59.3	2697
242	05JUN91	1256	36 52.7	122 47.0	2286
243	05JUN91	1428	36 52.7	122 34.6	1372
244	05JUN91	1555	36 52.0	122 22.3	823
245	05JUN91	1715	36 52.6	122 10.0	97
246	05JUN91	1800	36 49.0	122 5.0	102
247	05JUN91	1842	36 44.4	122 2.5	732
248	05JUN91	2033	36 39.3	121 56.8	75
249	05JUN91	2325	36 39.3	121 51.9	53
250	06JUN91	0002	36 42.6	121 54.6	86
251	06JUN91	0138	36 44.3	121 57.2	106
252	06JUN91	0225	36 46.0	121 51.9	69
253	06JUN91	0431	36 50.8	121 57.7	183
254	06JUN91	0807	37 10.7	122 28.4	68
255	06JUN91	0915	37 10.7	122 40.7	112
256	06JUN91	1029	37 10.7	122 53.0	421
257	06JUN91	1145	37 10.7	123 5.3	823
258	06JUN91	1259	37 16.6	123 11.5	1189
259	06JUN91	1410	37 22.4	123 17.7	1646
260	06JUN91	1540	37 22.3	123 5.4	823
261	06JUN91	1705	37 22.3	122 53.0	201
262	06JUN91	1822	37 22.2	122 41.0	86
263	06JUN91	1927	37 22.3	122 28.4	29
264	06JUN91	2032	37 16.5	122 29.0	46
265	06JUN91	2325	37 17.7	122 33.9	80
266	07JUN91	0106	37 16.4	122 49.2	185
267	07JUN91	0437	37 16.0	122 58.3	494
268	07JUN91	0632	37 30.8	122 59.3	219
269	07JUN91	0748	37 30.8	123 11.6	1280
270	07JUN91	0915	37 30.8	123 24.0	2377
271	07JUN91	1039	37 30.8	123 36.3	1829
272	07JUN91	1200	37 38.4	123 42.4	3338
273	07JUN91	1333	37 46.3	123 48.6	3429
274	07JUN91	1510	37 46.2	123 36.4	2652
275	07JUN91	1655	37 46.2	123 24.1	1463
276	07JUN91	1844	37 46.3	123 11.6	110
277	07JUN91	2030	37 39.5	123 2.5	113
278	07JUN91	2327	37 38.6	123 11.7	1244
279	08JUN91	0023	37 44.6	123 8.3	71
280	08JUN91	0342	37 51.1	123 16.9	102
281	08JUN91	0511	37 50.4	123 20.0	113
283	08JUN91	2035	37 38.0	122 48.2	60
284	08JUN91	2352	37 41.7	122 54.3	55
285	09JUN91	0045	37 47.5	122 52.0	55
286	09JUN91	0246	37 50.1	122 45.3	37
287	09JUN91	0442	37 57.1	122 54.4	48
288	09JUN91	0904	38 0.0	123 23.5	73

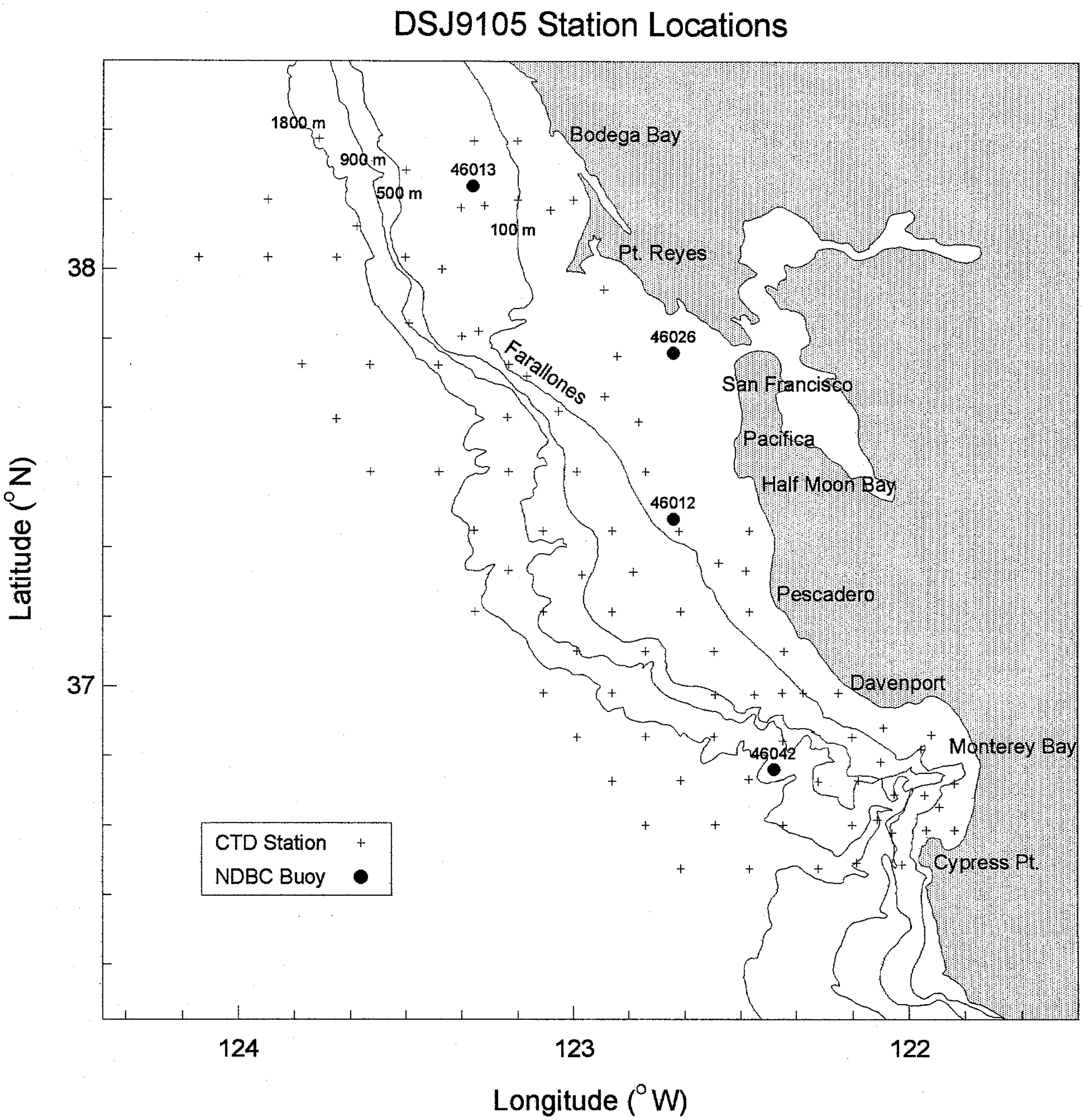
CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
289	09JUN91	1040	38 6.1	123 38.8	1463
290	09JUN91	1250	38 10.0	123 54.7	3493
291	09JUN91	1454	38 18.8	123 45.6	1701
292	09JUN91	1635	38 14.2	123 30.0	397
293	09JUN91	1814	38 18.5	123 17.8	104
294	09JUN91	1903	38 18.5	123 10.0	86
295	09JUN91	2030	38 10.0	123 0.0	55
296	09JUN91	2257	38 8.5	123 4.0	69
297	09JUN91	2343	38 10.0	123 9.9	91
298	10JUN91	0147	38 9.2	123 15.9	113
299	10JUN91	0447	38 8.9	123 20.1	143
300	10JUN91	1146	38 1.6	123 30.2	137
301	10JUN91	1309	38 1.7	123 42.4	2524
302	10JUN91	1440	38 1.6	123 54.8	3475
303	10JUN91	1610	38 1.6	124 7.0	3475

APPENDIX 2.1: DSJ9102 CTD STATIONS AND BATHYMETRIC MAP OF SURVEY REGION WITH LOCATIONS OF THE NDBC BUOYS

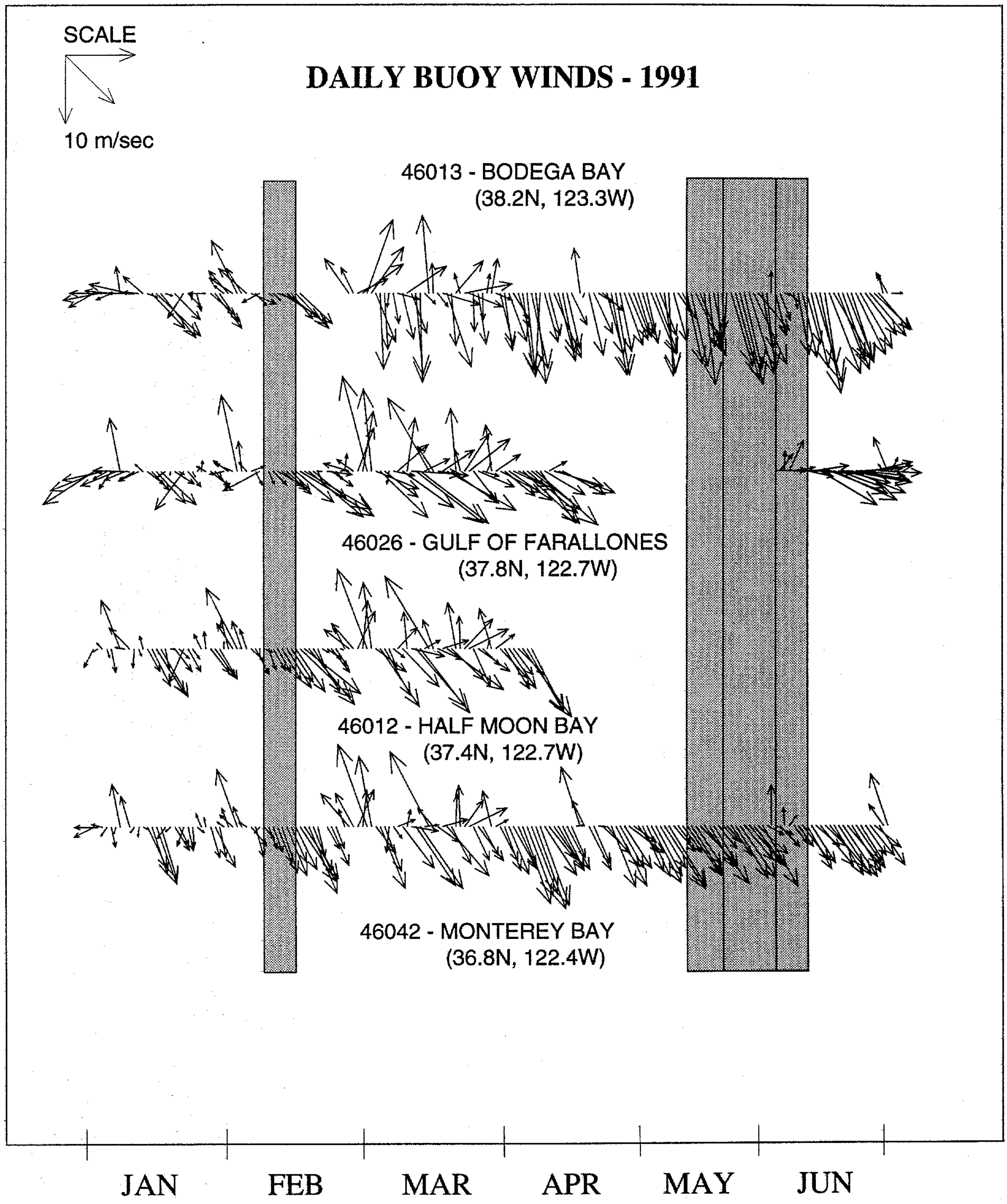
DSJ9102 Station Locations



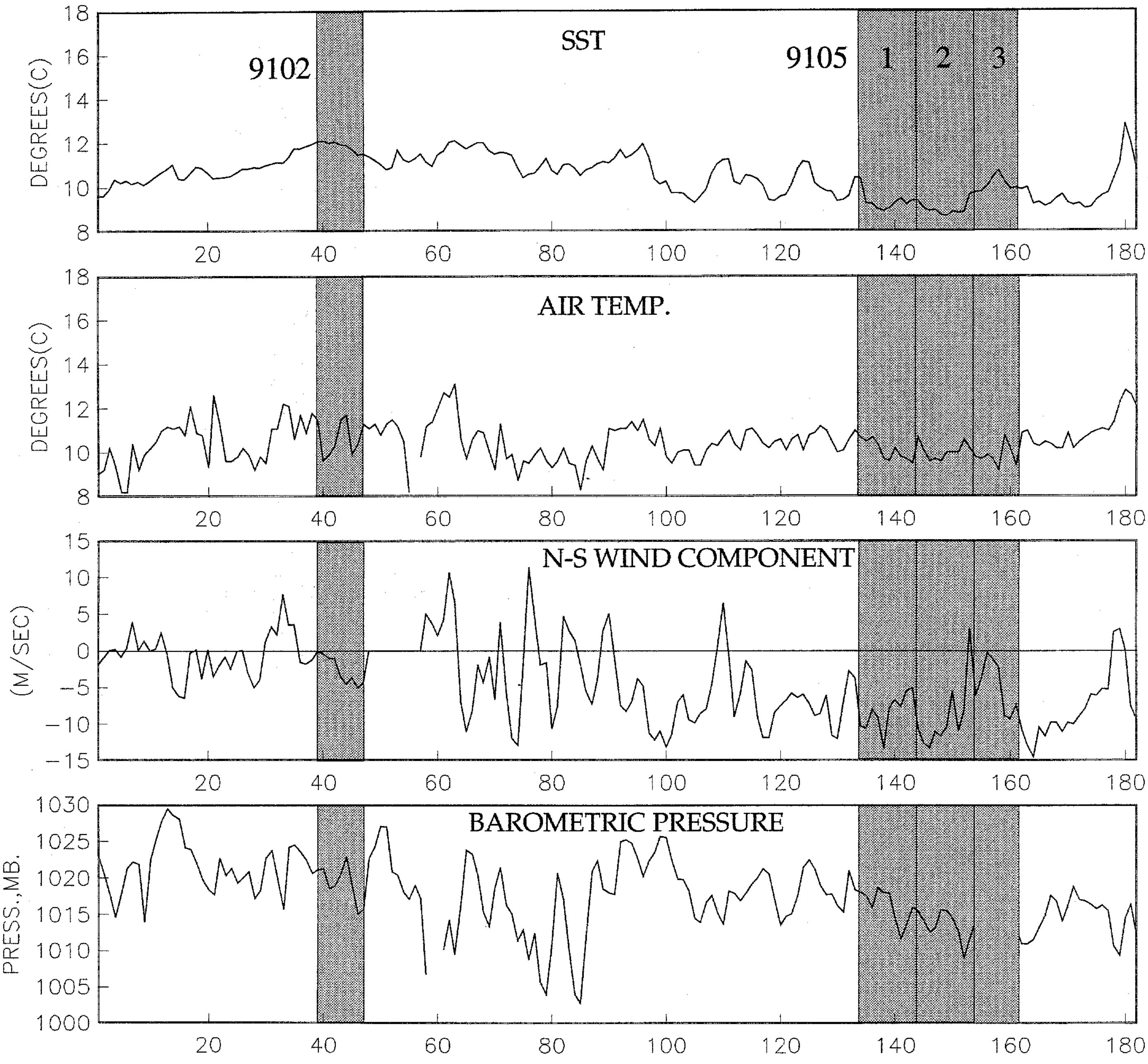
APPENDIX 2.2: DSJ9105 CTD STATIONS AND BATHYMETRIC MAP OF SURVEY REGION WITH LOCATIONS OF THE NDBC BUOYS


DSJ9105 Station Locations
Latitude (°N)
Longitude (°W)
38
37
124
123
122
1800 m
900 m
500 m
100 m
46013
46026
46012
46042
Bodega Bay
Pt. Reyes
Farallones
San Francisco
Pacifica
Half Moon Bay
Pescadero
Davenport
Monterey Bay
Cypress Pt.
CTD Station
NDBC Buoy

APPENDIX 3: METEOROLOGICAL TIME SERIES

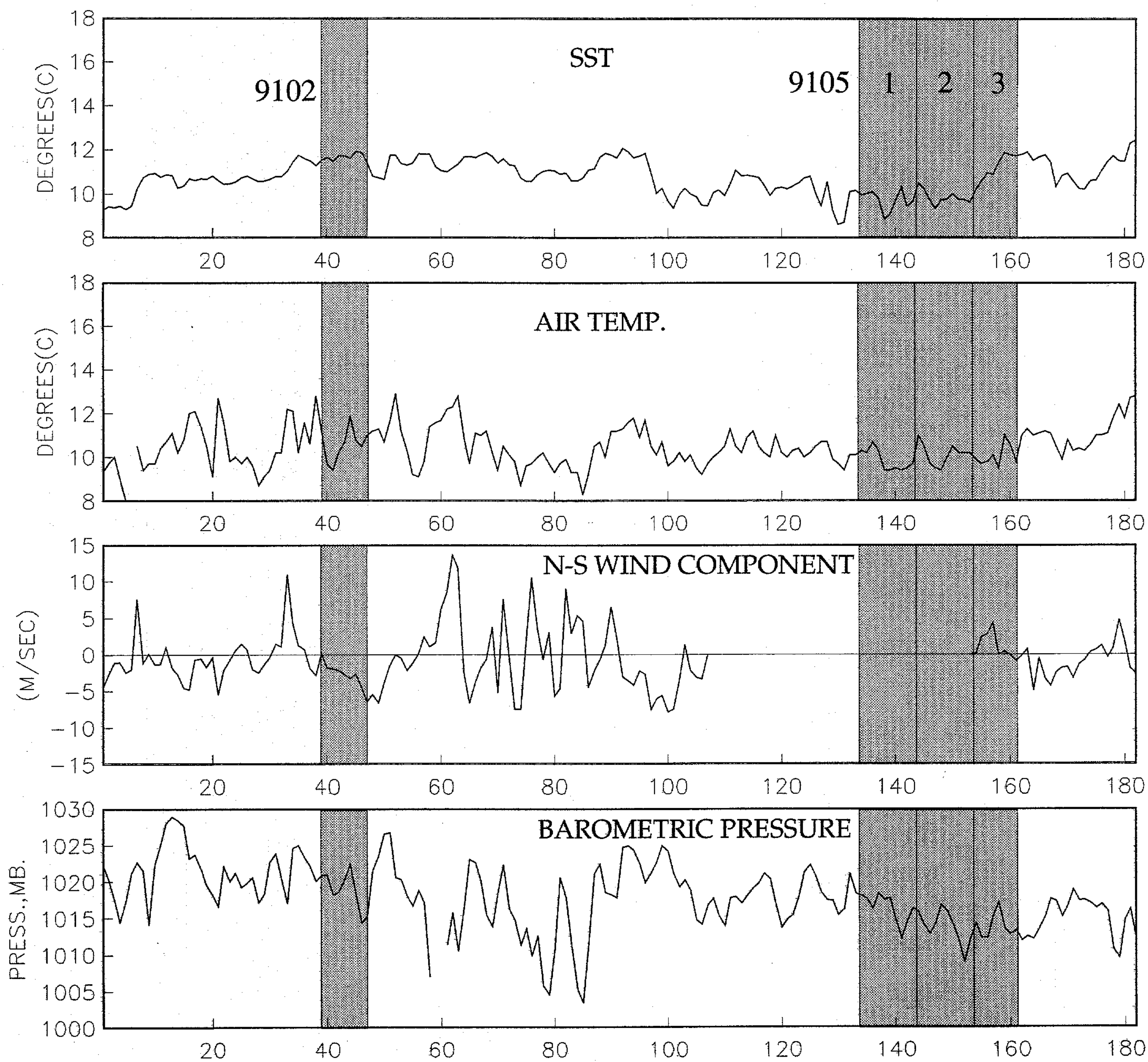

SCALE
10 m/sec
DAILY BUOY WINDS - 1991
46013 - BODEGA BAY
(38.2N, 123.3W)
46026 - GULF OF FARALLONES
(37.8N, 122.7W)
46012 - HALF MOON BAY
(37.4N, 122.7W)
46042 - MONTEREY BAY
(36.8N, 122.4W)
JAN
FEB
MAR
APR
MAY
JUN

BUOY 46013- BODEGA BAY (38.2N, 123.3W)

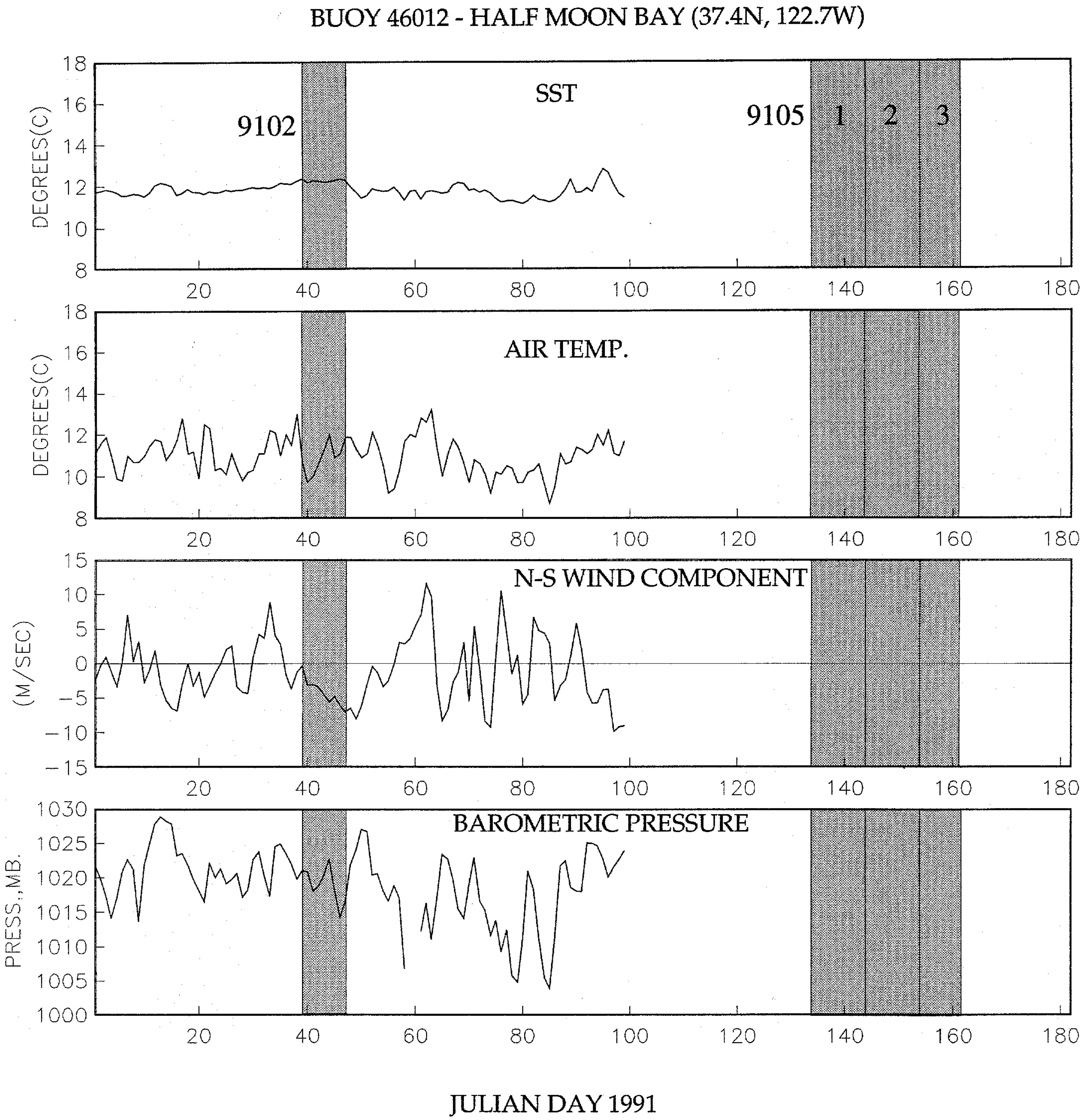


JULIAN DAY 1991

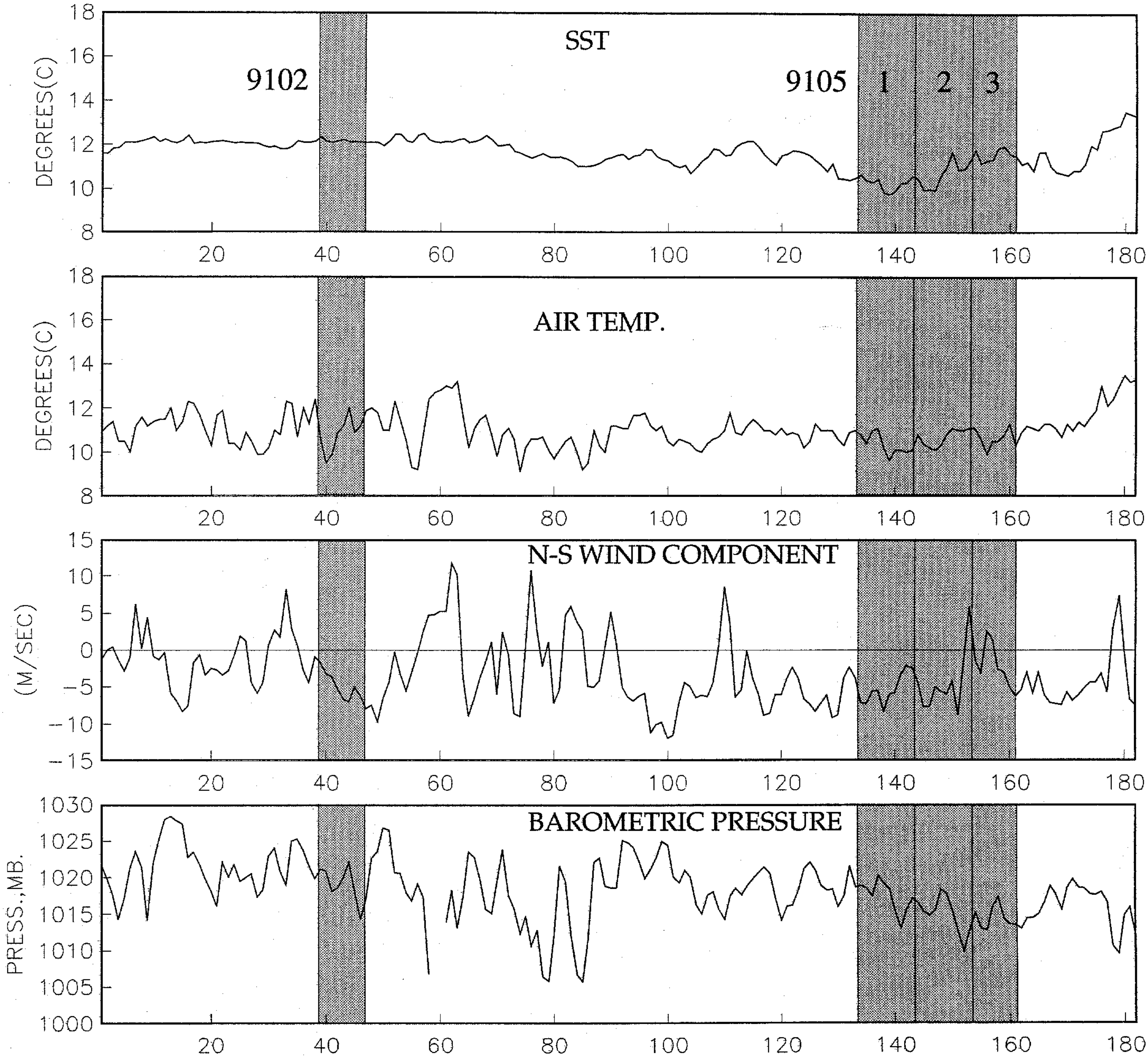
BUOY 42026 - FARALLONES (37.8N, 122.7W)



JULIAN DAY 1991


BUOY 46012 - HALF MOON BAY (37.4N, 122.7W)
SST
9102
9105
1
2
3
DEGREES(C)
AIR TEMP.
N-S WIND COMPONENT
(M/SEC)
BAROMETRIC PRESSURE
PRESS.,MB.
20
40
60
80
100
120
140
160
180
JULIAN DAY 1991

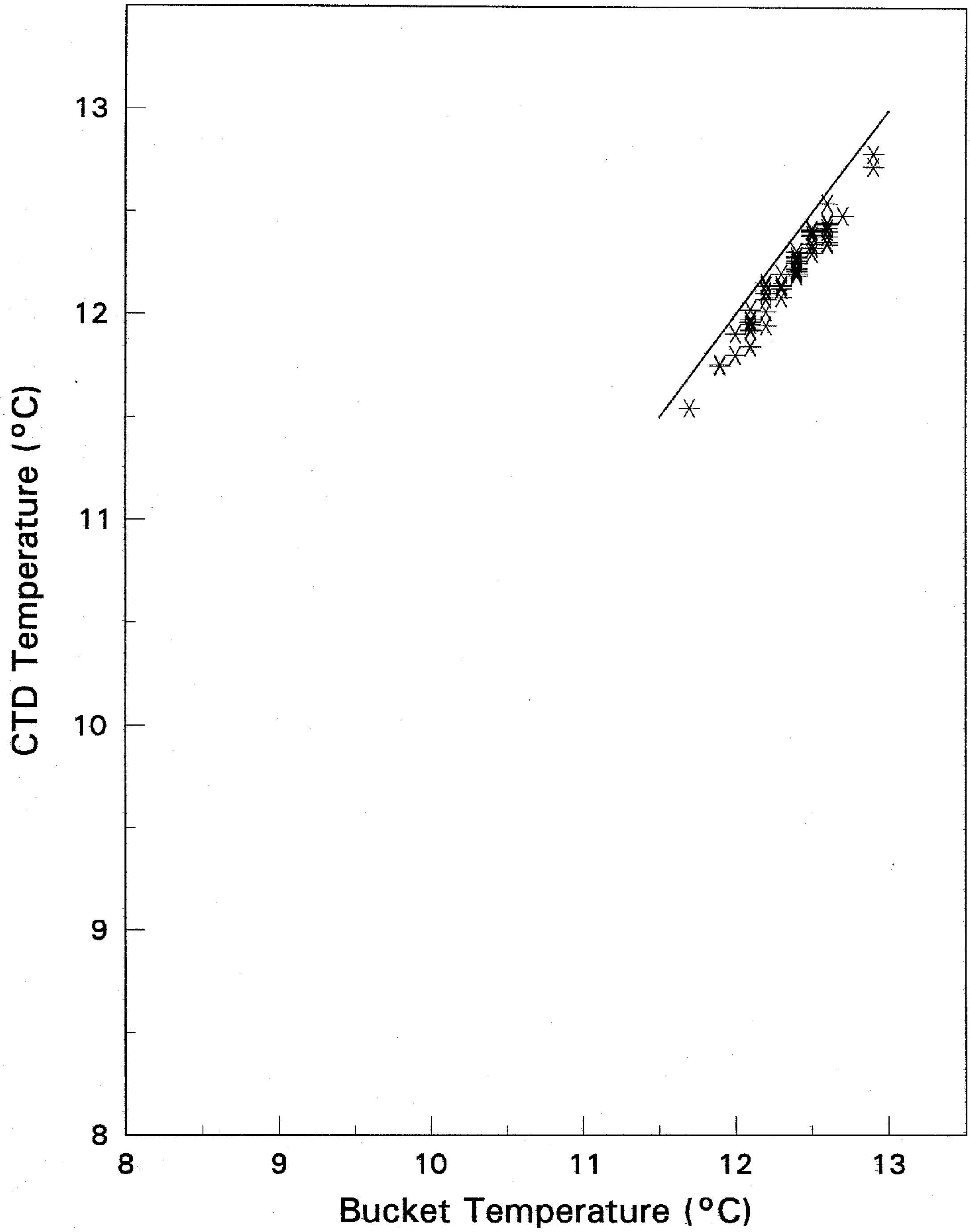
BUOY 46042- MONTEREY BAY (36.8N, 122.4W)



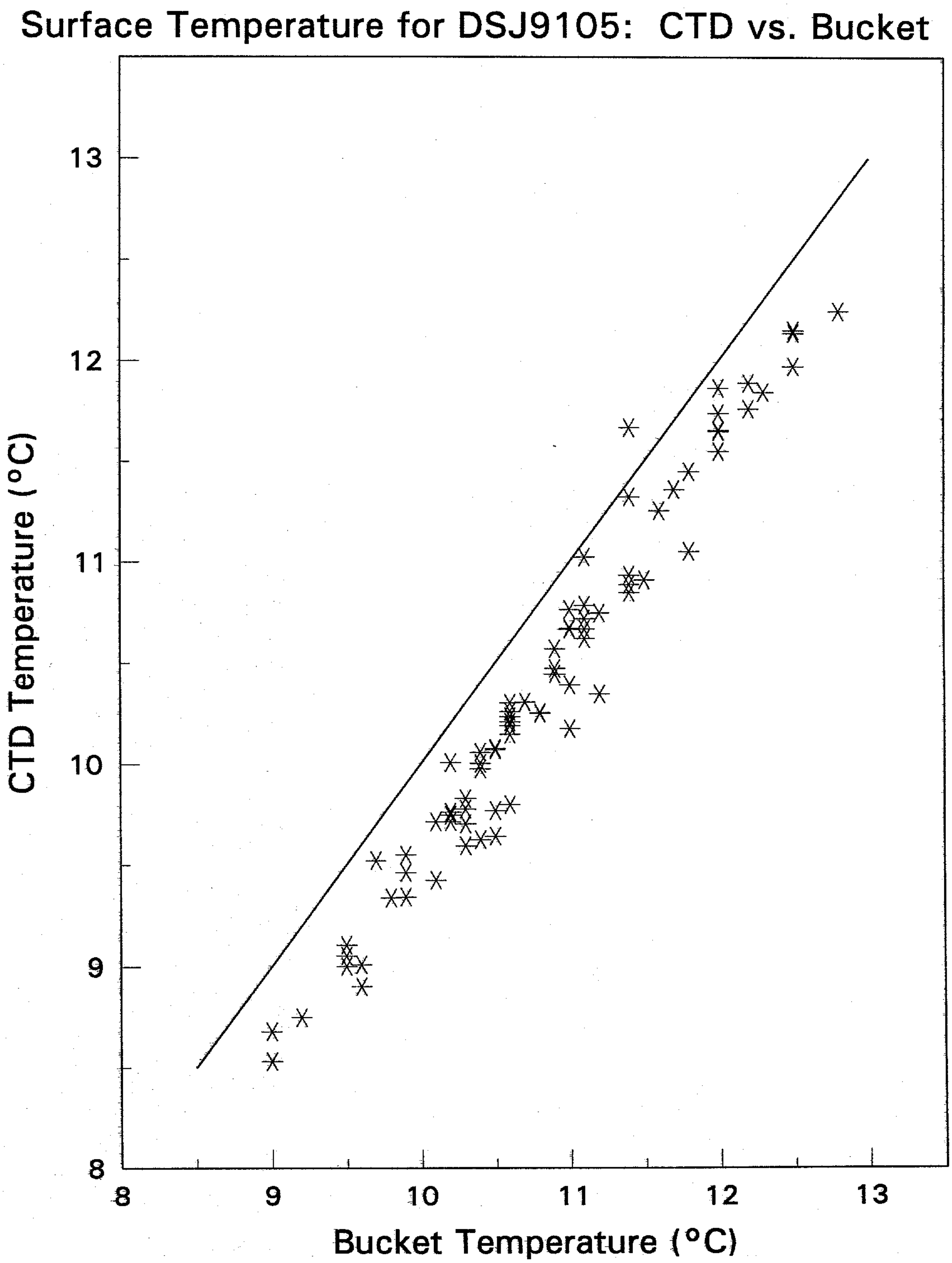
JULIAN DAY 1991

APPENDIX 4.1: REGRESSION COMPARISON OF CTD AND BUCKET TEMPERATURE FOR DSJ9102

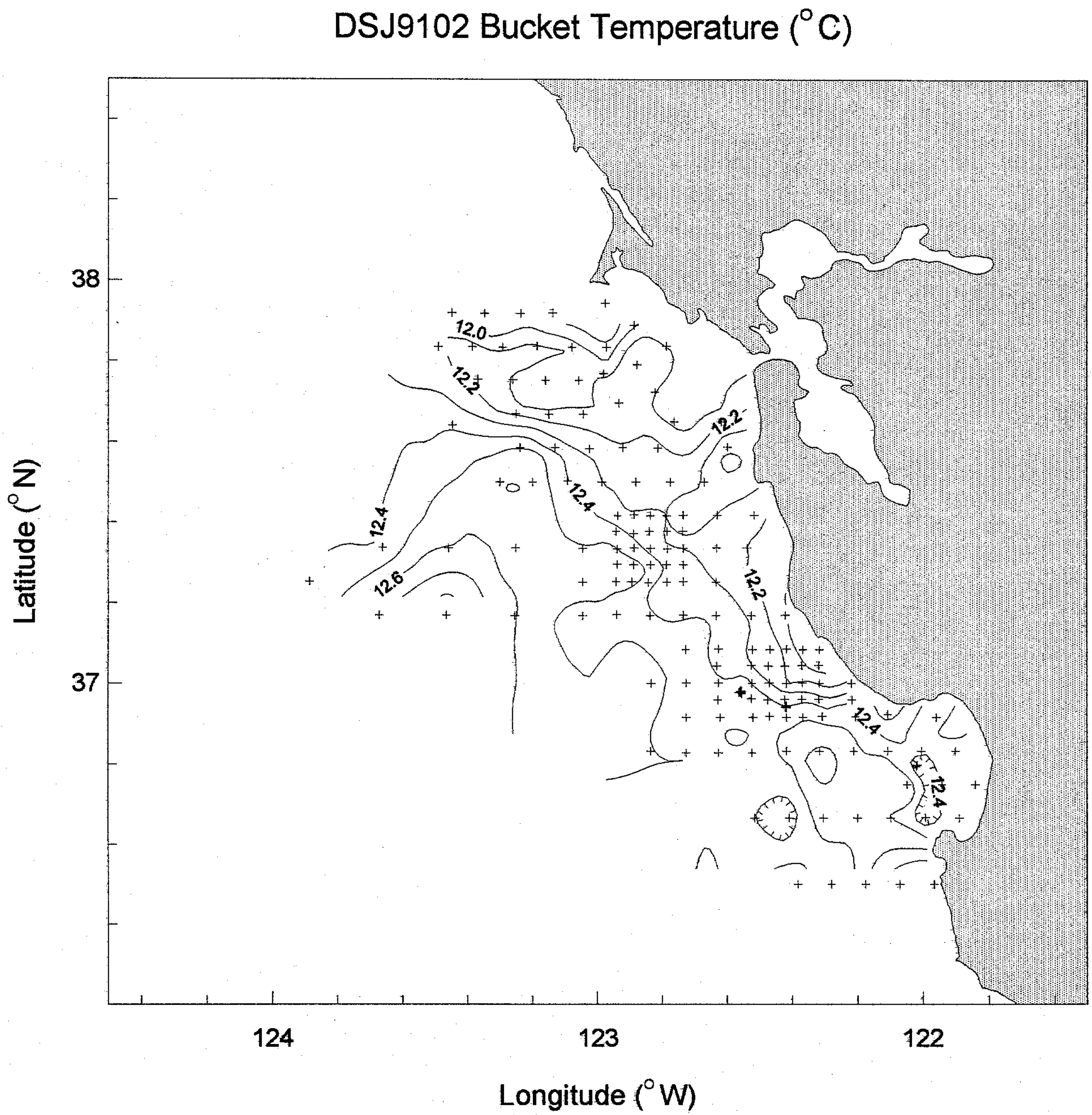
Surface Temperature for DSJ9102: CTD vs. Bucket

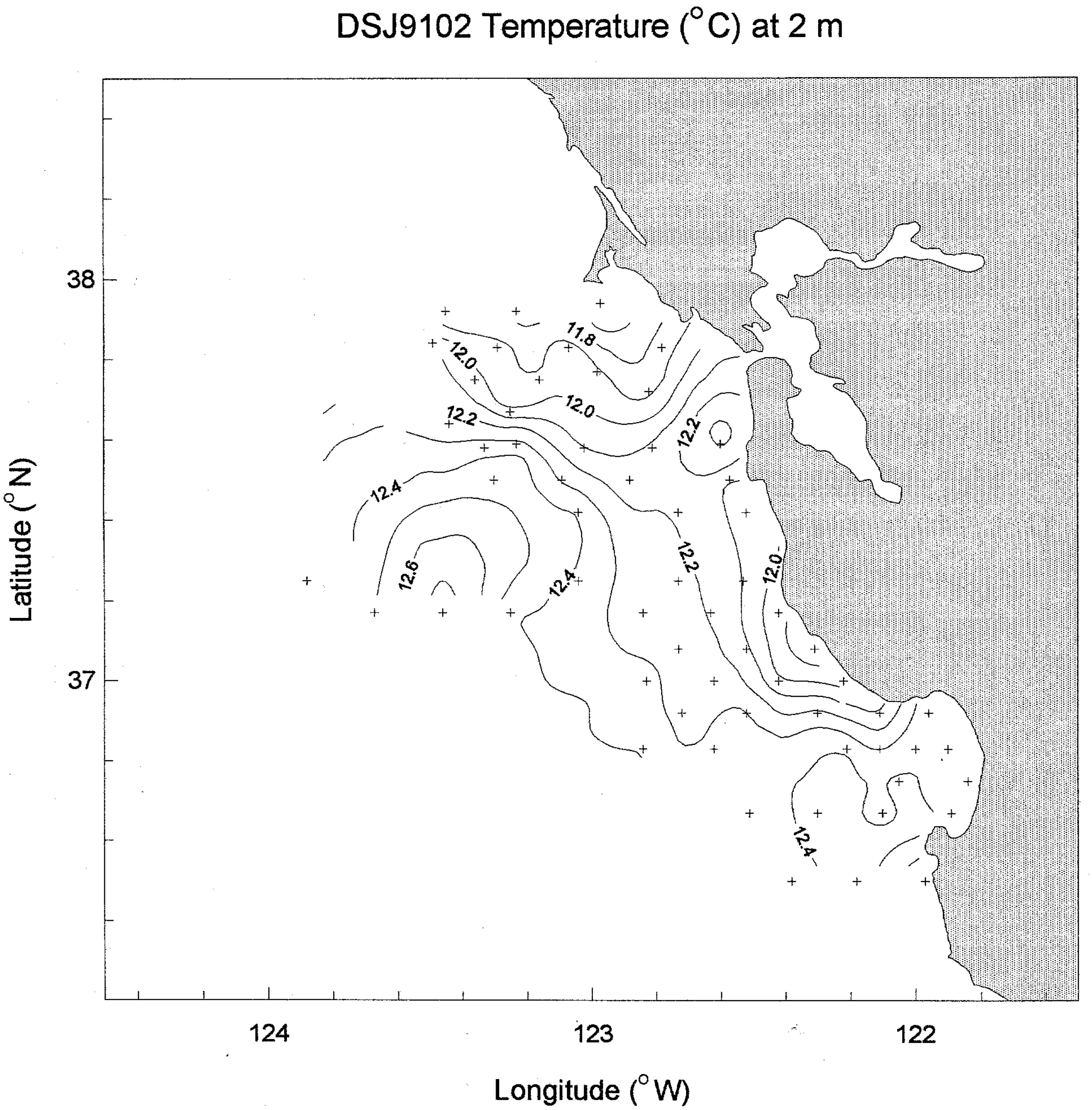


APPENDIX 4.2: REGRESSION COMPARISON OF CTD AND BUCKET TEMPERATURE FOR DSJ9105

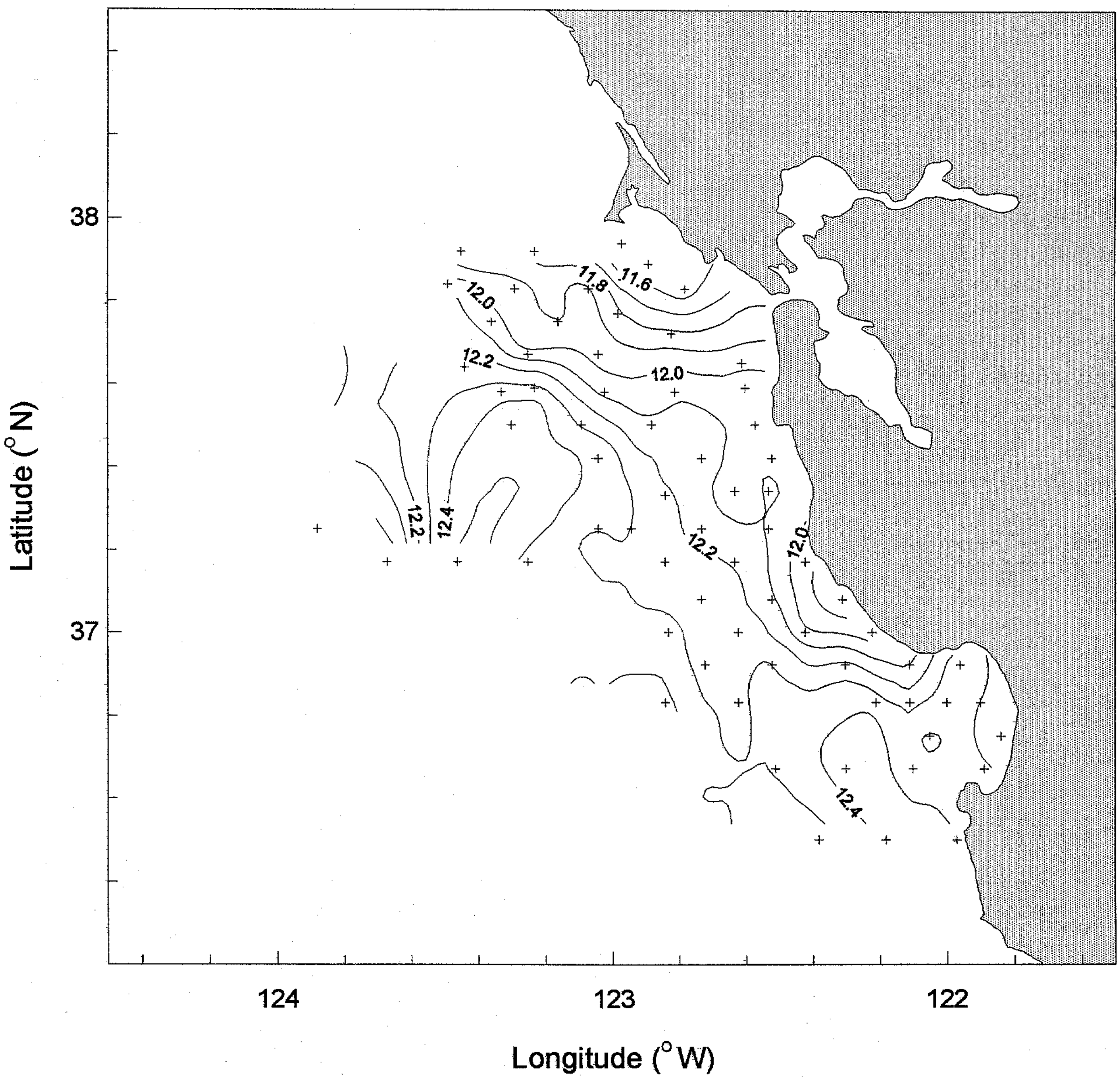

Surface Temperature for DSJ9105: CTD vs. Bucket
CTD Temperature (°C)
Bucket Temperature (°C)
13
12
11
10
9
8
8
9
10
11
12
13

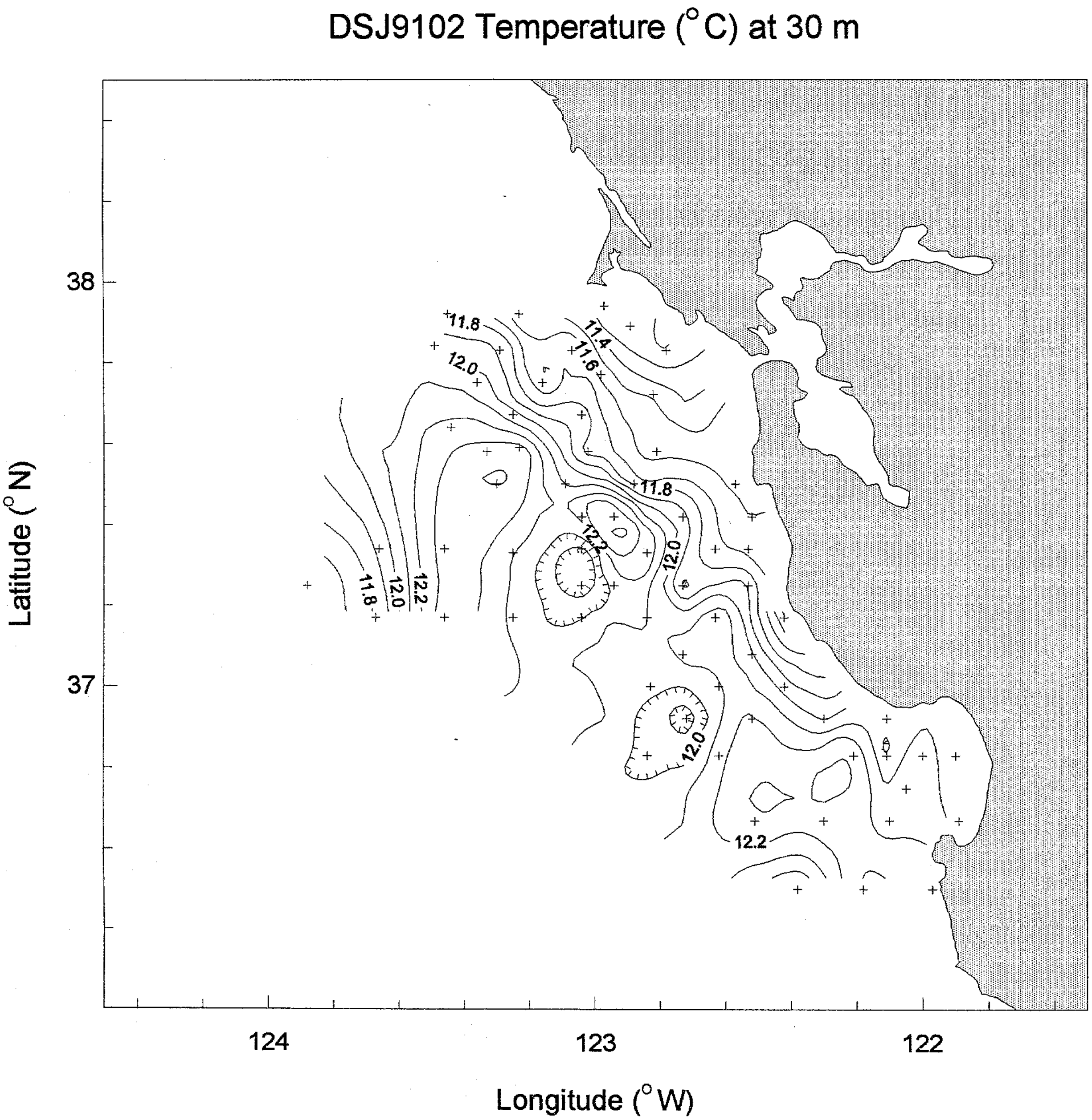
APPENDIX 5.1: HORIZONTAL MAPS OF CTD AND BUCKET TEMPERATURE FOR DSJ9102

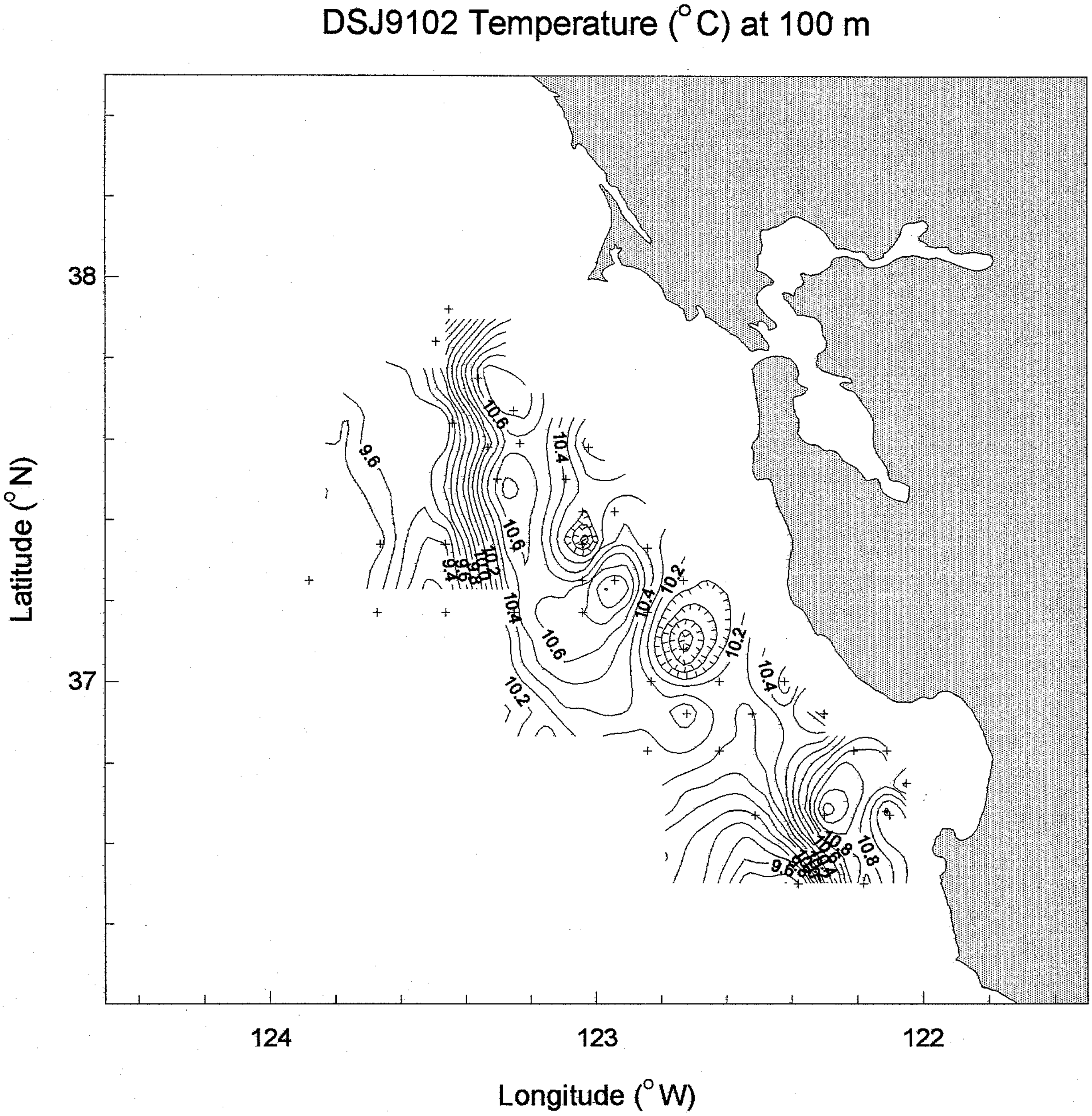

DSJ9102 Bucket Temperature (°C)
38
37
Latitude (°N)
124
123
122
Longitude (°W)
12.0
12.2
12.2
12.4
12.4
12.6
12.2
12.4
12.4


DSJ9102 Temperature (°C) at 2 m
Latitude (° N)
Longitude (° W)
38
37
124
123
122
11.8
12.0
12.0
12.2
12.2
12.4
12.6
12.4
12.2
12.0
12.4

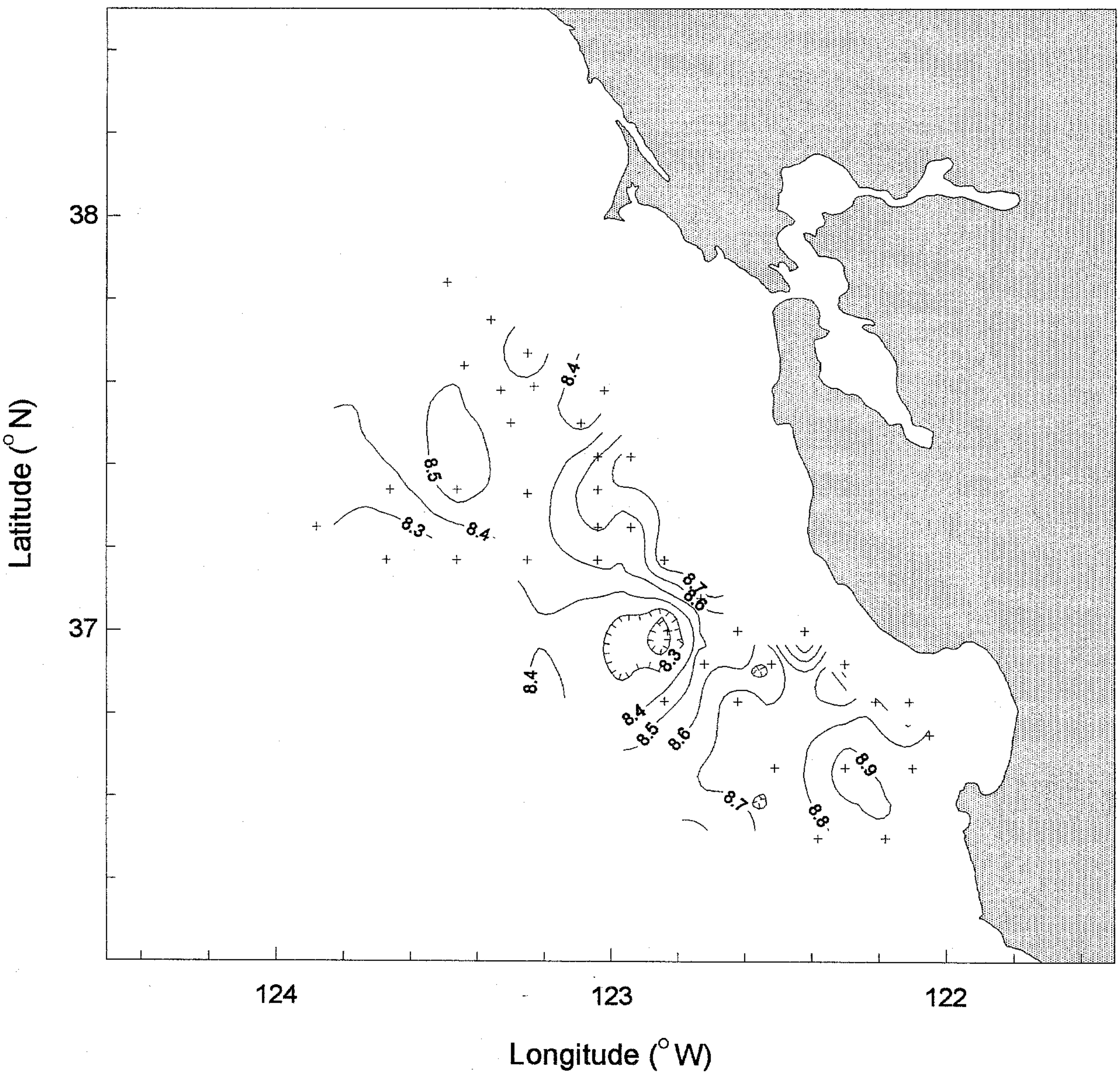
DSJ9102 Temperature (°C) at 10 m



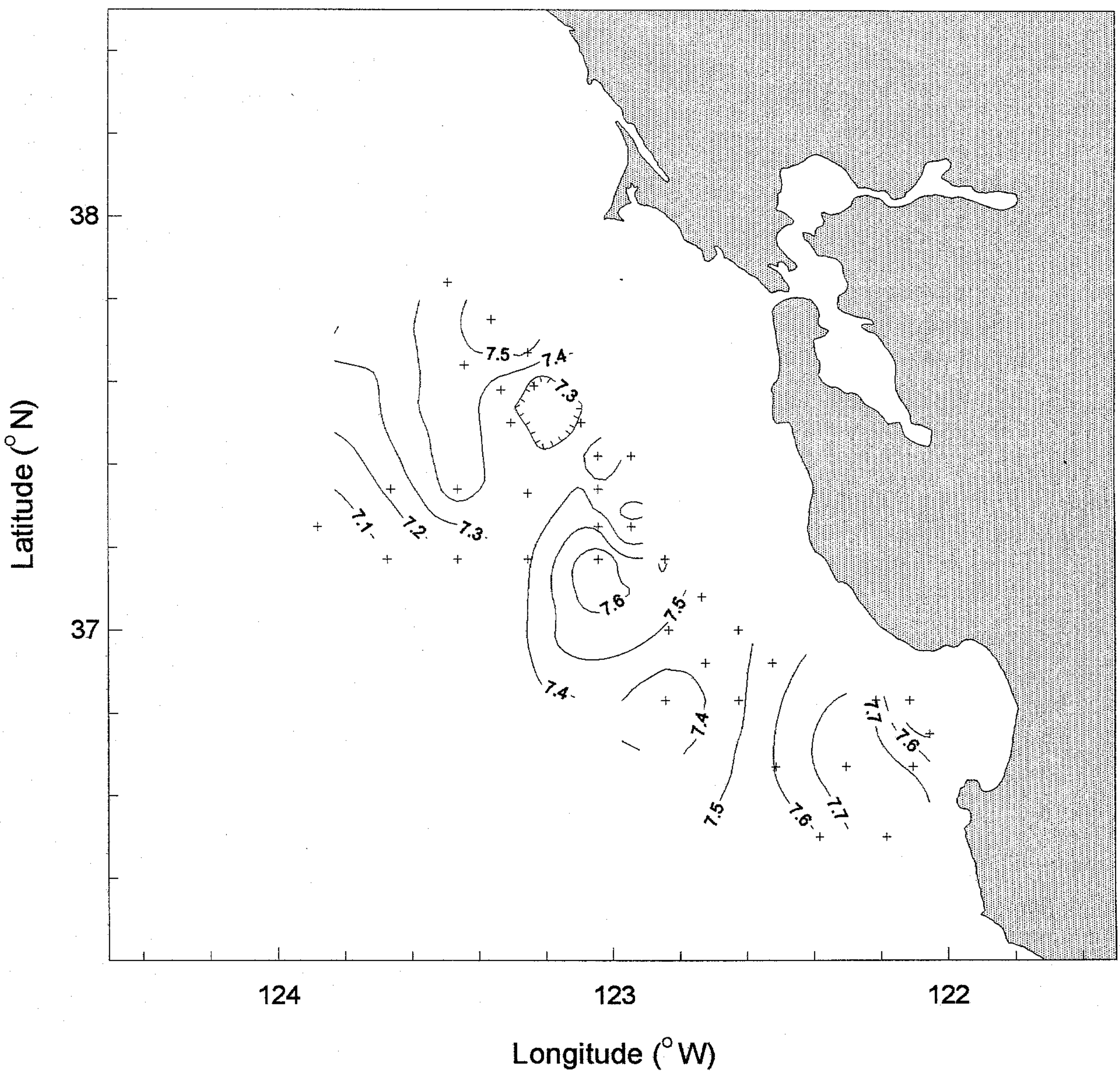

DSJ9102 Temperature (°C) at 30 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
11.8
12.0
11.4
11.6
11.8
12.2
12.0
11.8
12.0
12.2
12.0
12.2


DSJ9102 Temperature (°C) at 100 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)
10.6
9.6
10.4
10.2
9.4
10.8

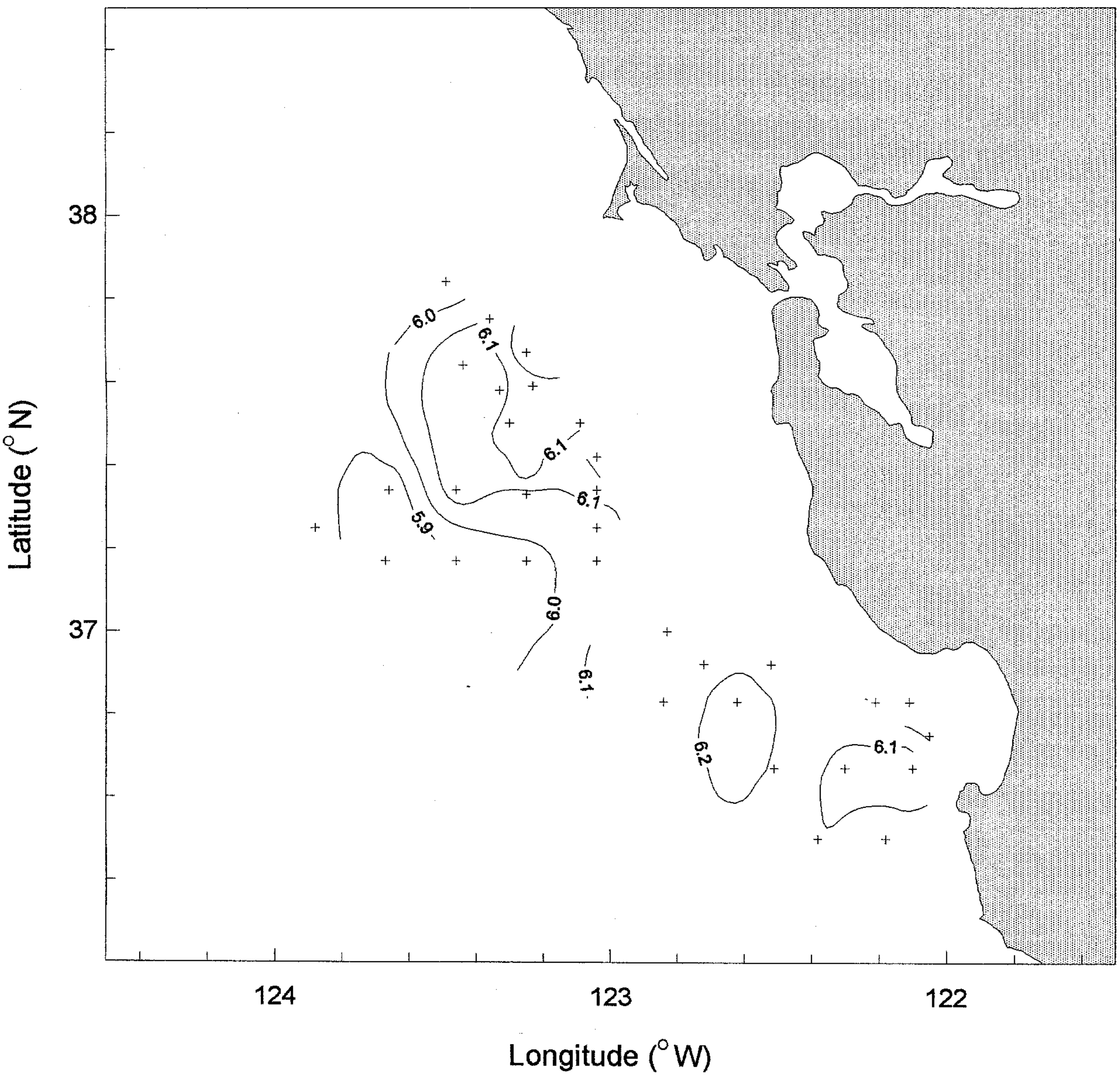
DSJ9102 Temperature (°C) at 200 m

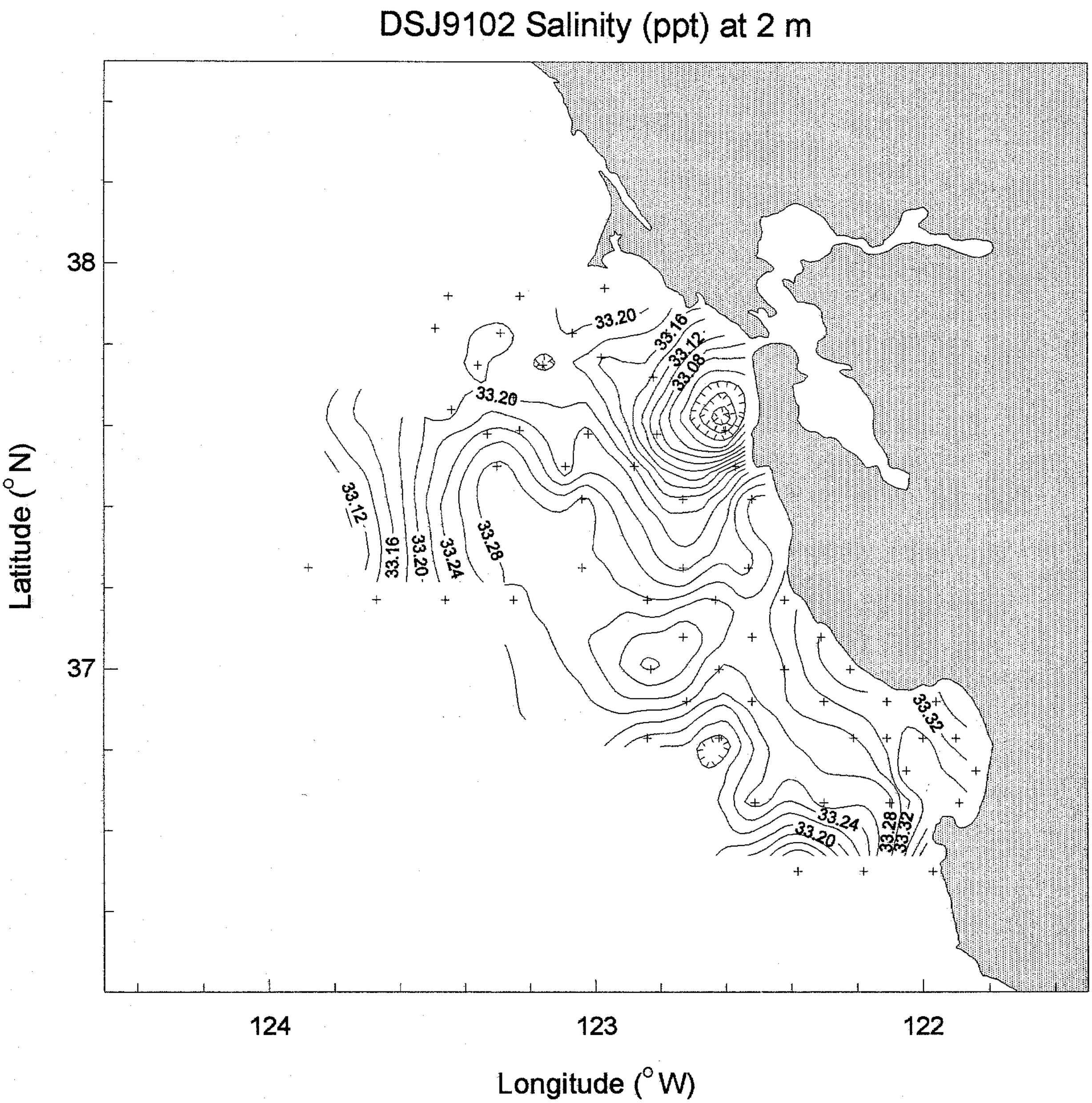


DSJ9102 Temperature (°C) at 300 m

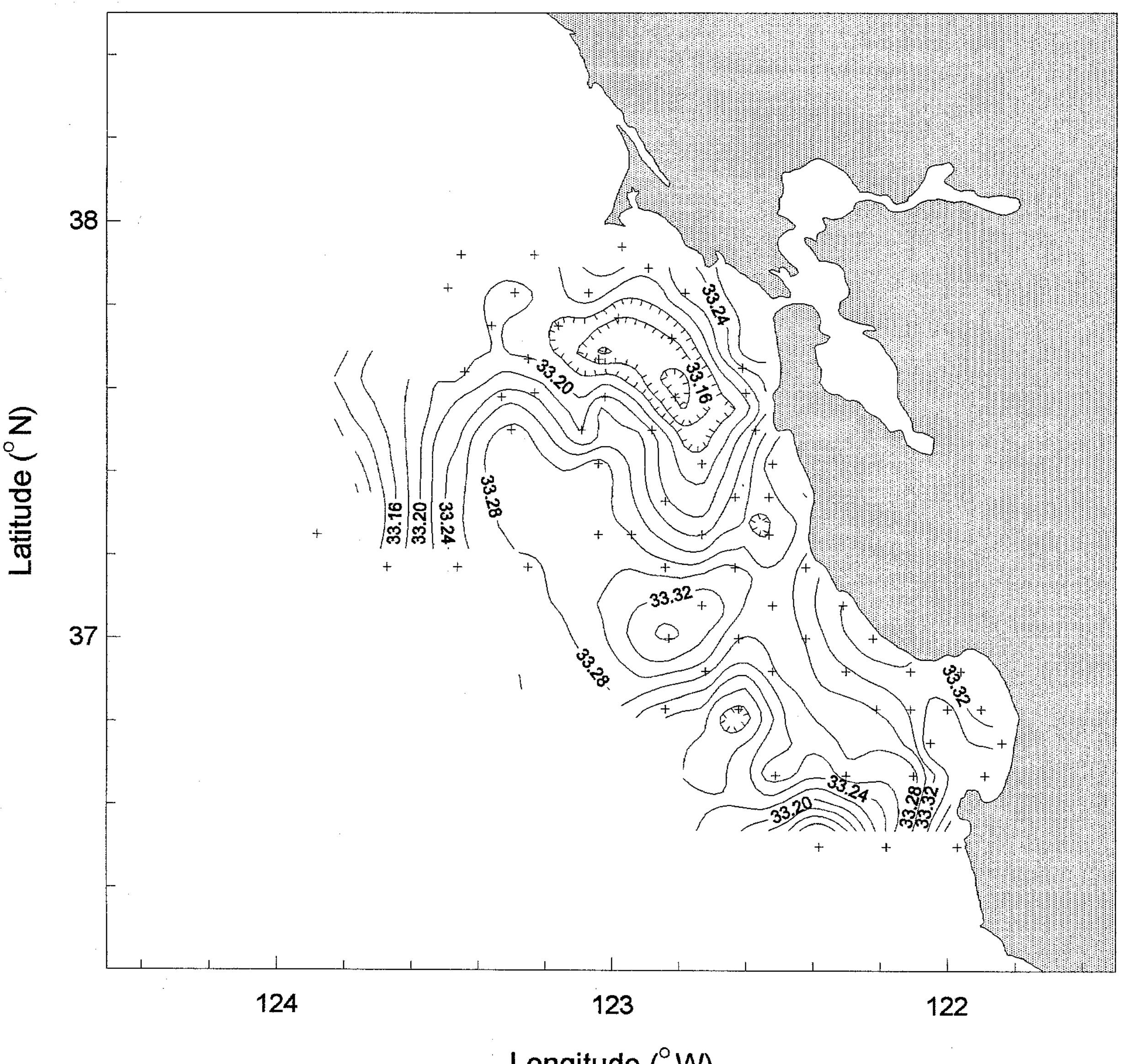


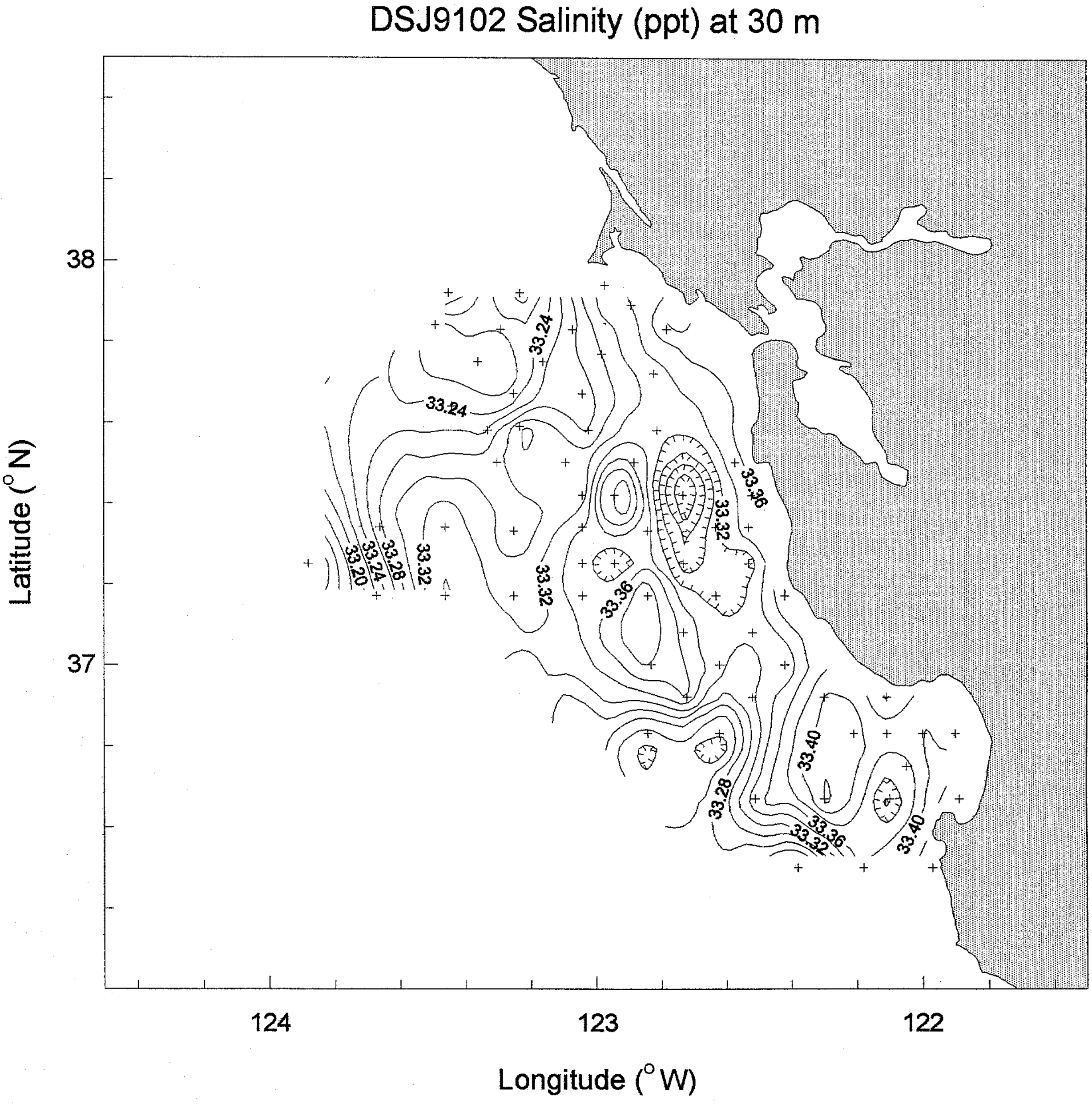
DSJ9102 Temperature (°C) at 500 m

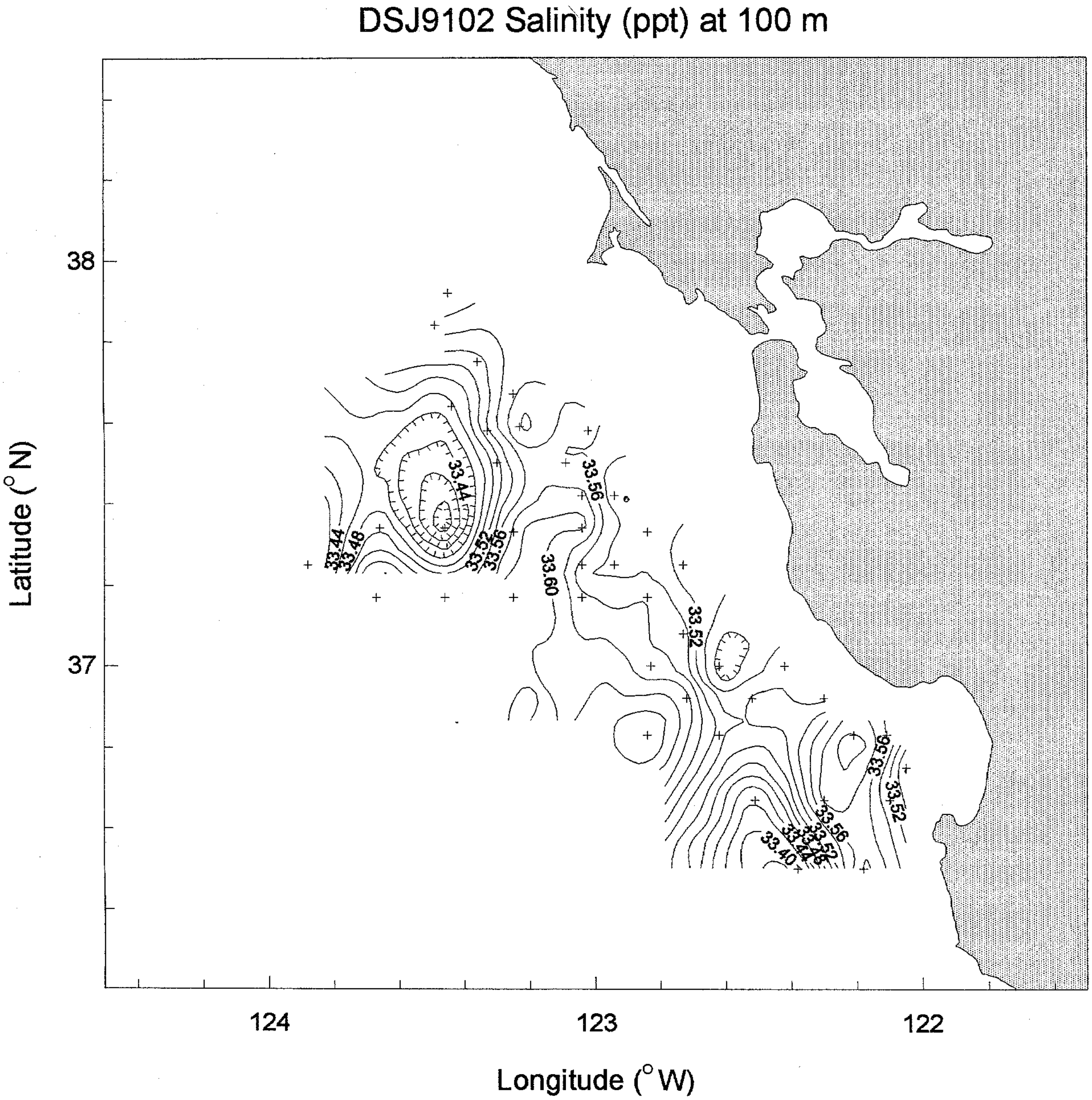



DSJ9102 Salinity (ppt) at 2 m
Latitude (° N)
Longitude (° W)
38
37
124
123
122
33.20
33.16
33.12
33.08
33.20
33.12
33.16
33.20
33.24
33.28
33.32
33.24
33.20
33.28
33.32

DSJ9102 Salinity (ppt) at 10 m

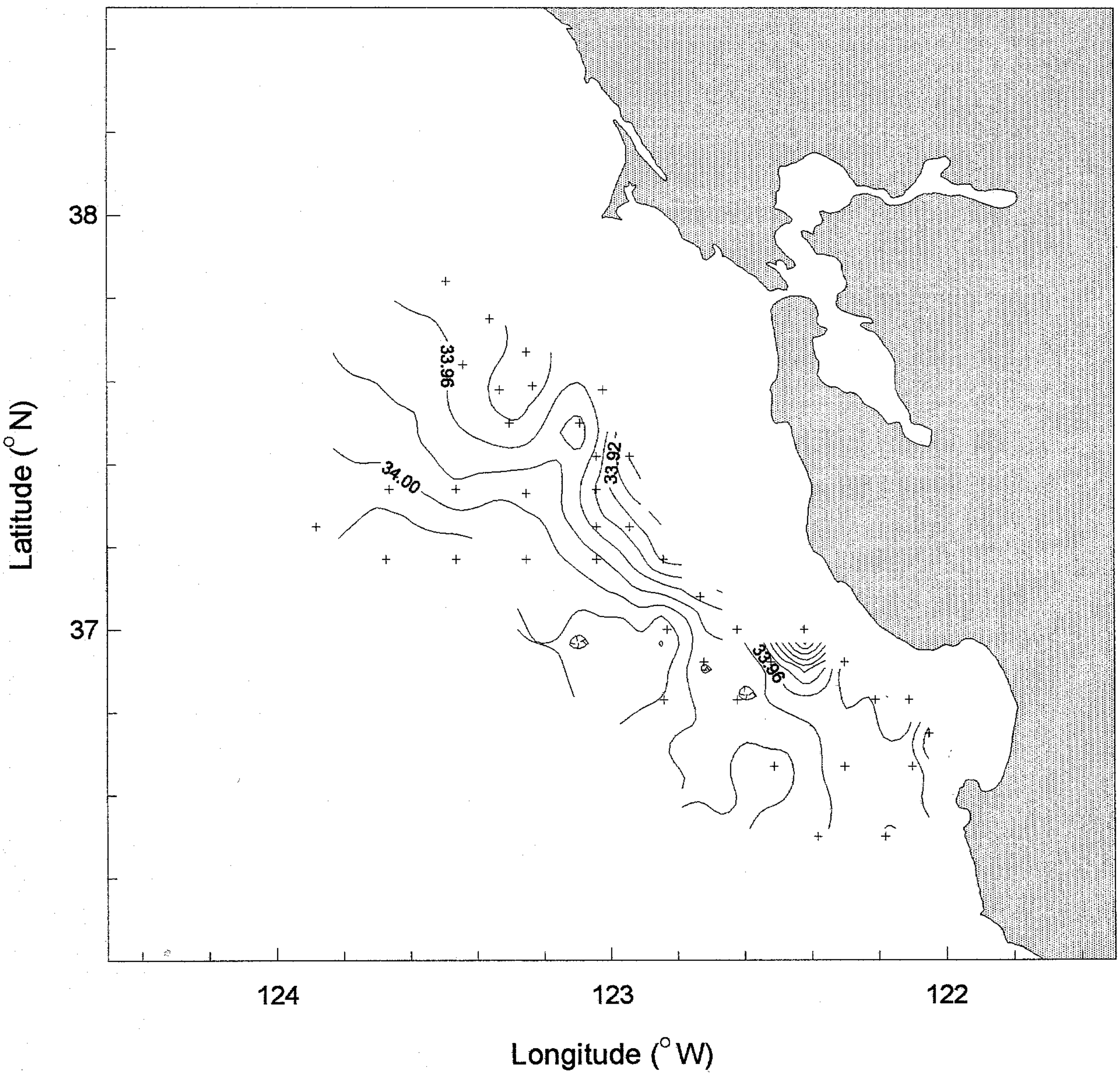



DSJ9102 Salinity (ppt) at 30 m
Latitude (° N)
Longitude (° W)
38
37
124
123
122
33.24
33.24
33.20
33.24
33.28
33.32
33.32
33.36
33.36
33.32
33.40
33.28
33.36
33.32
33.40

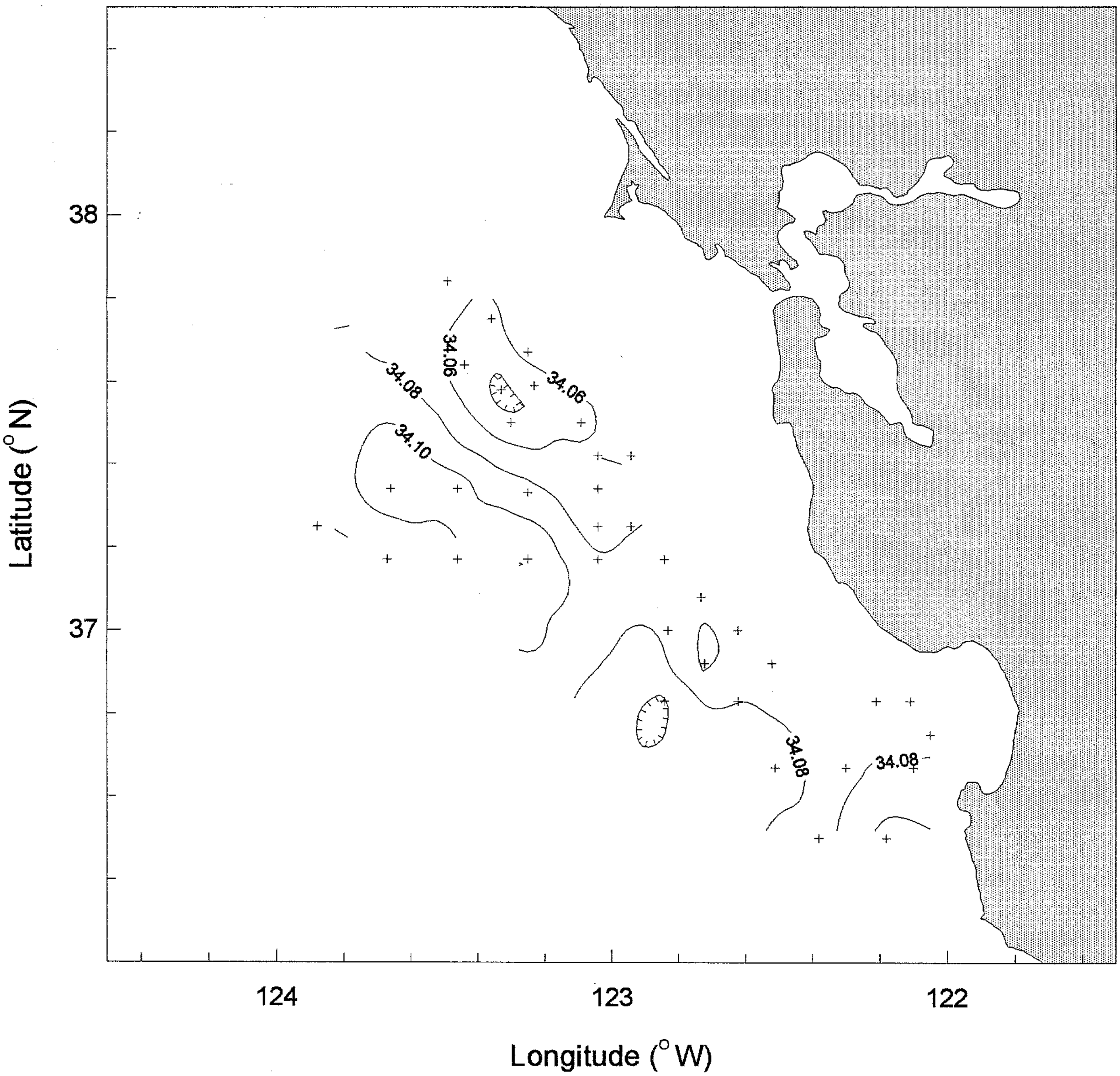


DSJ9102 Salinity (ppt) at 100 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)
33.44
33.48
33.52
33.56
33.60
33.40

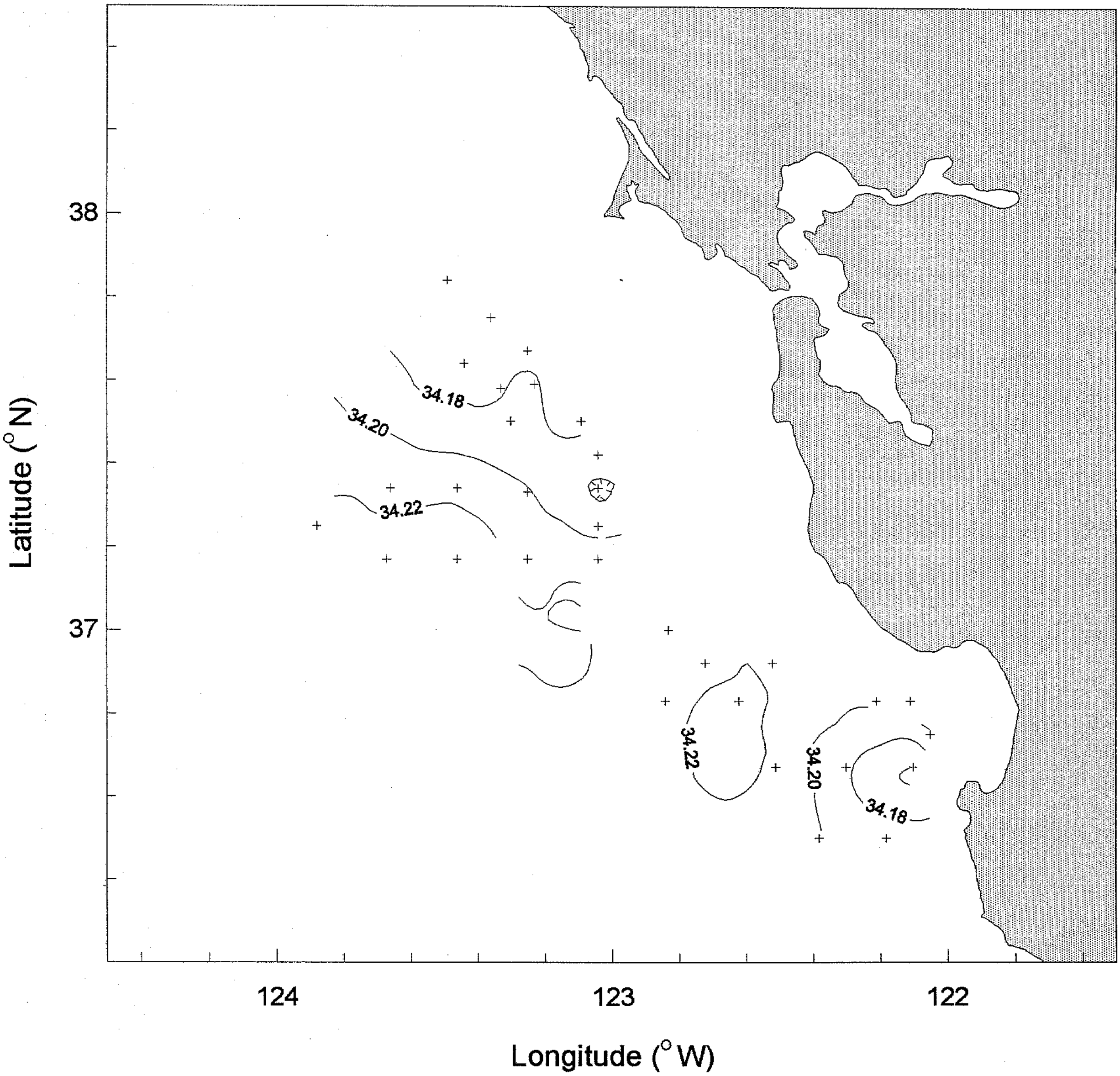
DSJ9102 Salinity (ppt) at 200 m



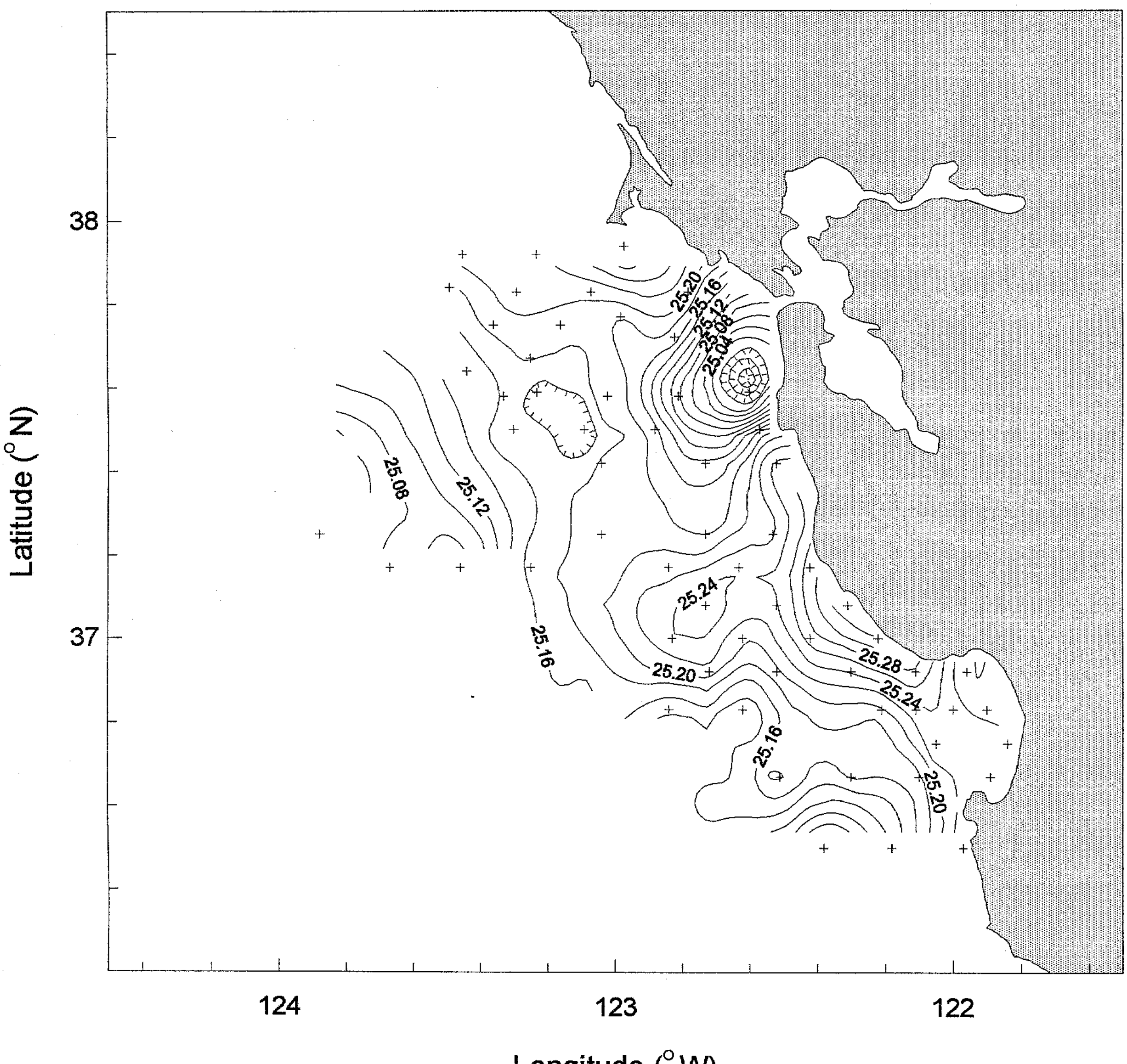
DSJ9102 Salinity (ppt) at 300 m



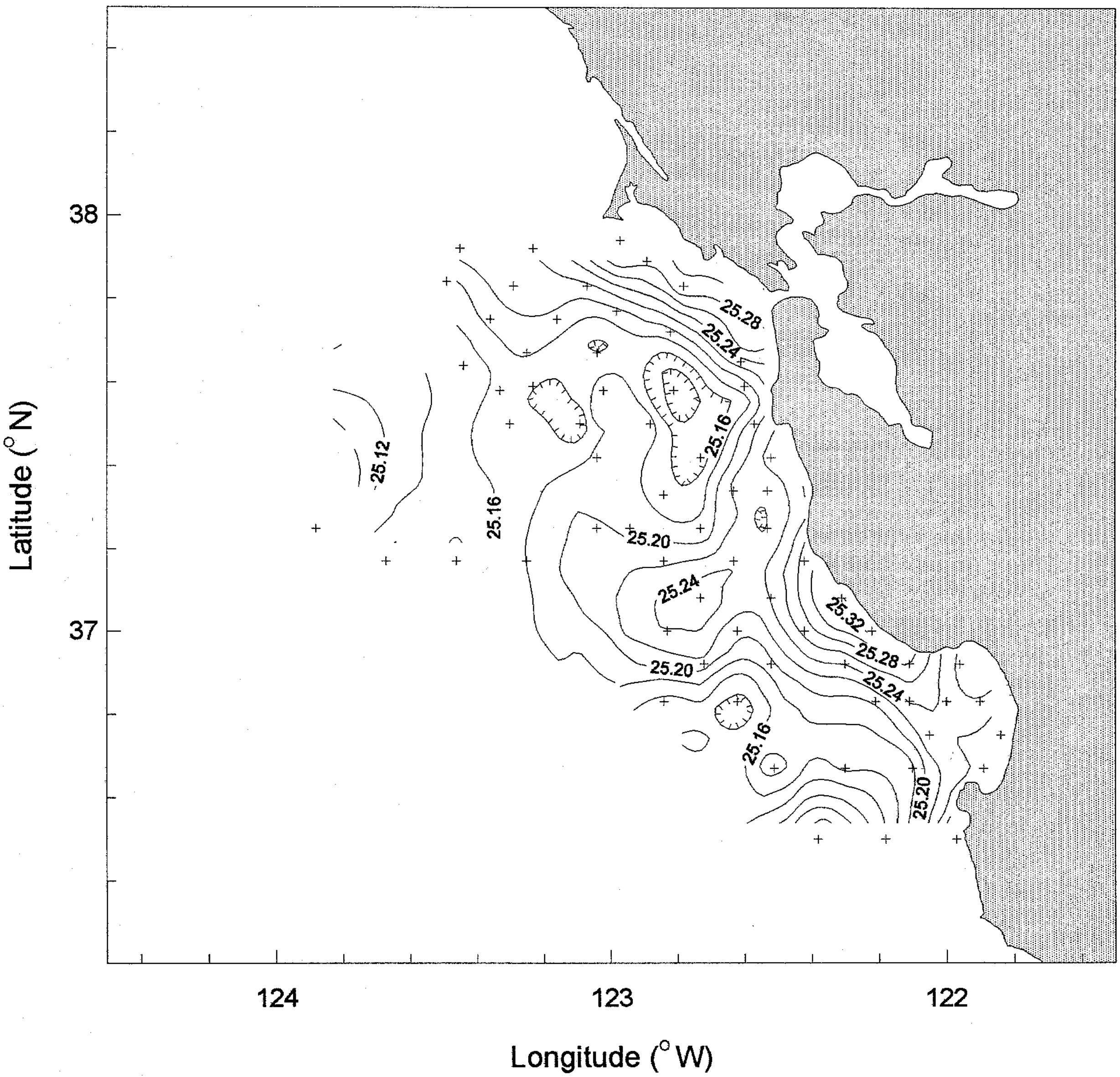
DSJ9102 Salinity (ppt) at 500 m



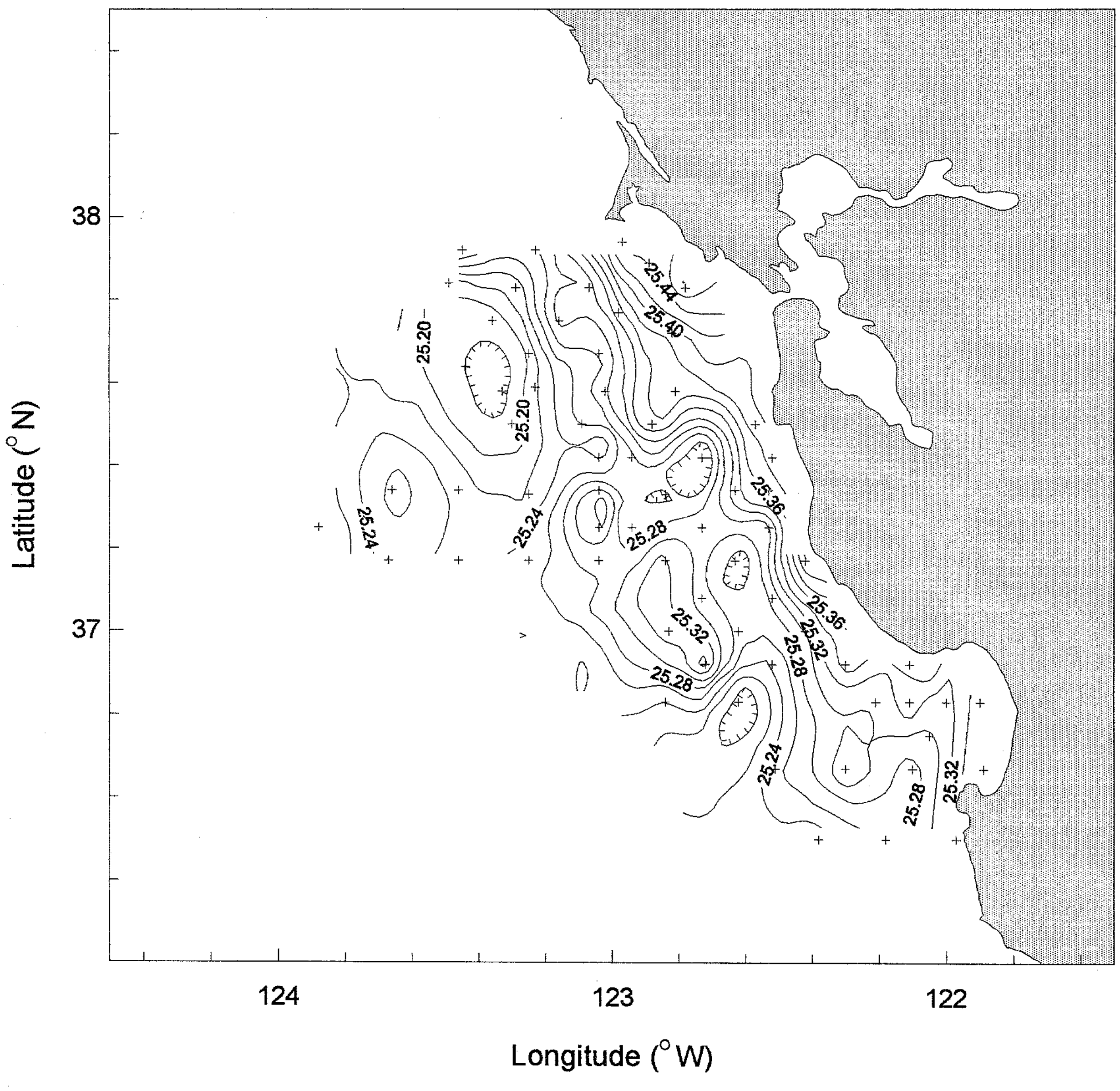
DSJ9102 Density (kg/m³) at 2 m



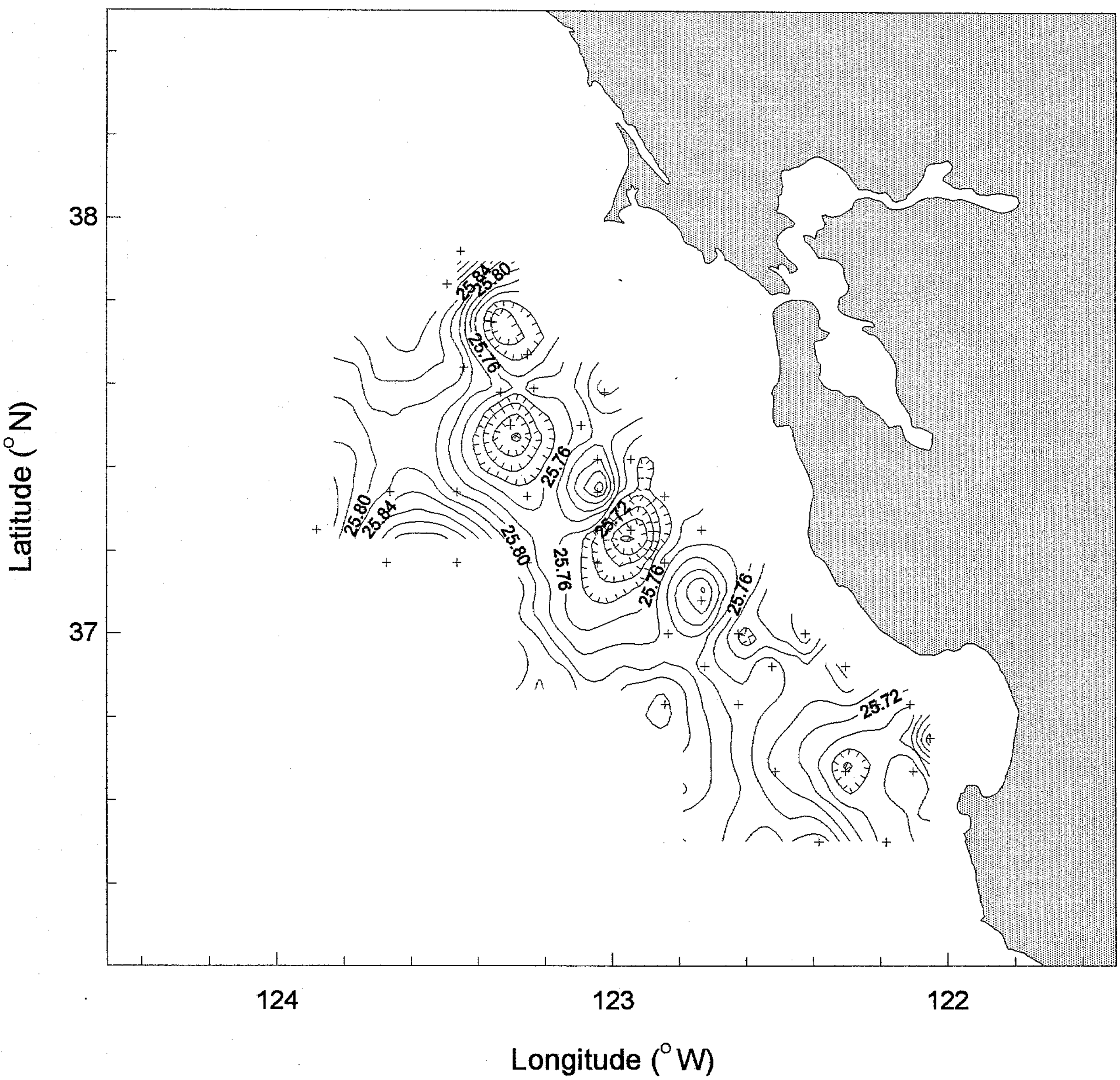
DSJ9102 Density (kg/m^3) at 10 m



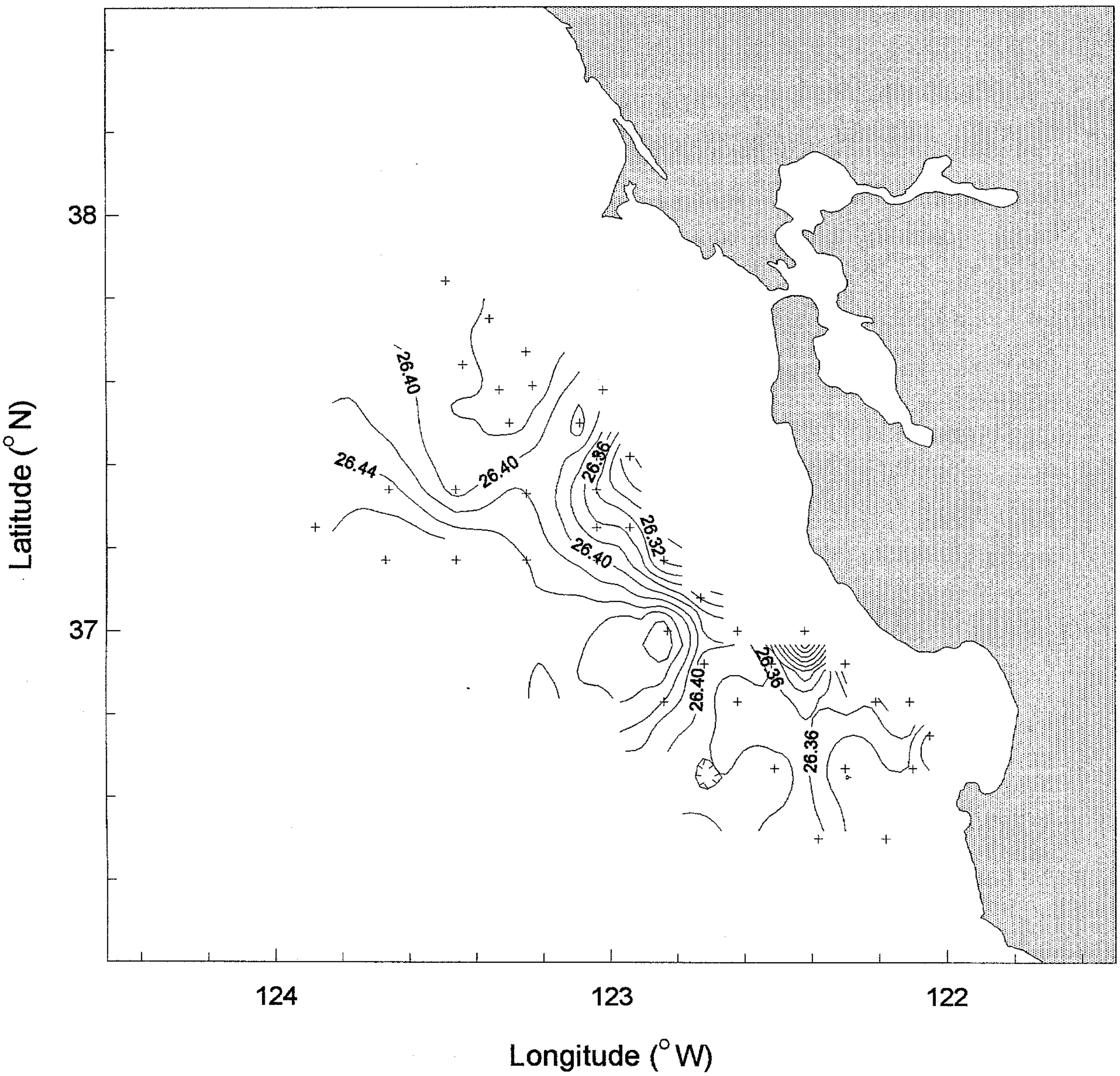
DSJ9102 Density (kg/m^3) at 30 m

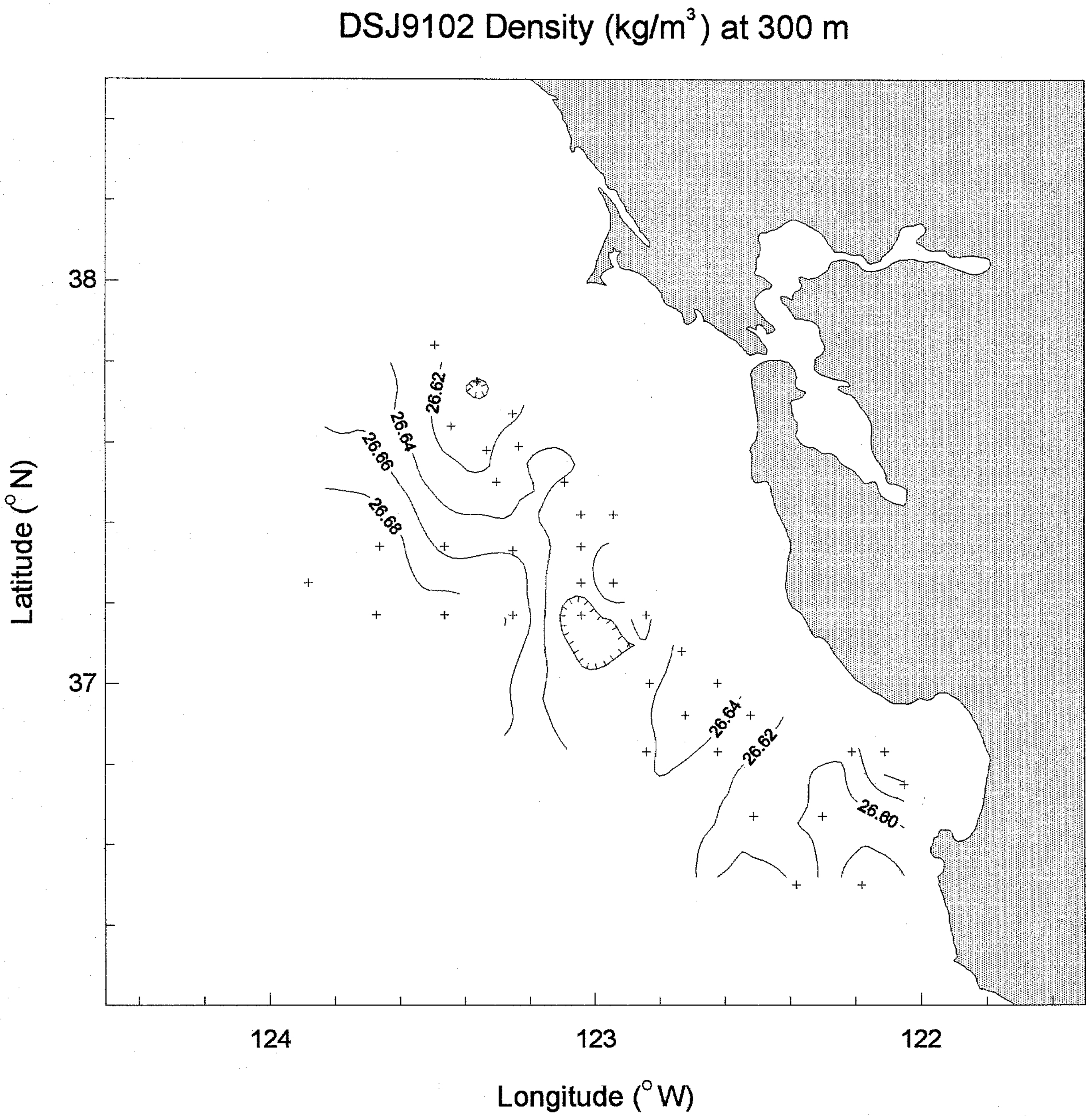


DSJ9102 Density (kg/m^3) at 100 m

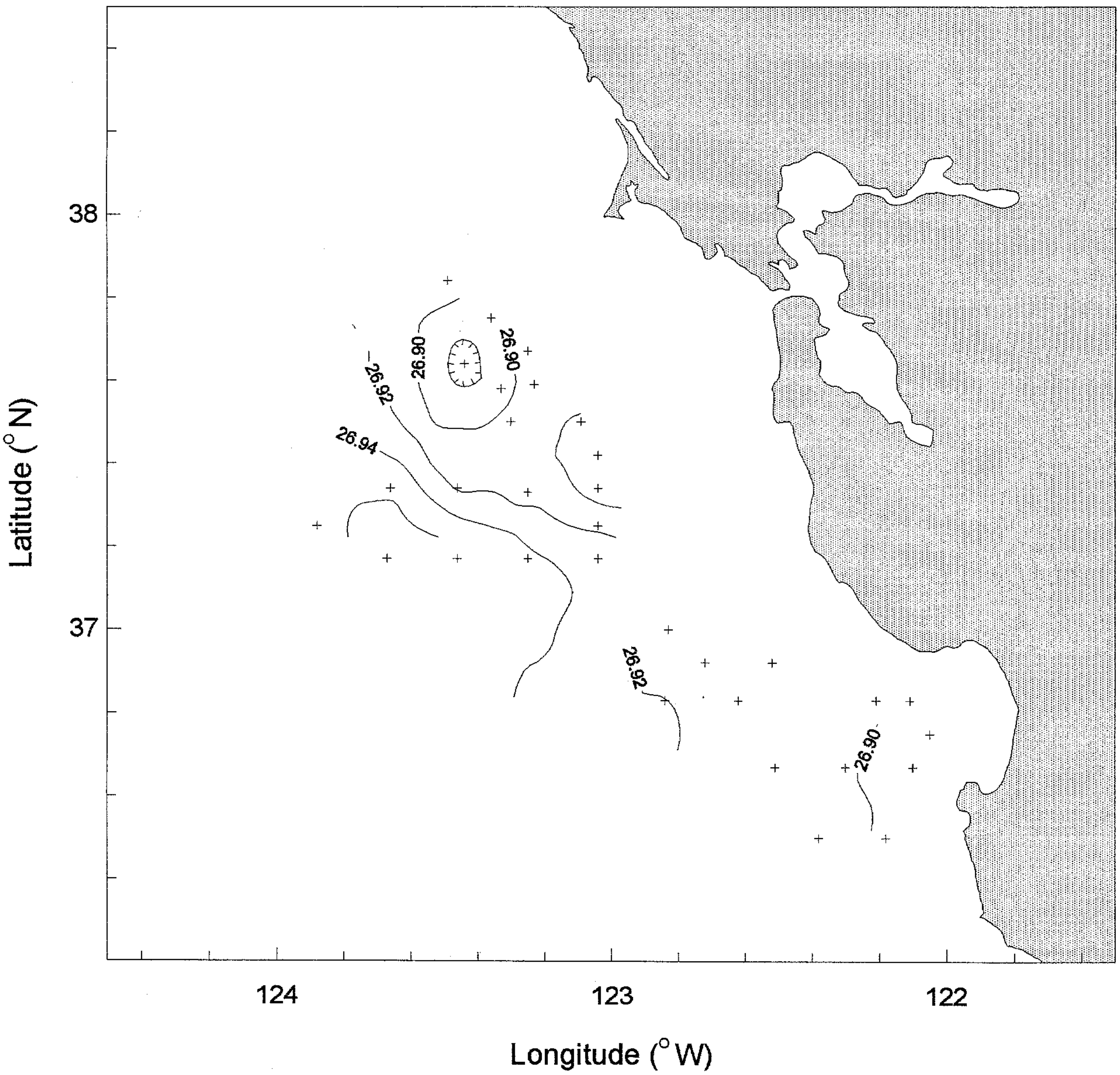


DSJ9102 Density (kg/m^3) at 200 m



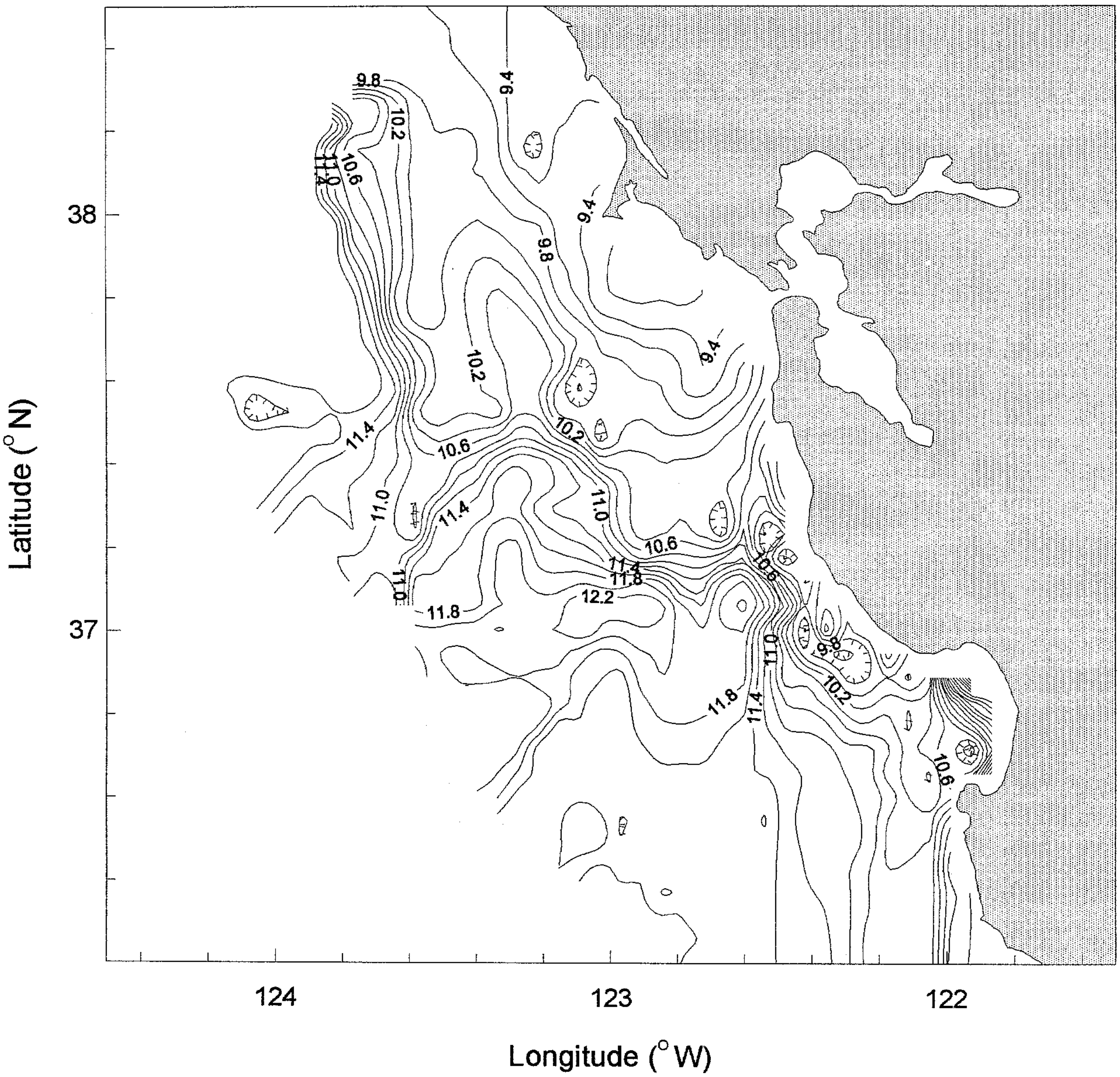

DSJ9102 Density (kg/m³) at 300 m
38
37
Latitude (° N)
124
123
122
Longitude (° W)
26.62
26.64
26.66
26.68
26.64
26.62
26.60

DSJ9102 Density (kg/m^3) at 500 m

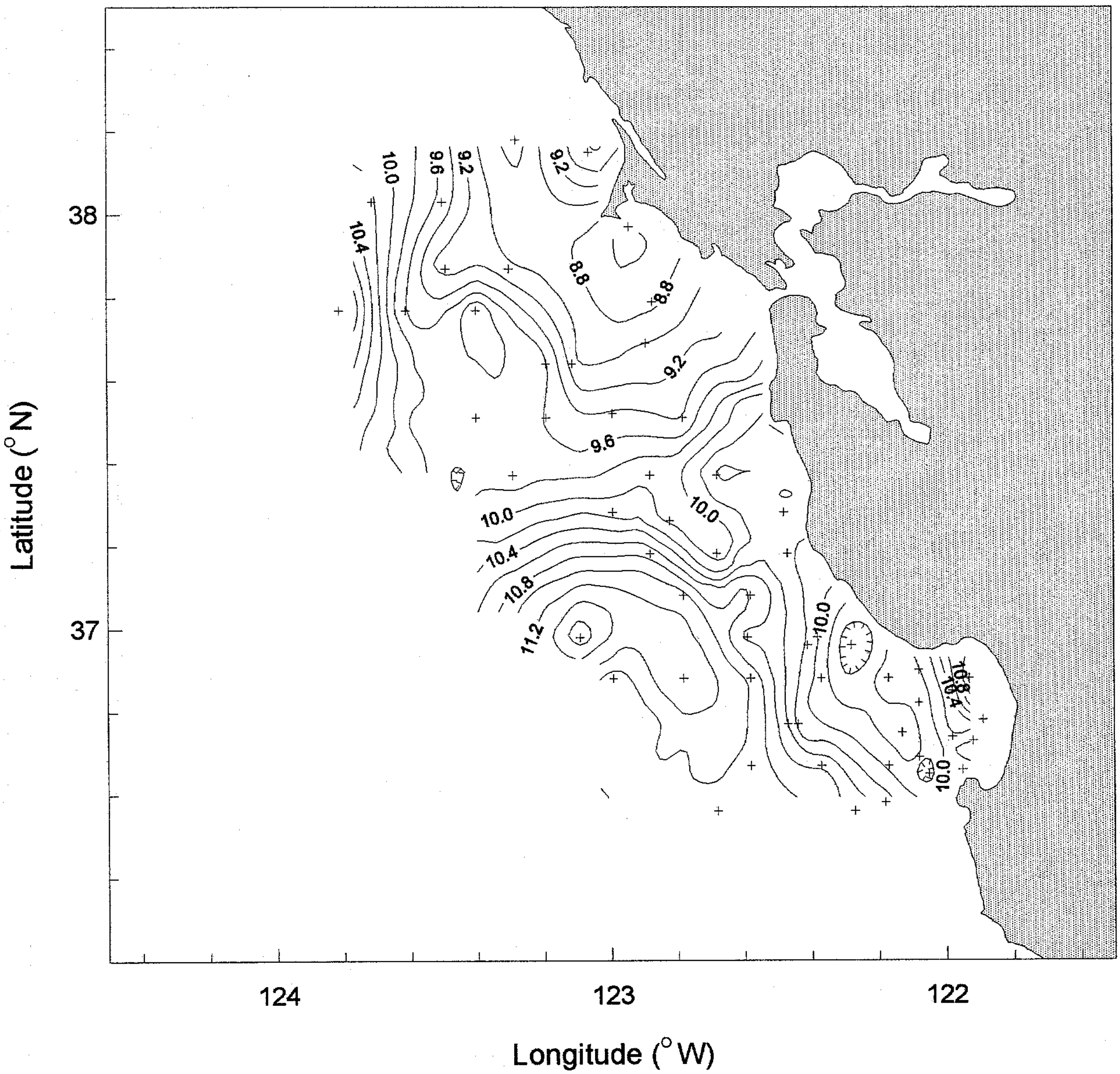


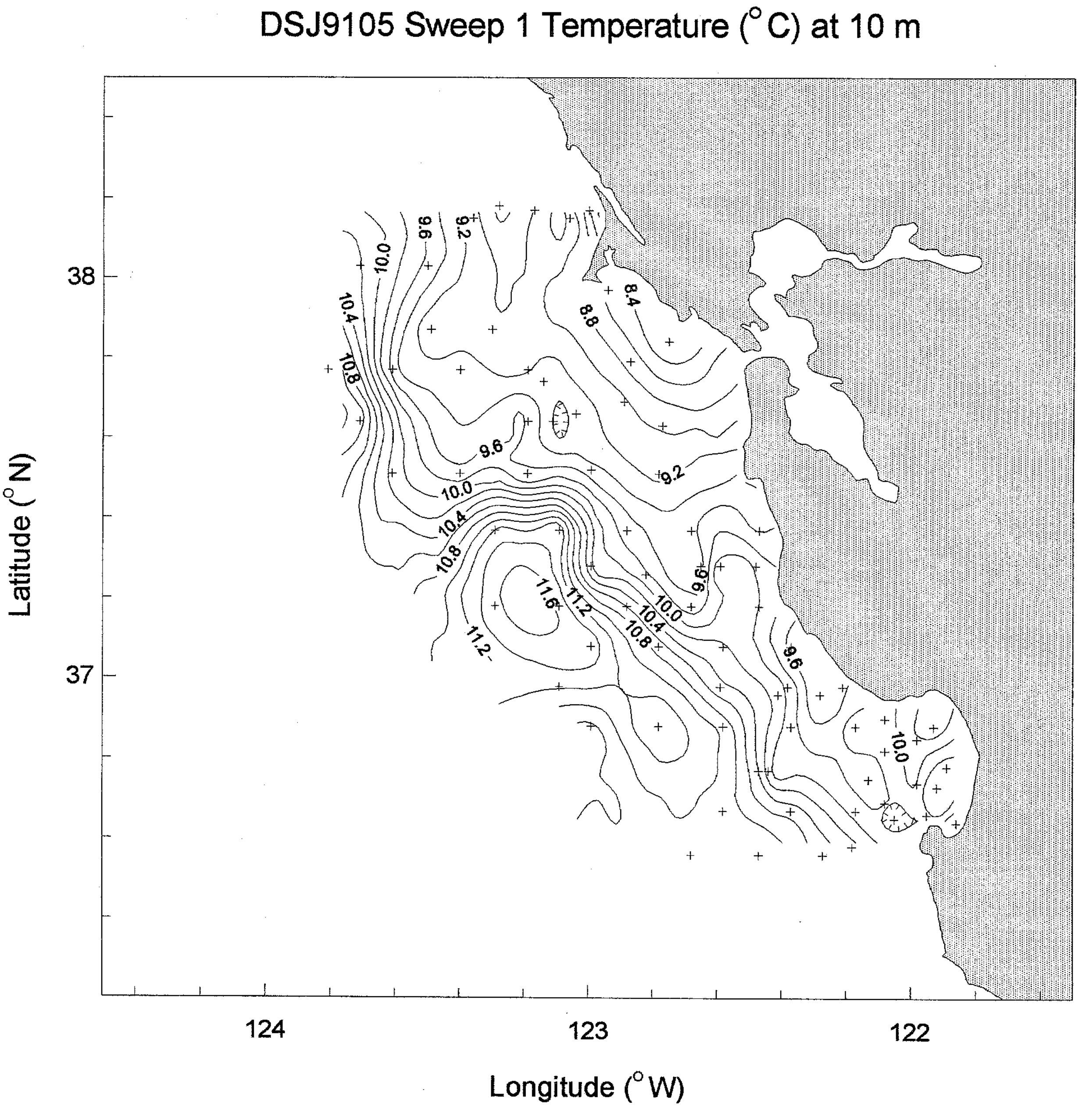
APPENDIX 5.2: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9105, SWEEP 1

DSJ9105 Sweep 1 TS Temperature (°C)

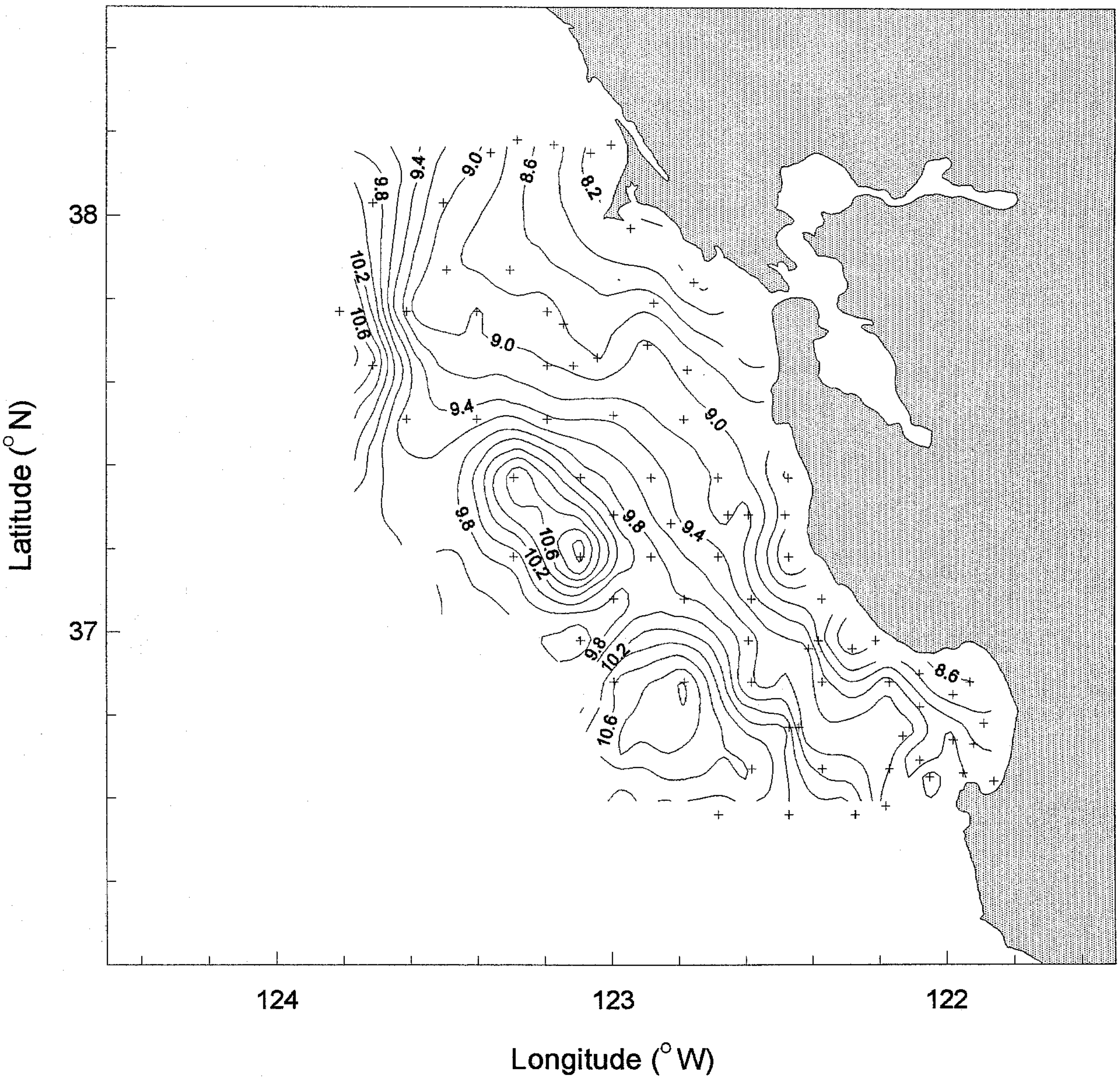


DSJ9105 Sweep 1 Temperature (°C) at 2 m

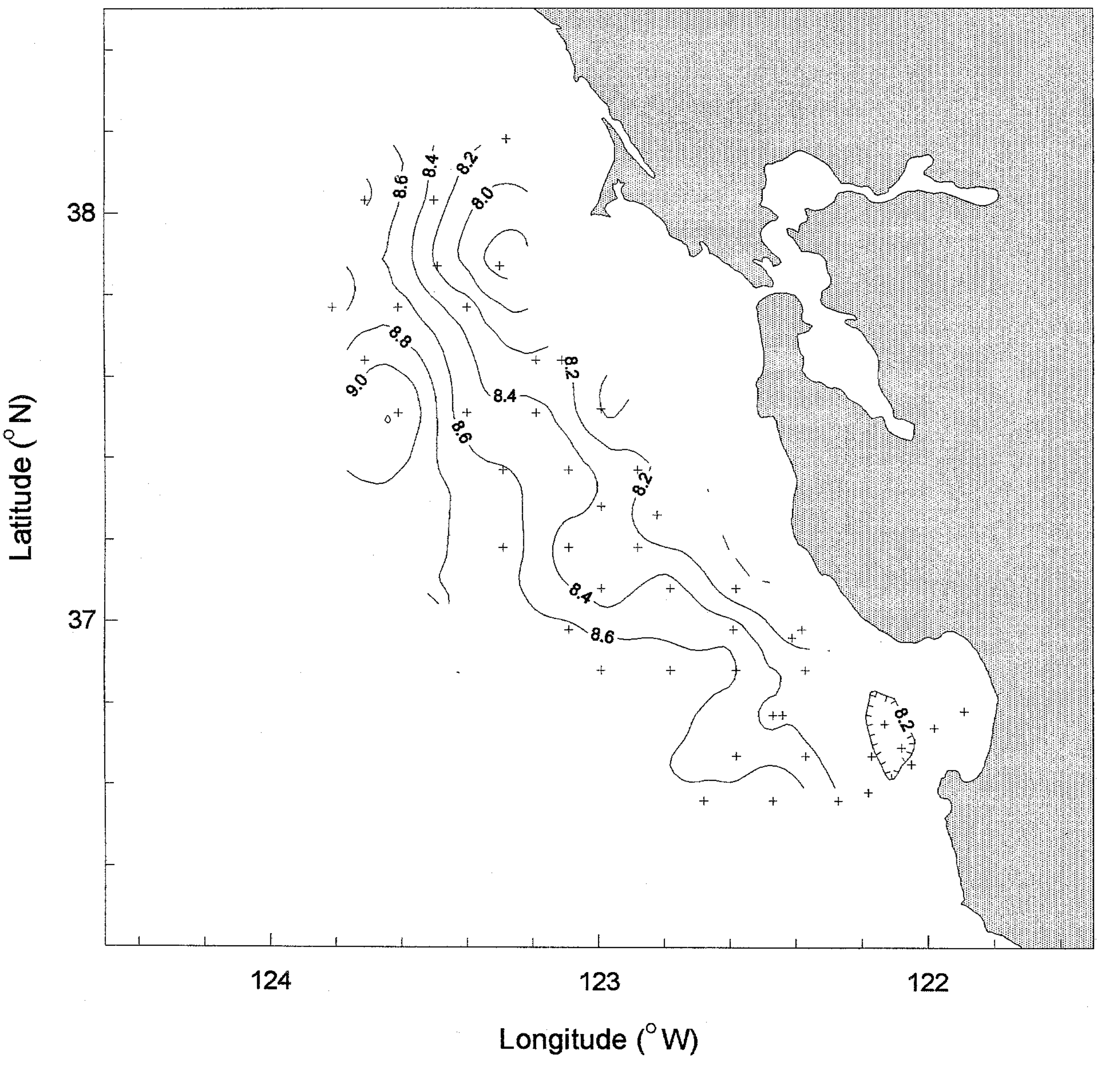


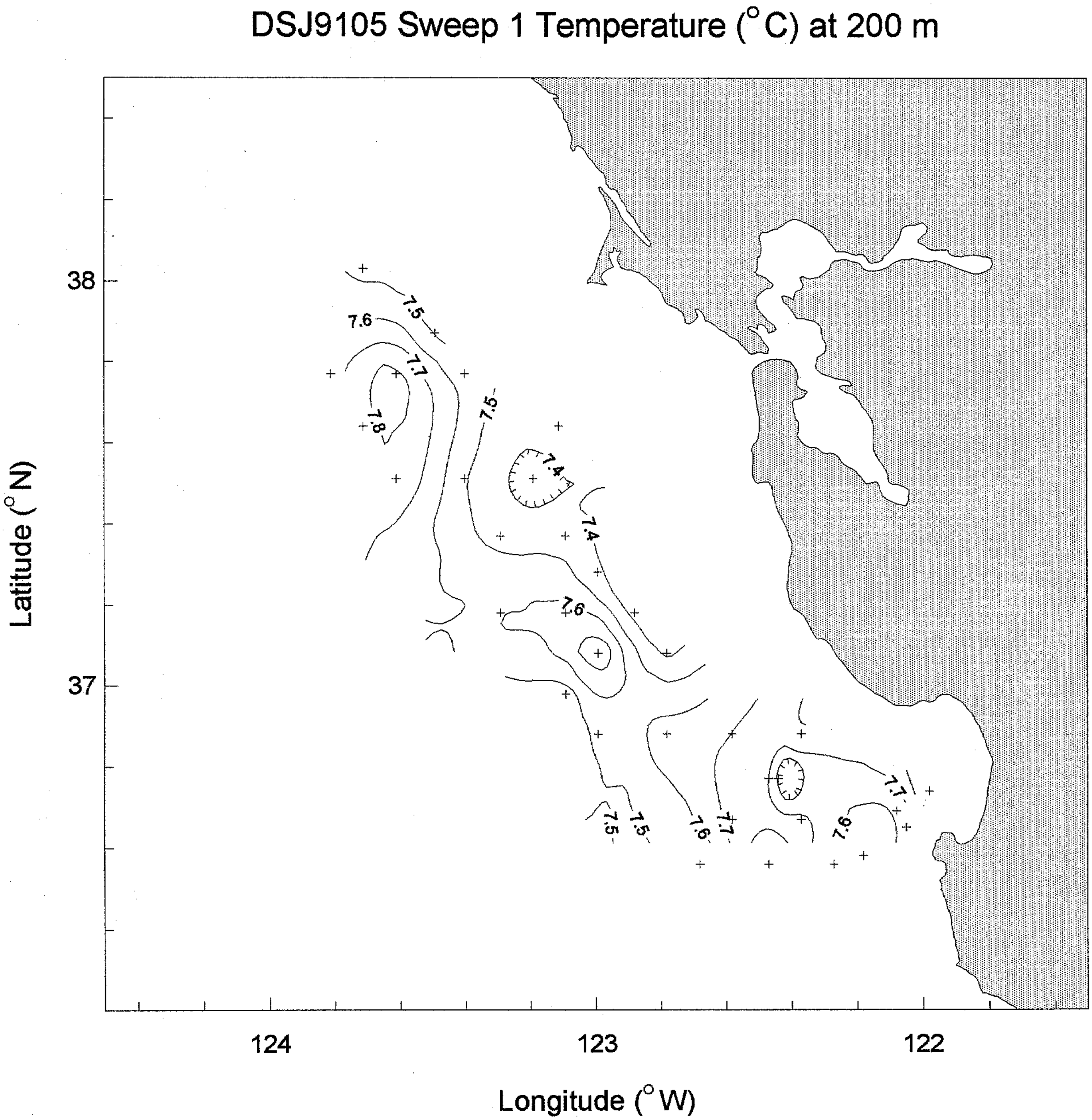

DSJ9105 Sweep 1 Temperature (°C) at 10 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)
10.8
10.4
10.0
9.6
9.2
8.8
8.4
11.2
11.6

DSJ9105 Sweep 1 Temperature (°C) at 30 m

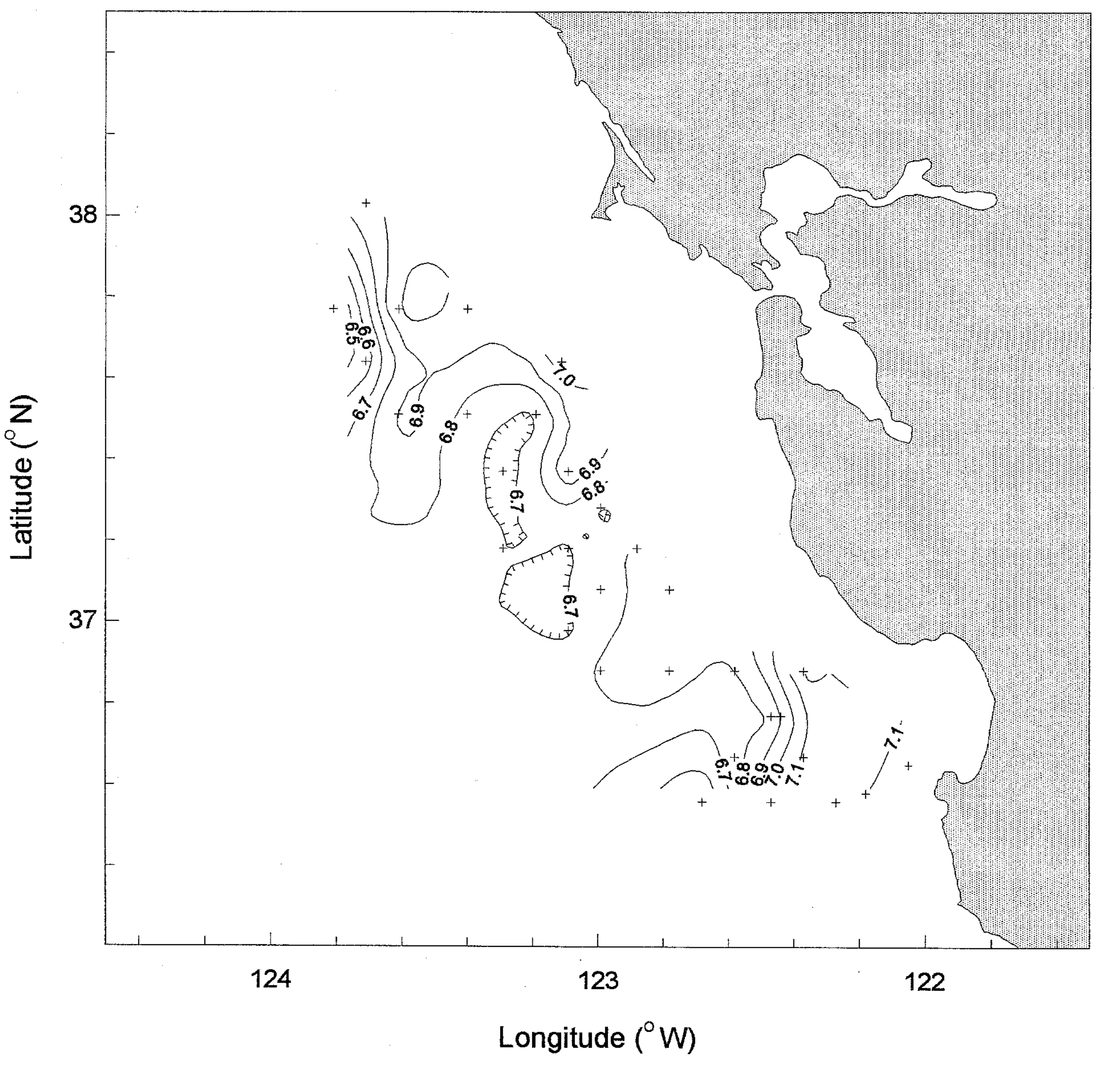


DSJ9105 Sweep 1 Temperature (°C) at 100 m

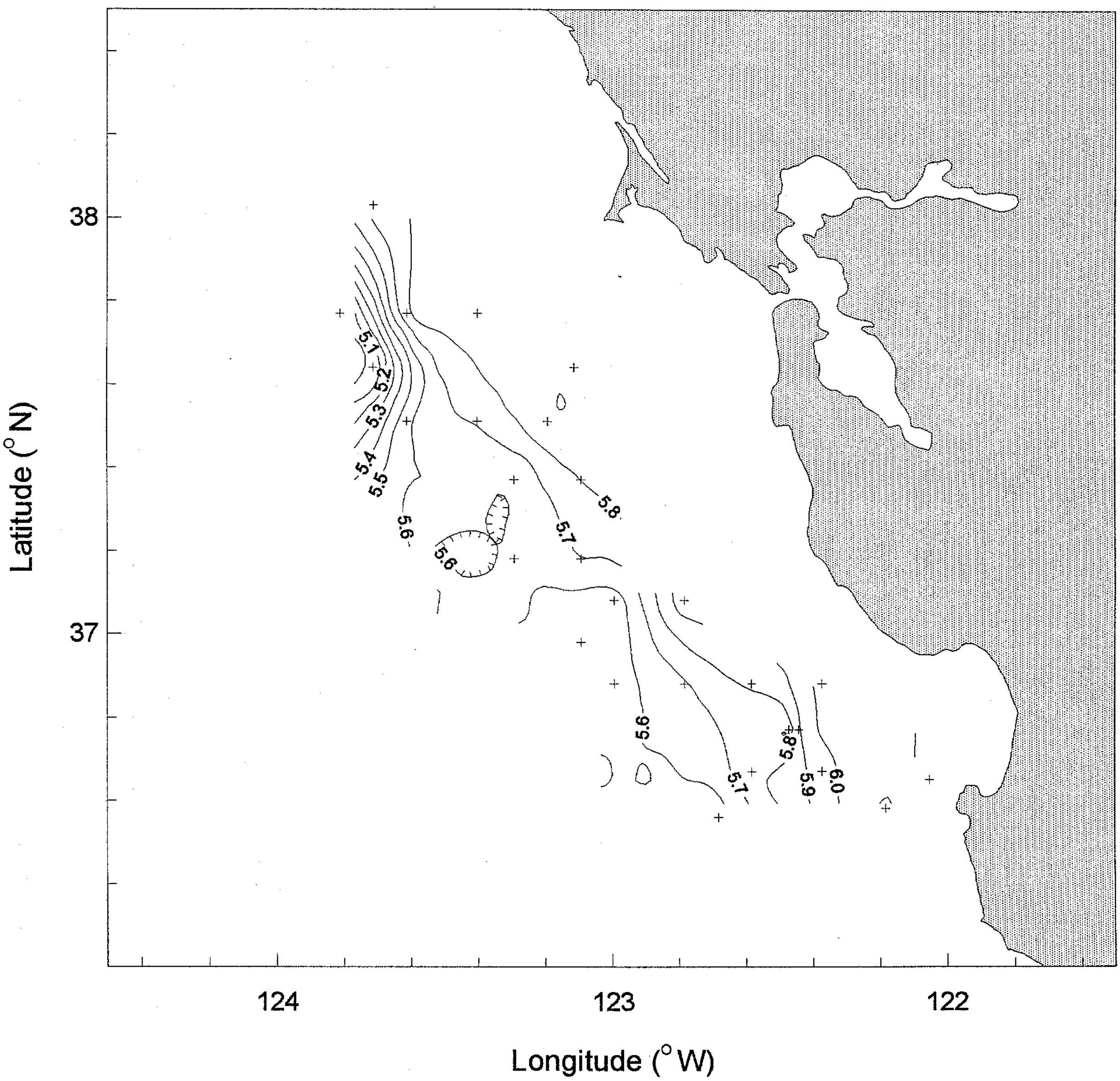


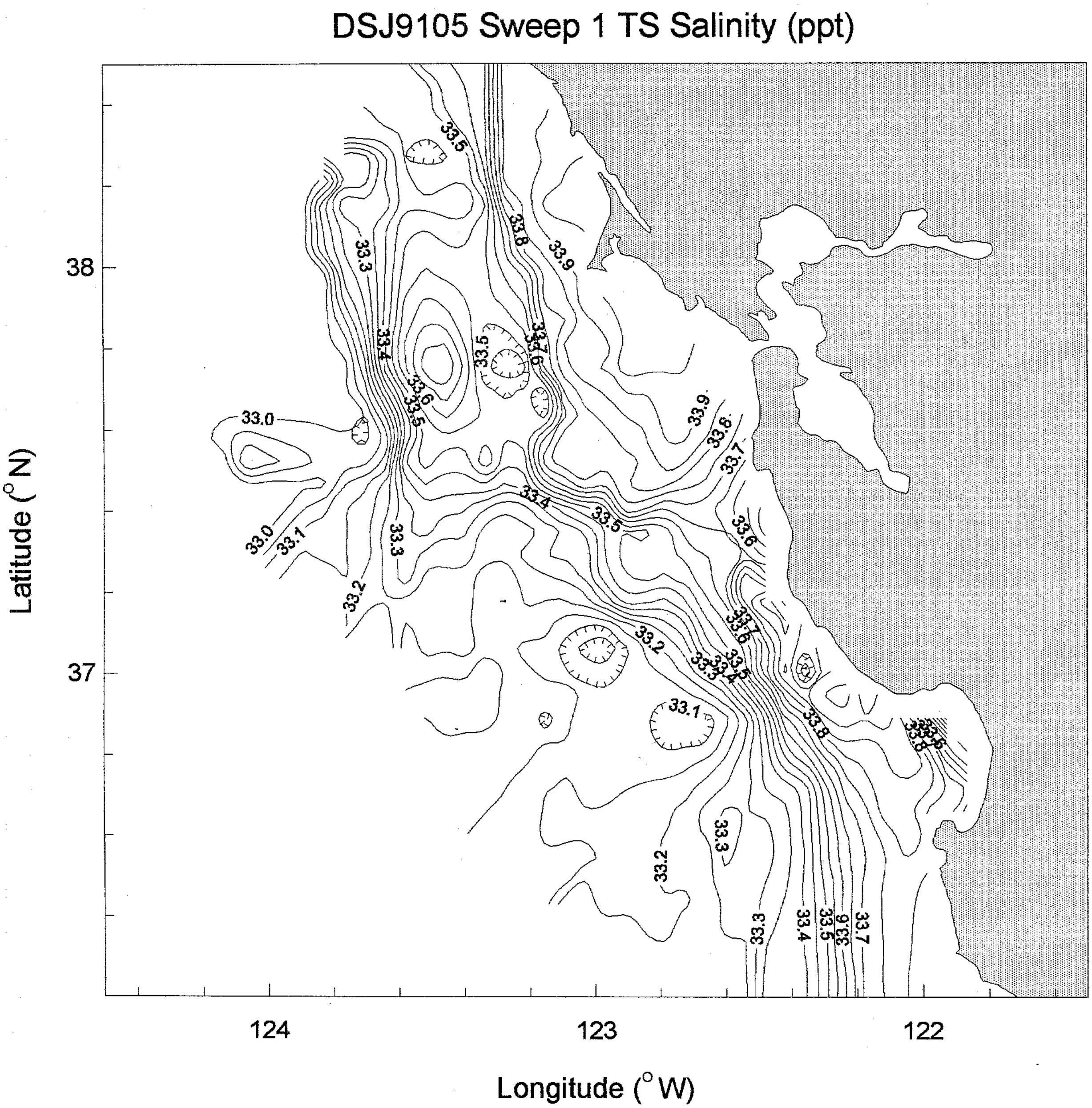

DSJ9105 Sweep 1 Temperature (°C) at 200 m
Latitude (°N)
38
37
Longitude (°W)
124
123
122
7.5
7.6
7.7
7.8
7.4

DSJ9105 Sweep 1 Temperature (°C) at 300 m

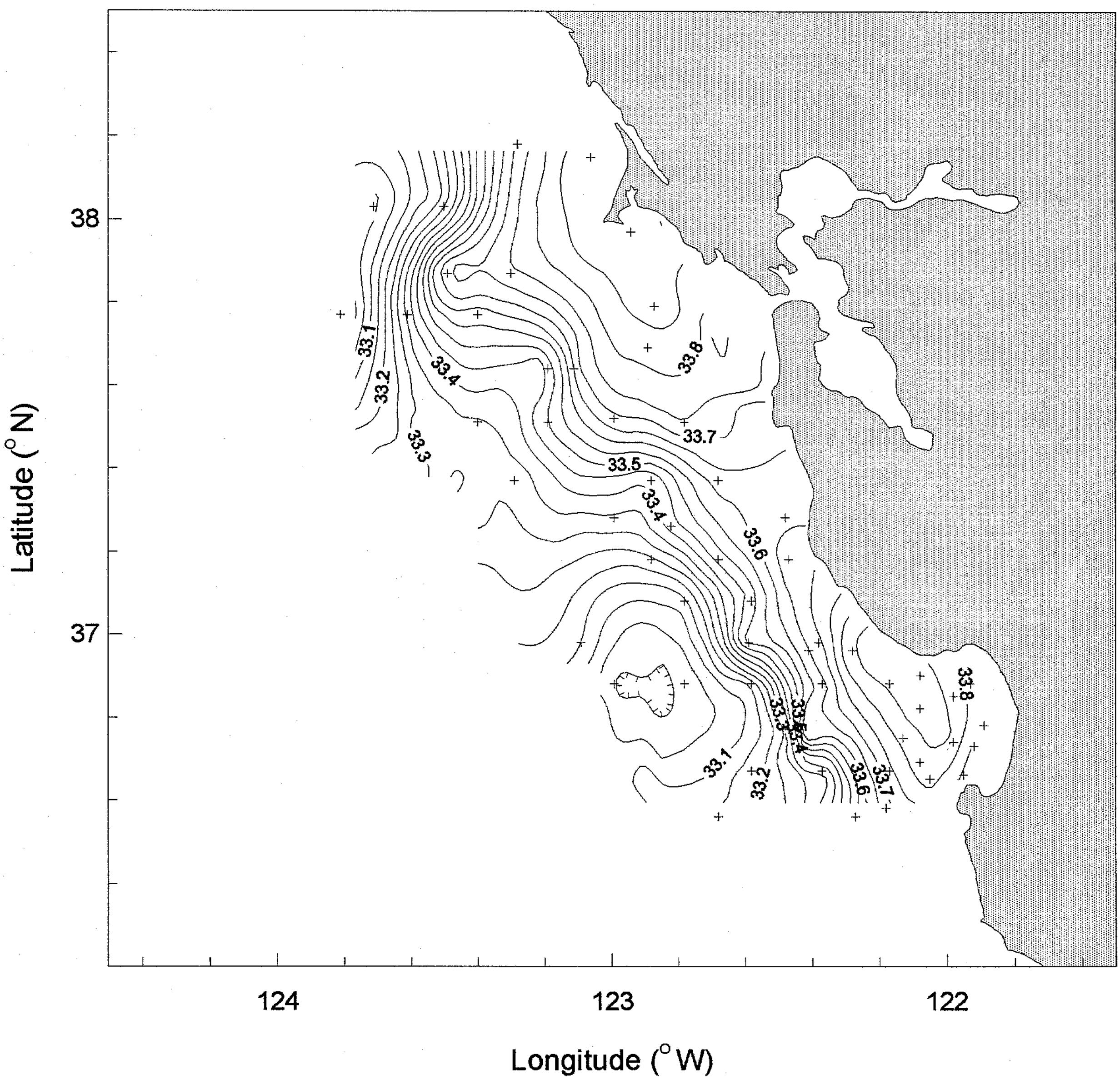


DSJ9105 Sweep 1 Temperature (°C) at 500 m

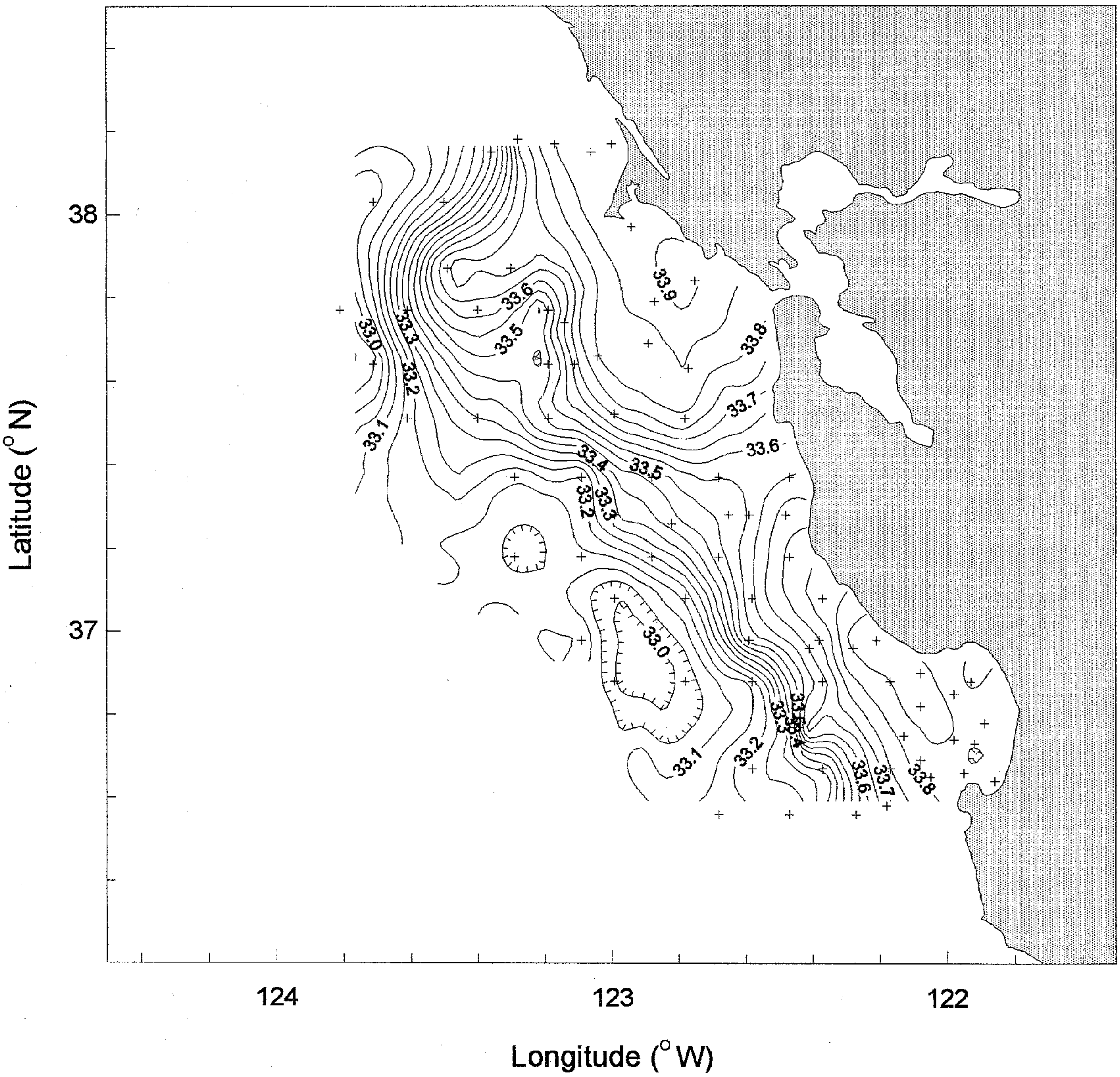



DSJ9105 Sweep 1 TS Salinity (ppt)
Latitude (° N)
38
37
124
123
122
Longitude (° W)
33.0
33.1
33.2
33.3
33.4
33.5
33.6
33.7
33.8
33.9

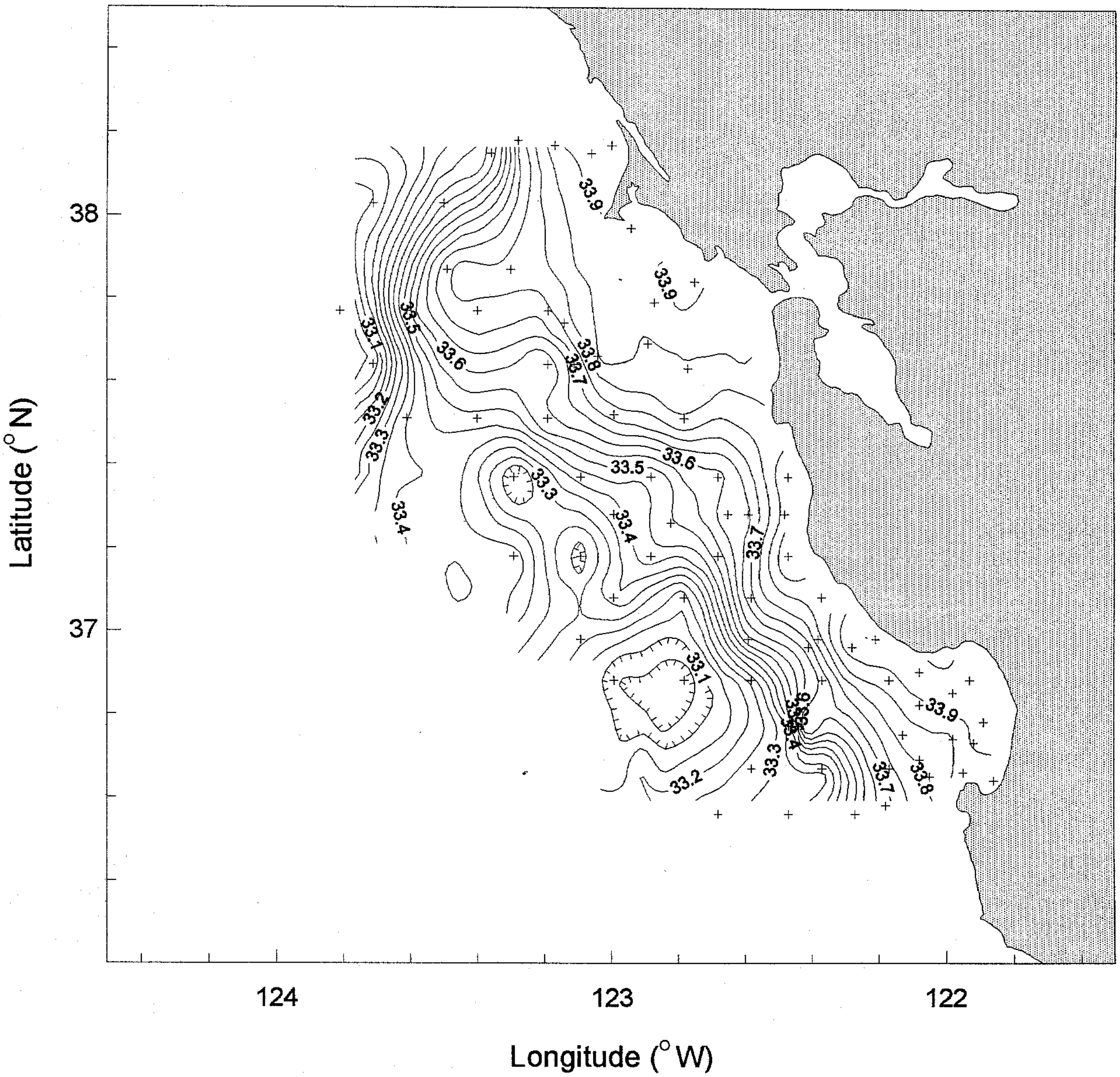
DSJ9105 Sweep 1 Salinity (ppt) at 2 m



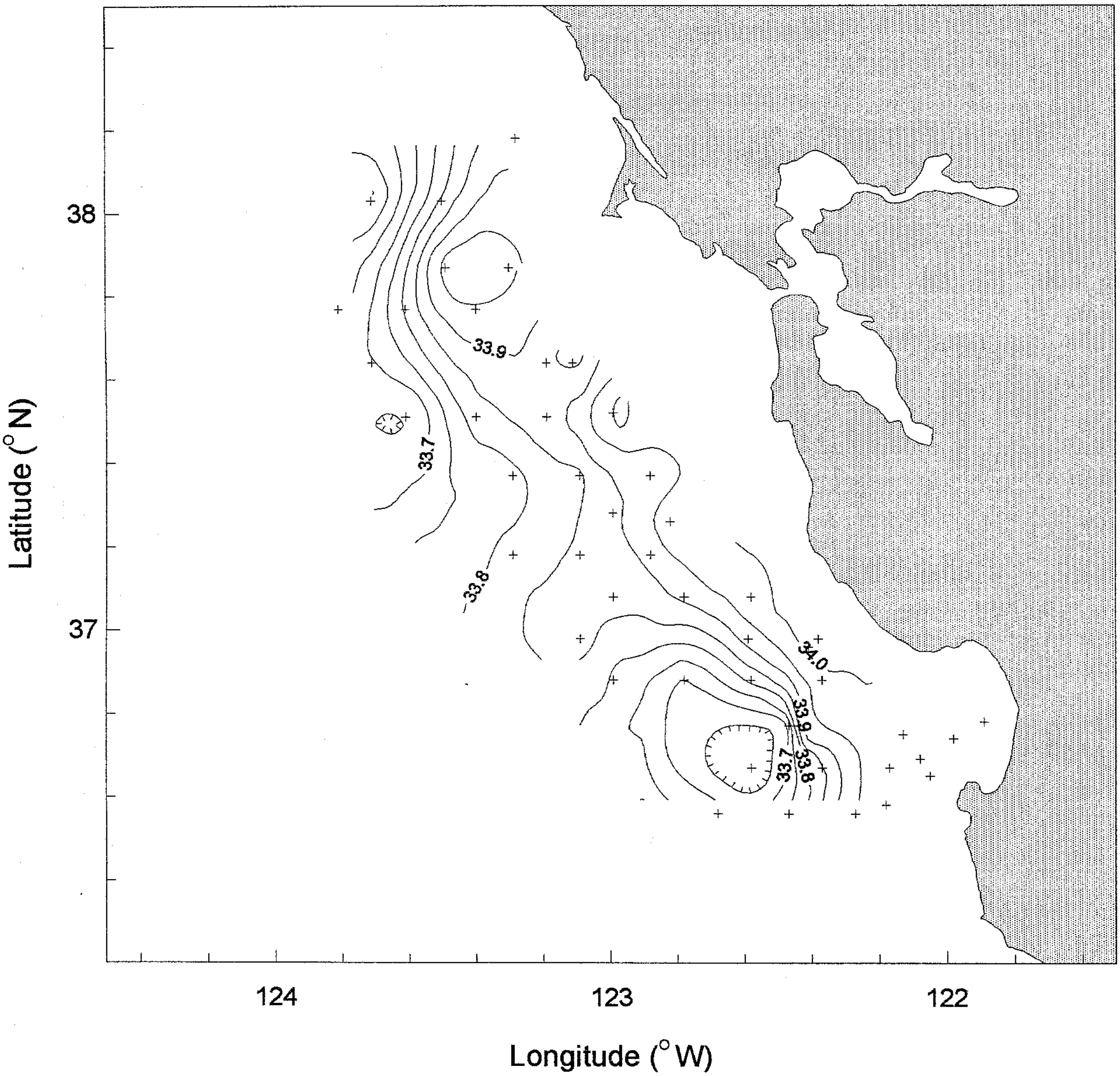
DSJ9105 Sweep 1 Salinity (ppt) at 10 m

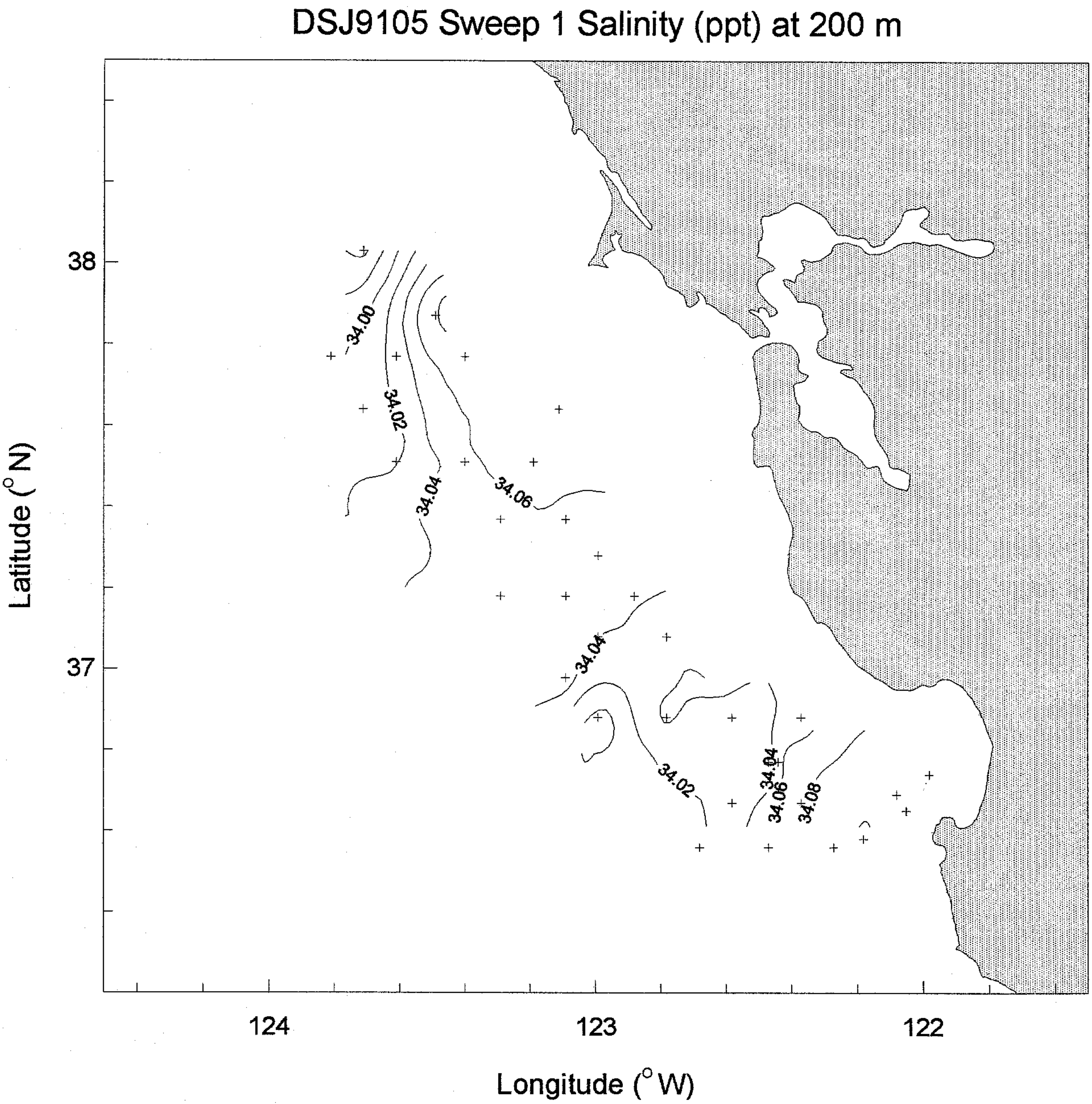


DSJ9105 Sweep 1 Salinity (ppt) at 30 m

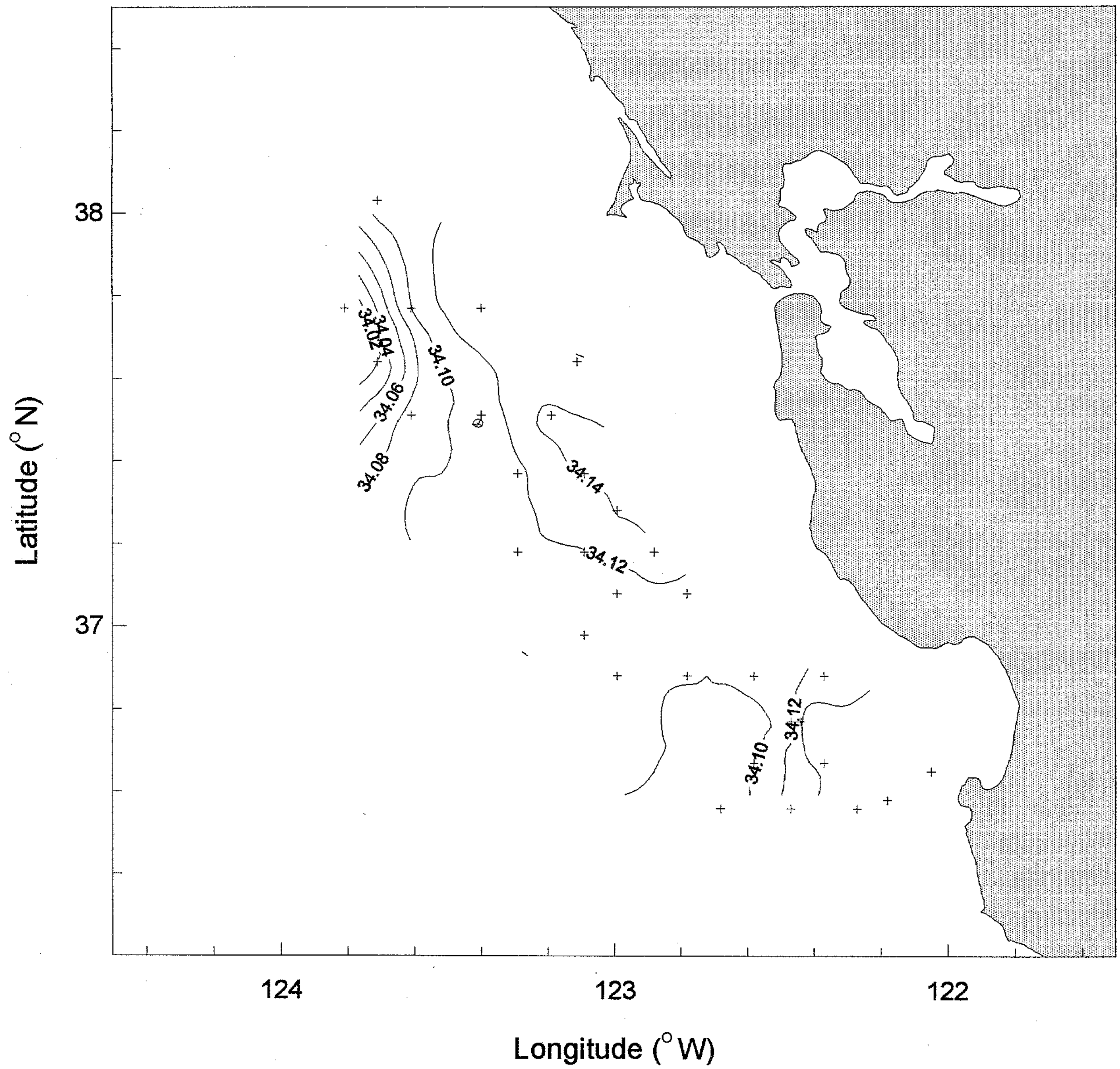


DSJ9105 Sweep 1 Salinity (ppt) at 100 m

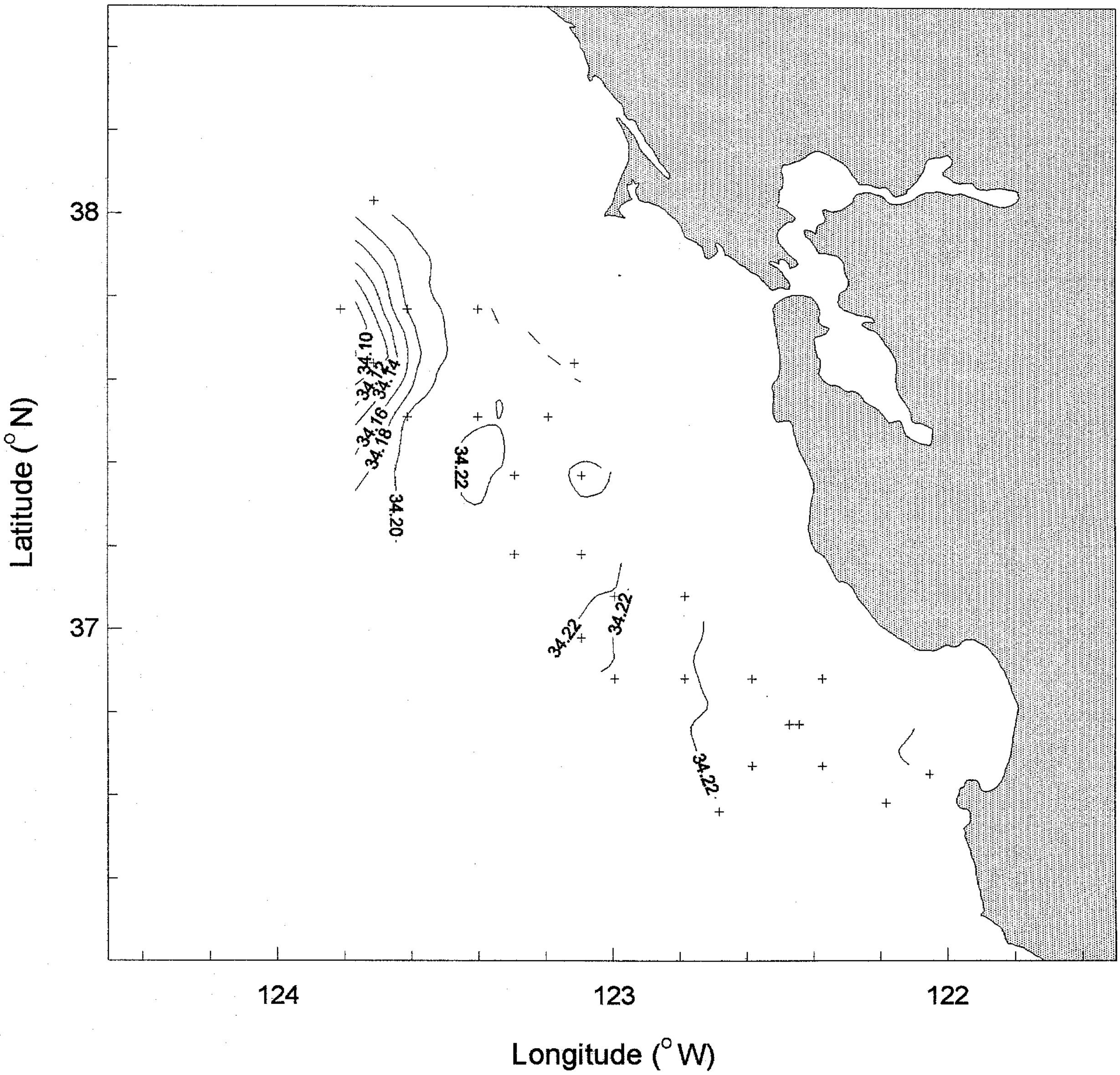



DSJ9105 Sweep 1 Salinity (ppt) at 200 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
34.00
34.02
34.04
34.06
34.04
34.02
34.04
34.06
34.08

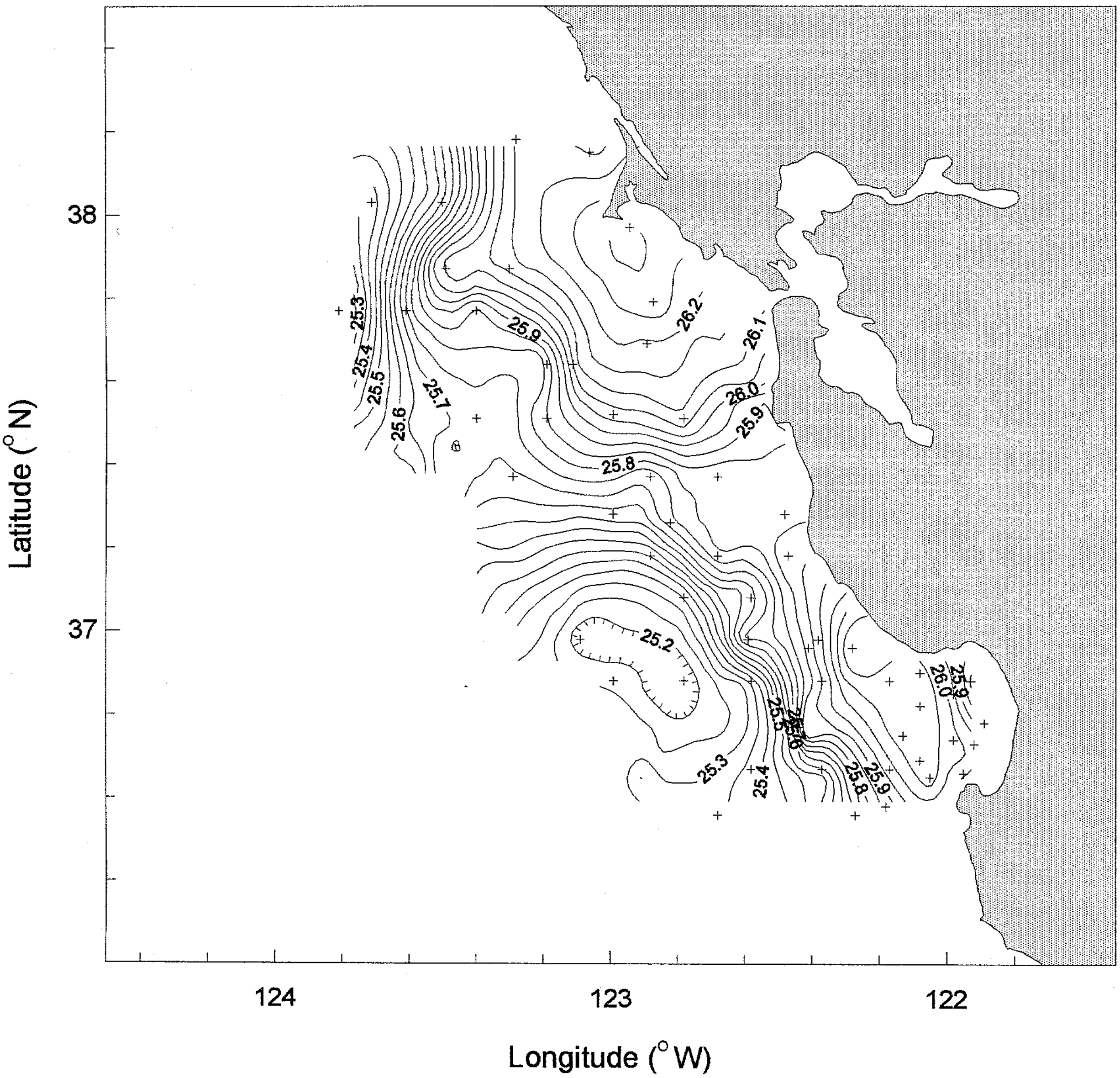
DSJ9105 Sweep 1 Salinity (ppt) at 300 m



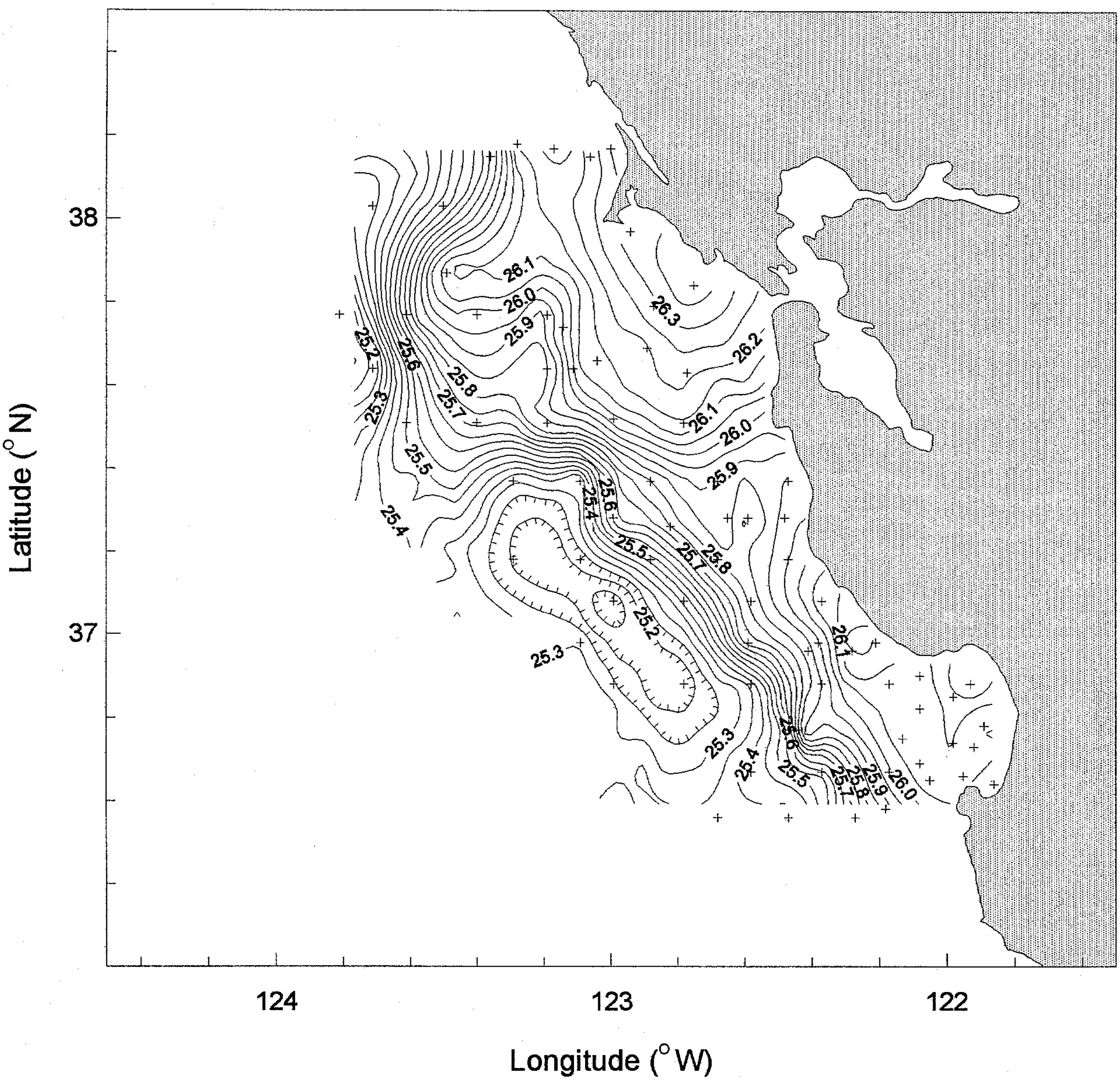
DSJ9105 Sweep 1 Salinity (ppt) at 500 m



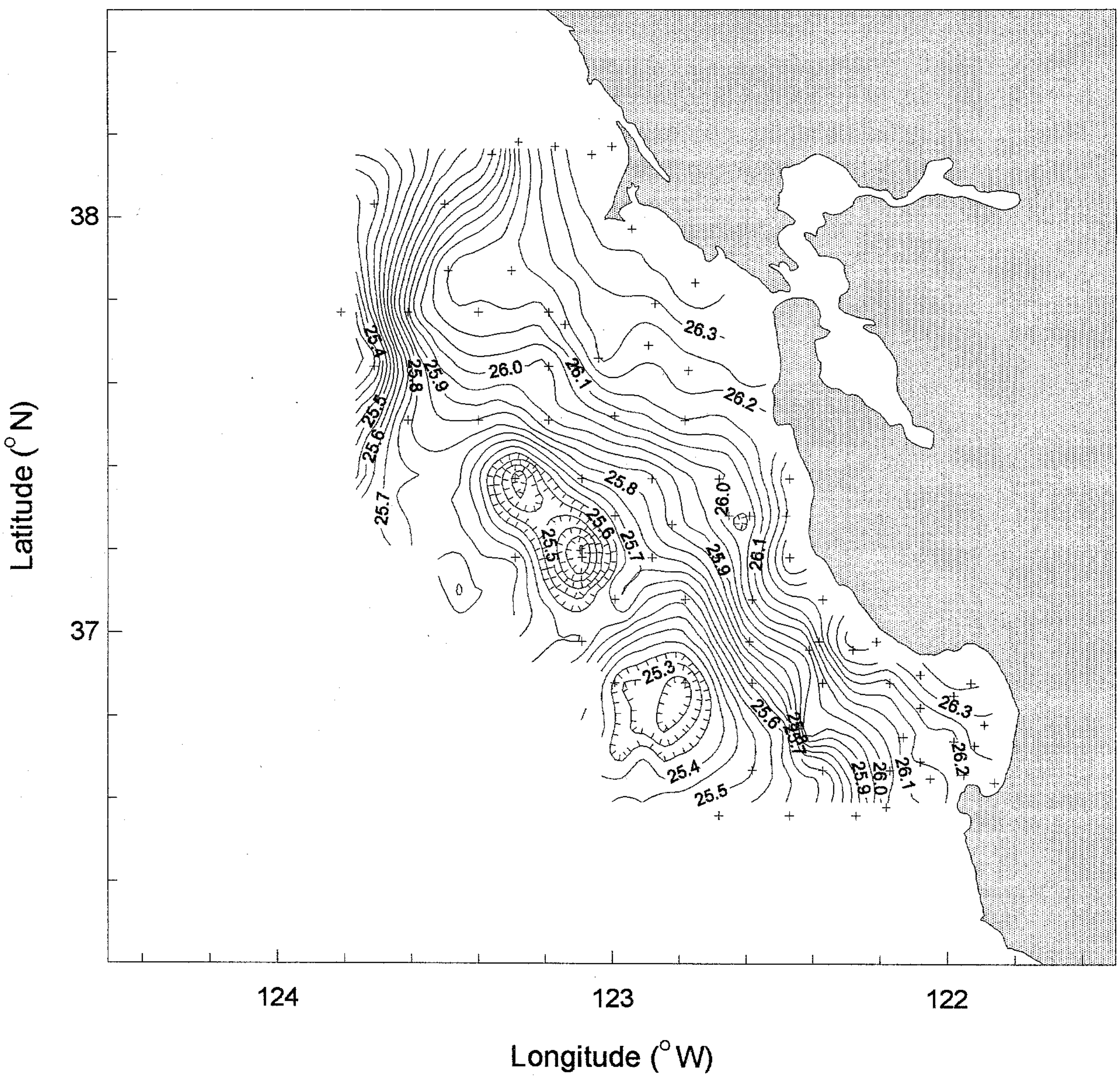
DSJ9105 Sweep 1 Density (kg/m^3) at 2 m



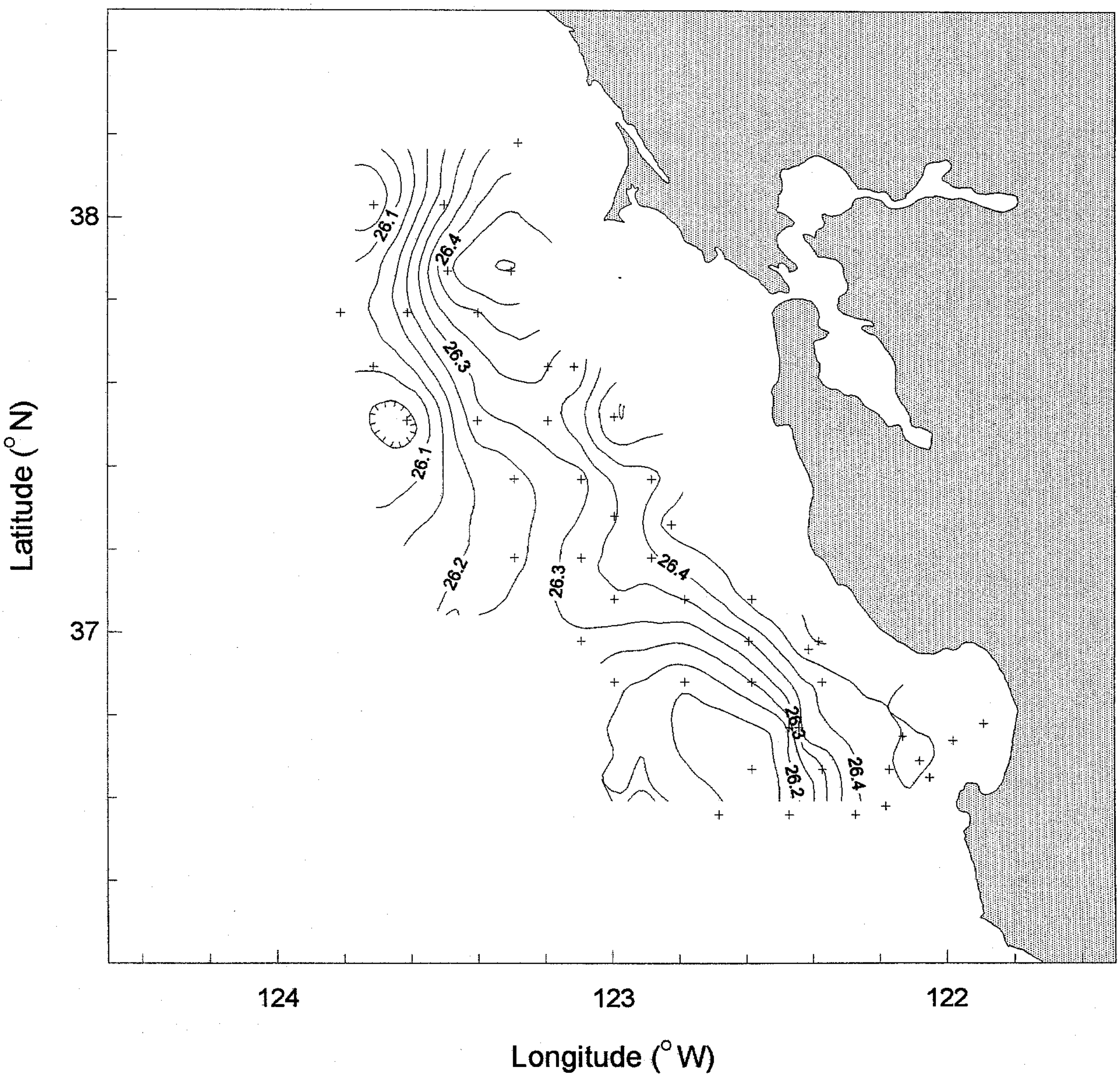
DSJ9105 Sweep 1 Density (kg/m^3) at 10 m



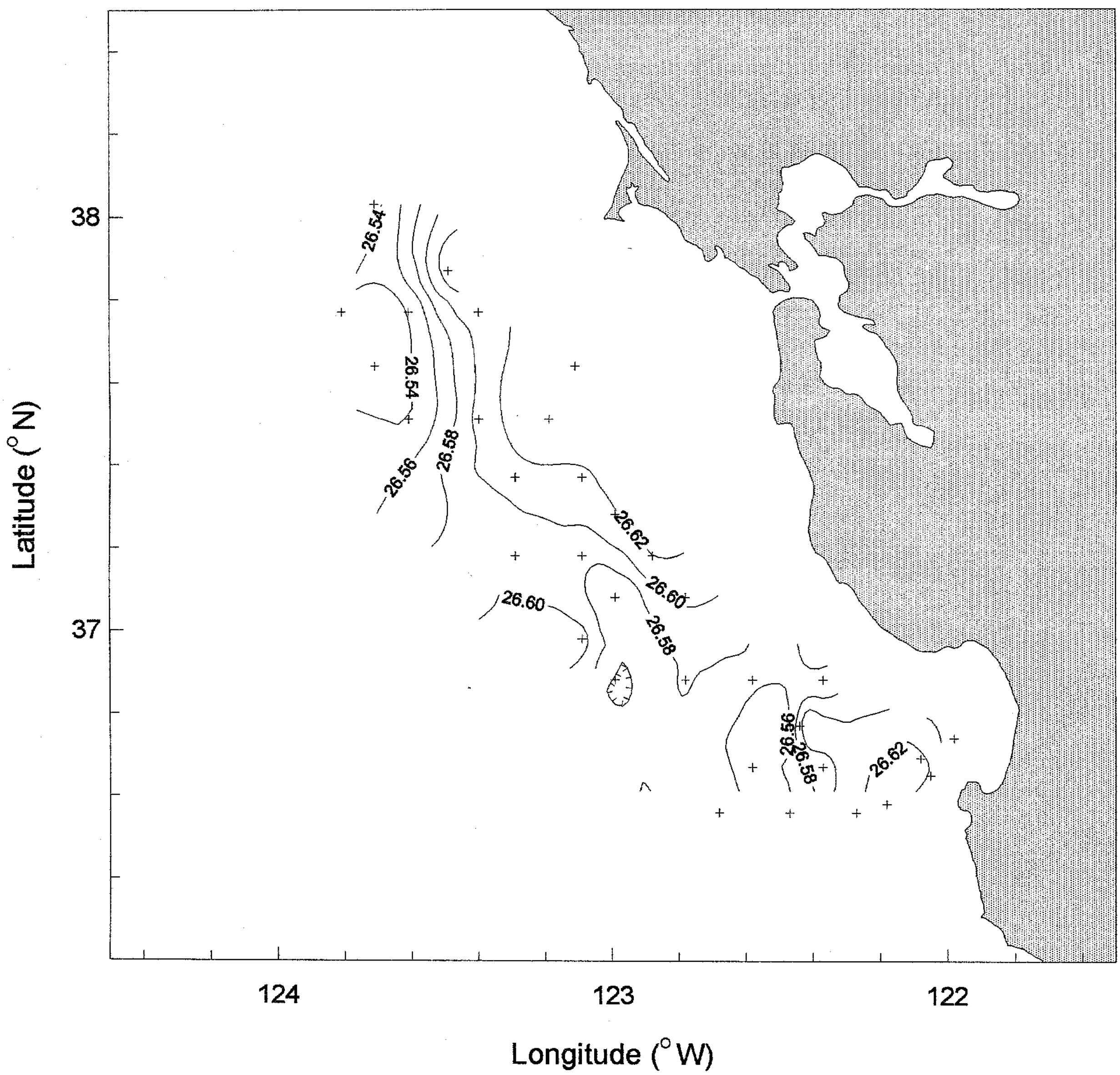
DSJ9105 Sweep 1 Density (kg/m^3) at 30 m



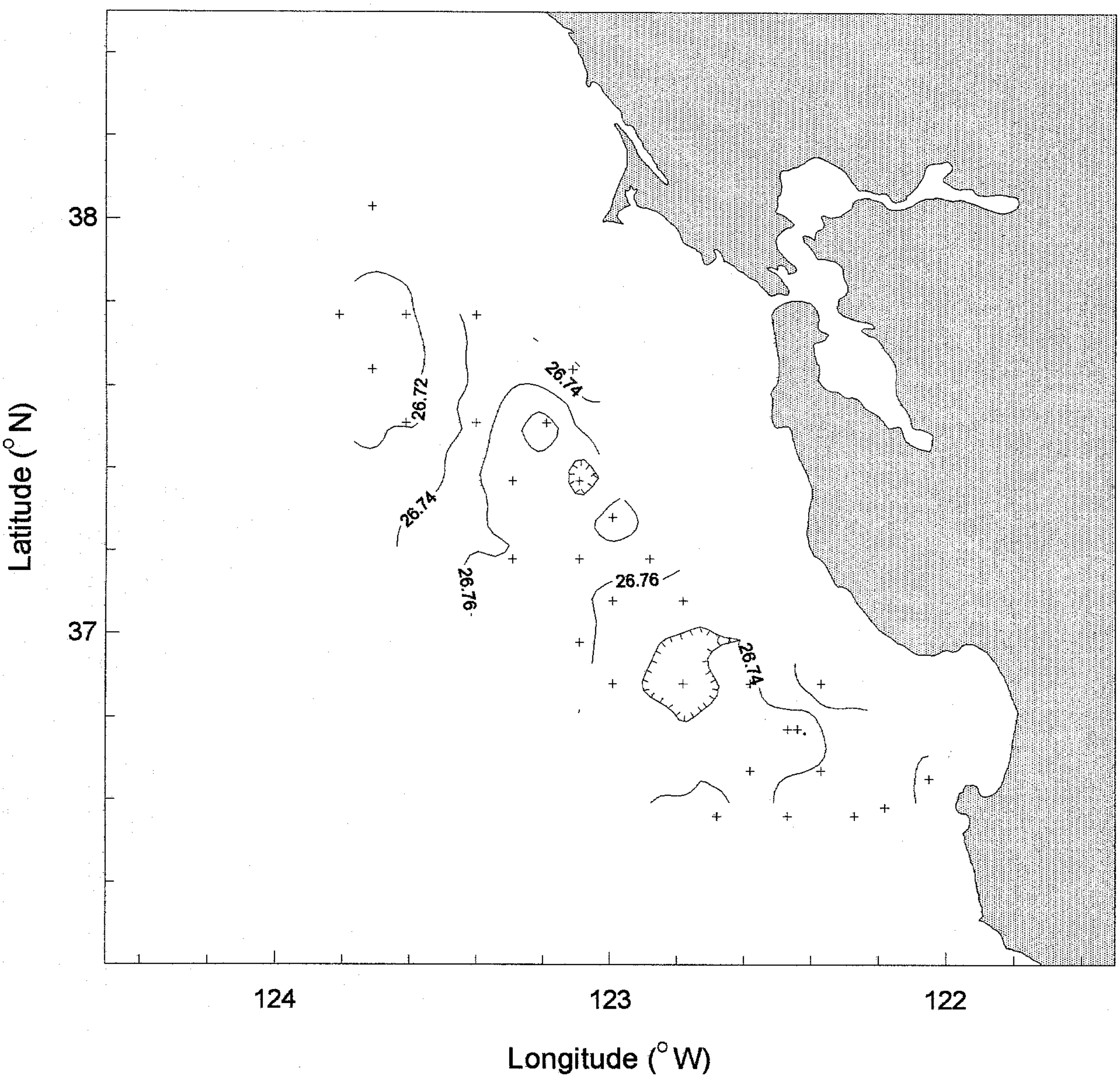
DSJ9105 Sweep 1 Density (kg/m^3) at 100 m



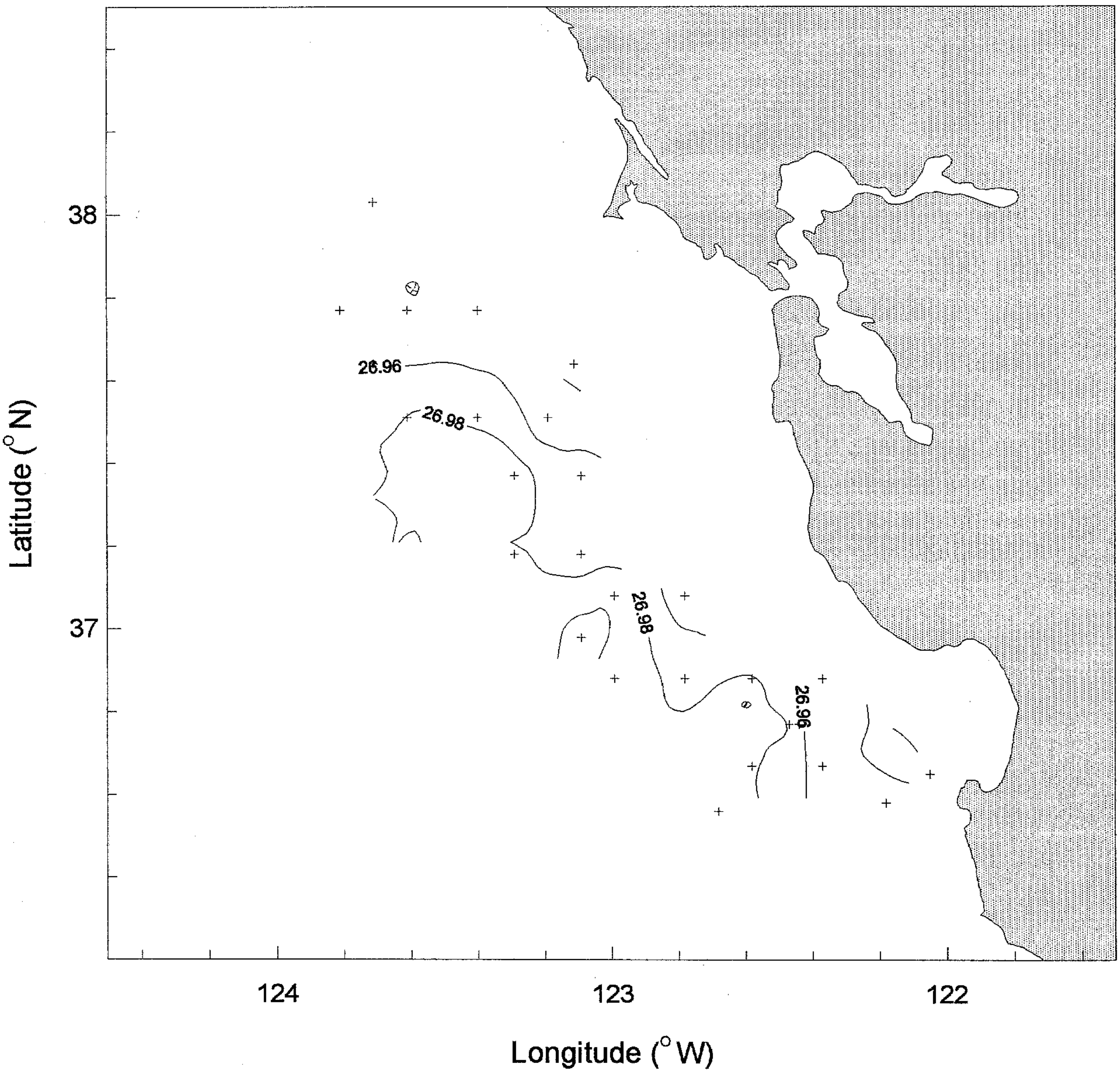
DSJ9105 Sweep 1 Density (kg/m^3) at 200 m



DSJ9105 Sweep 1 Density (kg/m^3) at 300 m

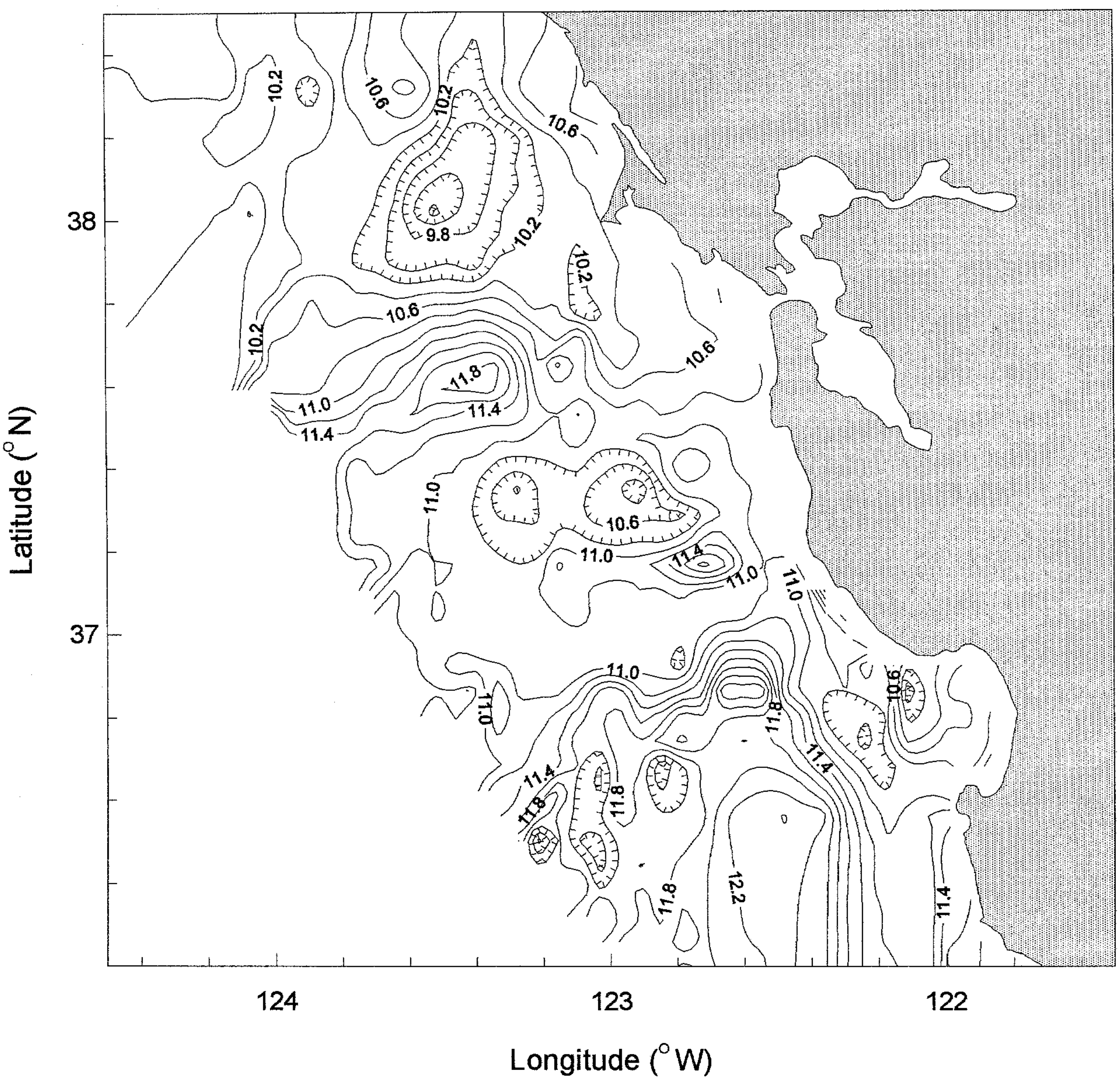


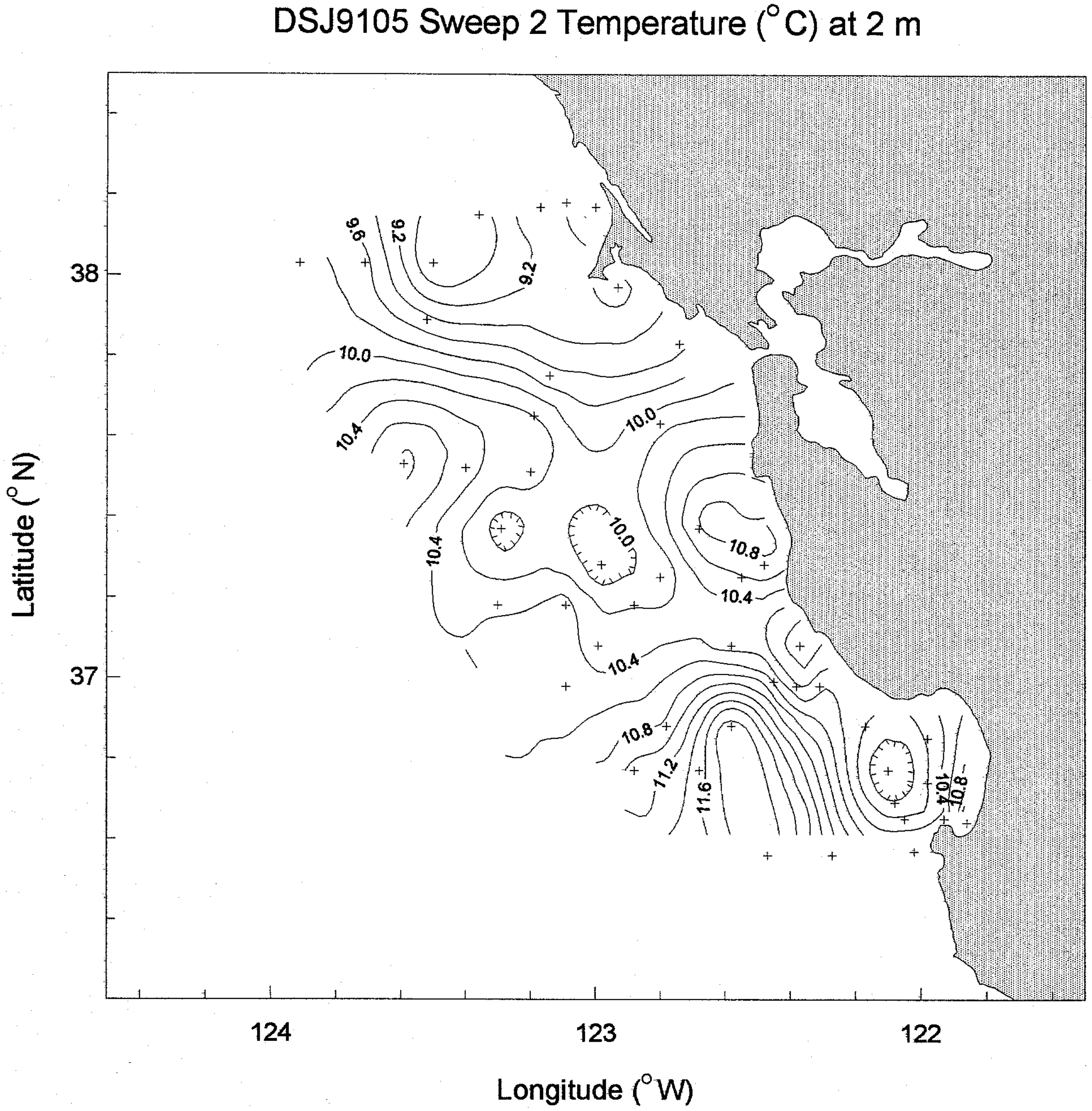
DSJ9105 Sweep 1 Density (kg/m^3) at 500 m



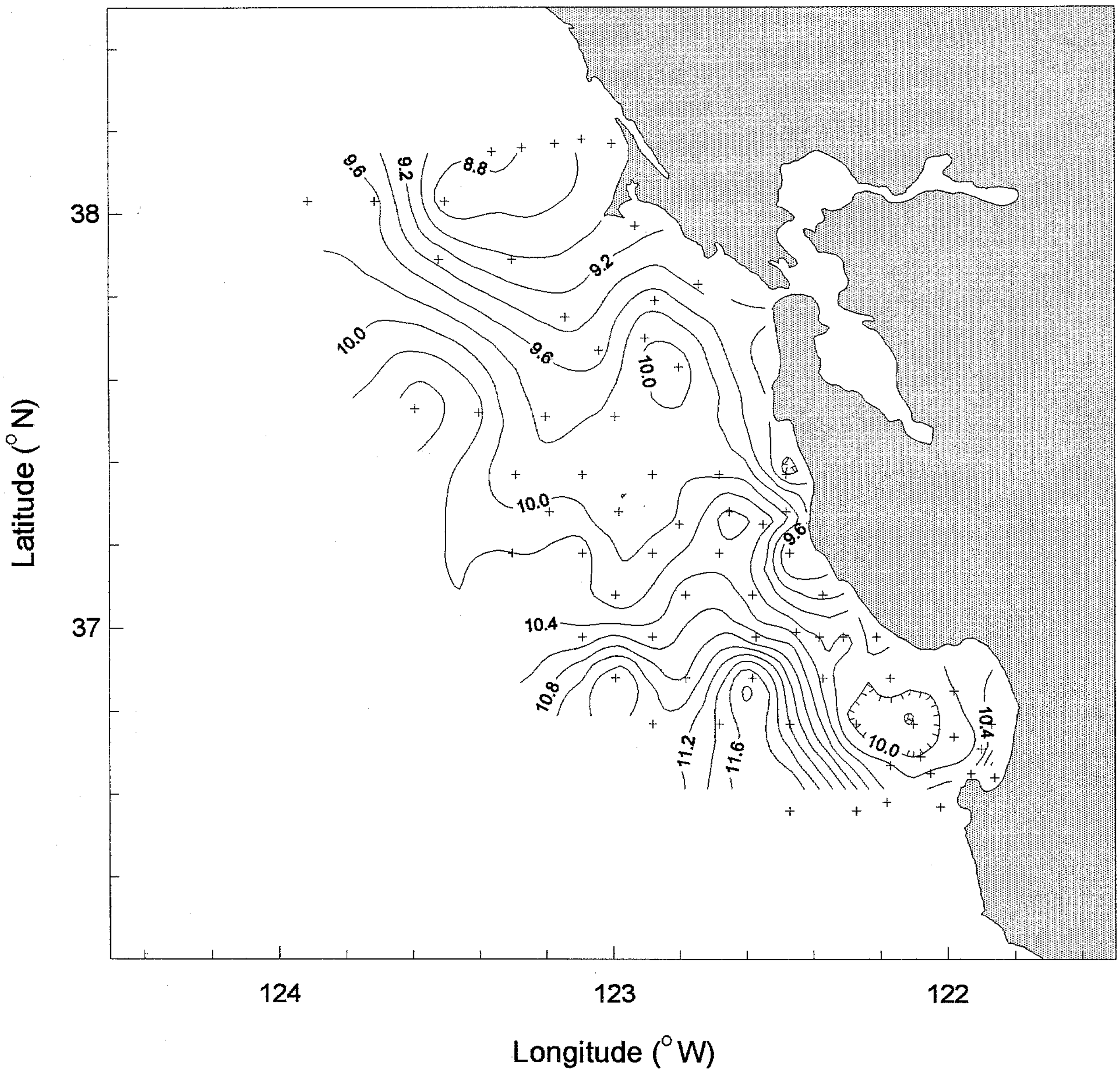
APPENDIX 5.3: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9105, SWEEP 2

DSJ9105 Sweep 2 TS Temperature (°C)

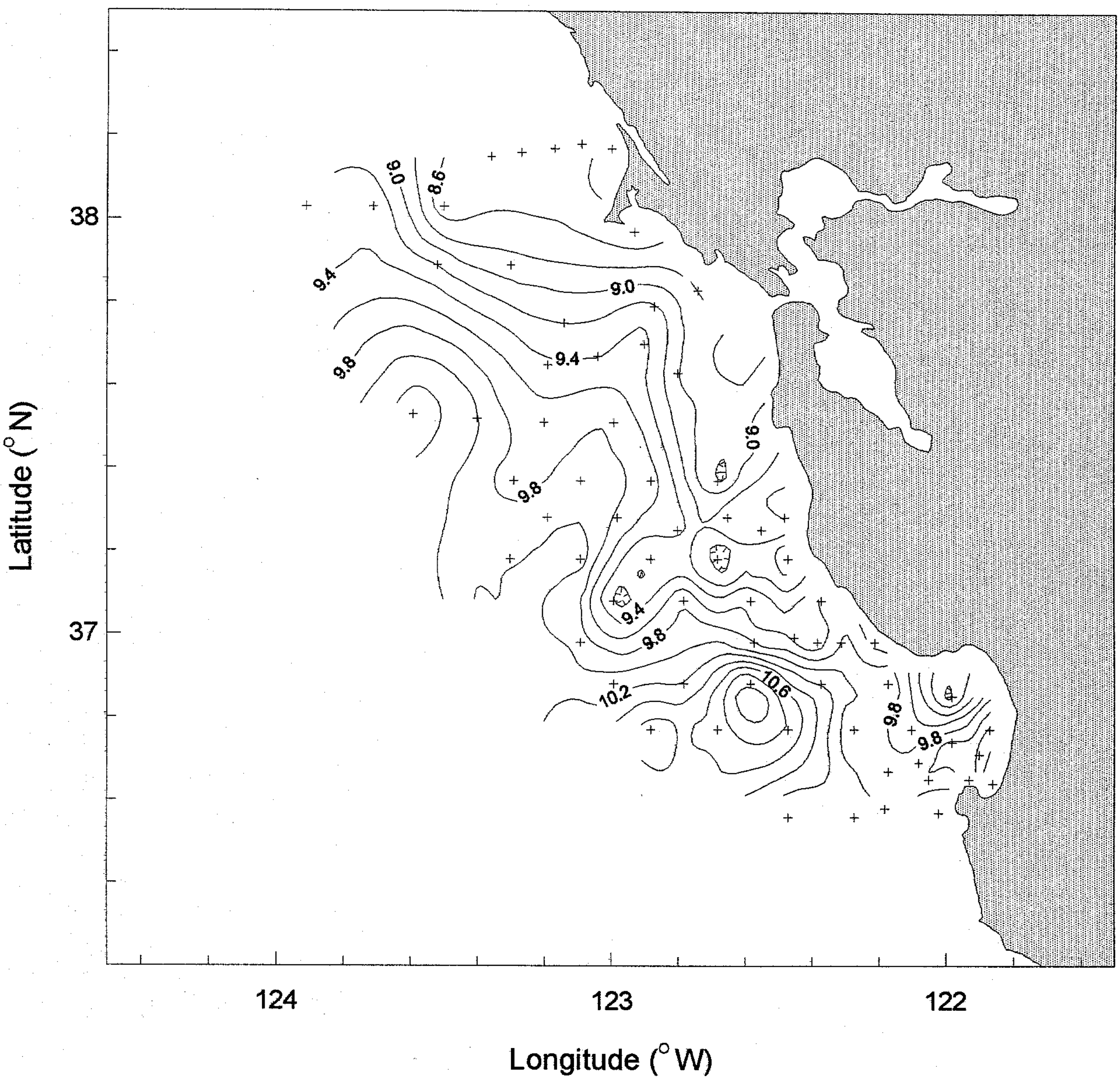



DSJ9105 Sweep 2 Temperature (°C) at 2 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)
9.6
9.2
9.2
10.0
10.0
10.4
10.4
10.0
10.8
10.4
10.4
10.8
11.2
11.6
10.4
10.8

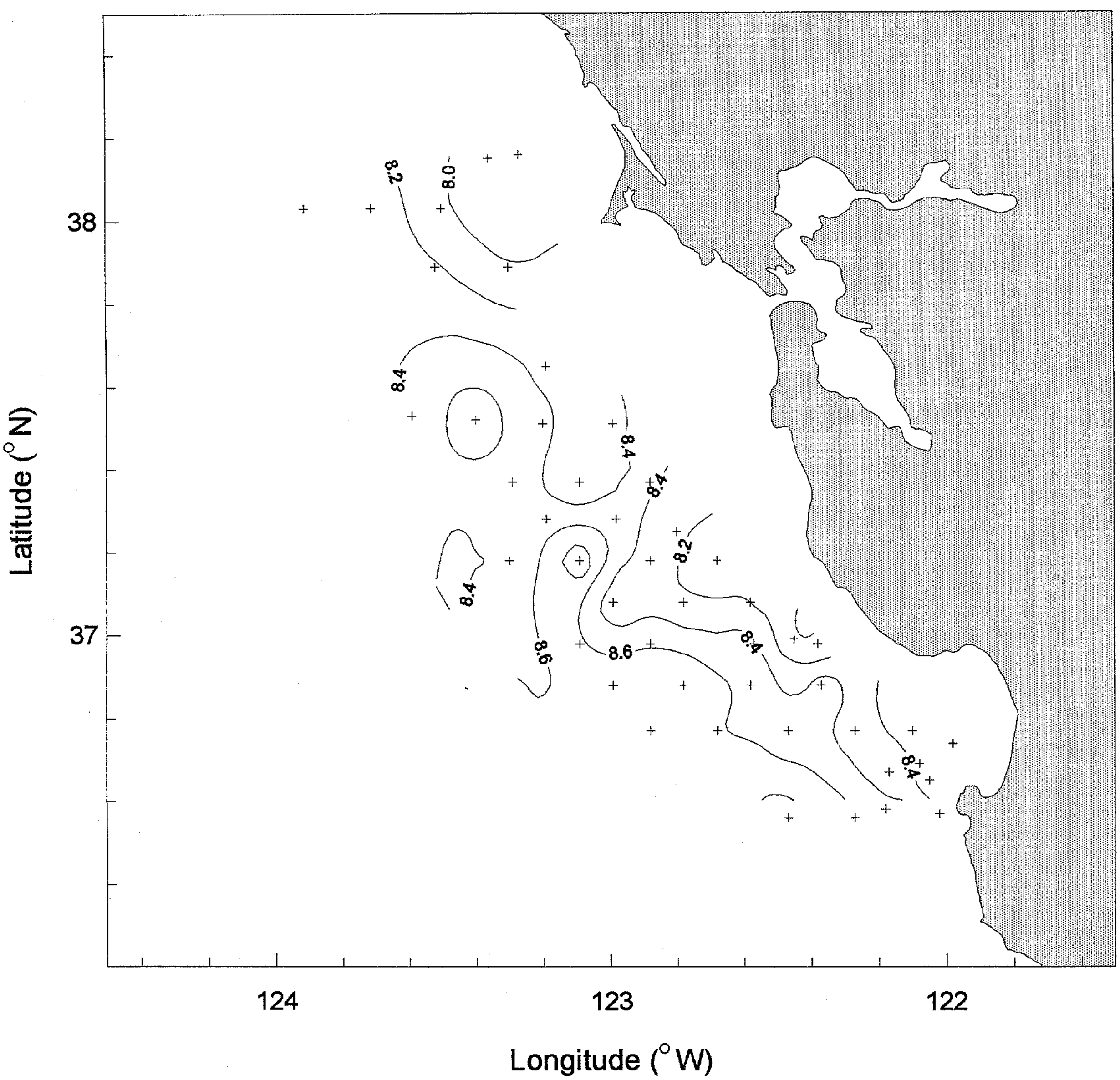
DSJ9105 Sweep 2 Temperature (°C) at 10 m



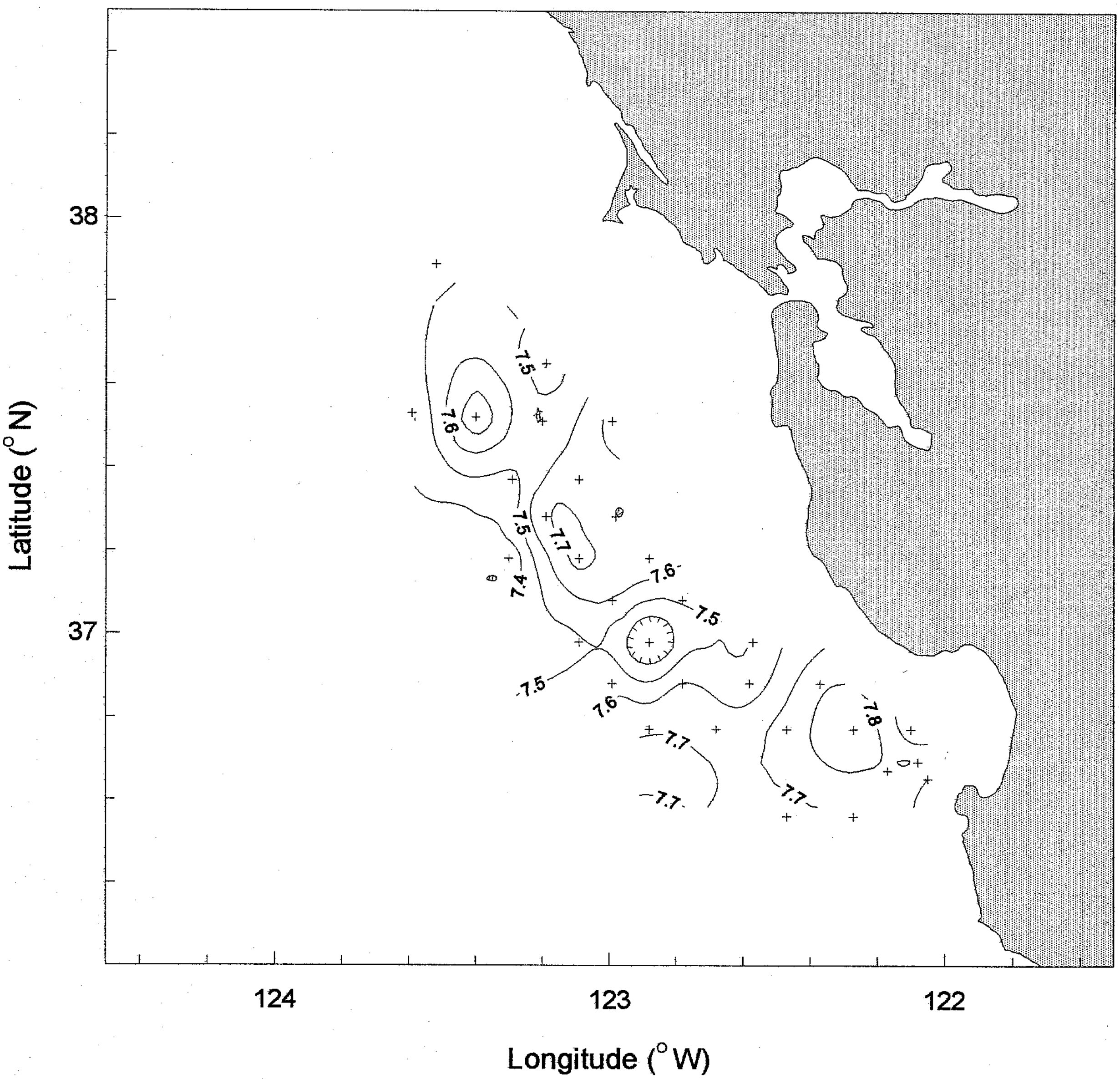
DSJ9105 Sweep 2 Temperature (°C) at 30 m



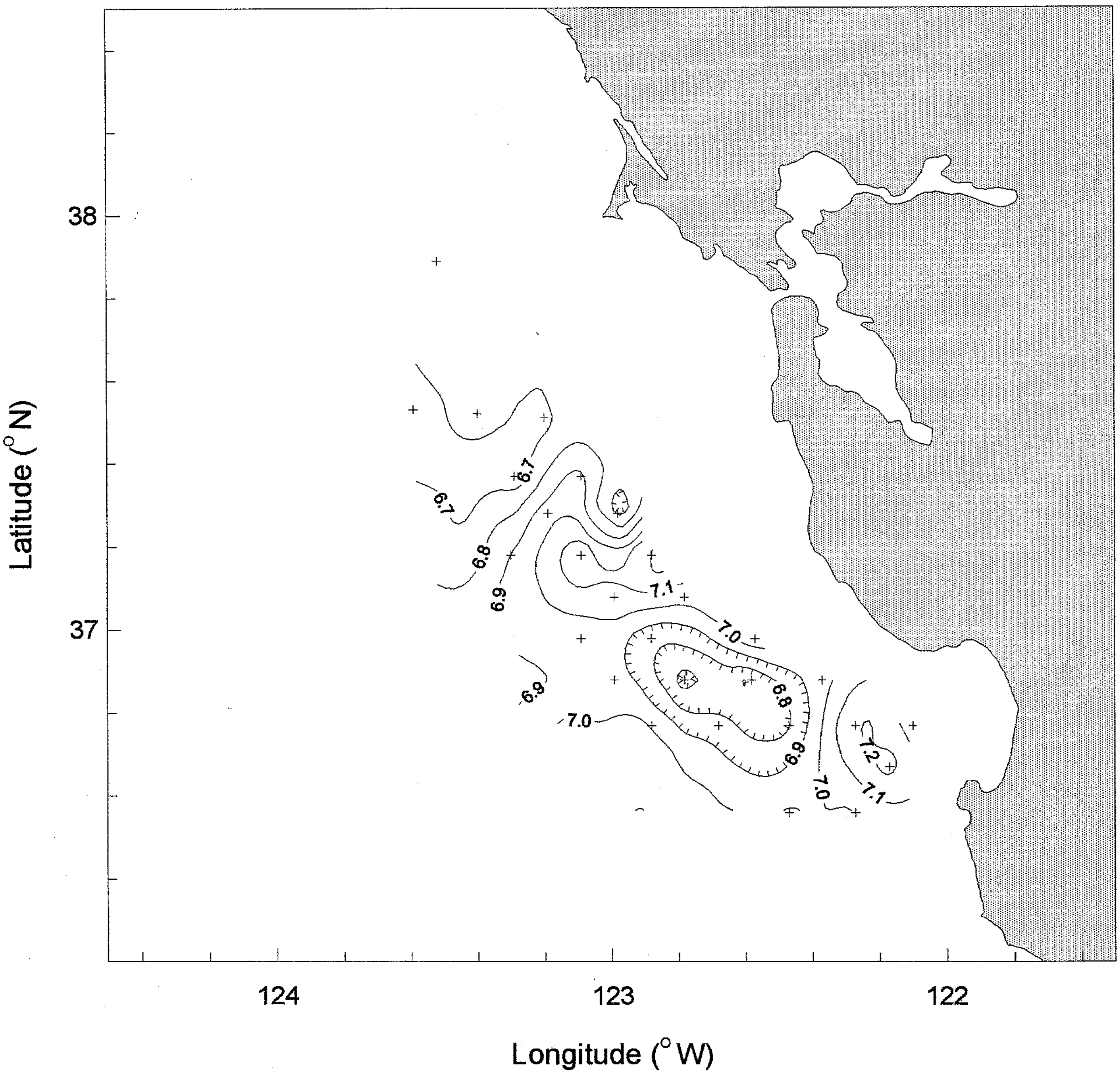
DSJ9105 Sweep 2 Temperature (°C) at 100 m

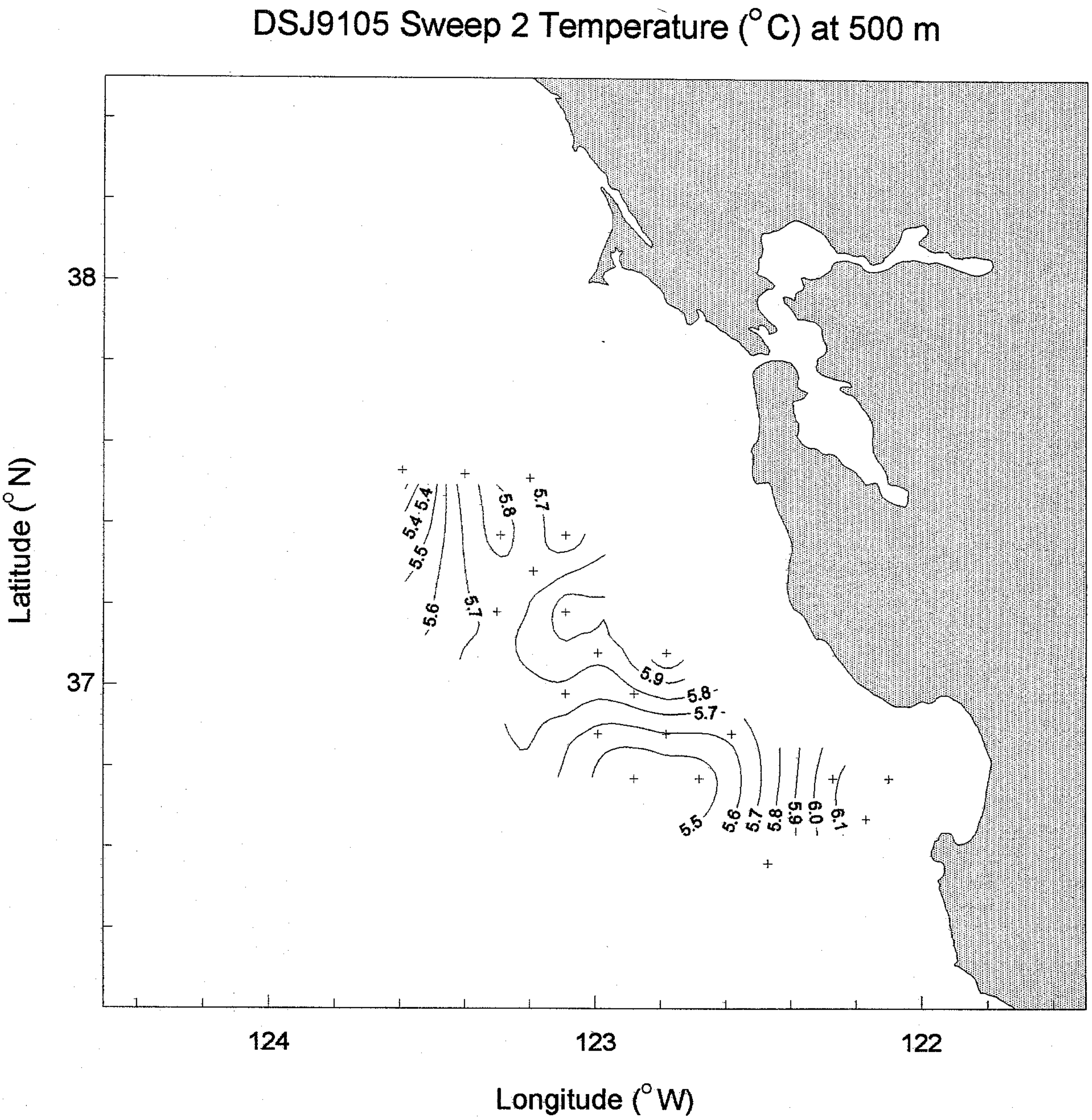


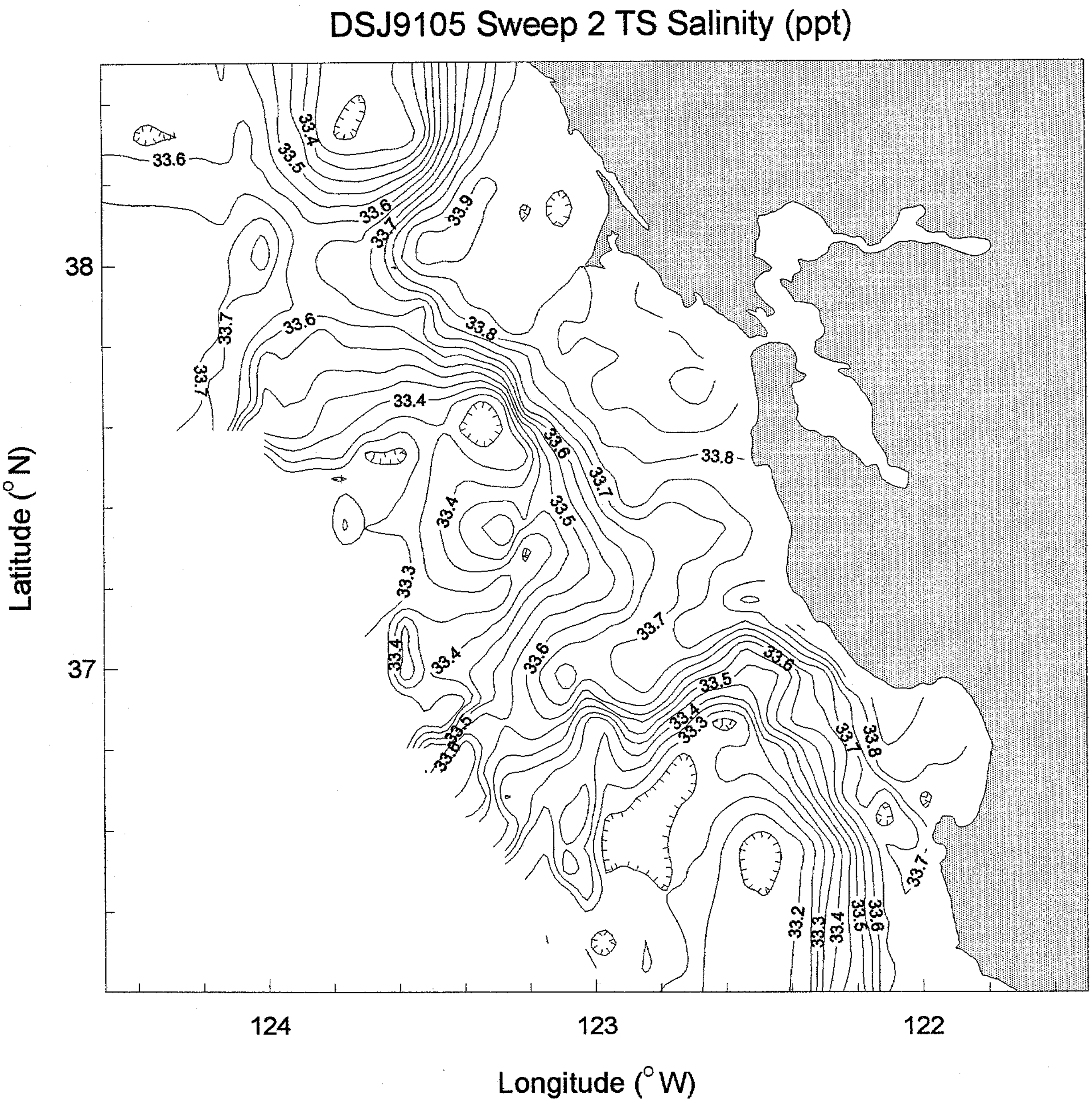
DSJ9105 Sweep 2 Temperature (°C) at 200 m



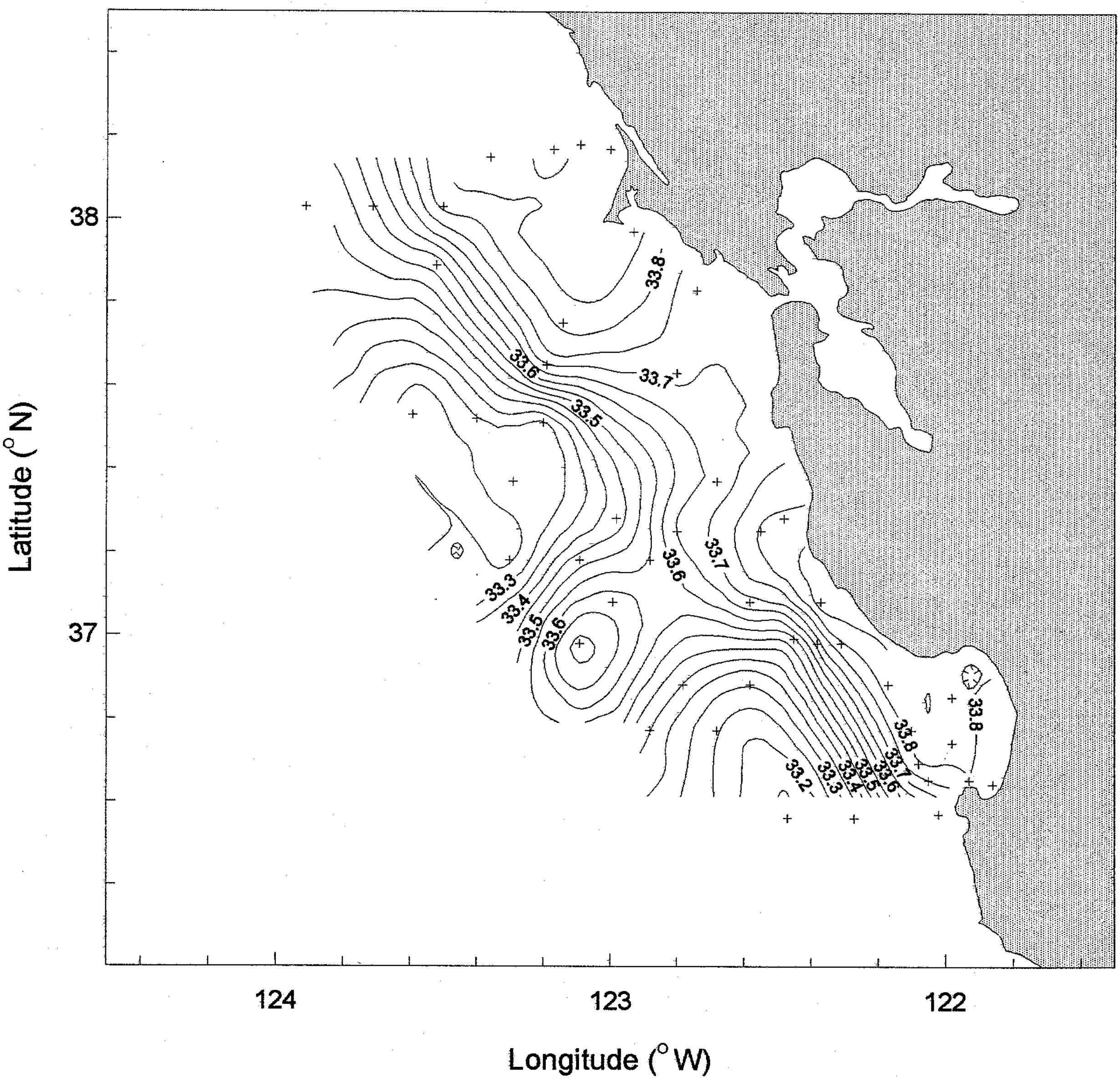
DSJ9105 Sweep 2 Temperature (°C) at 300 m



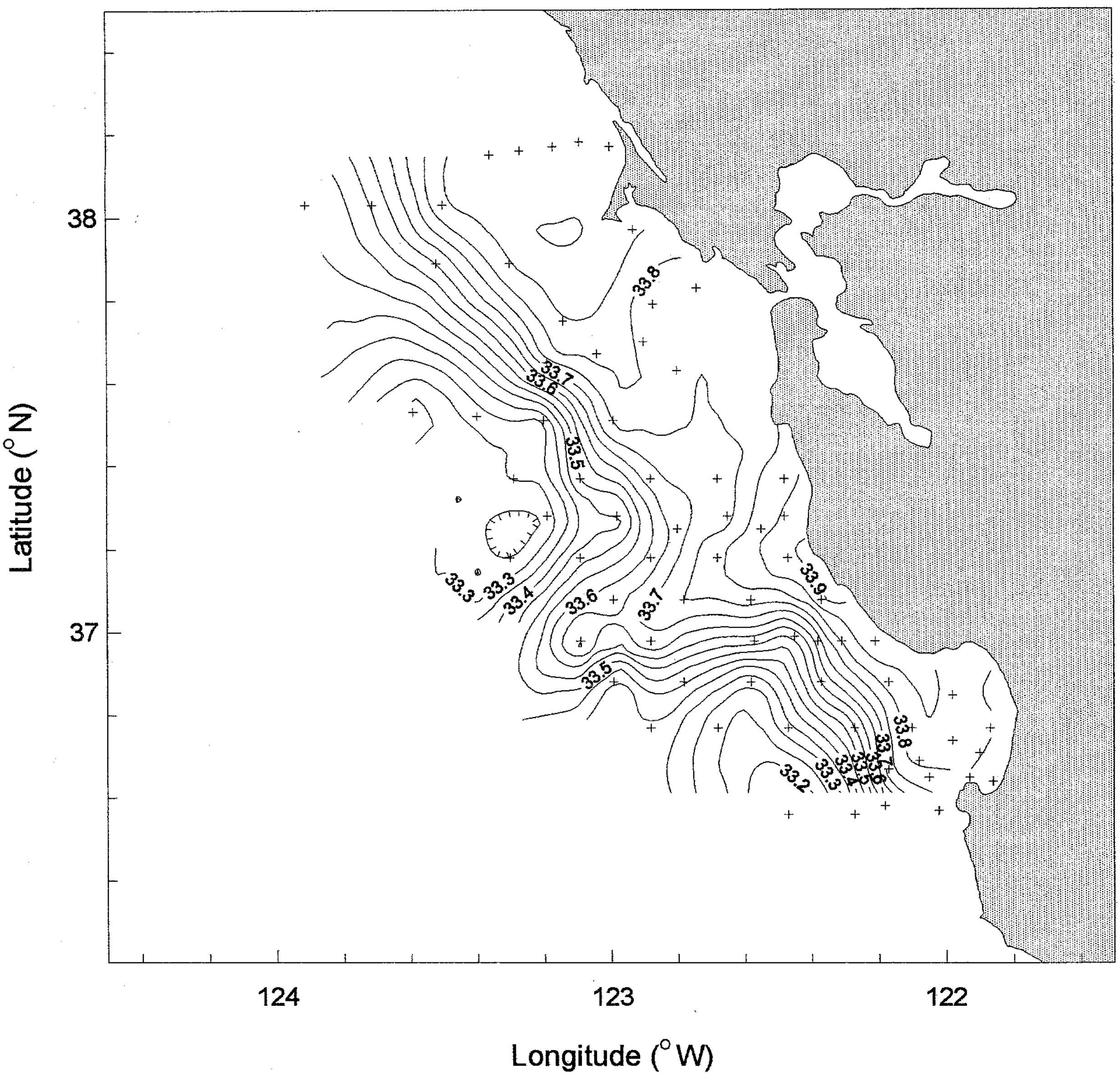

DSJ9105 Sweep 2 Temperature (°C) at 500 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
5.4
5.5
5.6
5.7
5.8
5.9
6.0
6.1


DSJ9105 Sweep 2 TS Salinity (ppt)
Latitude (° N)
Longitude (° W)
38
37
124
123
122

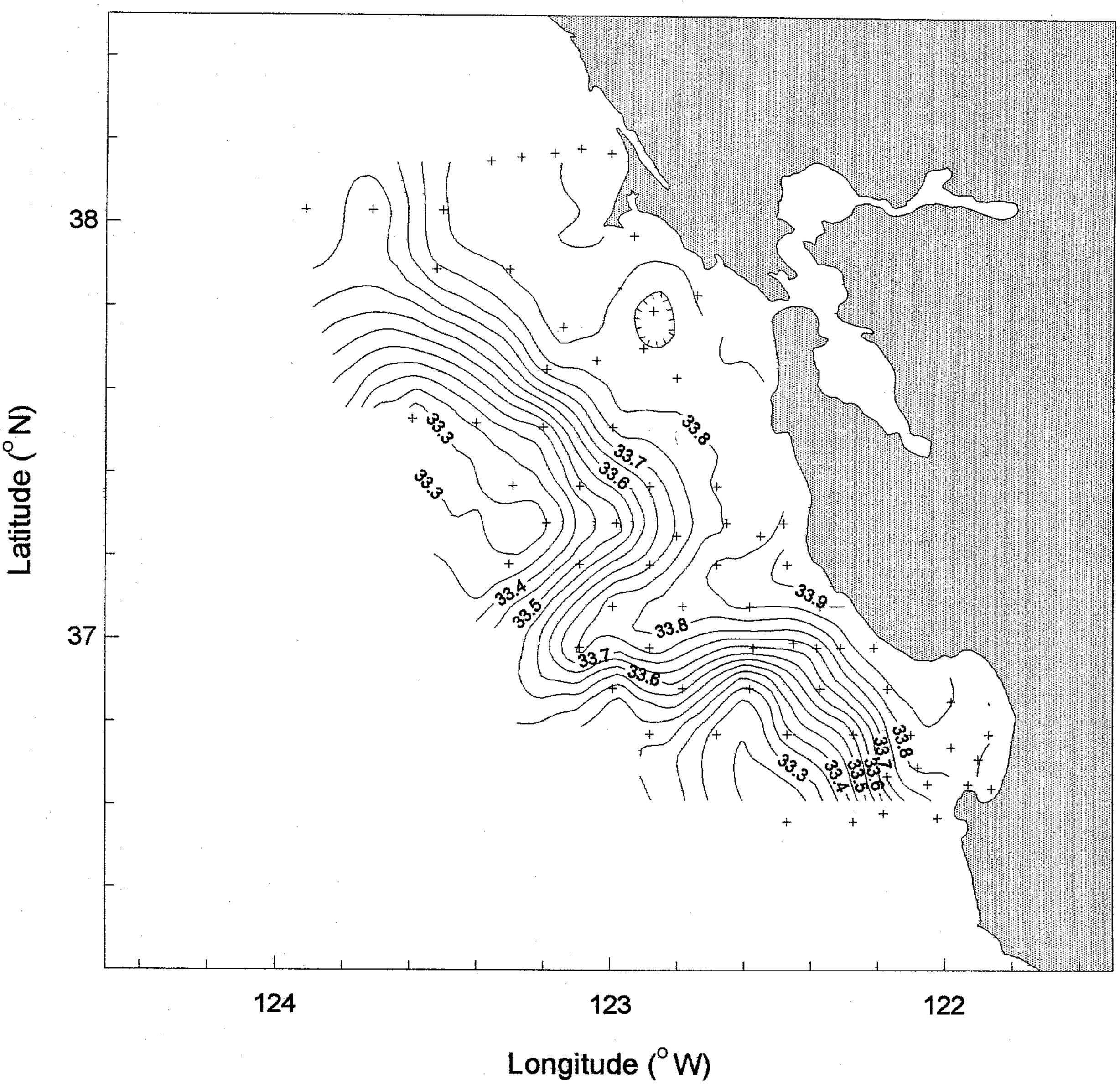
DSJ9105 Sweep 2 Salinity (ppt) at 2 m



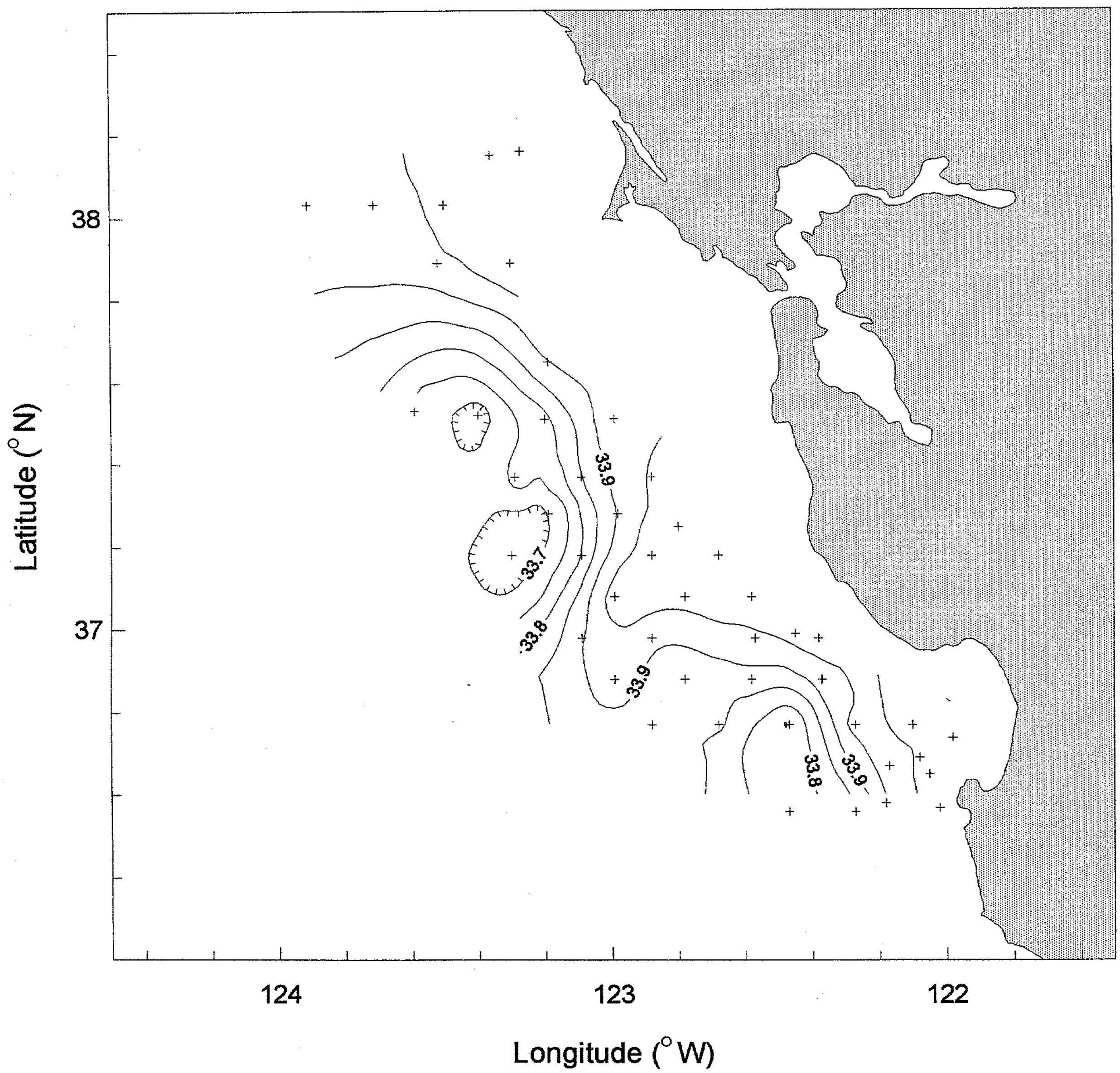
DSJ9105 Sweep 2 Salinity (ppt) at 10 m



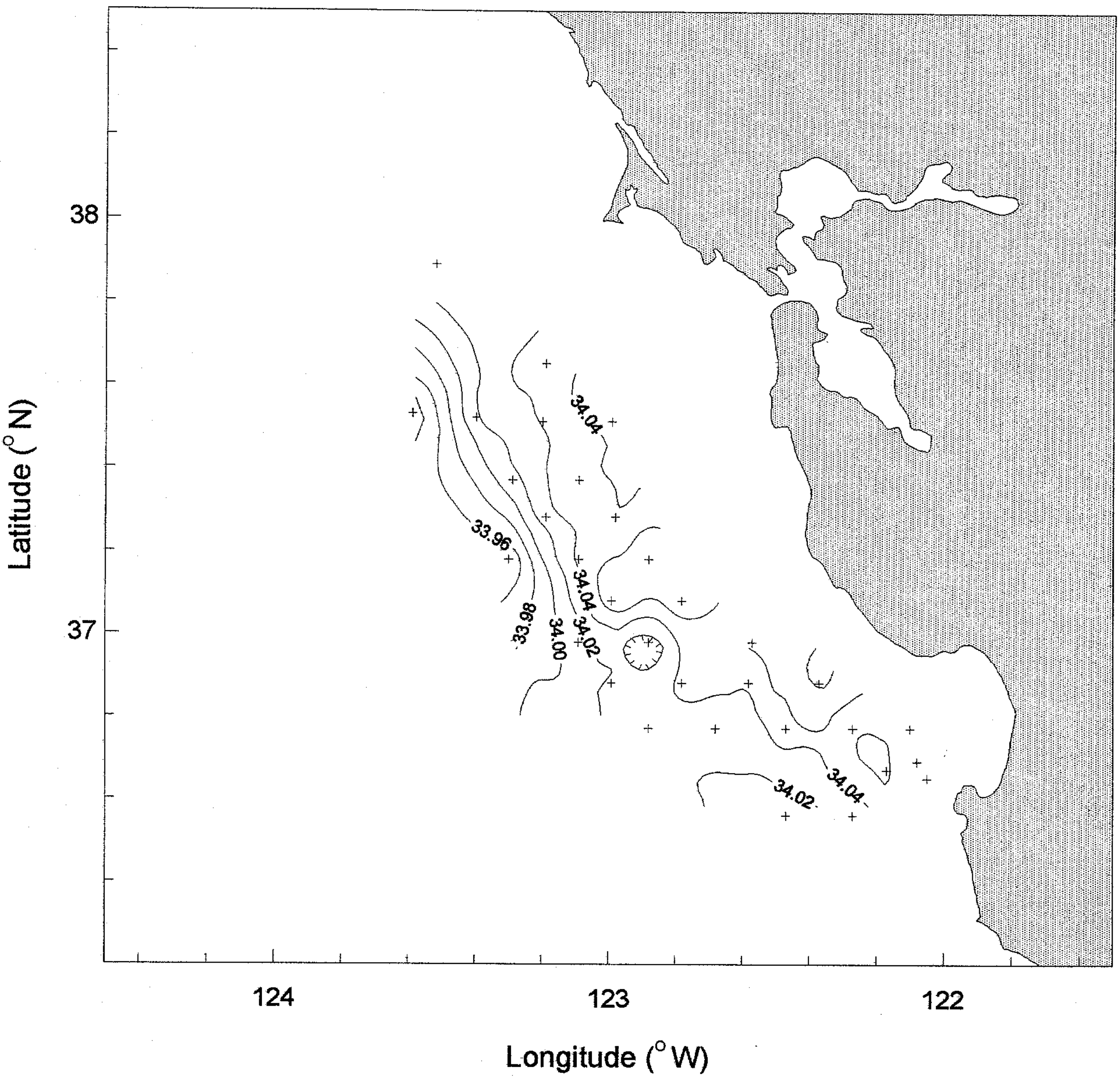
DSJ9105 Sweep 2 Salinity (ppt) at 30 m



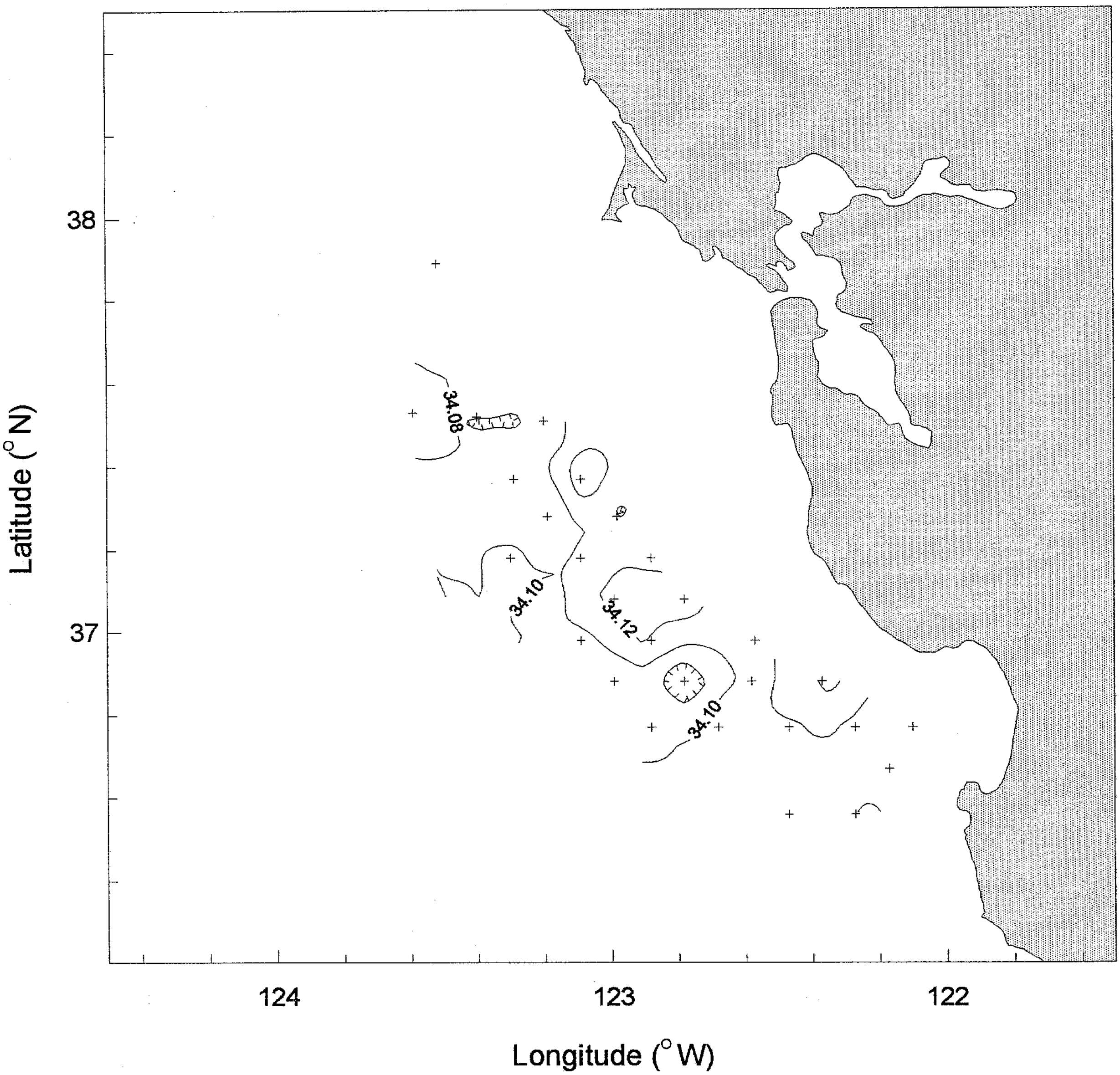
DSJ9105 Sweep 2 Salinity (ppt) at 100 m

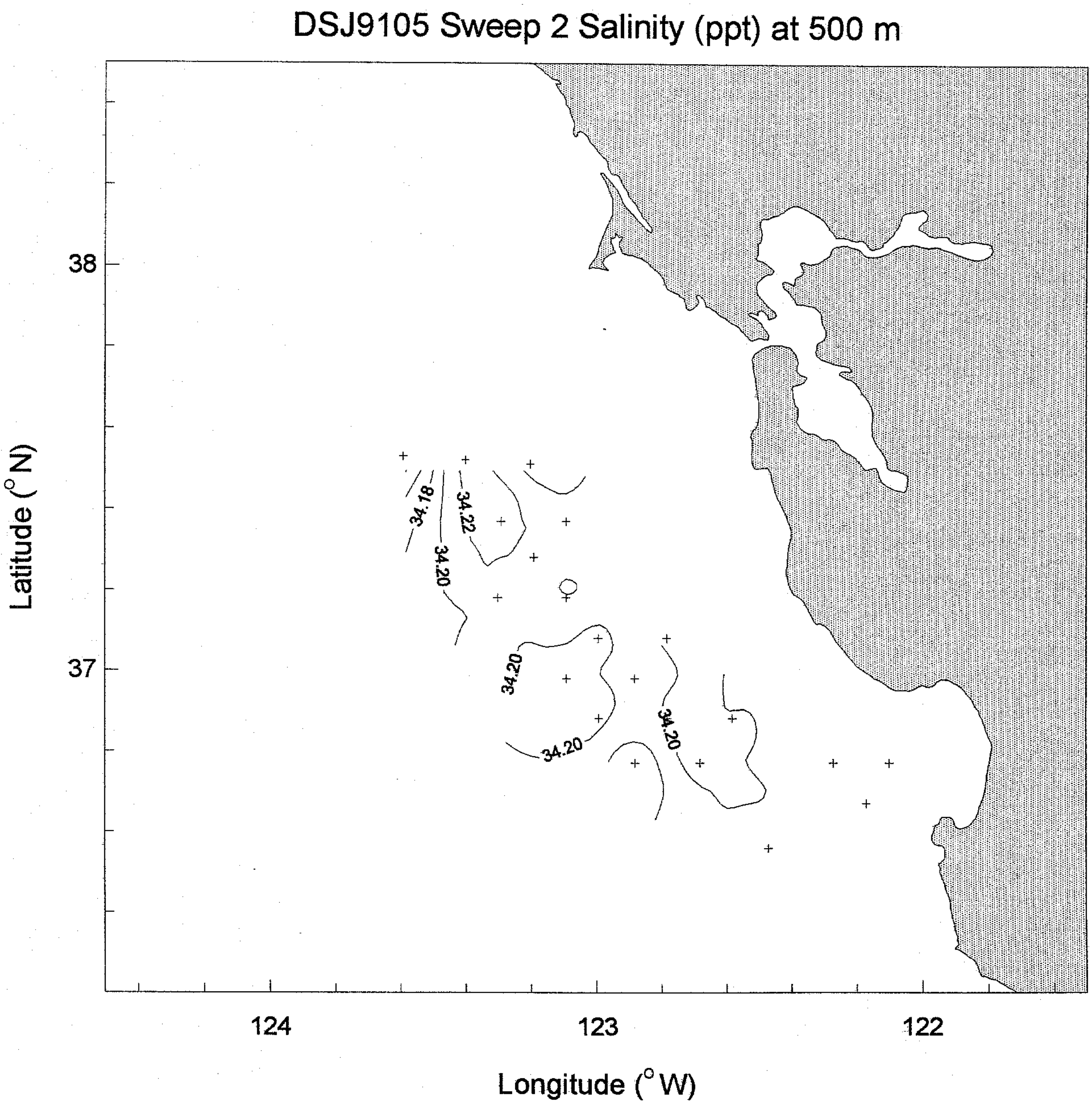


DSJ9105 Sweep 2 Salinity (ppt) at 200 m



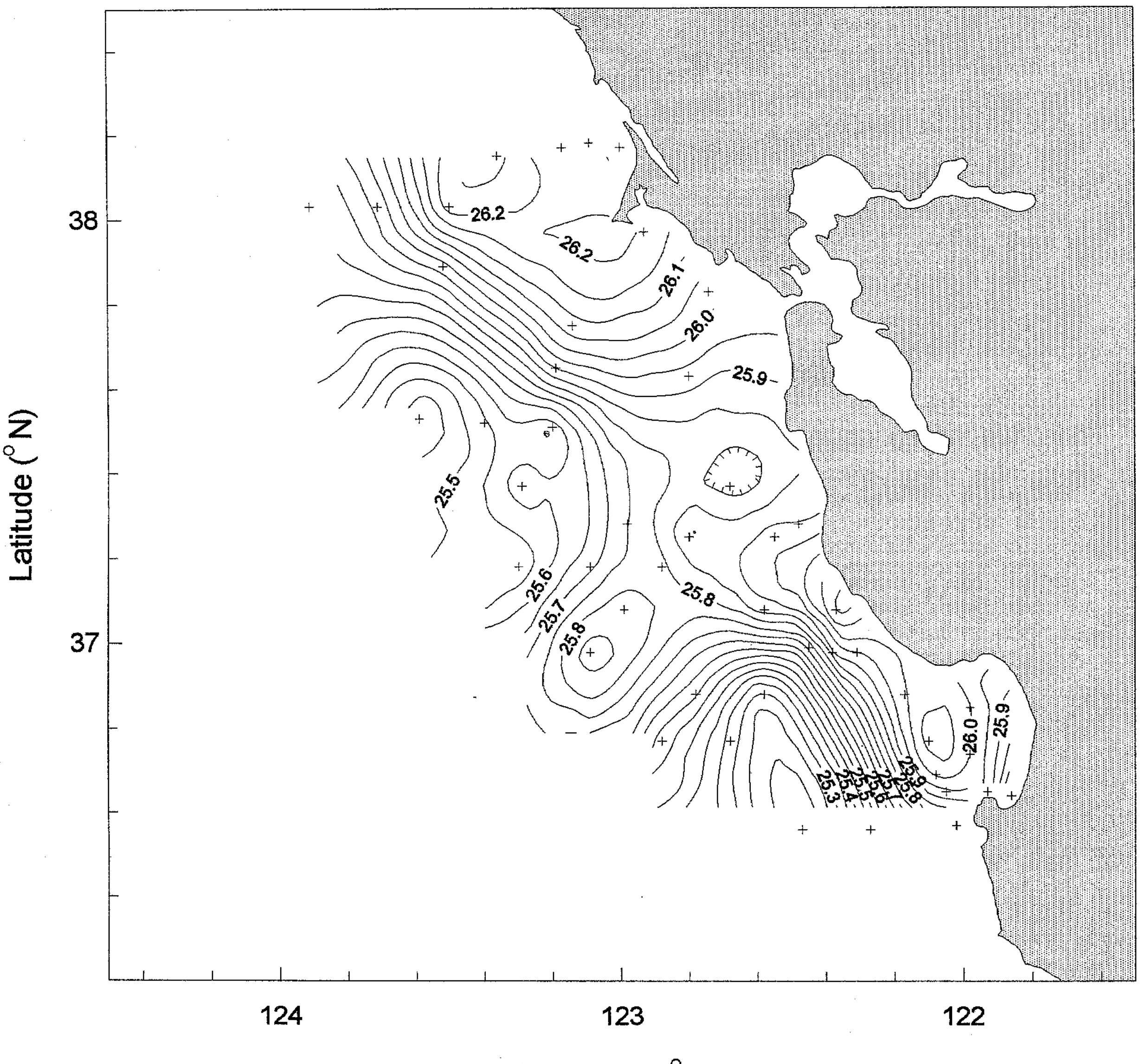
DSJ9105 Sweep 2 Salinity (ppt) at 300 m



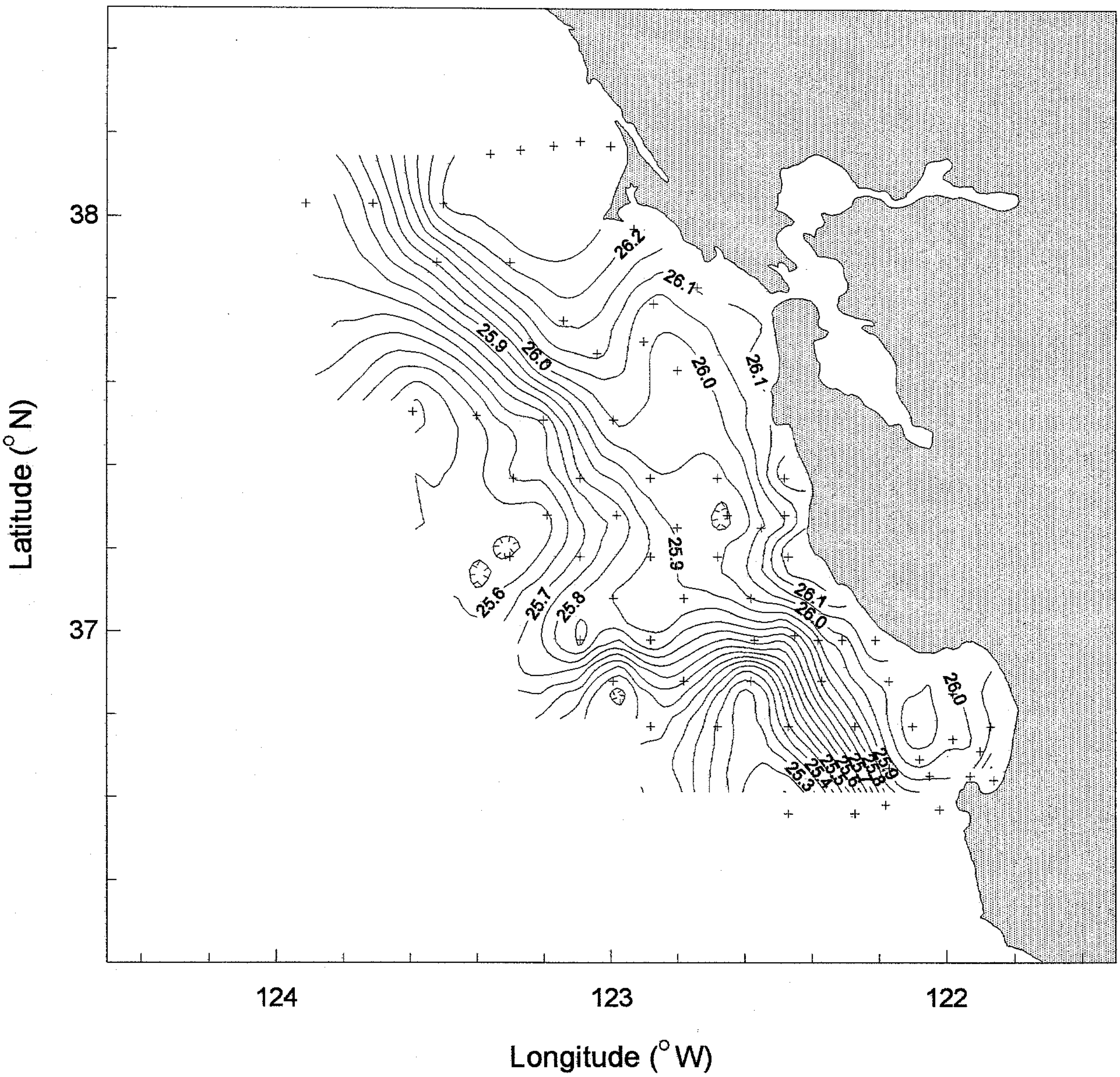


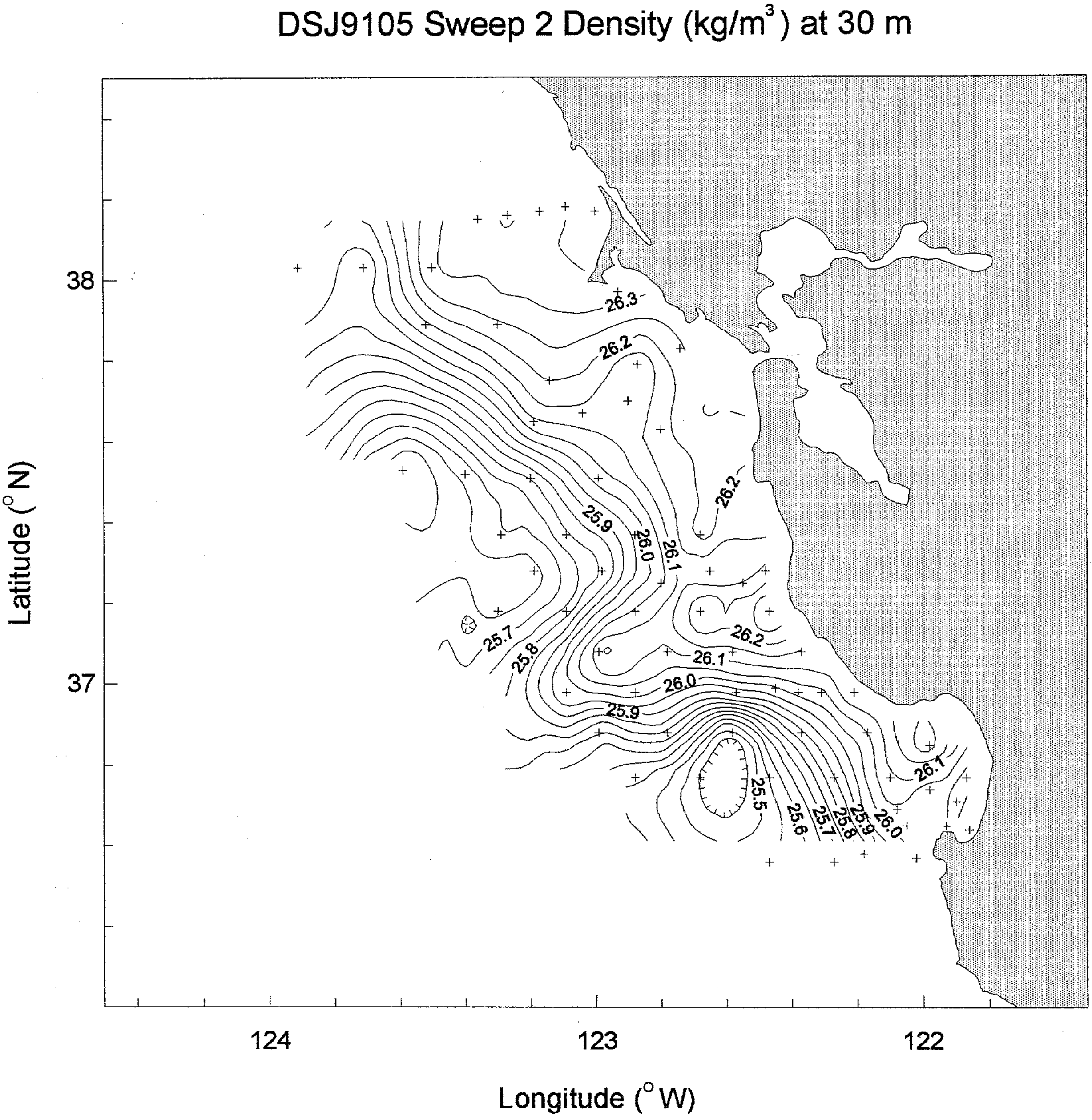
DSJ9105 Sweep 2 Salinity (ppt) at 500 m
38
37
Latitude (° N)
124
123
122
Longitude (° W)
34.18
34.22
34.20
34.20
34.20
34.20

DSJ9105 Sweep 2 Density (kg/m^3) at 2 m

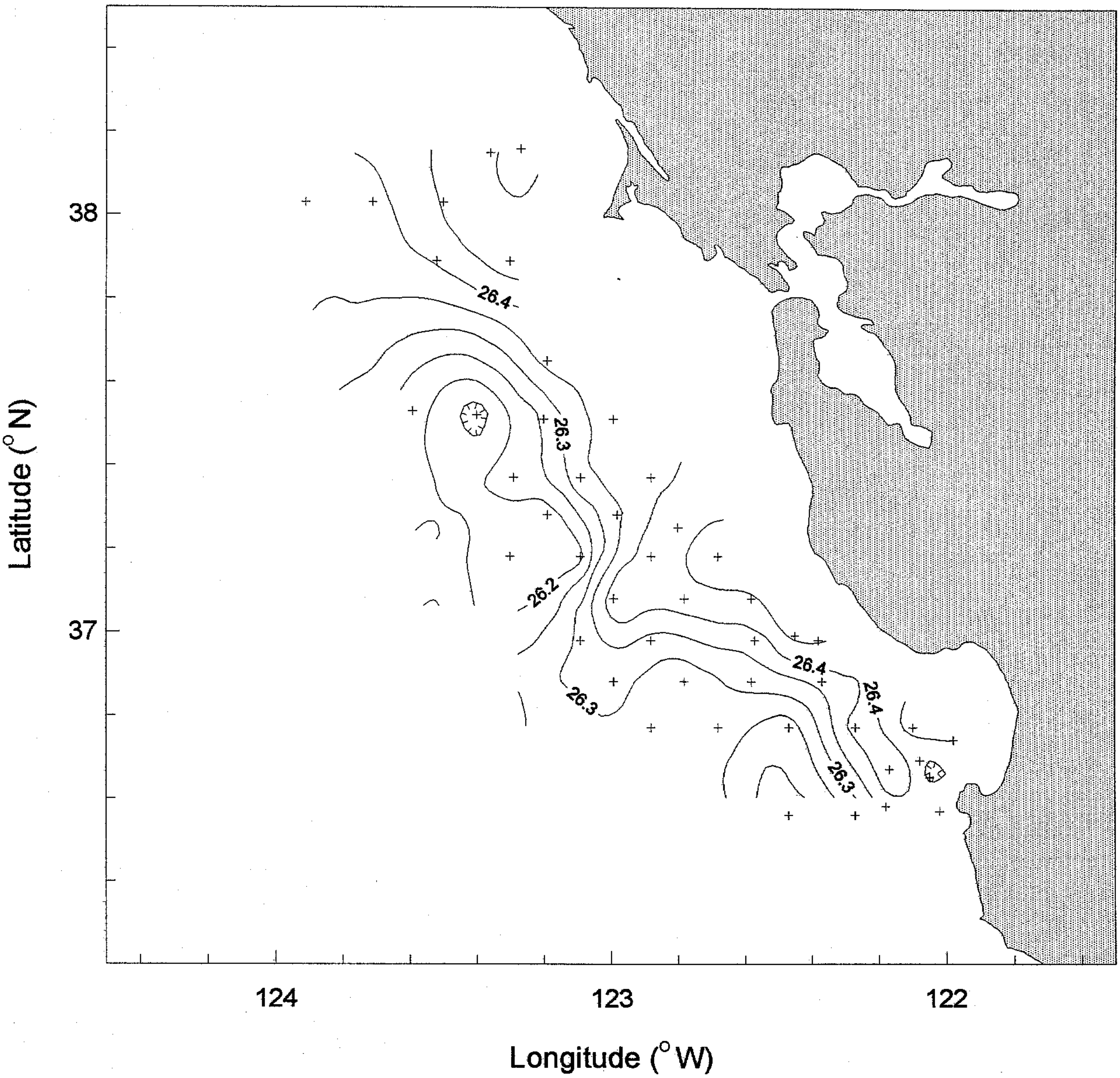


DSJ9105 Sweep 2 Density (kg/m^3) at 10 m

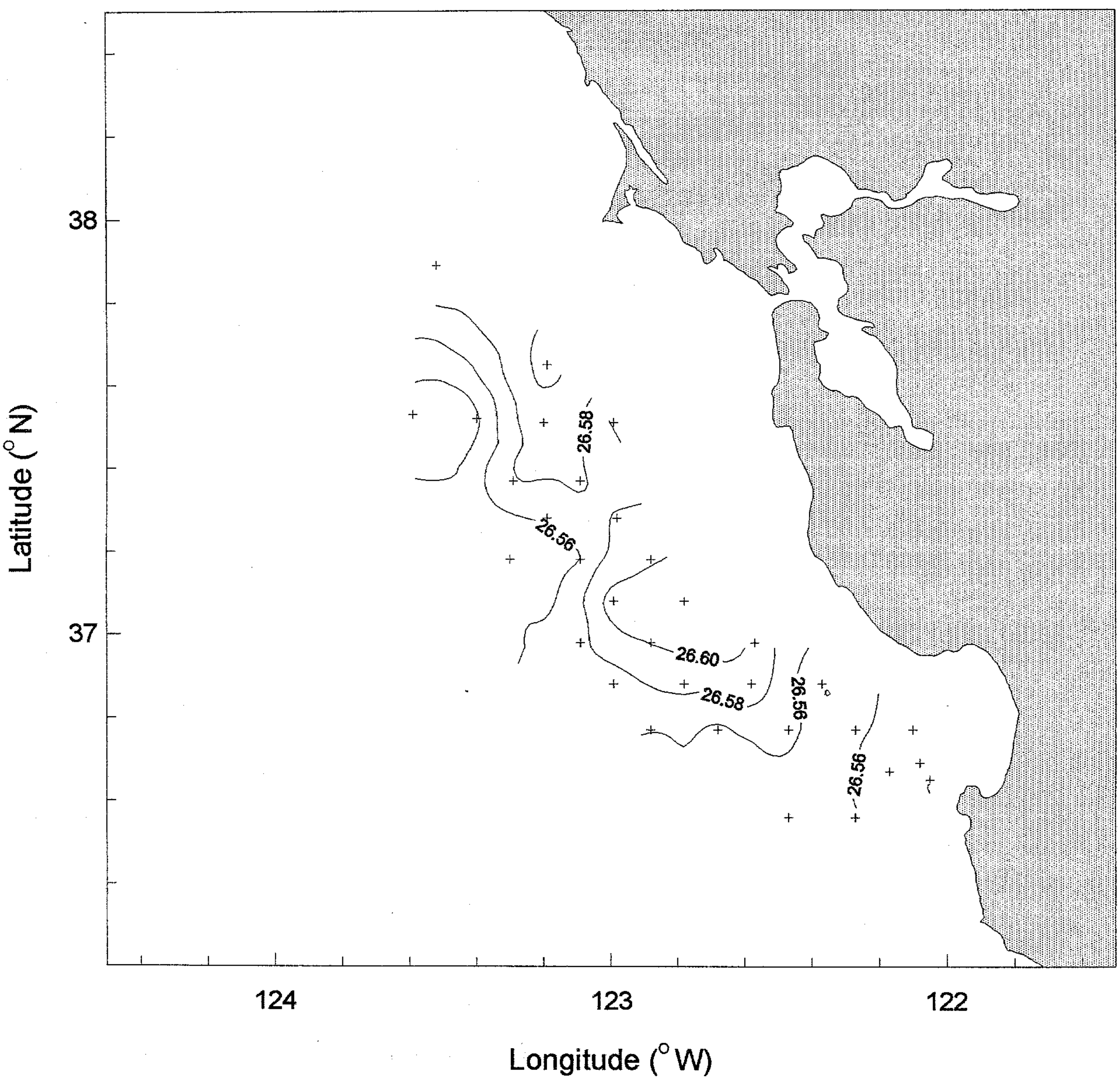


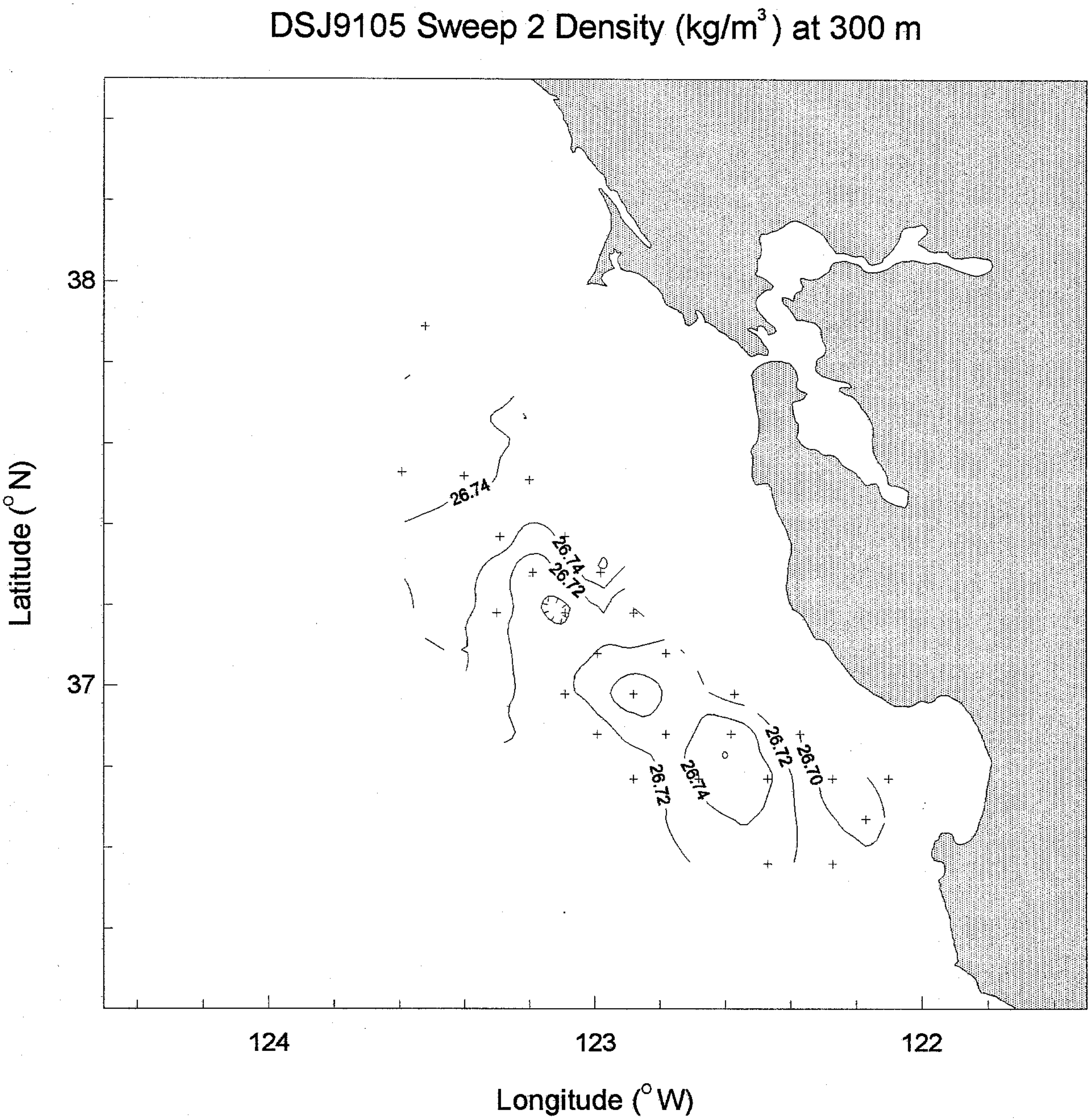

DSJ9105 Sweep 2 Density (kg/m³) at 30 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
26.3
26.2
26.1
26.0
25.9
25.8
25.7
25.6
25.5

DSJ9105 Sweep 2 Density (kg/m^3) at 100 m

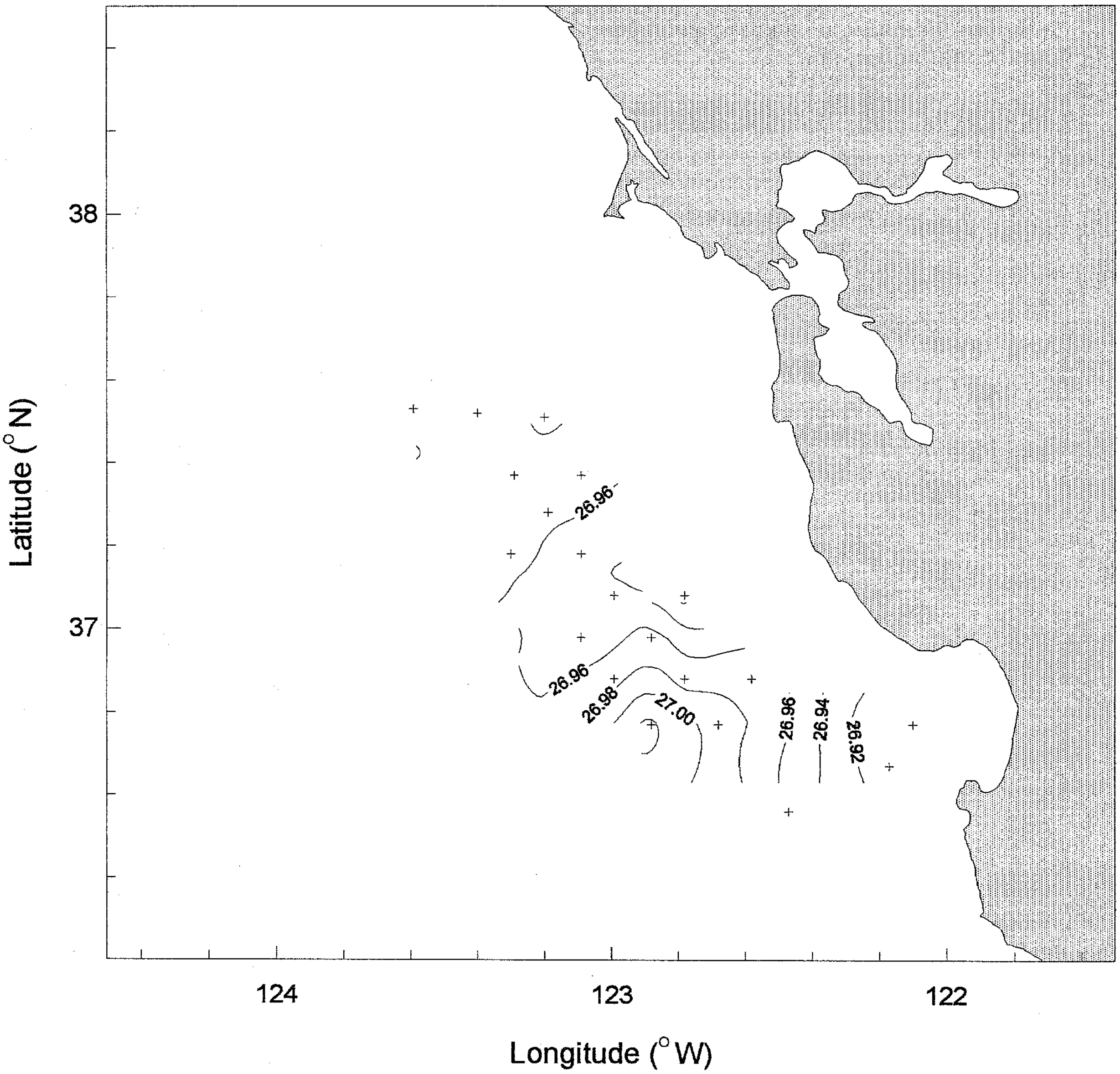


DSJ9105 Sweep 2 Density (kg/m^3) at 200 m



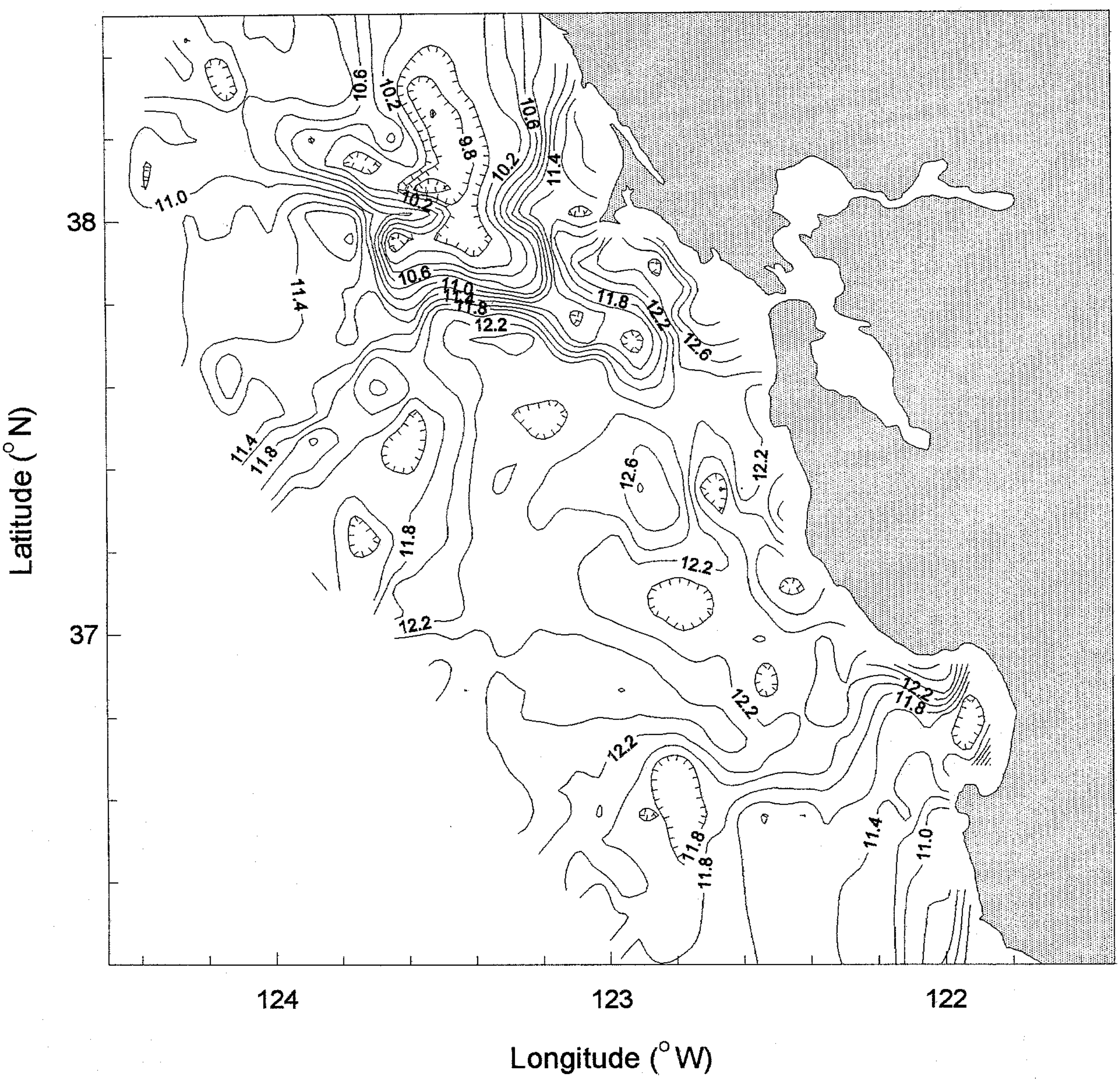

DSJ9105 Sweep 2 Density (kg/m³) at 300 m
38
37
Latitude (° N)
124
123
122
Longitude (° W)
26.74
26.74
26.72
26.72
26.74
26.72
26.70

DSJ9105 Sweep 2 Density (kg/m^3) at 500 m

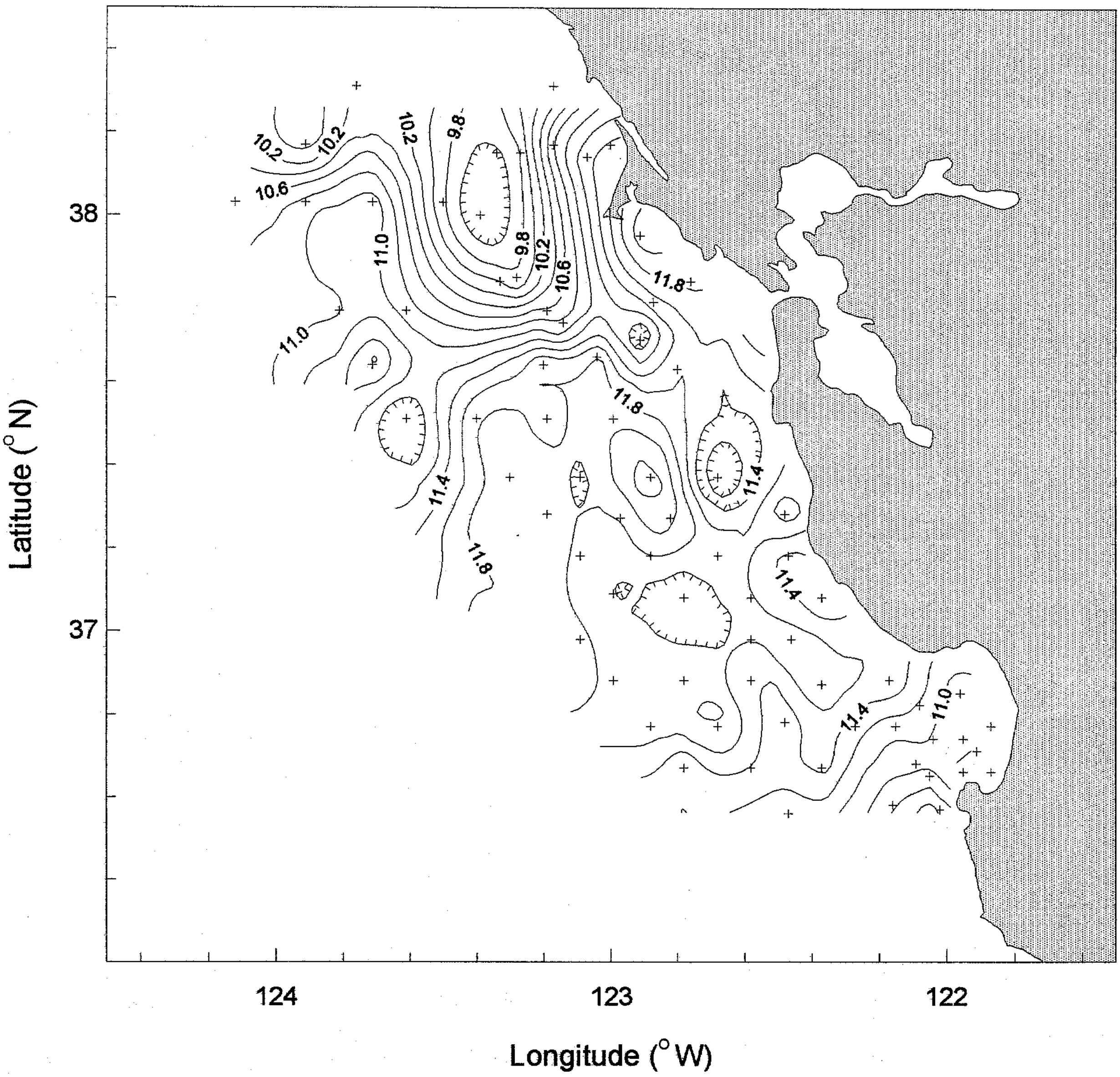


APPENDIX 5.4: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9105, SWEEP 3

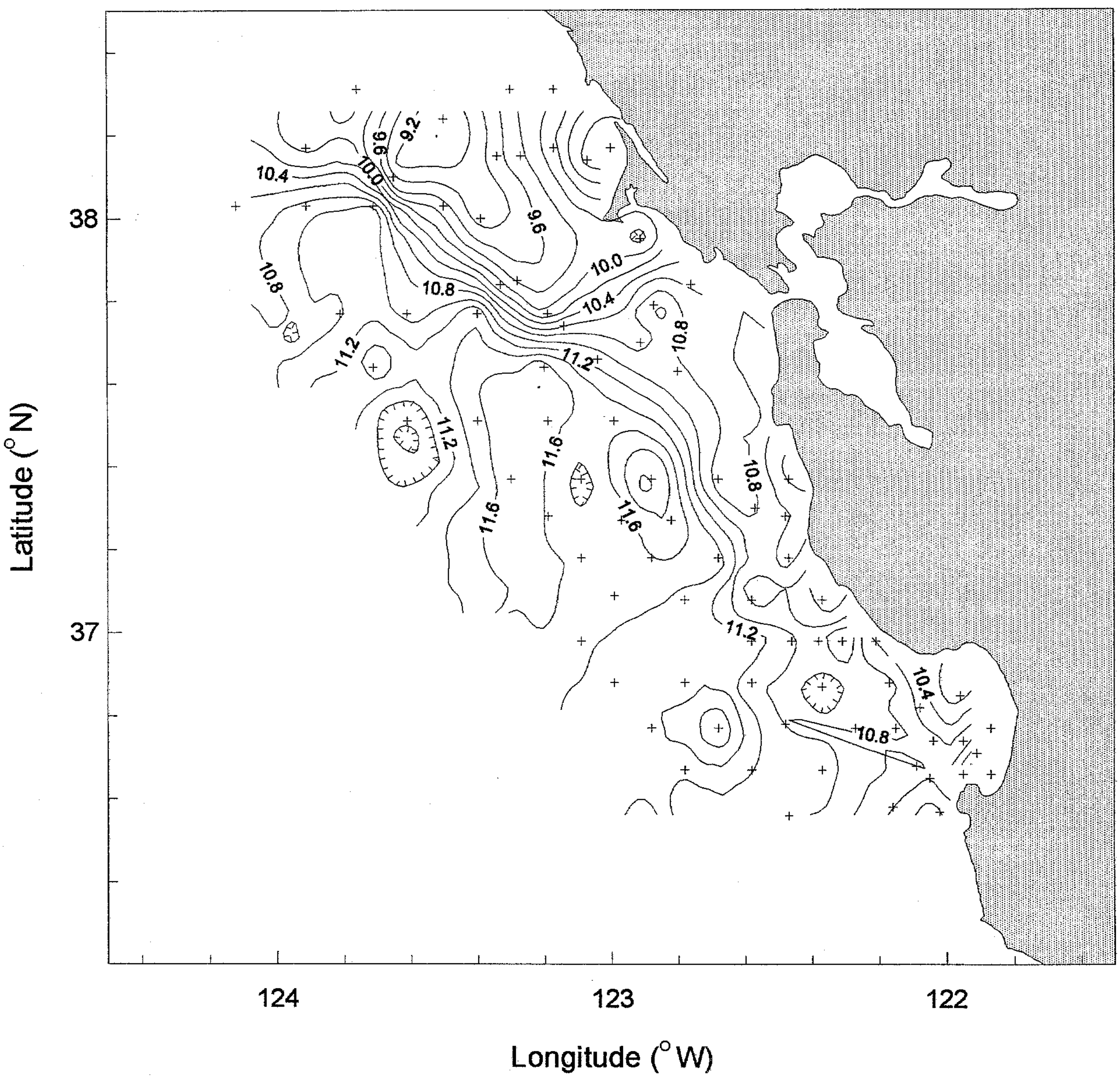
DSJ9105 Sweep 3 TS Temperature (°C)

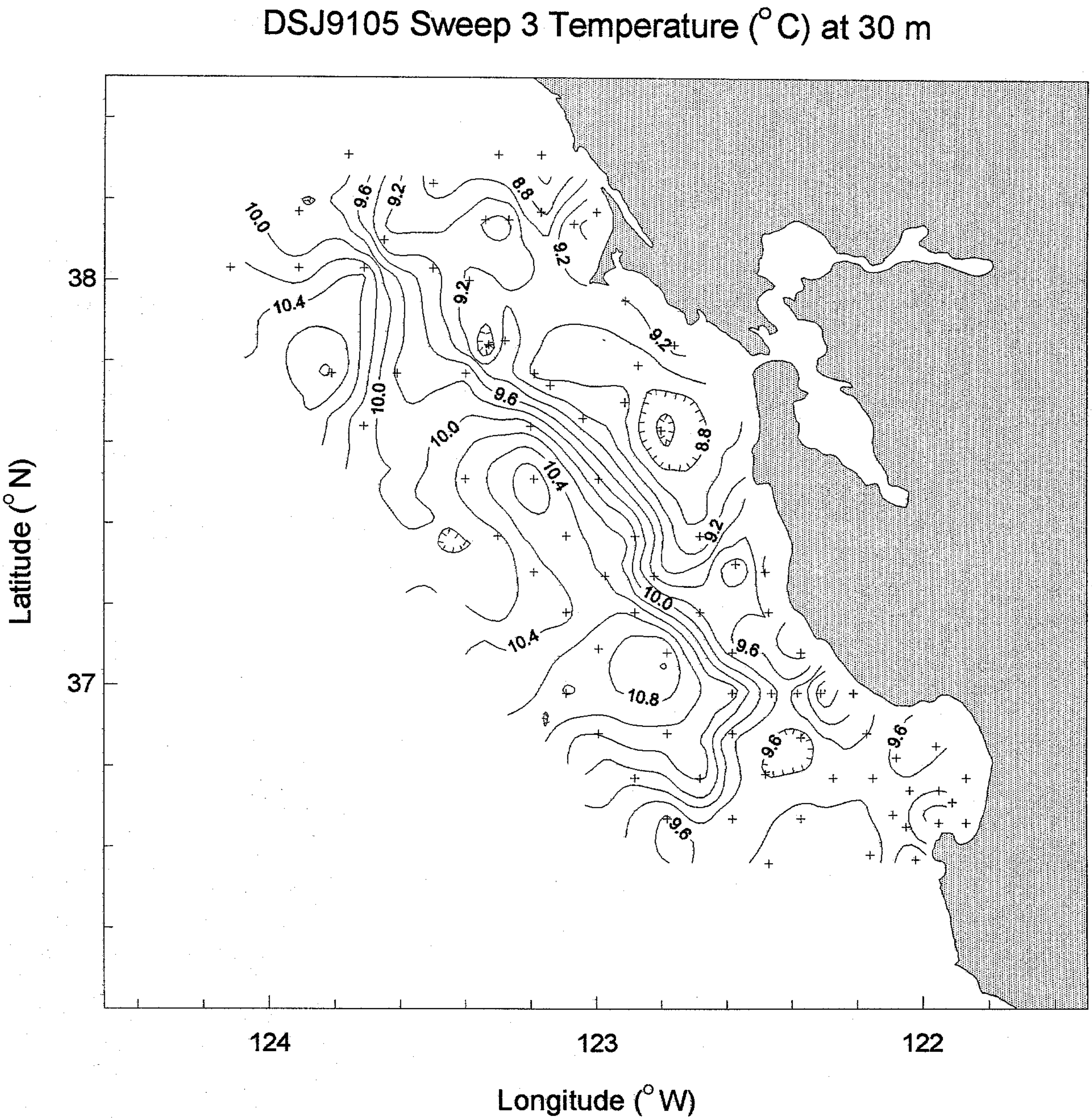


DSJ9105 Sweep 3 Temperature (°C) at 2 m



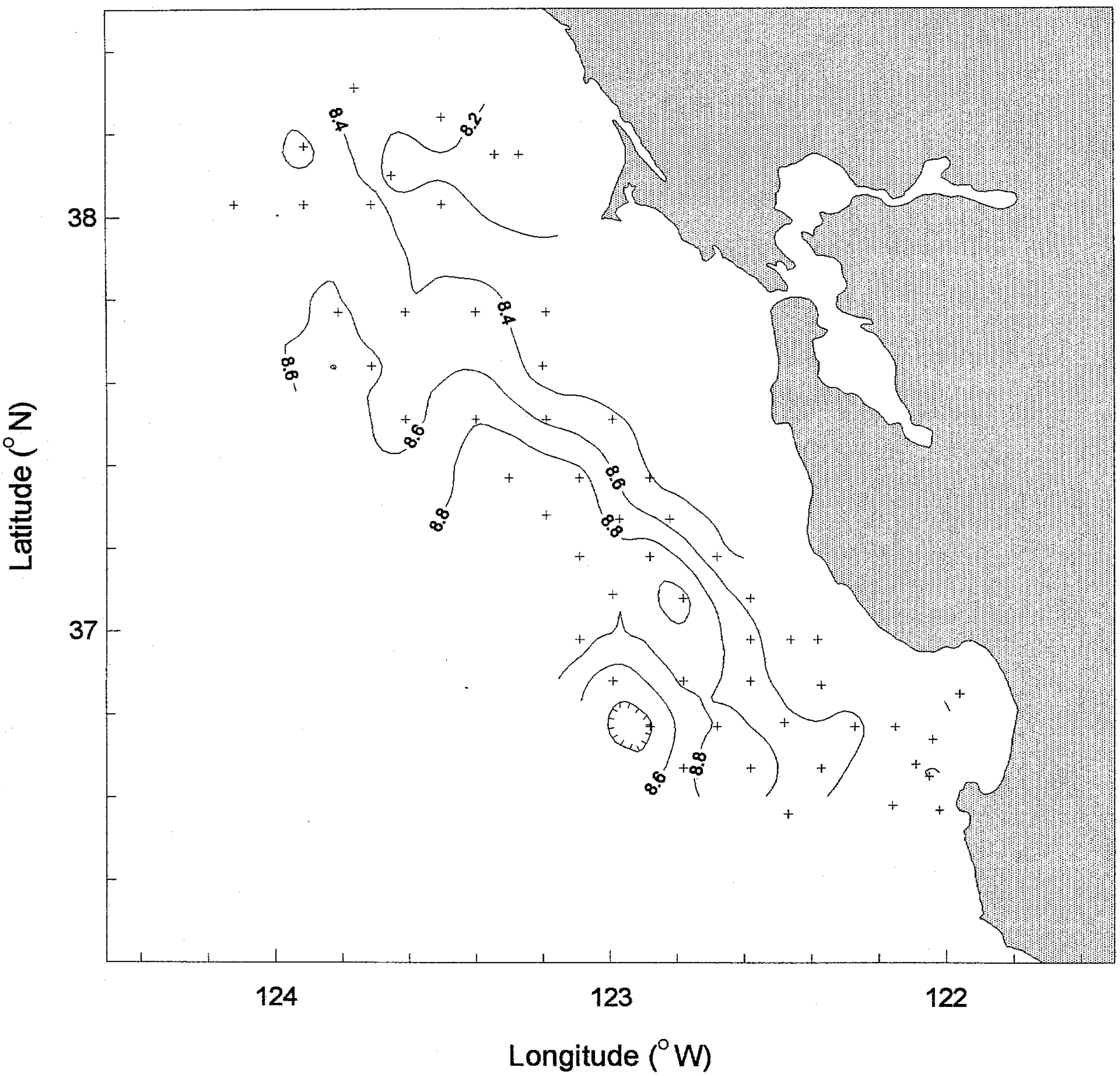
DSJ9105 Sweep 3 Temperature (°C) at 10 m

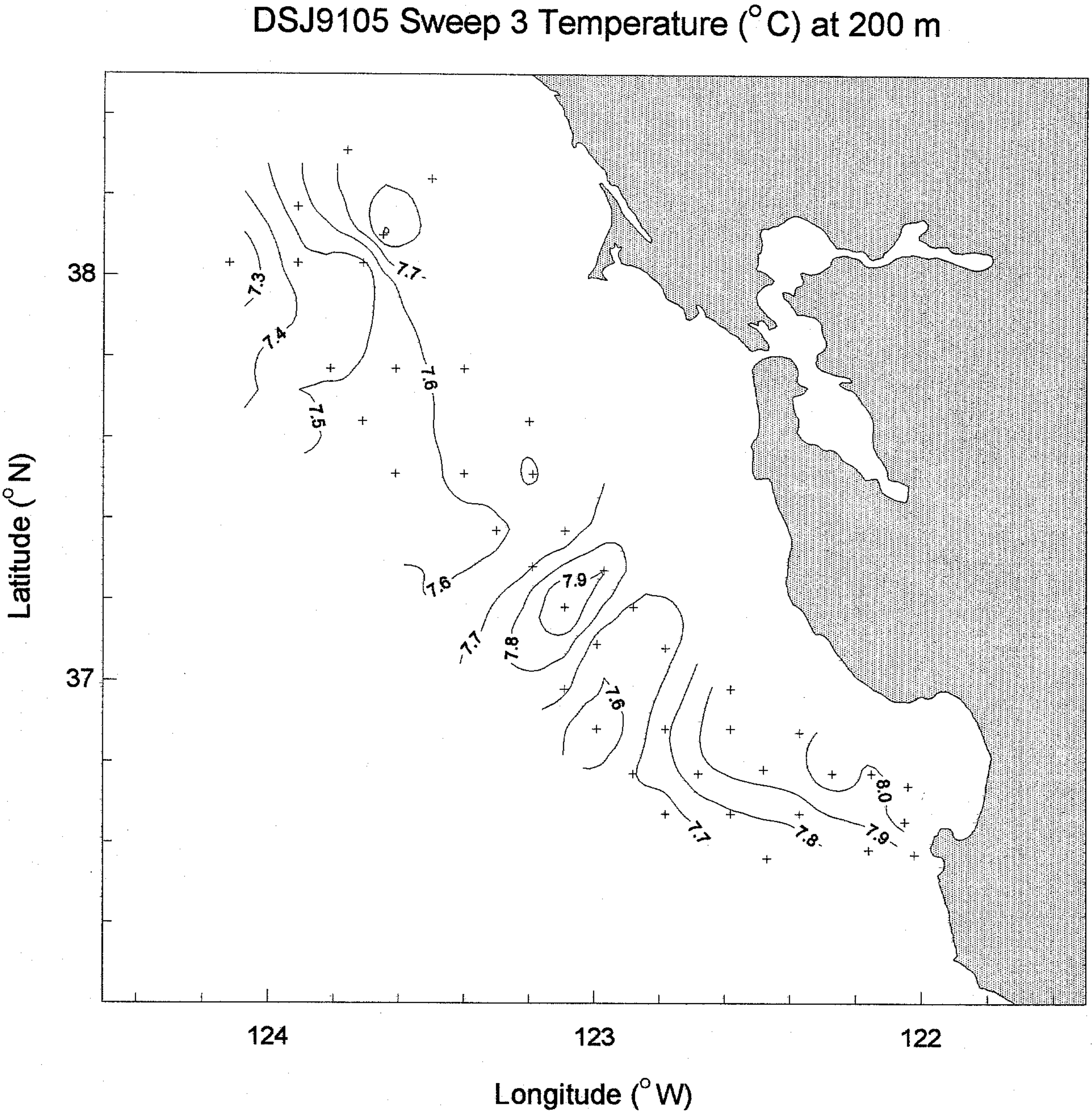


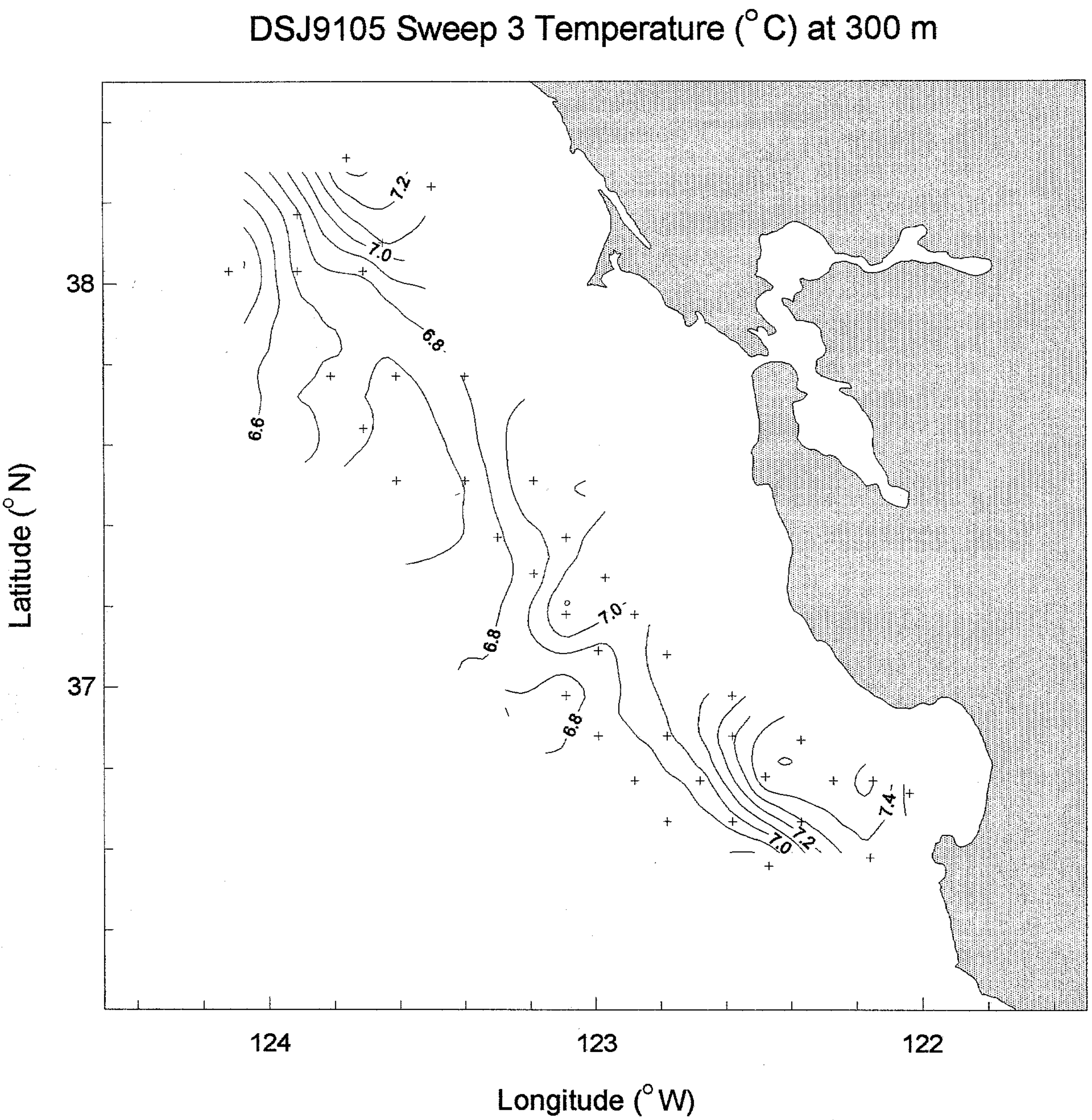


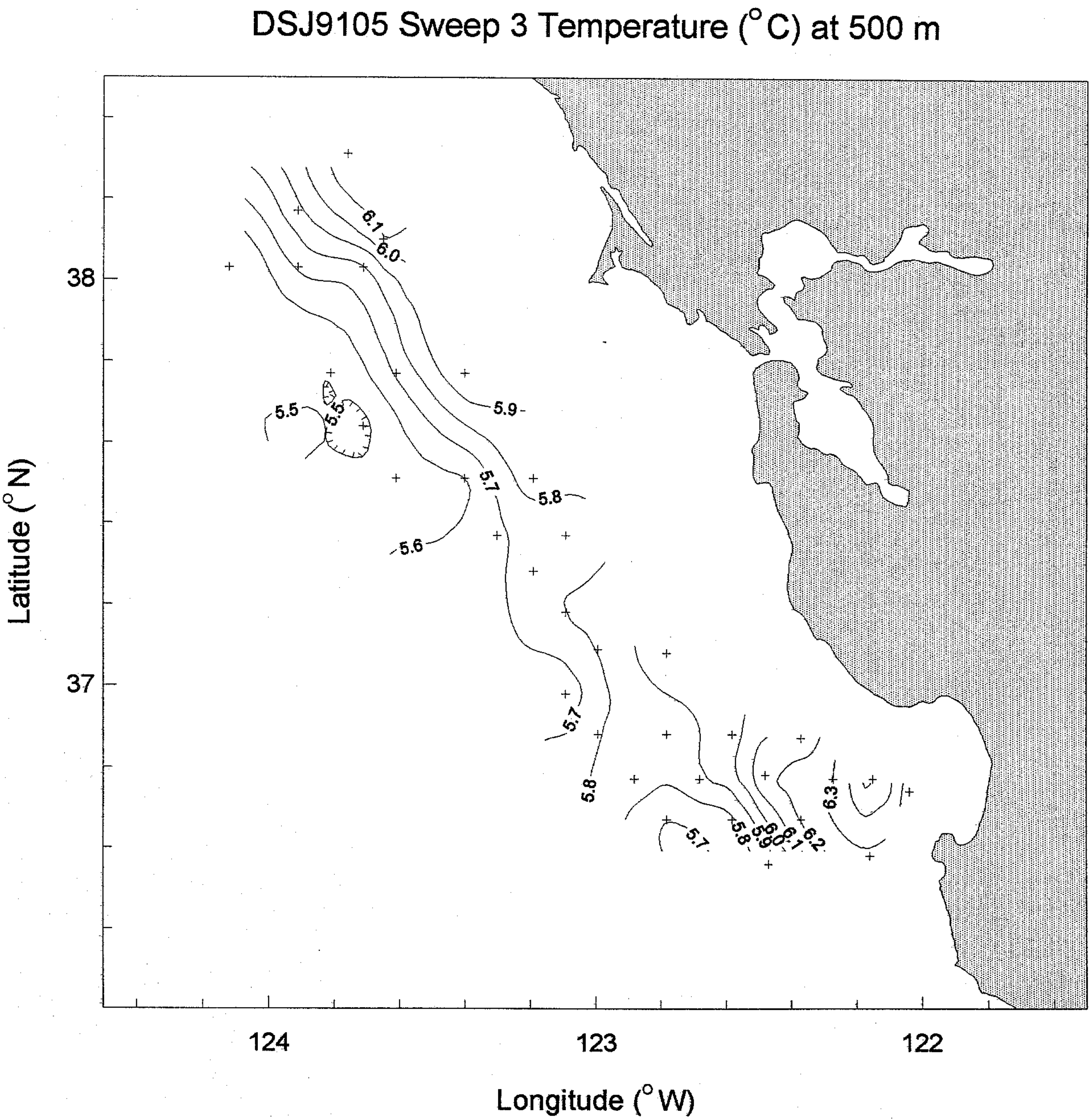
DSJ9105 Sweep 3 Temperature (°C) at 30 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
10.0
9.6
9.2
8.8
10.4
10.8

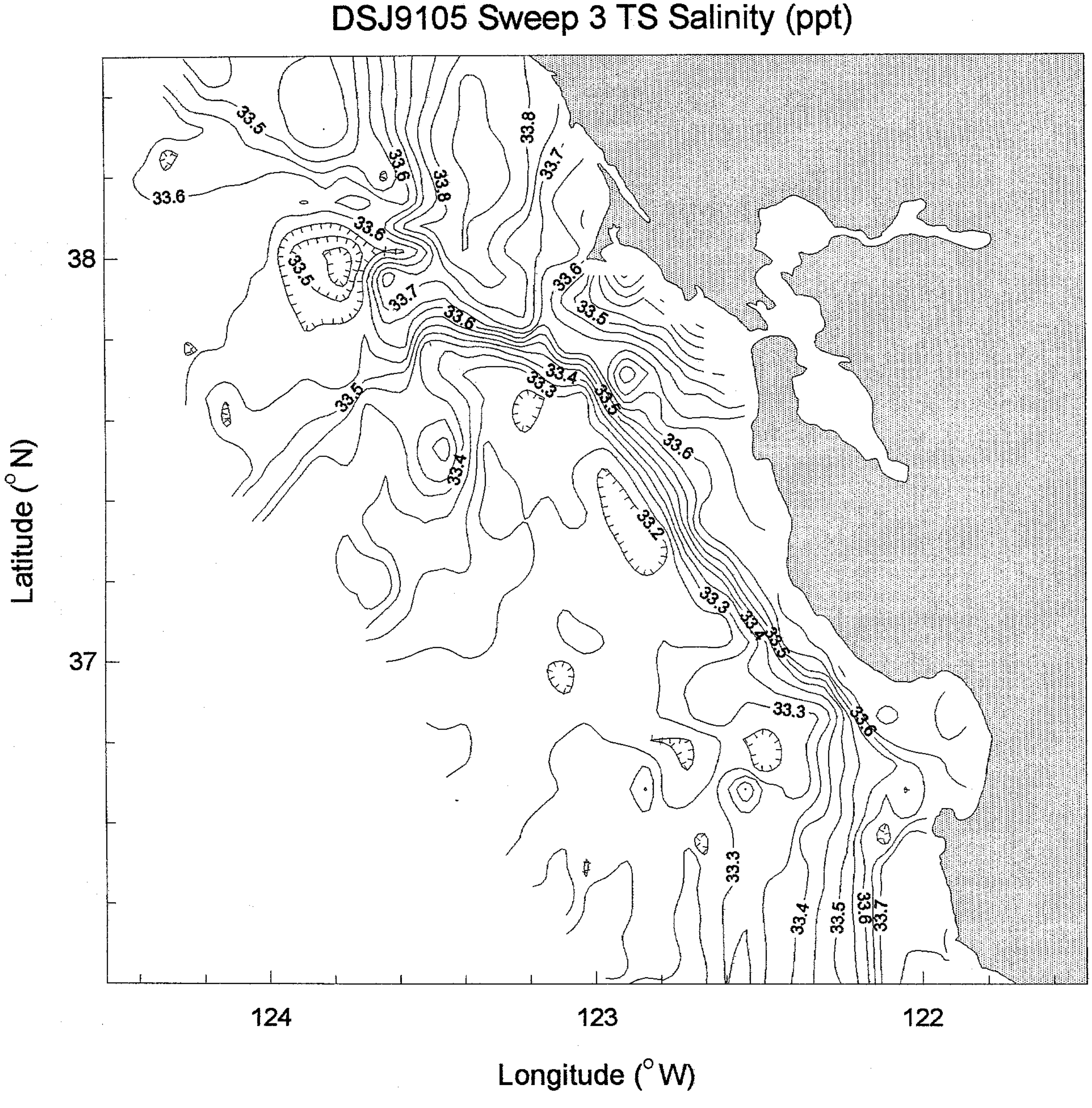
DSJ9105 Sweep 3 Temperature (°C) at 100 m



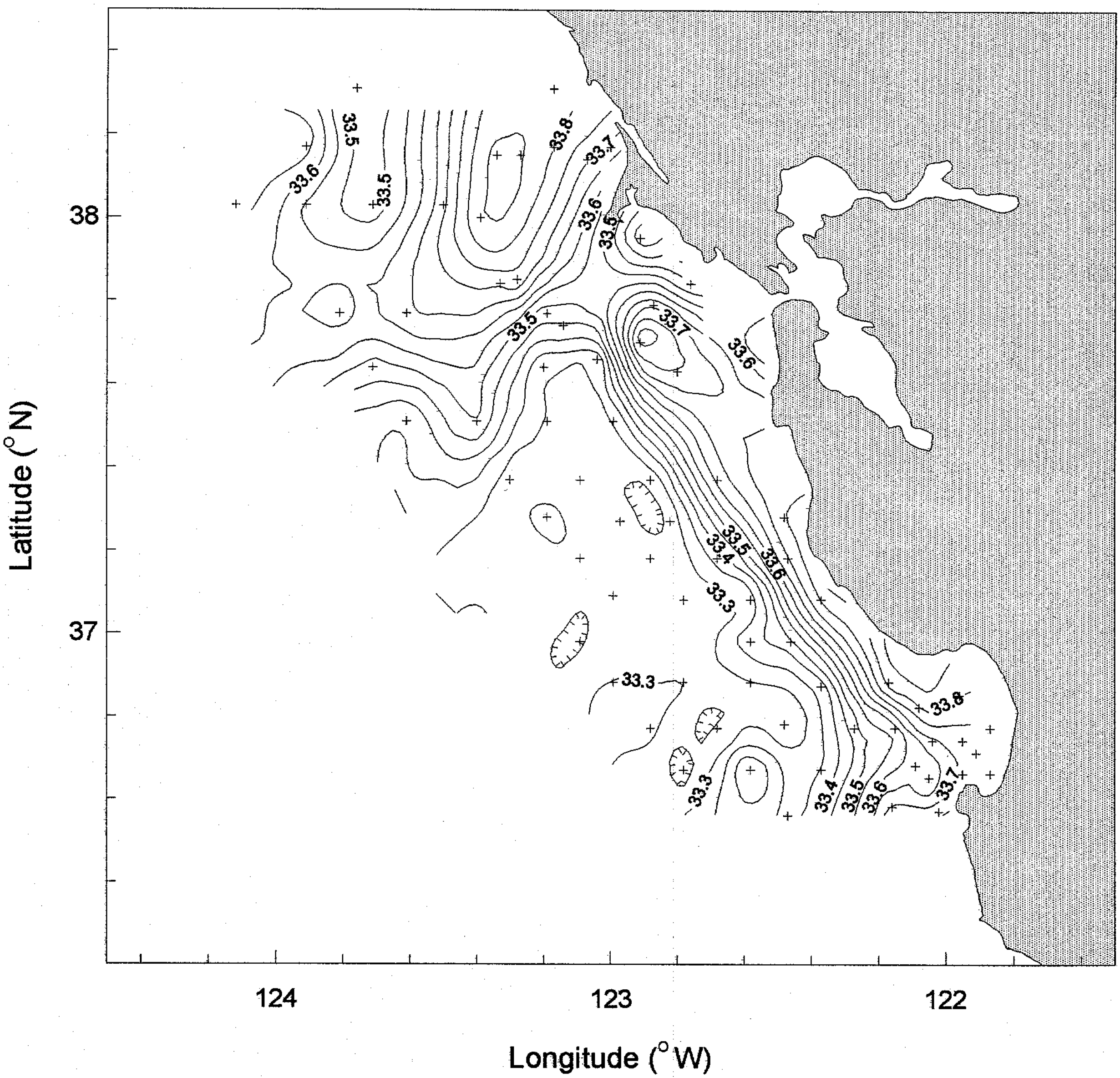

DSJ9105 Sweep 3 Temperature (°C) at 200 m
38
37
124
123
122
Latitude (°N)
Longitude (°W)
7.3
7.4
7.5
7.6
7.7
7.6
7.6
7.7
7.8
7.9
7.6
7.7
7.8
7.9
8.0


DSJ9105 Sweep 3 Temperature (°C) at 300 m
Latitude (°N)
38
37
Longitude (°W)
124
123
122
7.2
7.0
6.8
6.6
6.8
7.0
6.8
6.8
7.0
7.2
7.4

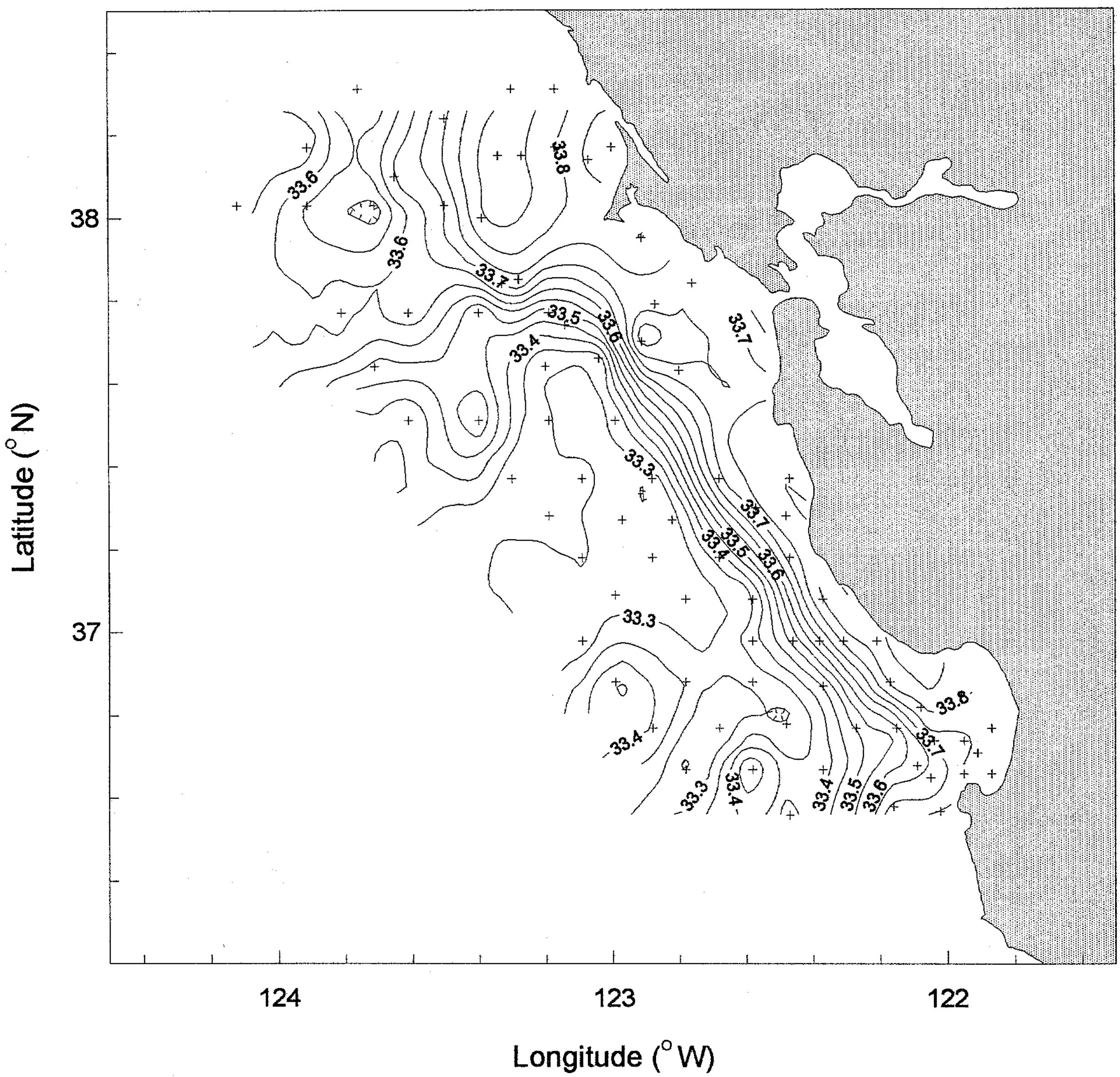

DSJ9105 Sweep 3 Temperature (°C) at 500 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)
6.1
6.0
5.9
5.8
5.7
5.6
5.5
5.5
5.7
5.8
5.7
5.8
5.9
6.0
6.1
6.2
6.3


DSJ9105 Sweep 3 TS Salinity (ppt)
Latitude (° N)
Longitude (° W)
38
37
124
123
122
33.5
33.6
33.8
33.7
33.4
33.3
33.2

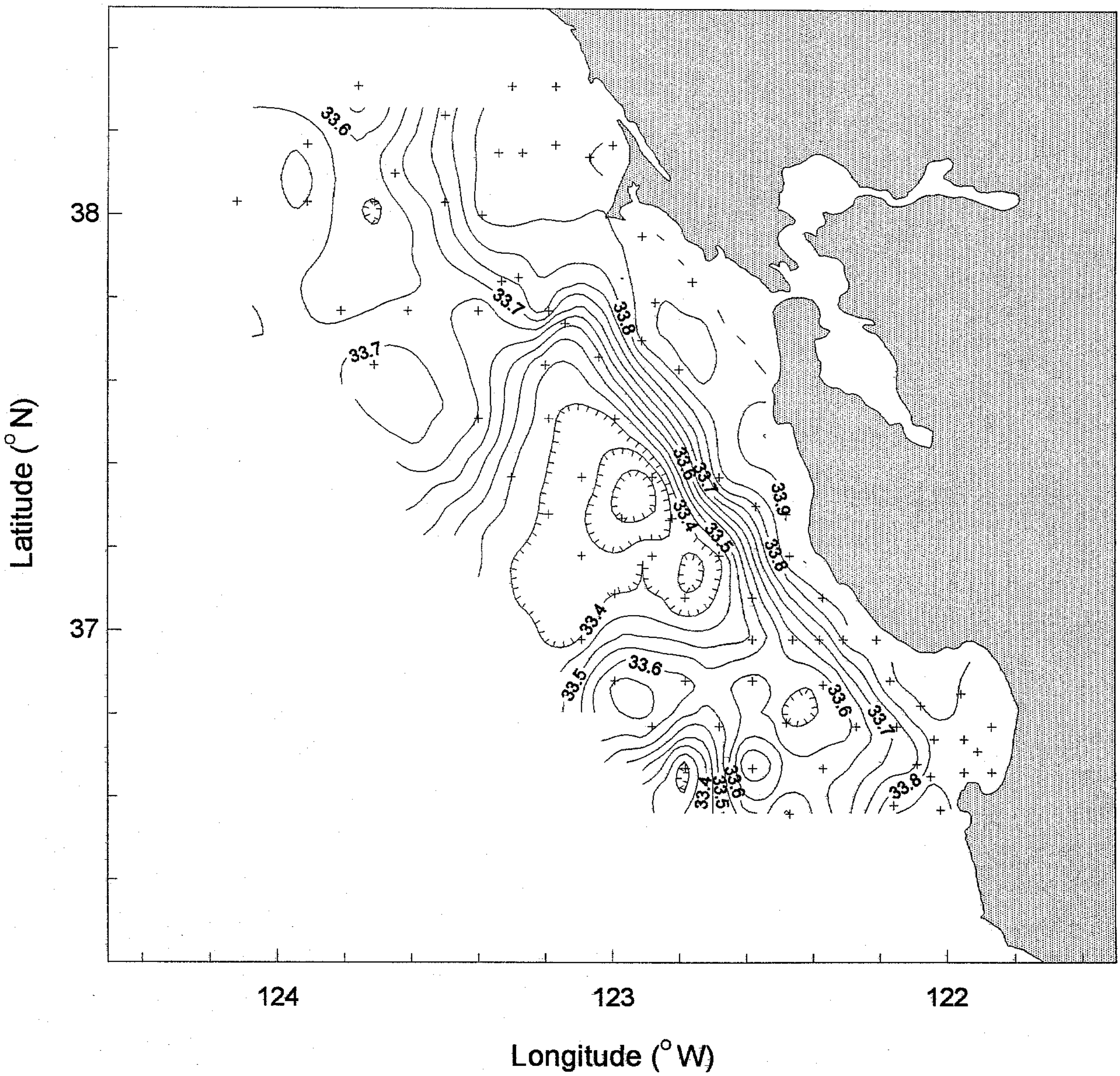
DSJ9105 Sweep 3 Salinity (ppt) at 2 m



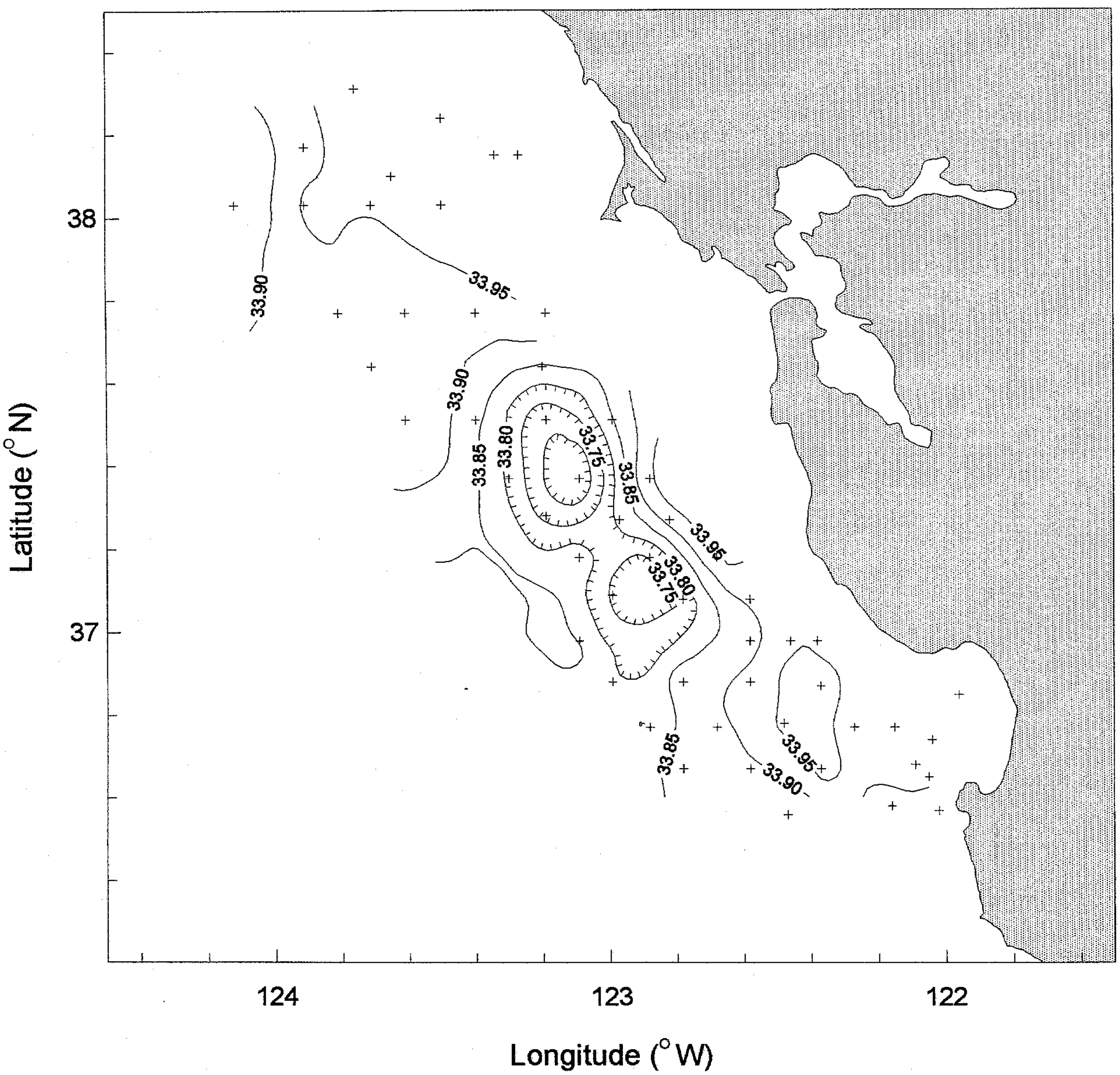
DSJ9105 Sweep 3 Salinity (ppt) at 10 m



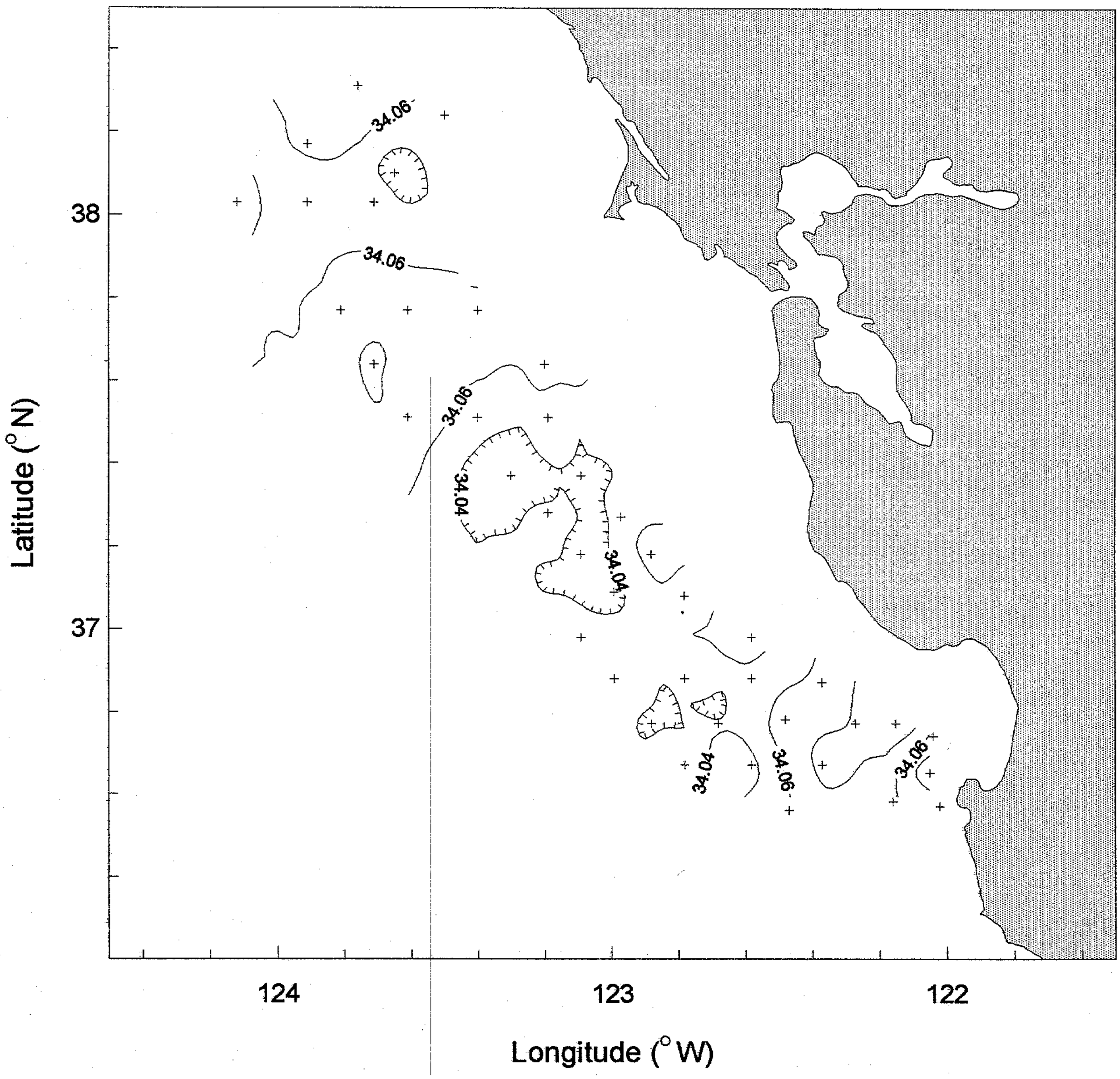
DSJ9105 Sweep 3 Salinity (ppt) at 30 m



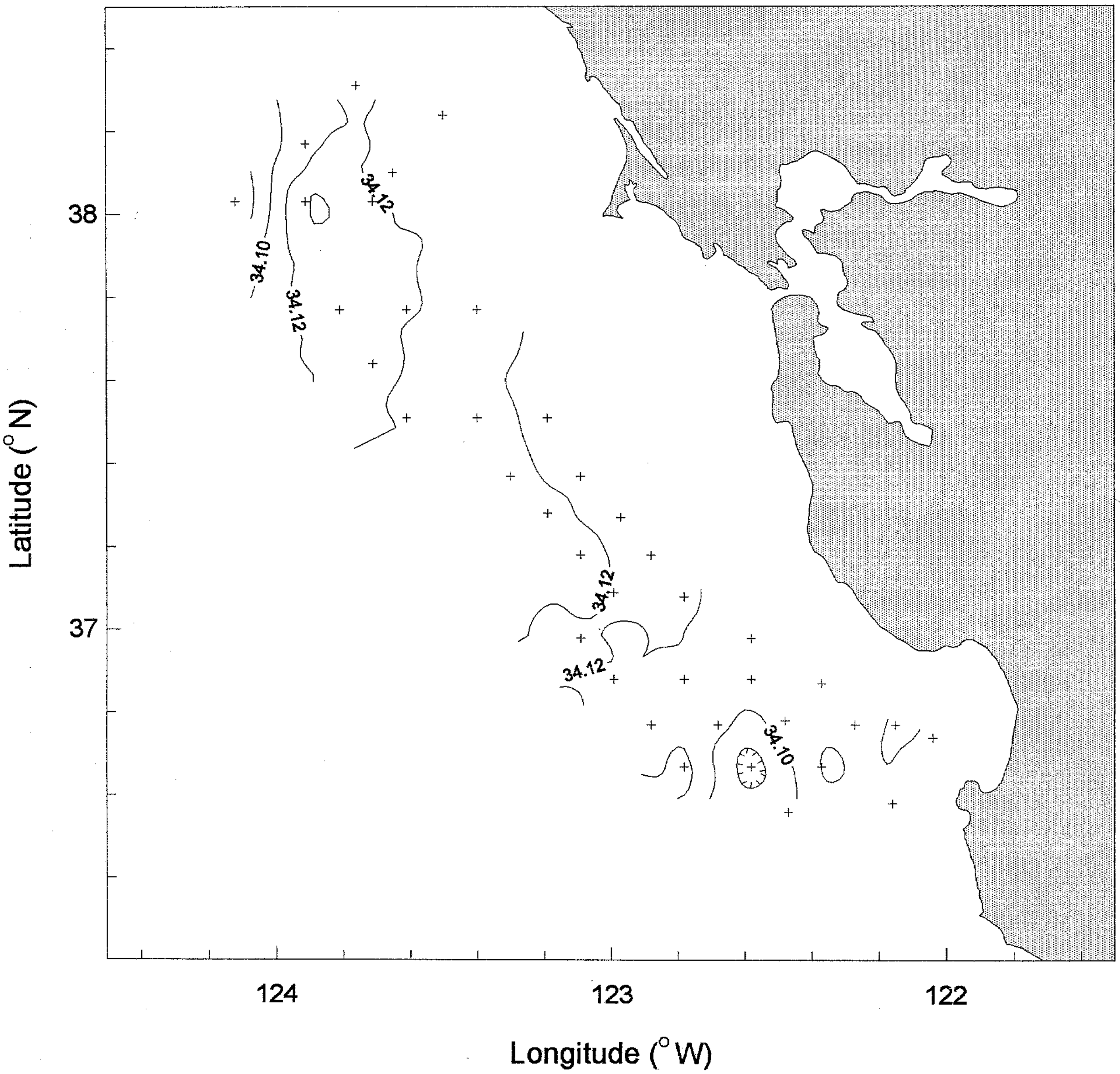
DSJ9105 Sweep 3 Salinity (ppt) at 100 m



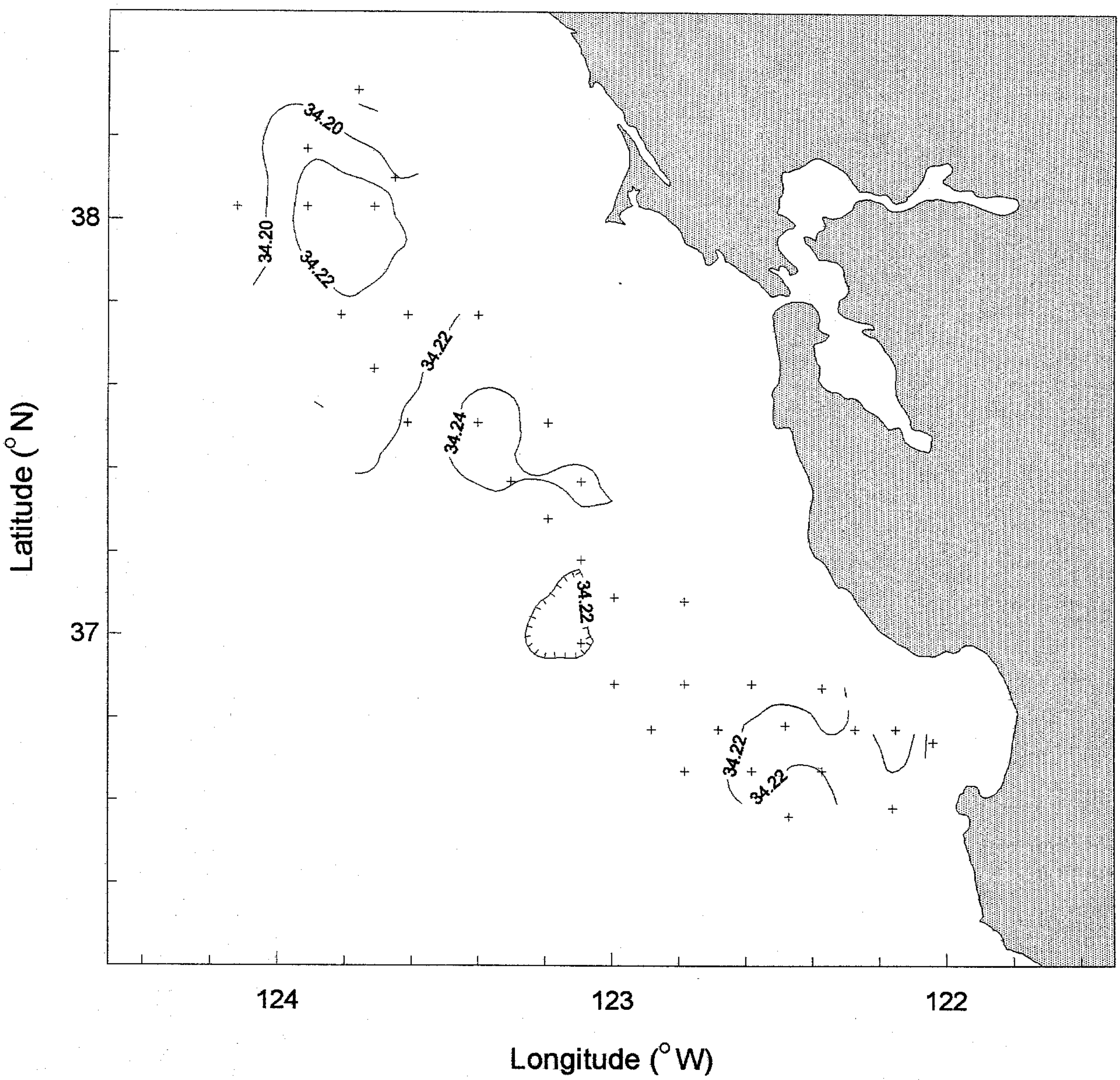
DSJ9105 Sweep 3 Salinity (ppt) at 200 m



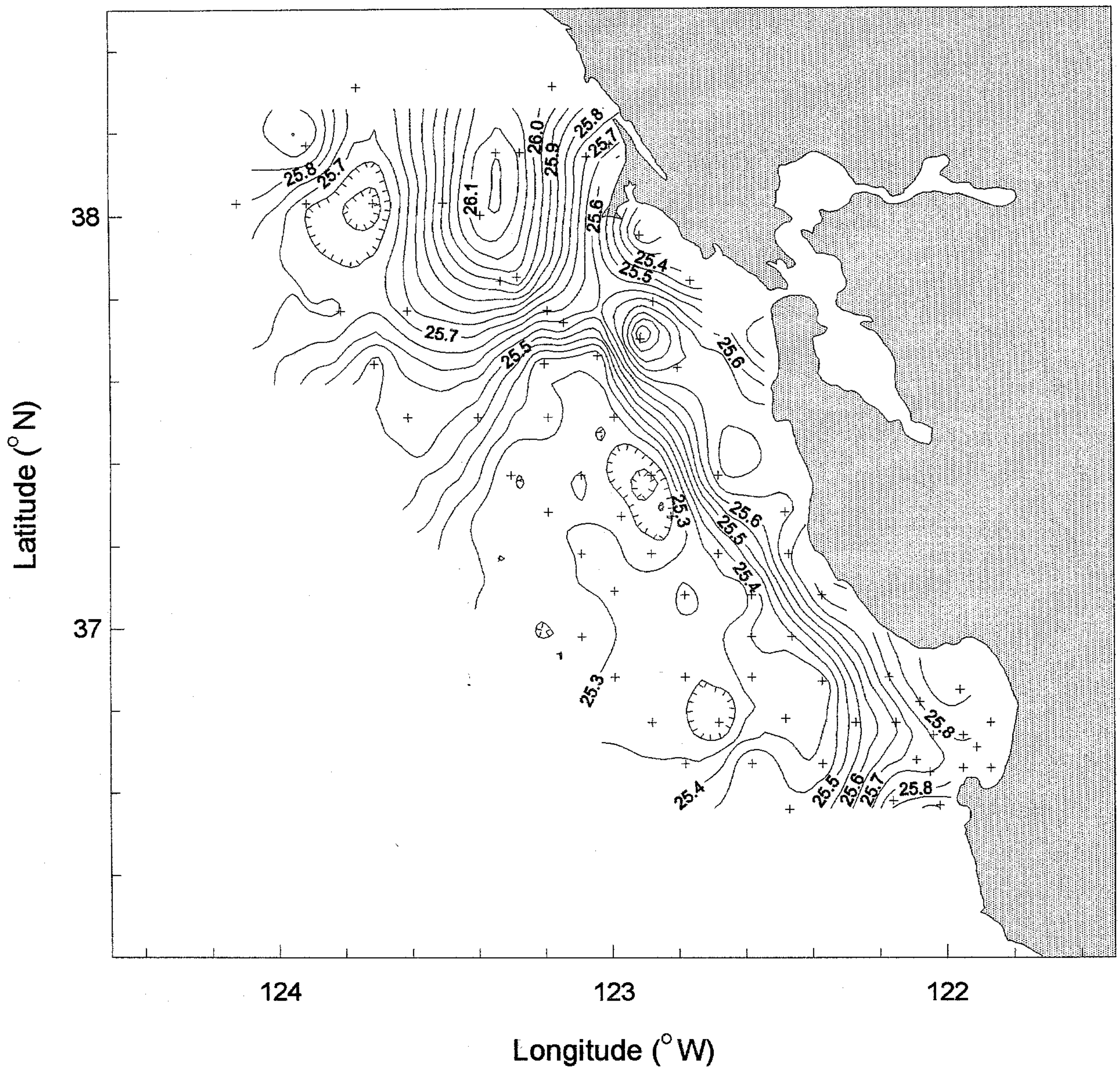
DSJ9105 Sweep 3 Salinity (ppt) at 300 m



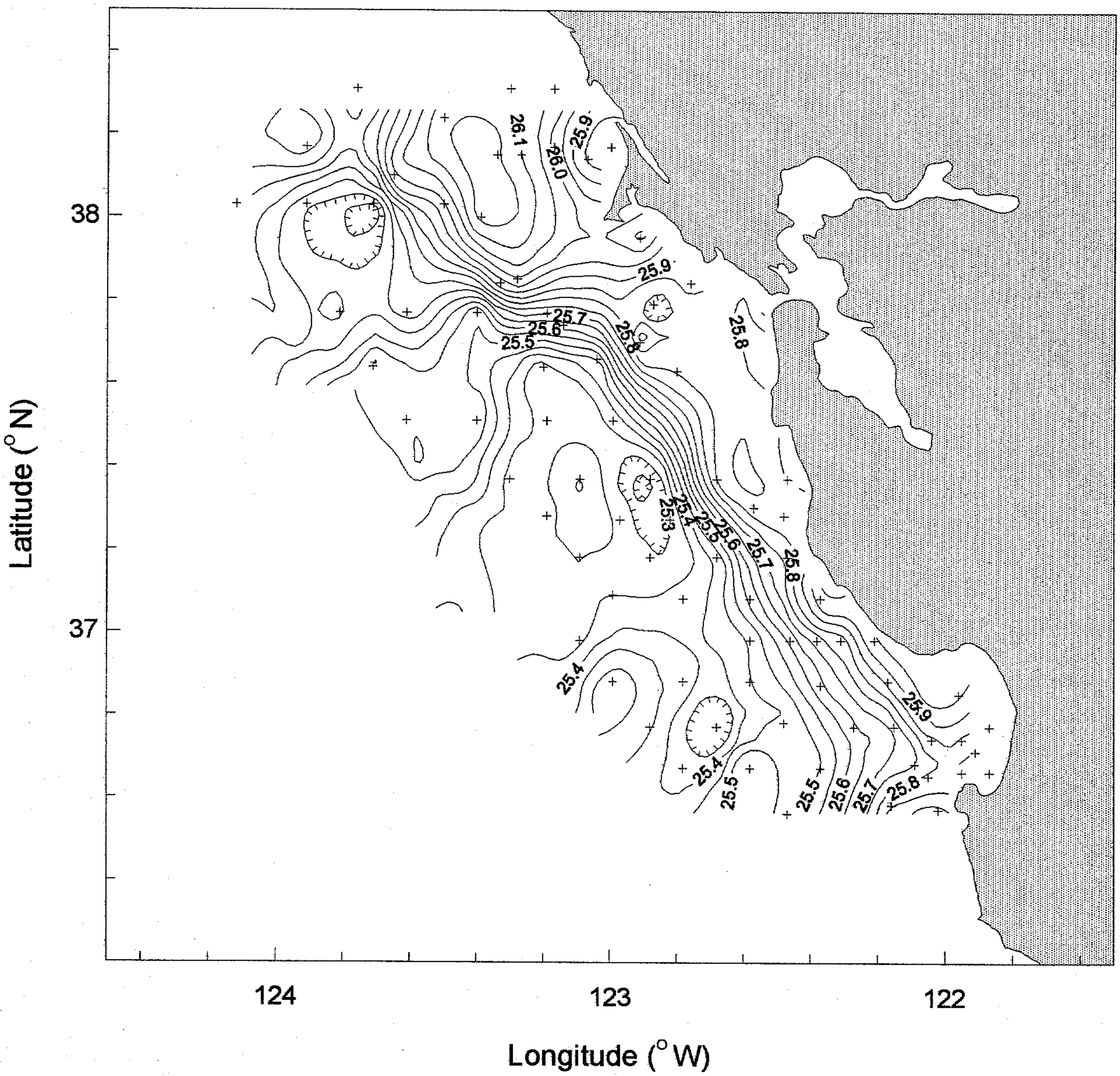
DSJ9105 Sweep 3 Salinity (ppt) at 500 m



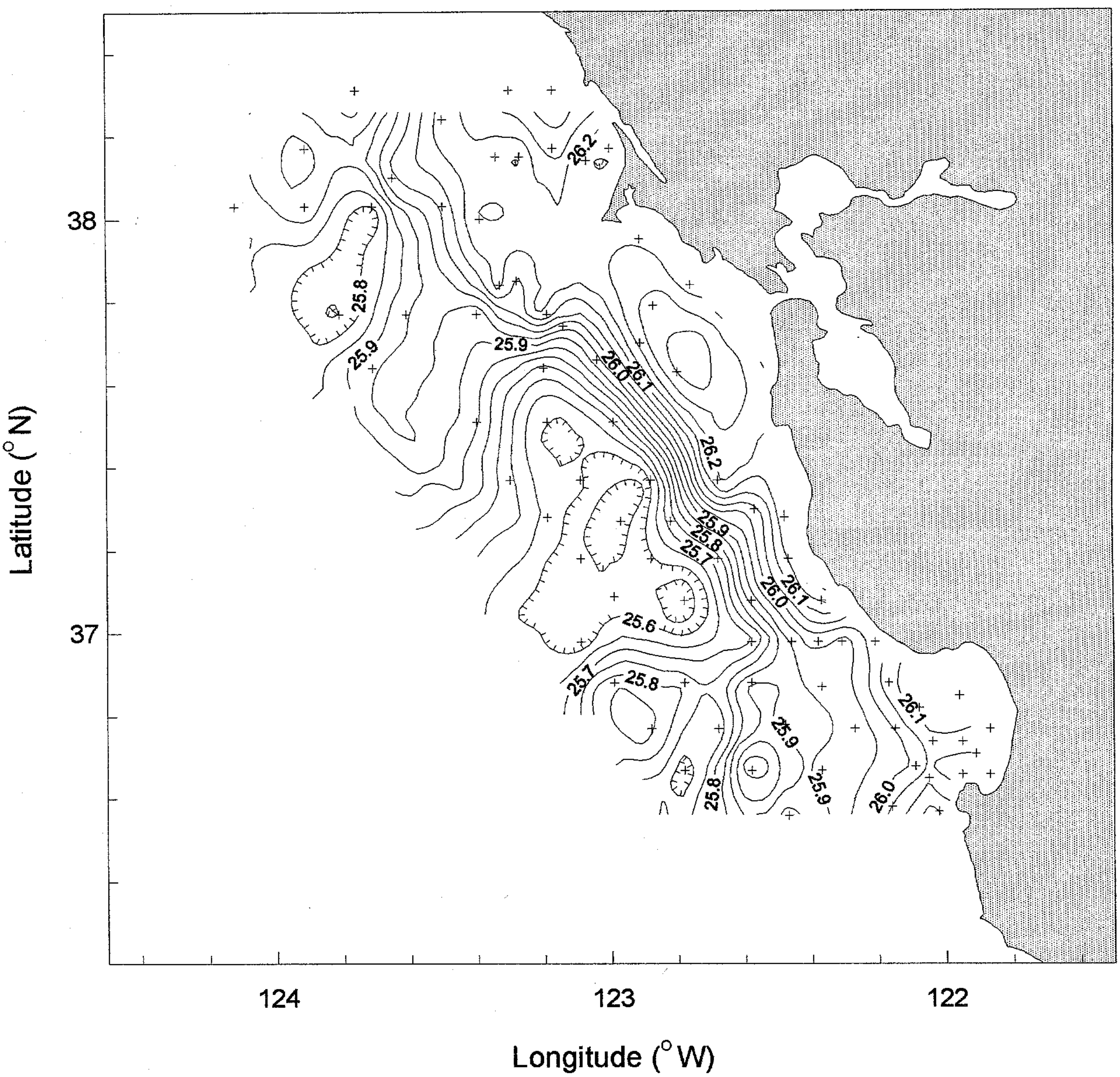
DSJ9105 Sweep 3 Density (kg/m³) at 2 m



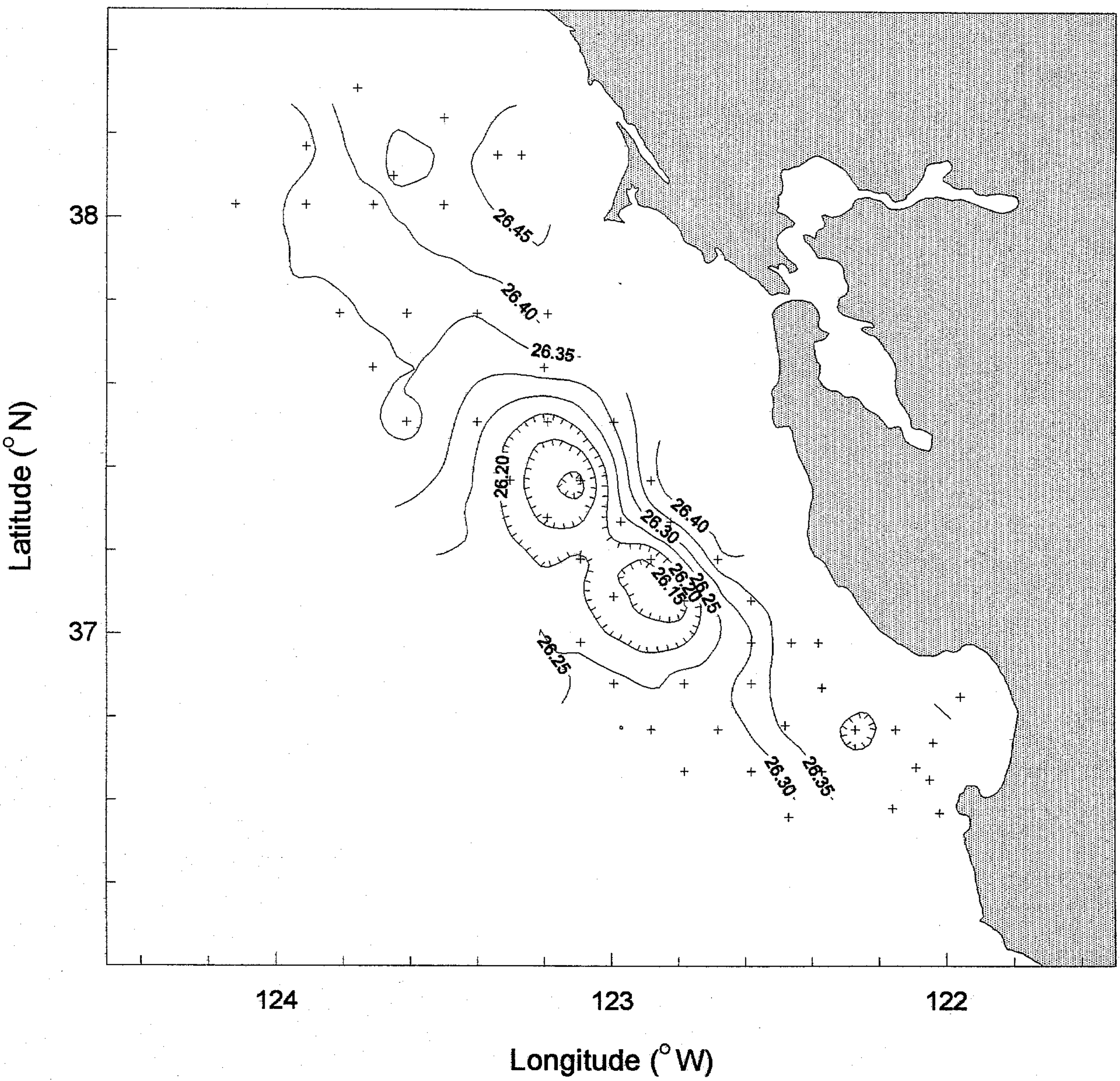
DSJ9105 Sweep 3 Density (kg/m^3) at 10 m

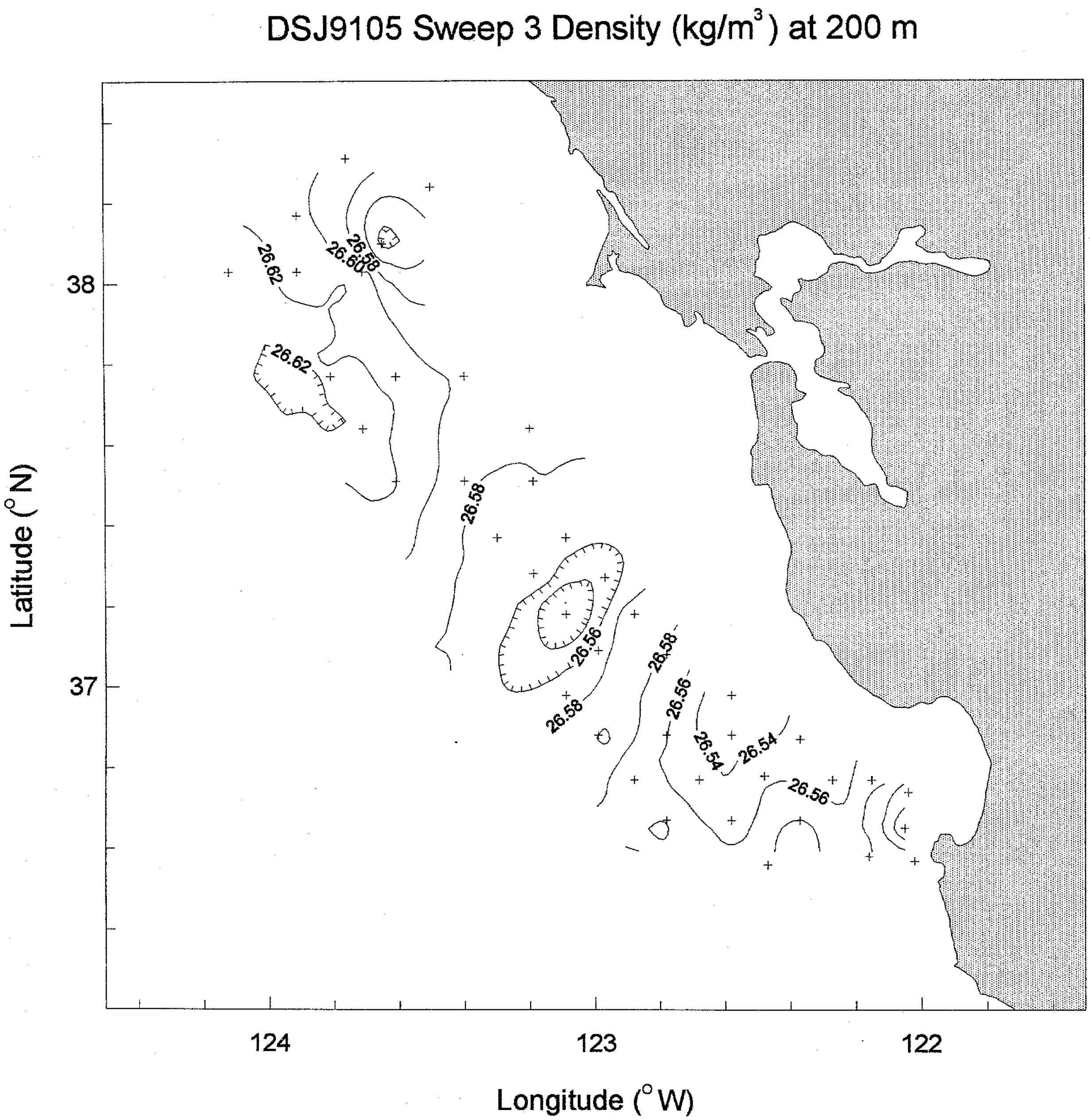


DSJ9105 Sweep 3 Density (kg/m^3) at 30 m



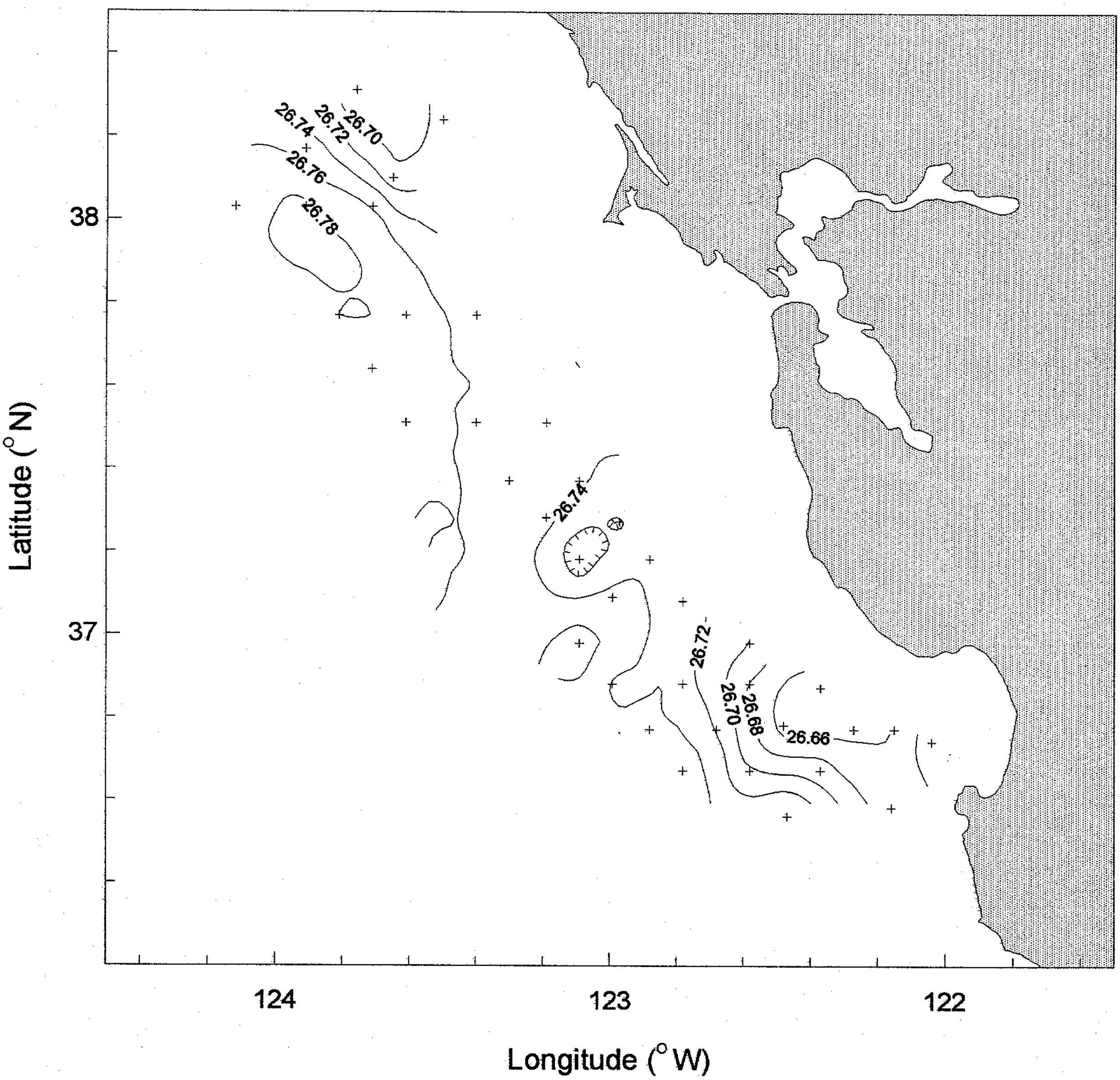
DSJ9105 Sweep 3 Density (kg/m^3) at 100 m



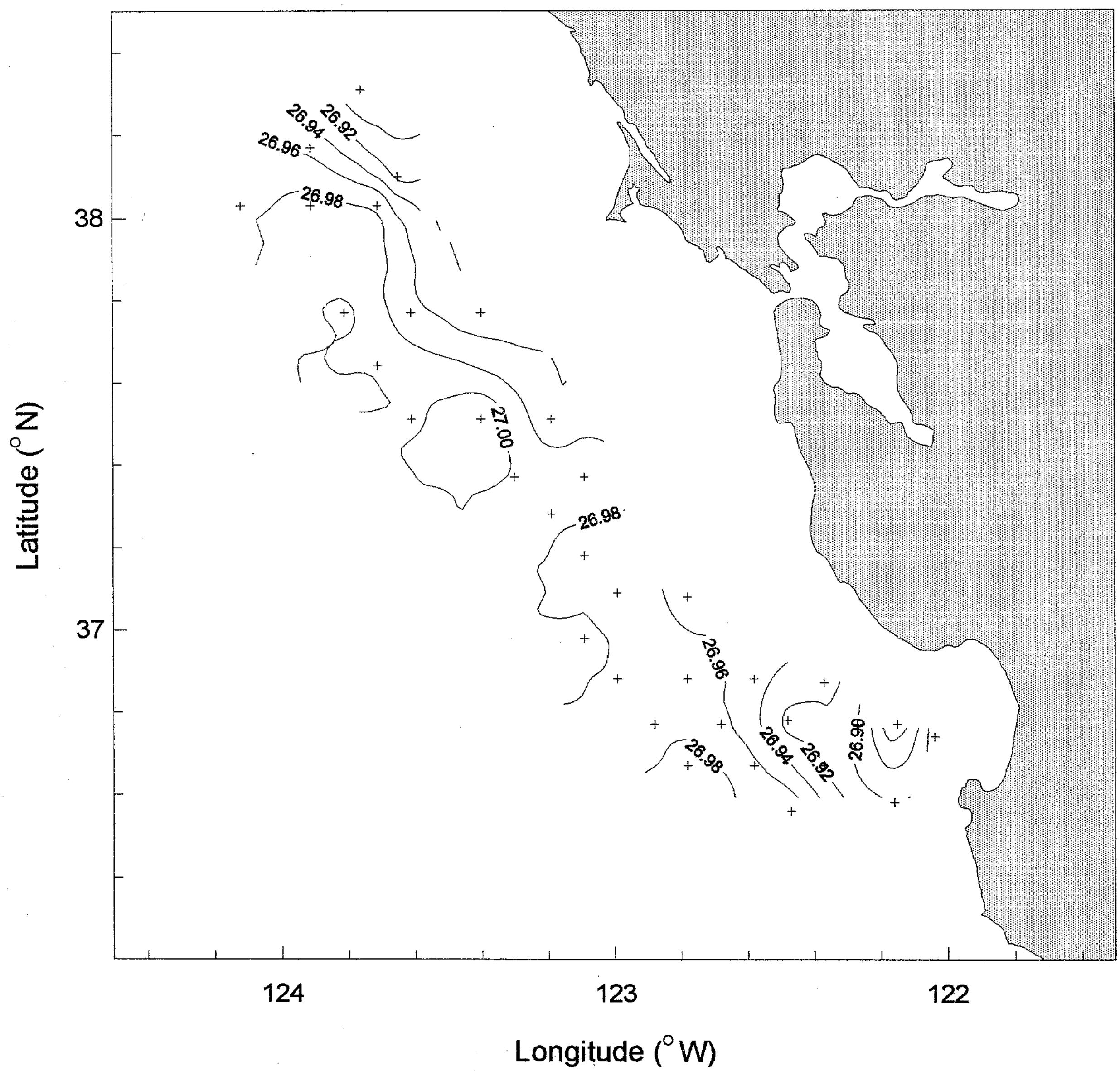


DSJ9105 Sweep 3 Density (kg/m³) at 200 m
38
37
124
123
122
Latitude (°N)
Longitude (°W)
26.62
26.60
26.58
26.62
26.58
26.56
26.58
26.58
26.56
26.54
26.54
26.56

DSJ9105 Sweep 3 Density (kg/m^3) at 300 m

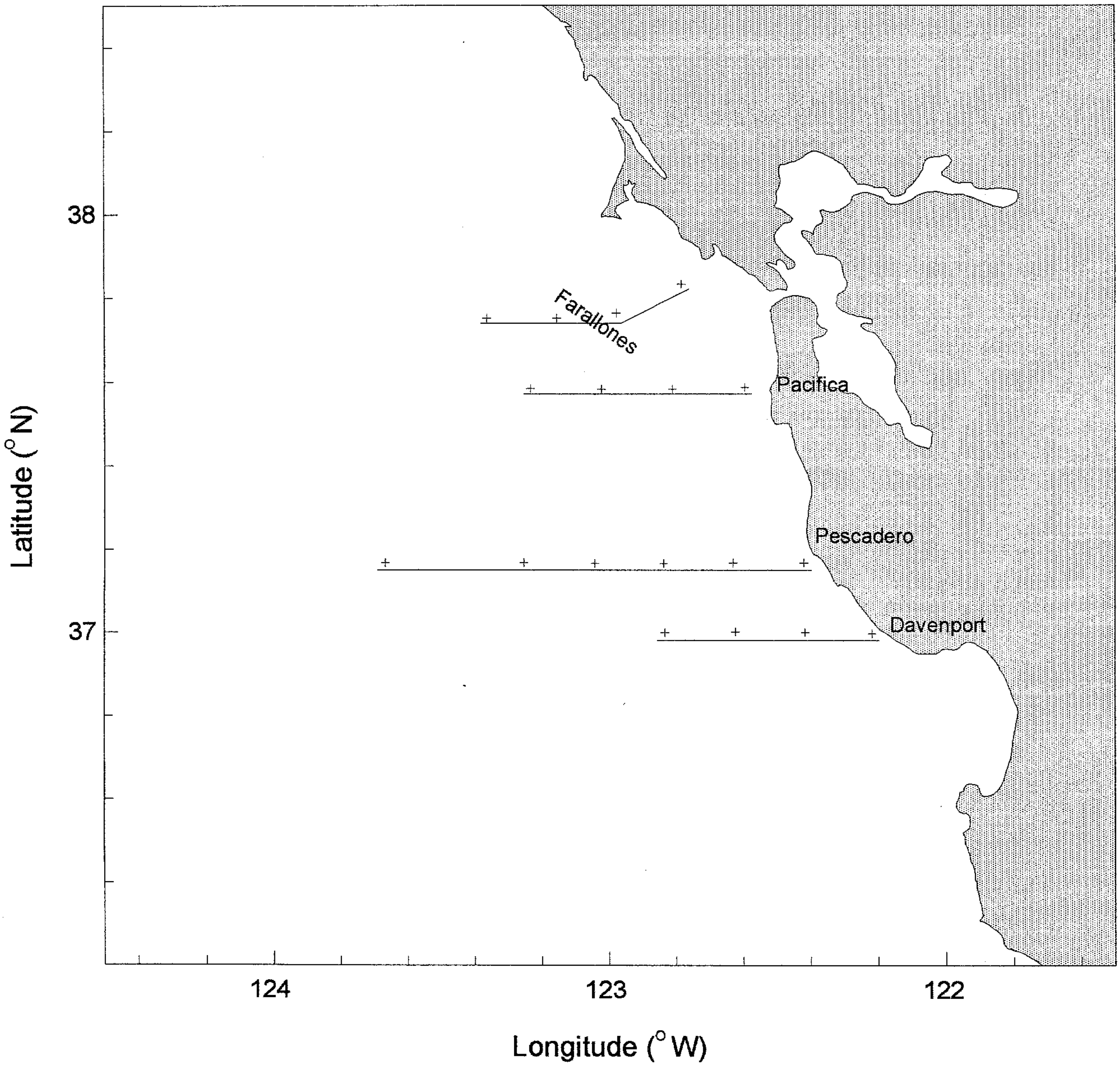


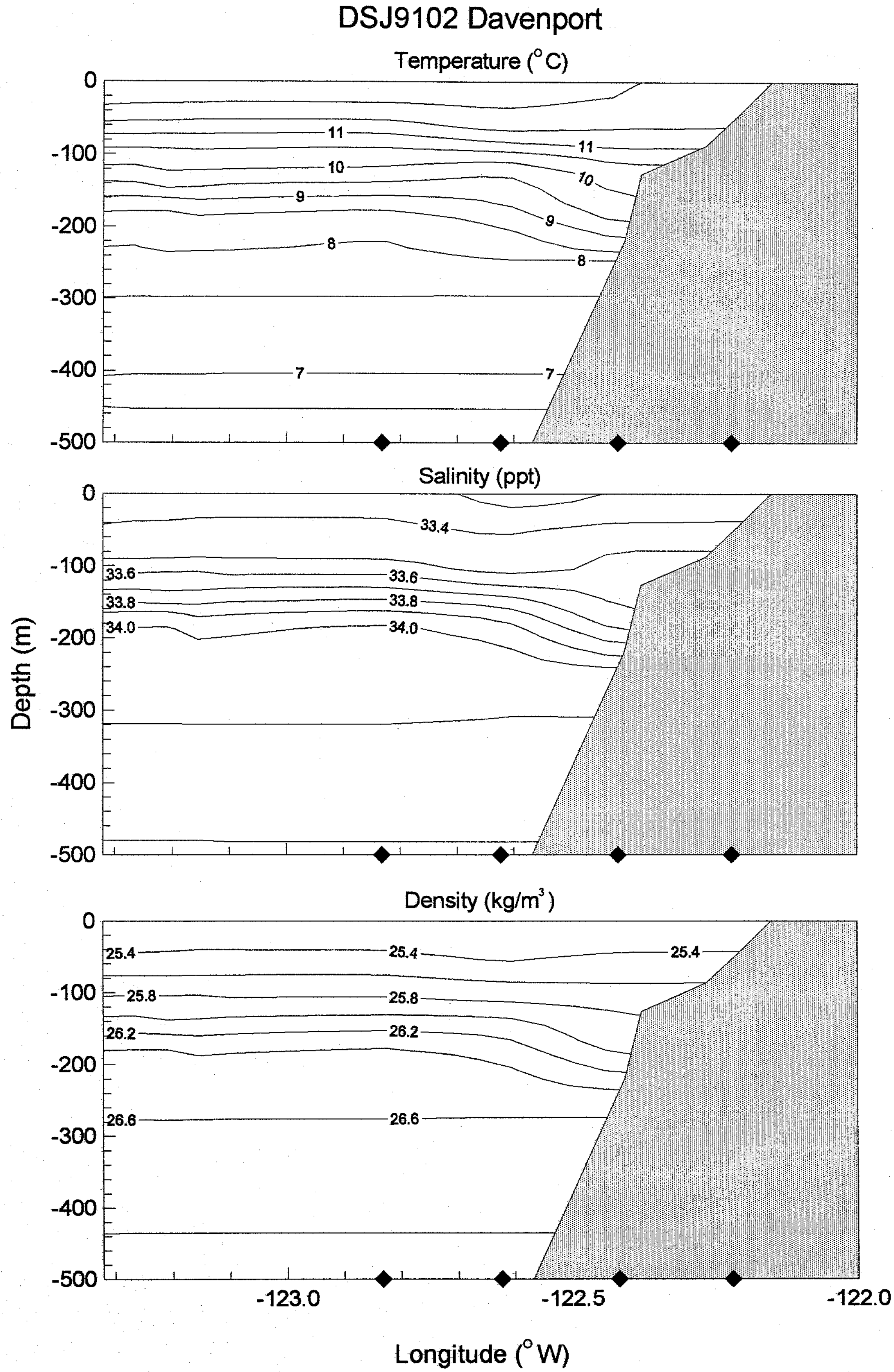
DSJ9105 Sweep 3 Density (kg/m^3) at 500 m

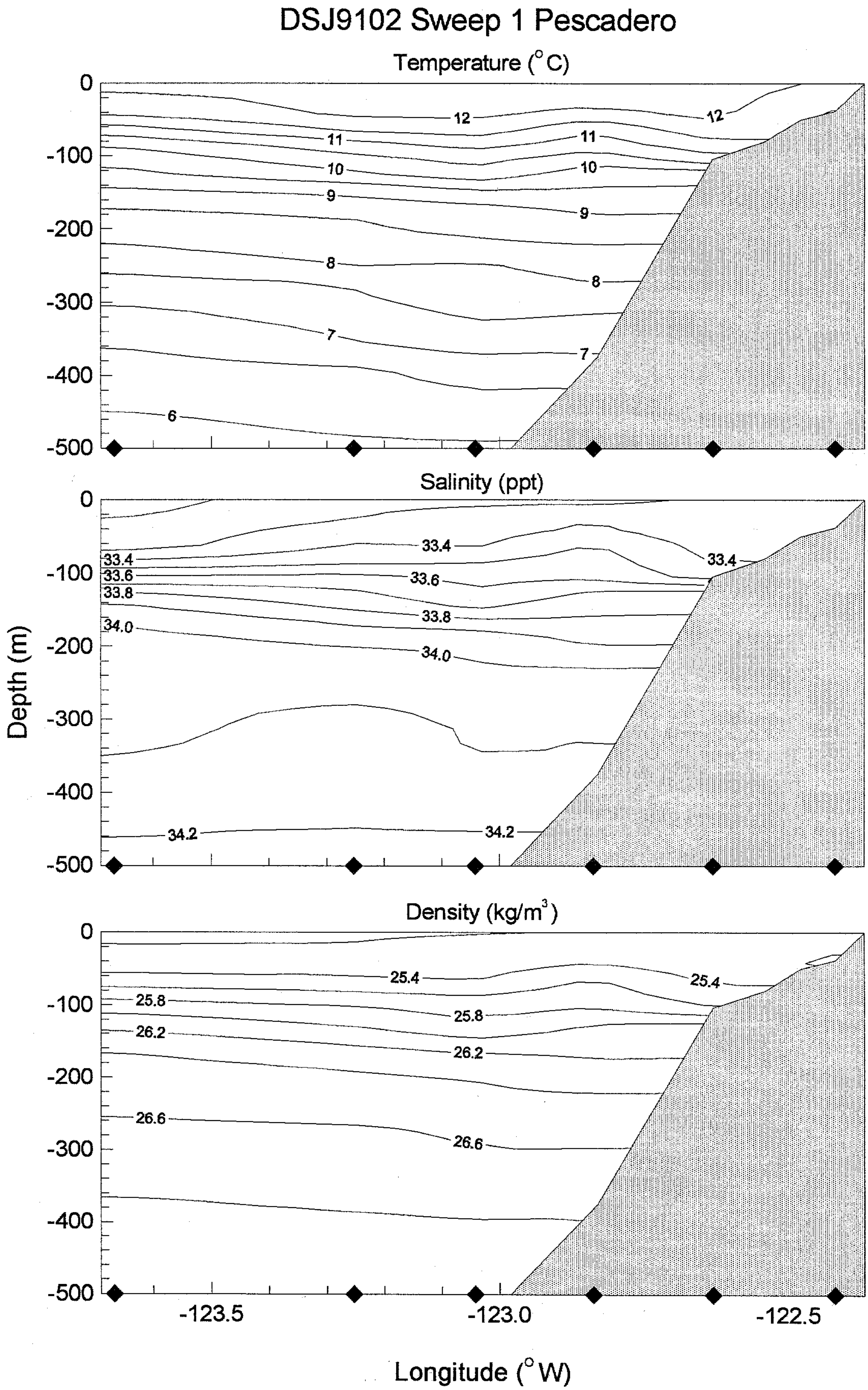


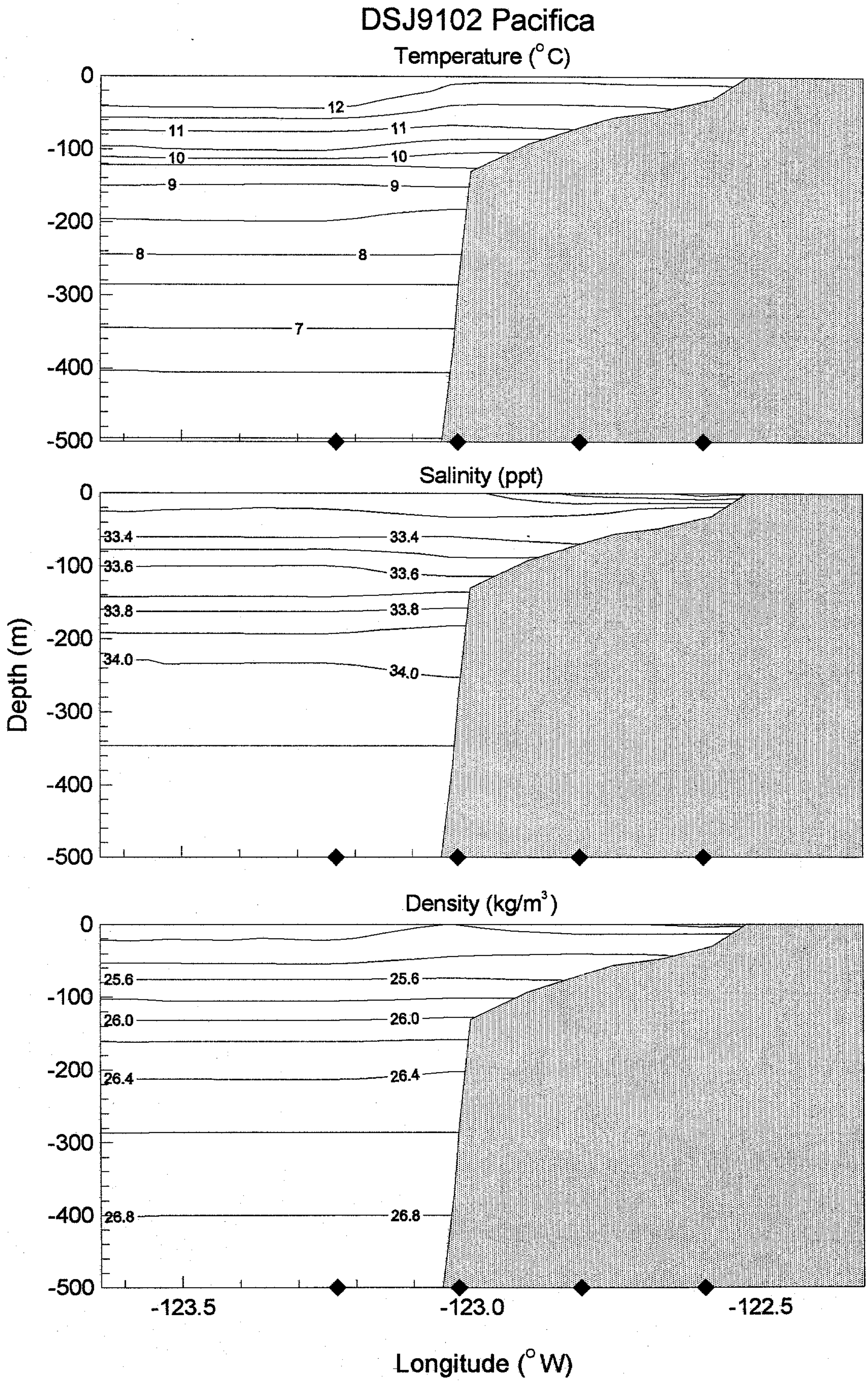
APPENDIX 6.1: VERTICAL TRANSECTS FOR DSJ9102

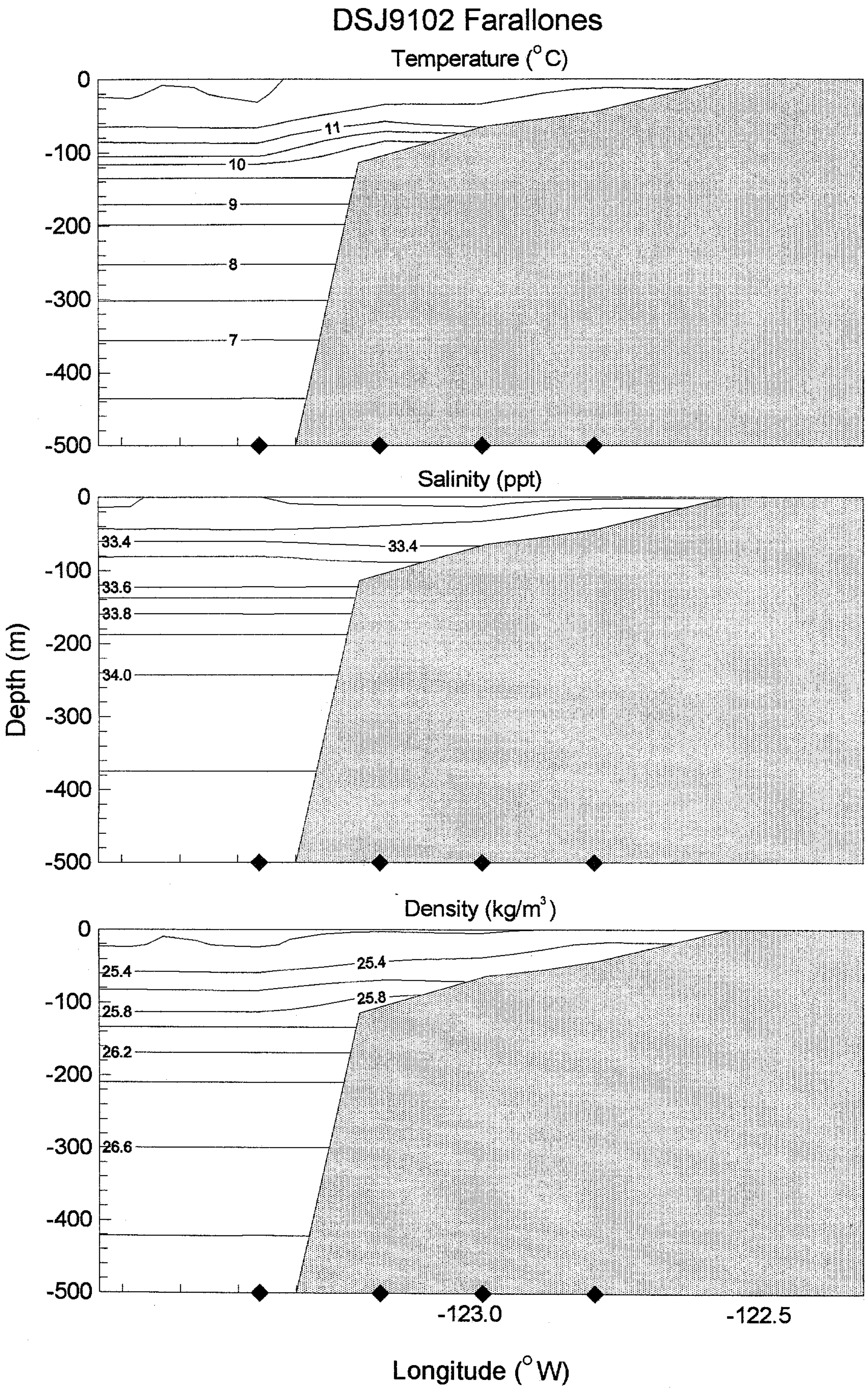
DSJ9102 Vertical Transect Stations



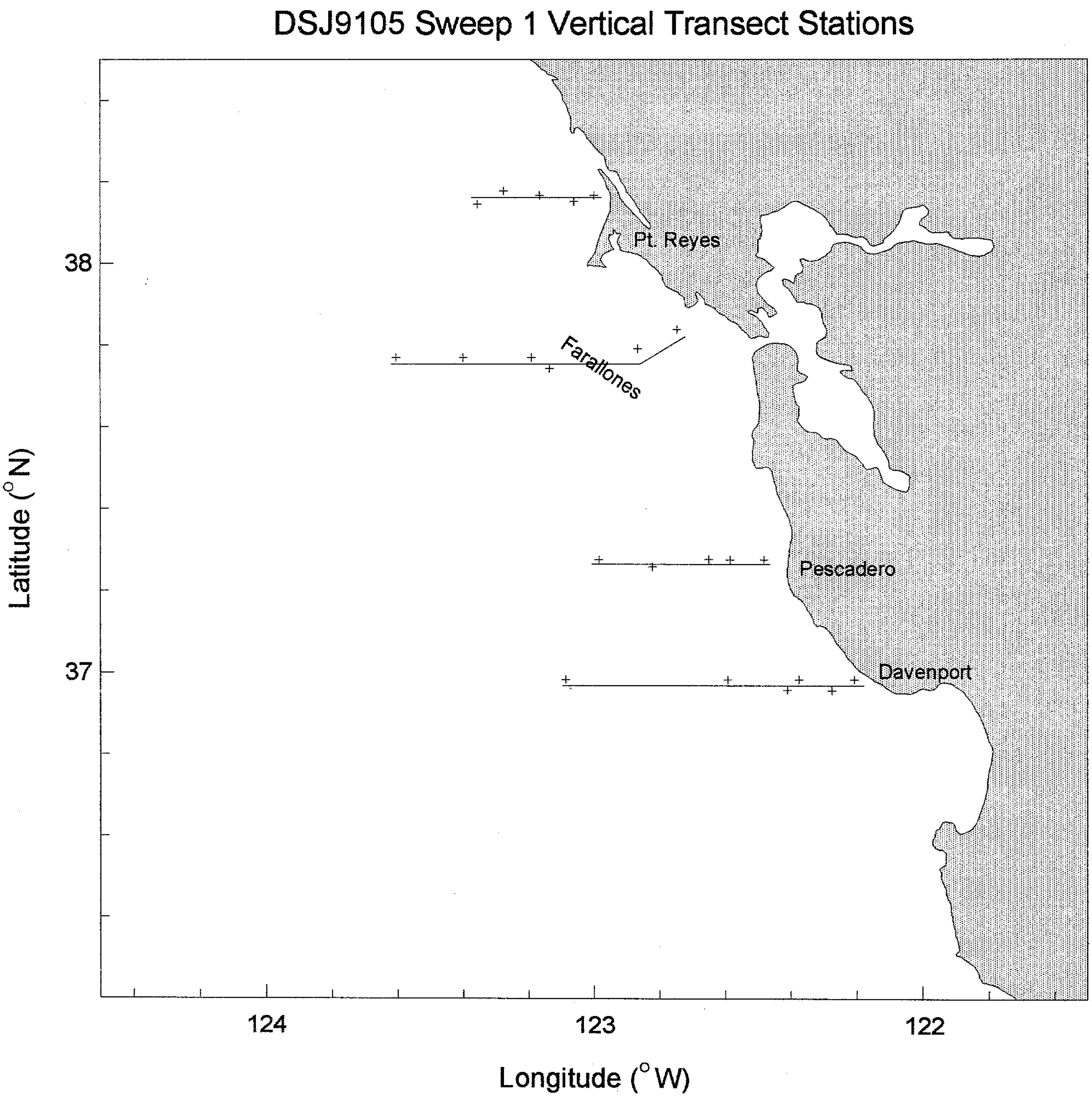

DSJ9102 Davenport
Temperature (°C)
11
11
10
10
9
9
8
8
7
7
Salinity (ppt)
33.4
33.6
33.6
33.8
33.8
34.0
34.0
Density (kg/m³)
25.4
25.4
25.4
25.8
25.8
26.2
26.2
26.6
26.6
Depth (m)
0
-100
-200
-300
-400
-500
-123.0
-122.5
-122.0
Longitude (° W)

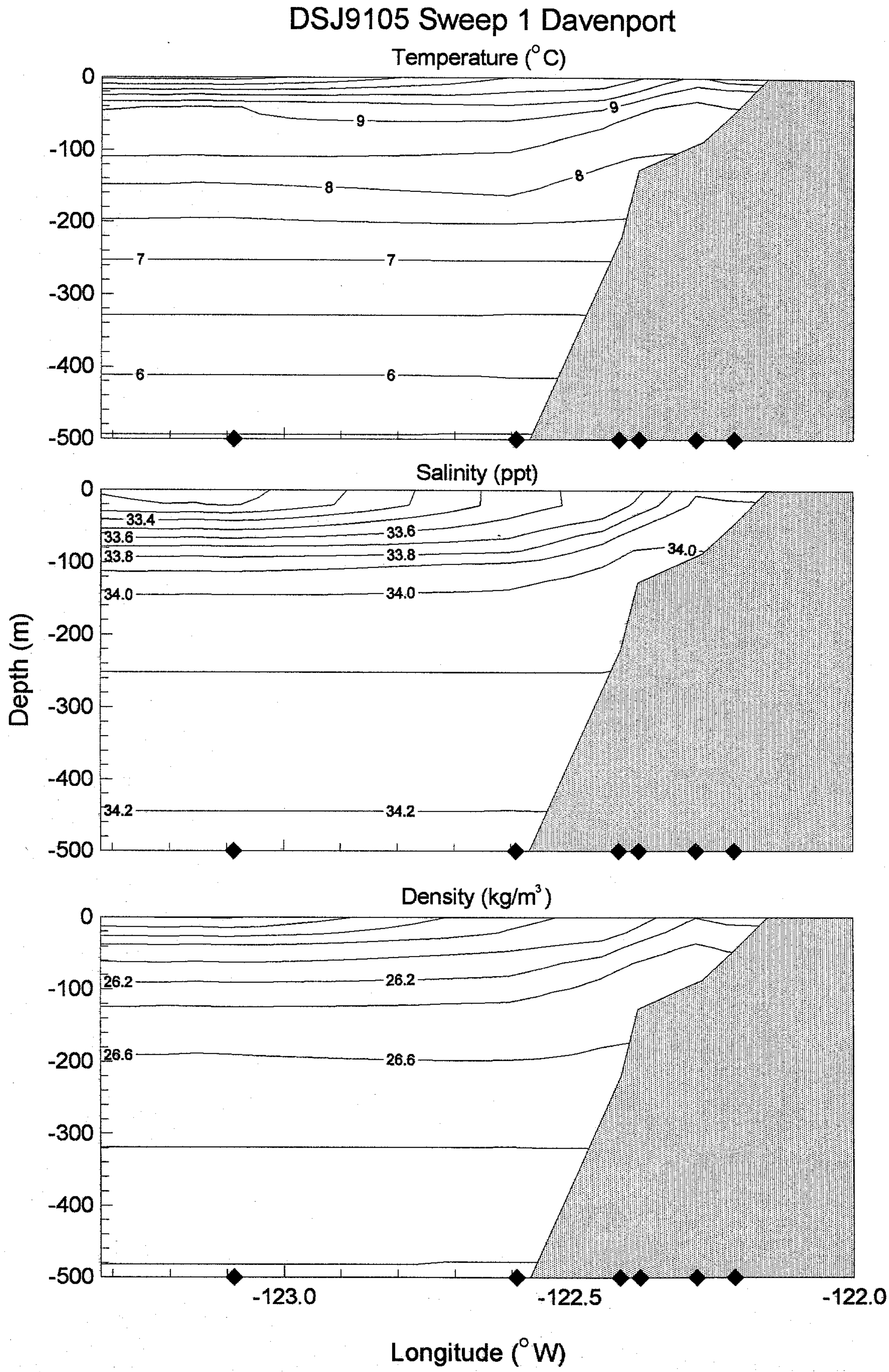

DSJ9102 Sweep 1 Pescadero
Temperature (°C)
Salinity (ppt)
Density (kg/m3)
Depth (m)
Longitude (°W)
0
-100
-200
-300
-400
-500
12
11
10
9
8
7
6
33.4
33.6
33.8
34.0
34.2
25.4
25.8
26.2
26.6
-123.5
-123.0
-122.5


DSJ9102 Pacifica
Temperature (°C)
12
11
11
10
10
9
9
8
8
7
Salinity (ppt)
33.4
33.4
33.6
33.6
33.8
33.8
34.0
34.0
Density (kg/m³)
25.6
25.6
26.0
26.0
26.4
26.4
26.8
26.8
Depth (m)
0
-100
-200
-300
-400
-500
-123.5
-123.0
-122.5
Longitude (°W)

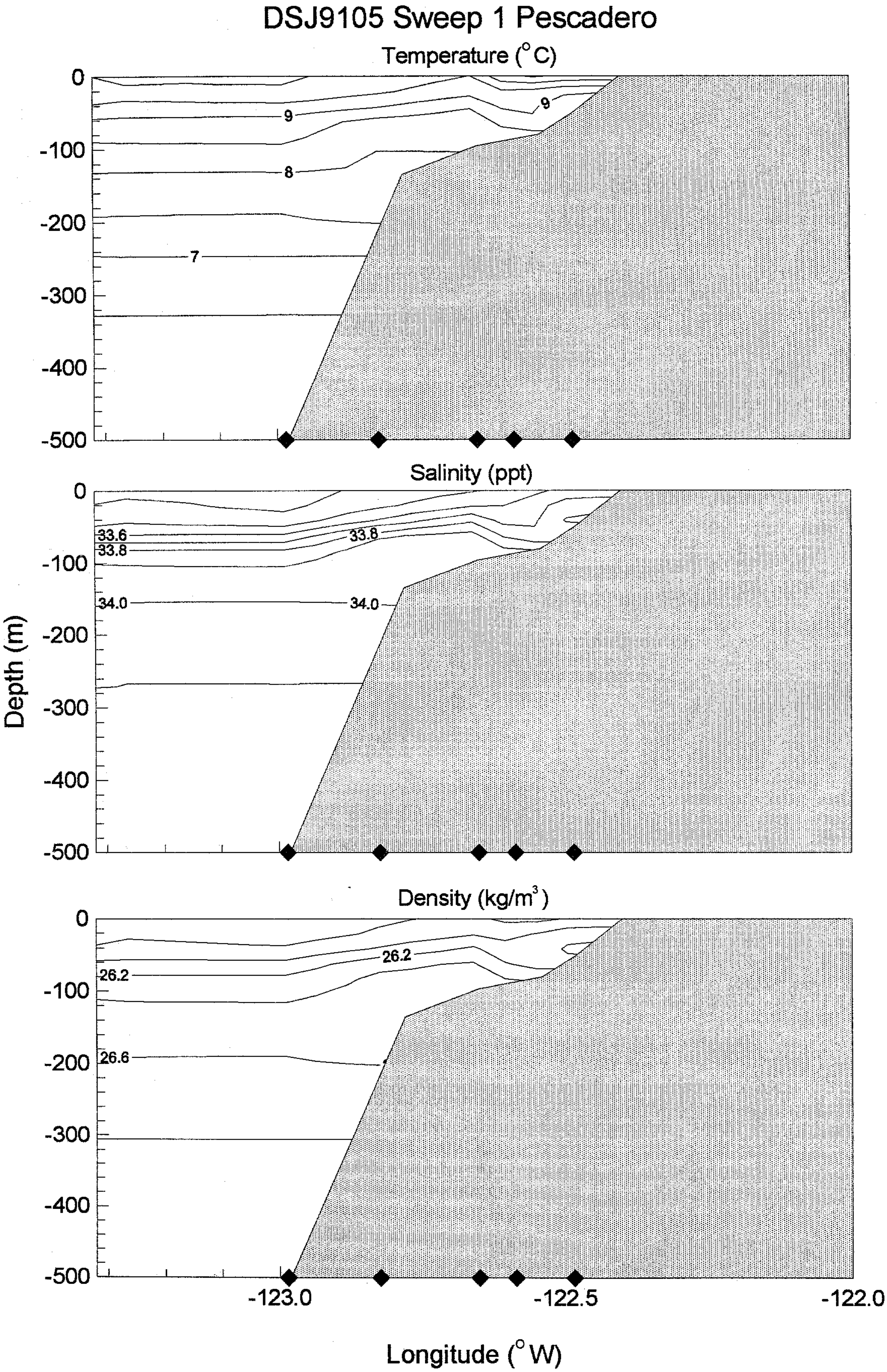

DSJ9102 Farallones
Temperature (°C)
11
10
9
8
7
Salinity (ppt)
33.4
33.4
33.6
33.8
34.0
Density (kg/m³)
25.4
25.4
25.8
25.8
26.2
26.6
Depth (m)
0
-100
-200
-300
-400
-500
-123.0
-122.5
Longitude (°W)

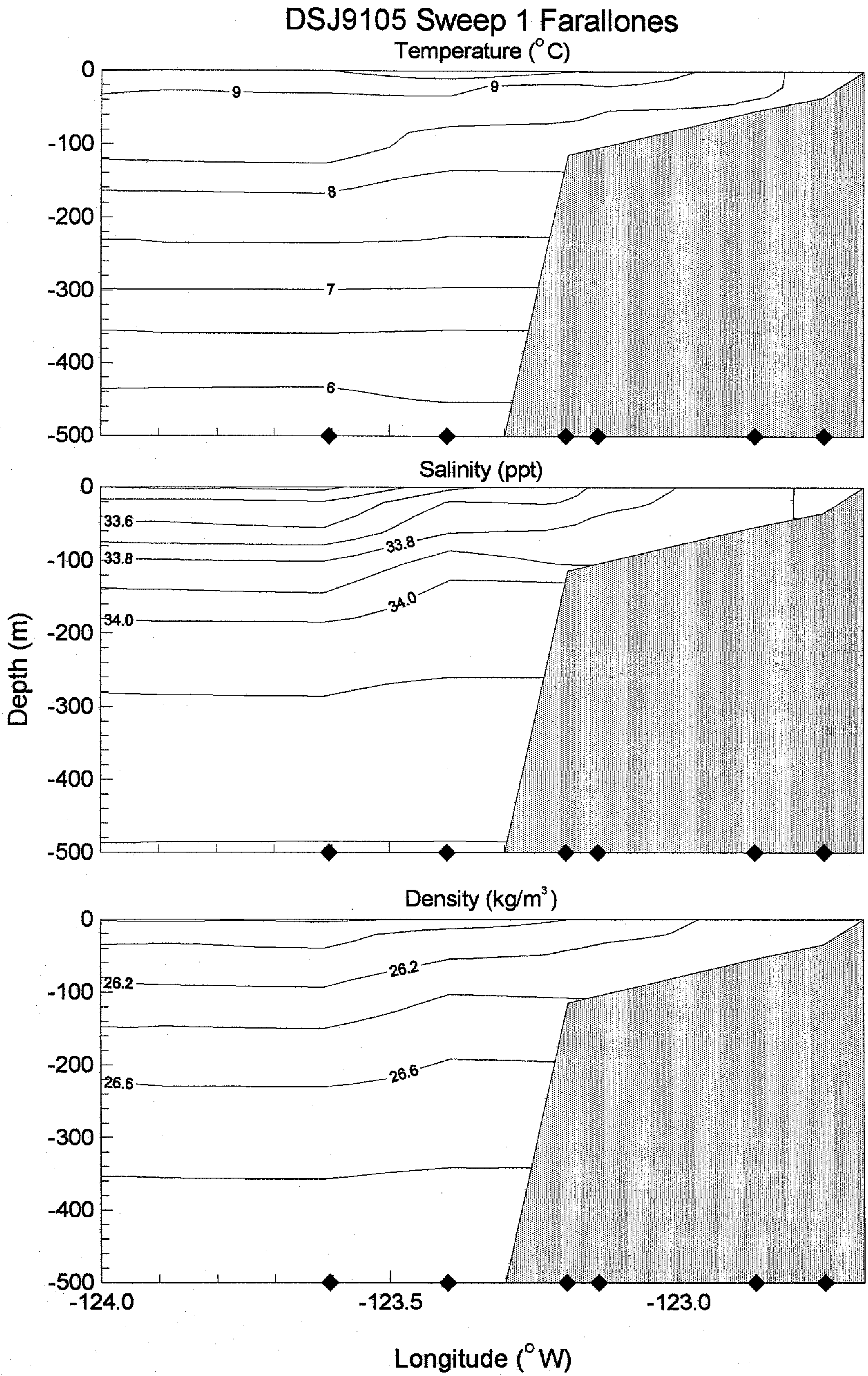
APPENDIX 6.2: VERTICAL TRANSECTS FOR DSJ9105

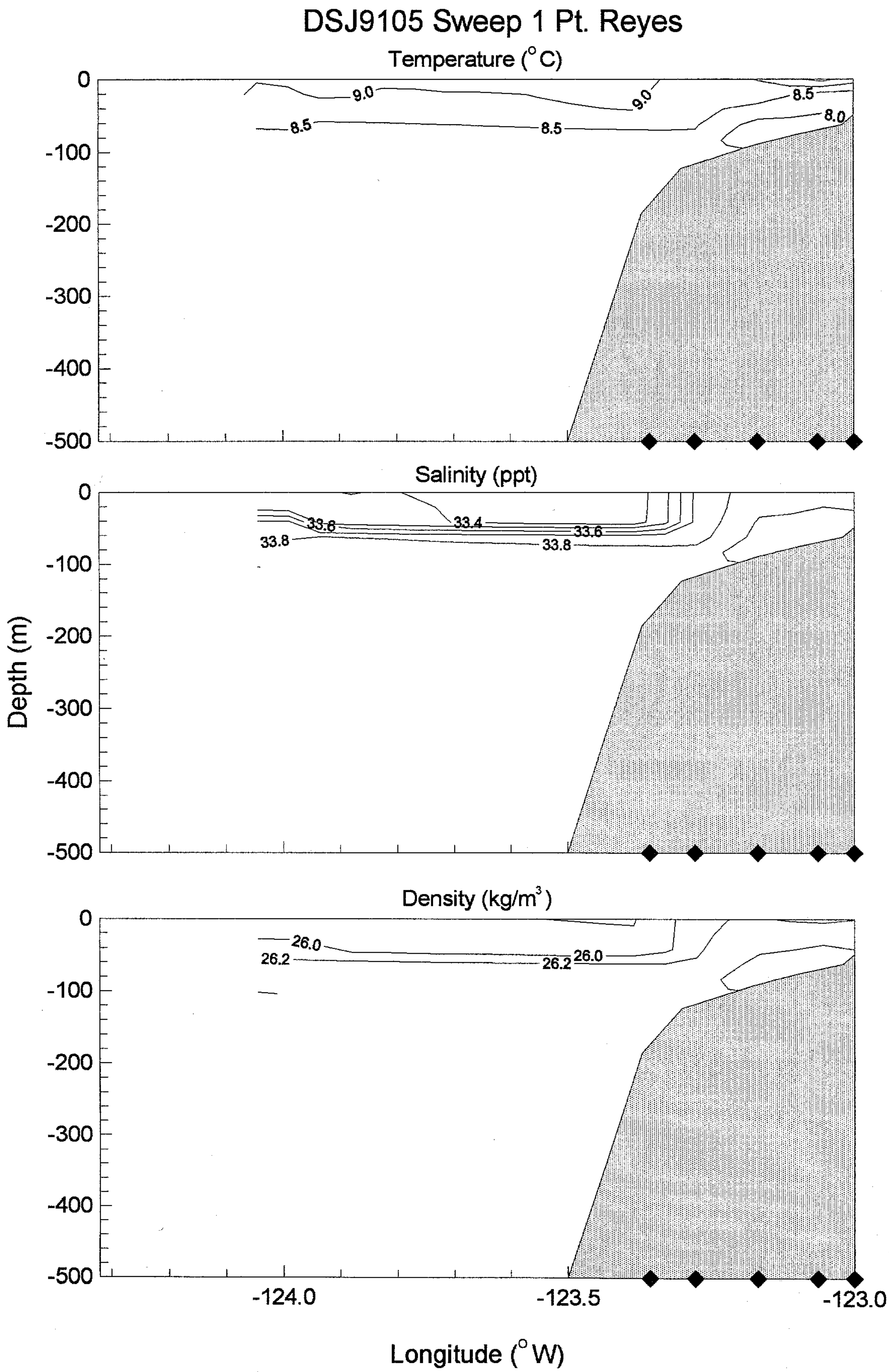

DSJ9105 Sweep 1 Vertical Transect Stations
Pt. Reyes
Farallones
Pescadero
Davenport
38
37
Latitude (° N)
124
123
122
Longitude (° W)



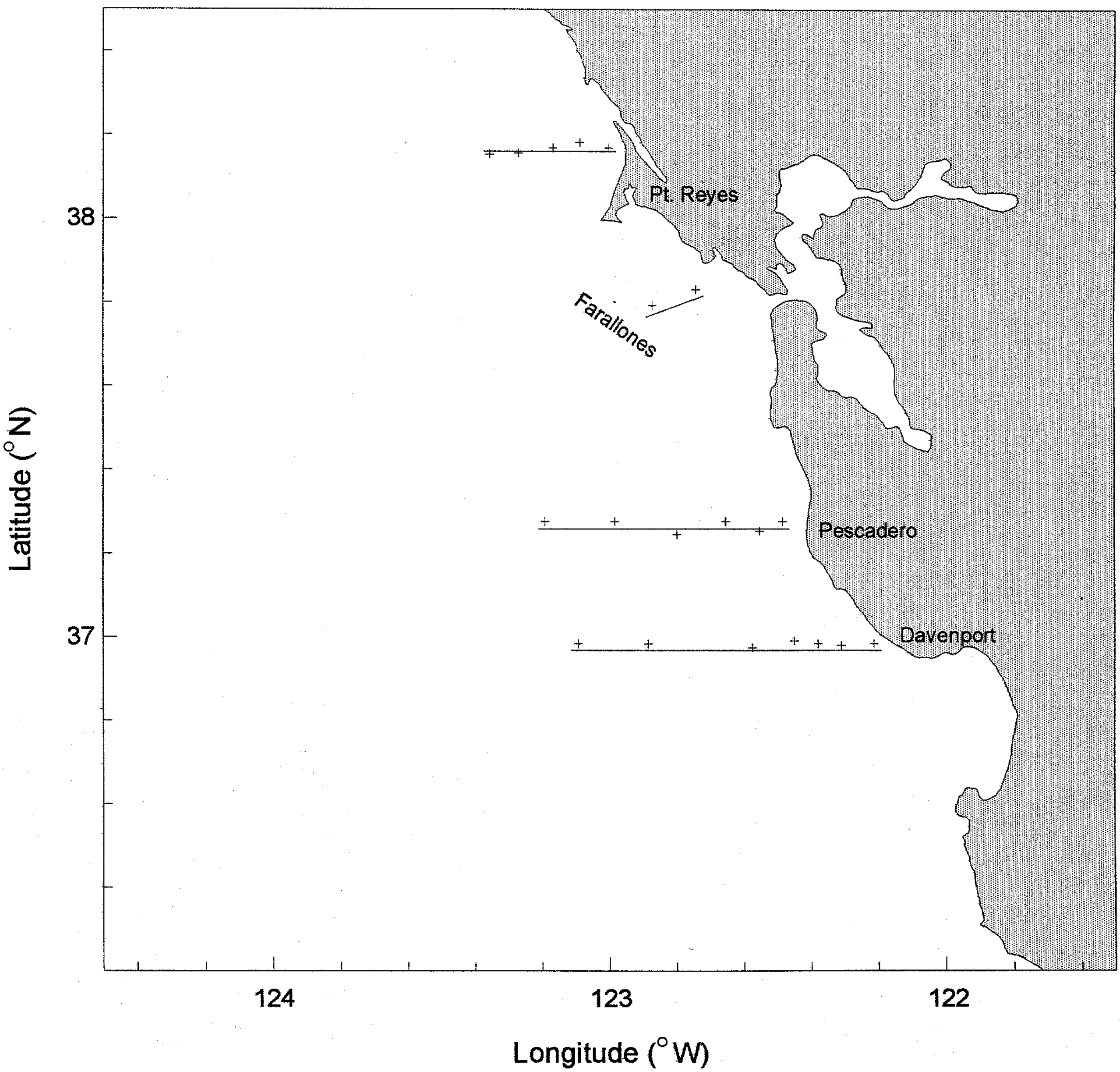
DSJ9105 Sweep 1 Davenport
Temperature (°C)
Salinity (ppt)
Density (kg/m³)
Depth (m)
Longitude (° W)
0
-100
-200
-300
-400
-500
9
8
7
6
33.4
33.6
33.8
34.0
34.2
26.2
26.6
-123.0
-122.5
-122.0

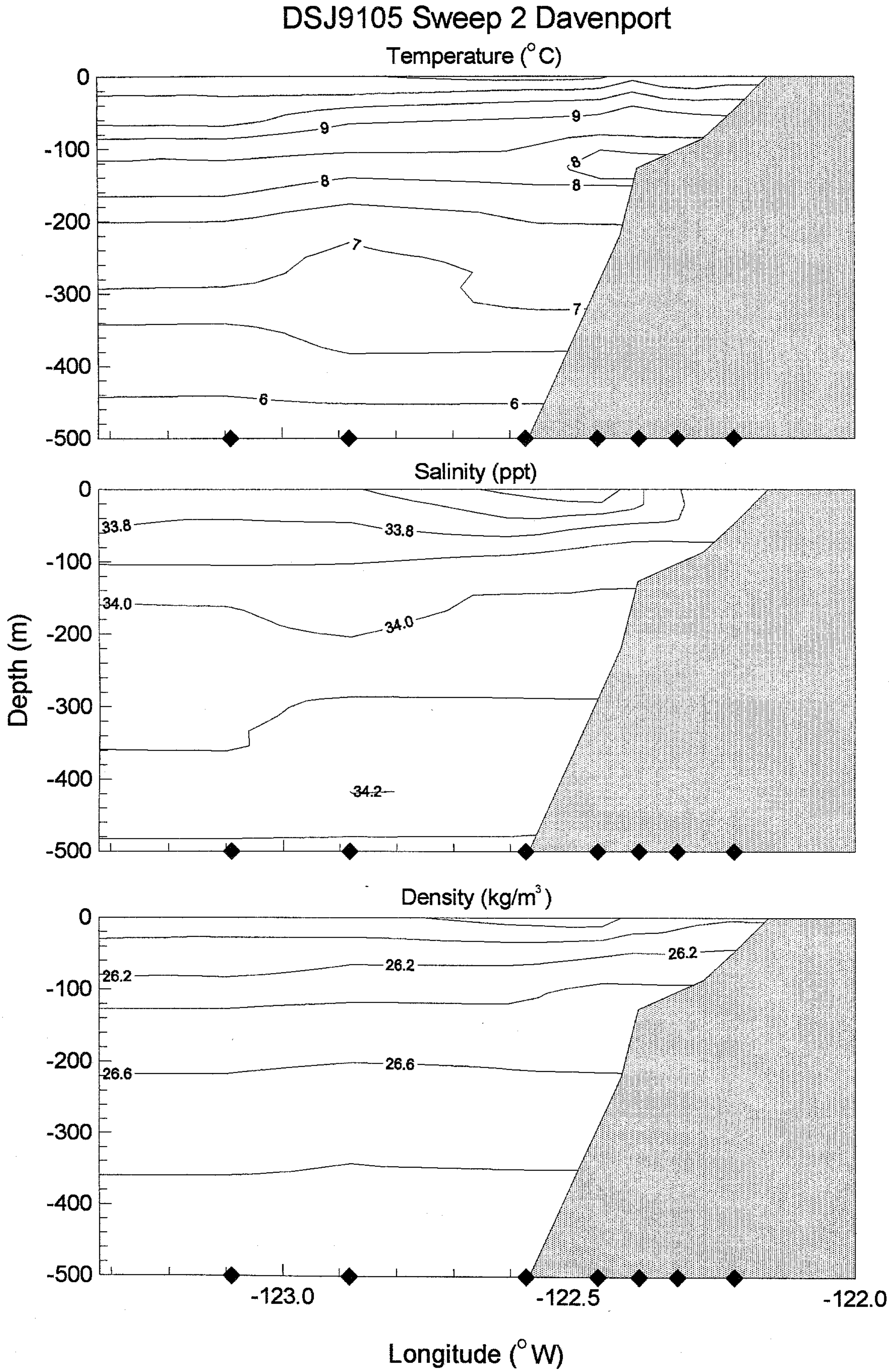

DSJ9105 Sweep 1 Pescadero
Temperature (°C)
9
9
8
7
Salinity (ppt)
33.6
33.8
33.8
34.0
34.0
Density (kg/m³)
26.2
26.2
26.6
Depth (m)
0
-100
-200
-300
-400
-500
-123.0
-122.5
-122.0
Longitude (°W)


DSJ9105 Sweep 1 Farallones
Temperature (°C)
Salinity (ppt)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
-100
-200
-300
-400
-500
9
8
7
6
33.6
33.8
34.0
26.2
26.6
-124.0
-123.5
-123.0

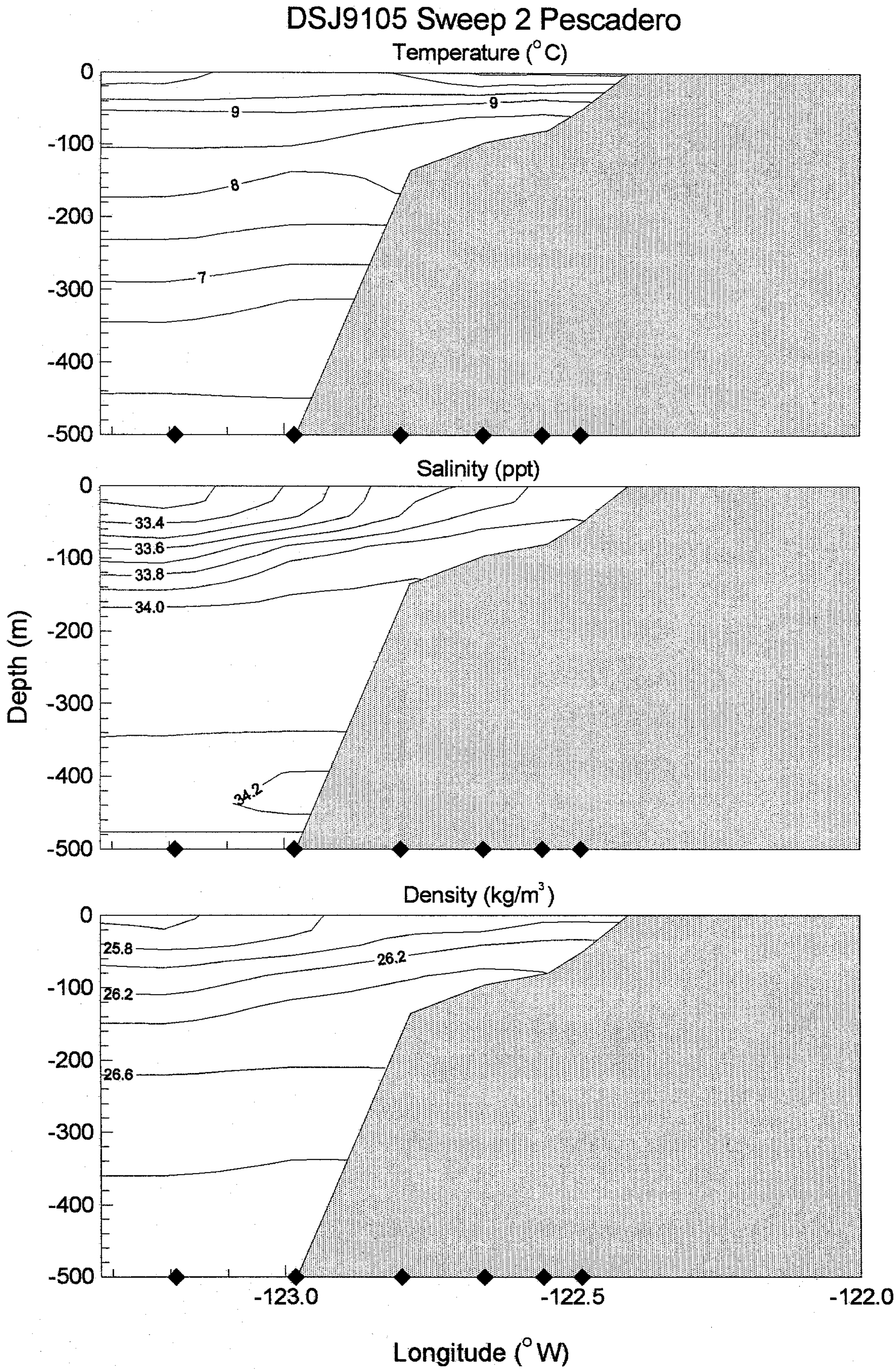

DSJ9105 Sweep 1 Pt. Reyes
Temperature (°C)
9.0
9.0
8.5
8.5
8.5
8.0
Salinity (ppt)
33.6
33.4
33.6
33.8
33.8
Density (kg/m³)
26.0
26.2
26.2
26.0
Depth (m)
0
-100
-200
-300
-400
-500
-124.0
-123.5
-123.0
Longitude (°W)

DSJ9105 Sweep 2 Vertical Transect Stations

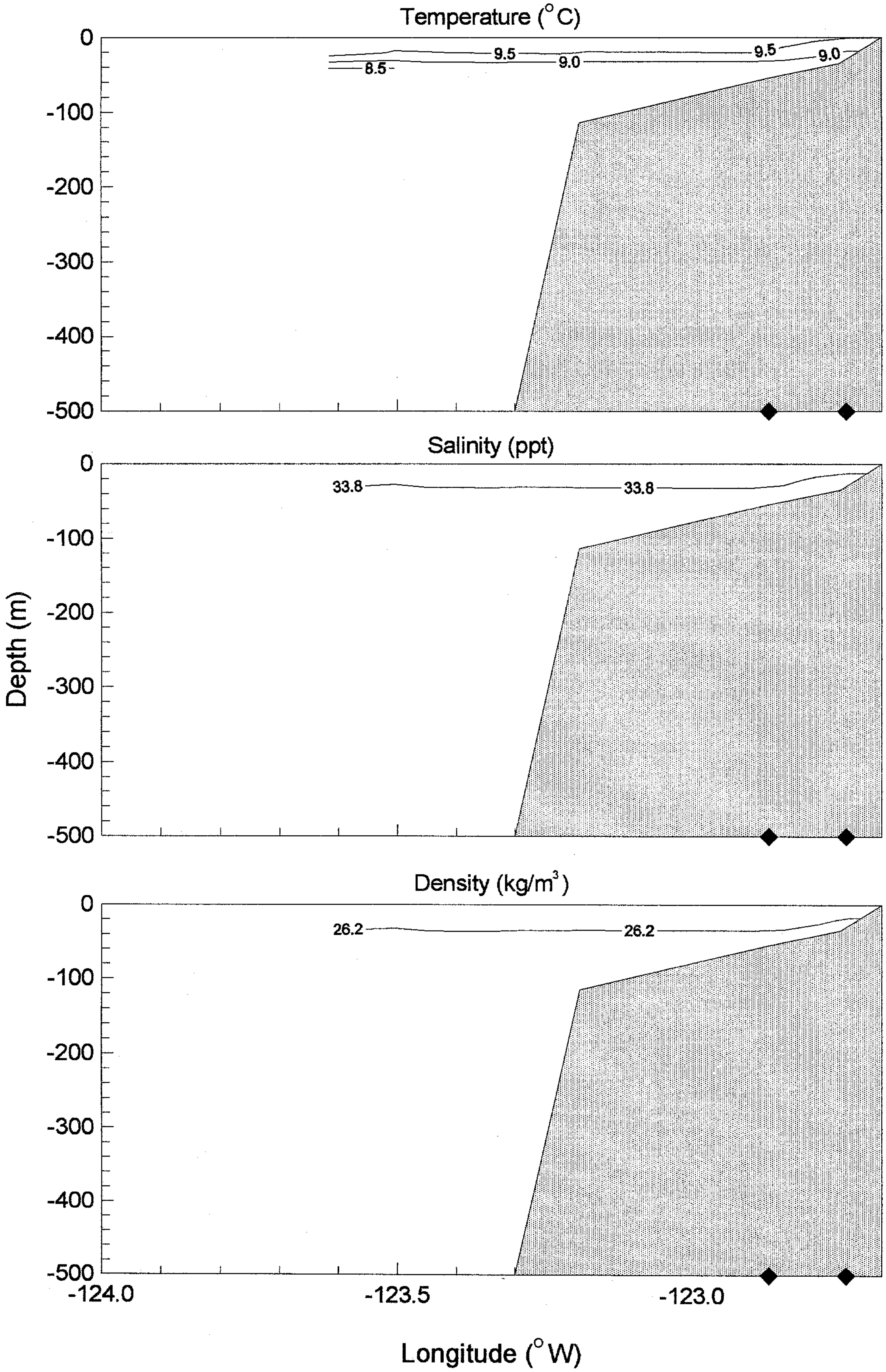


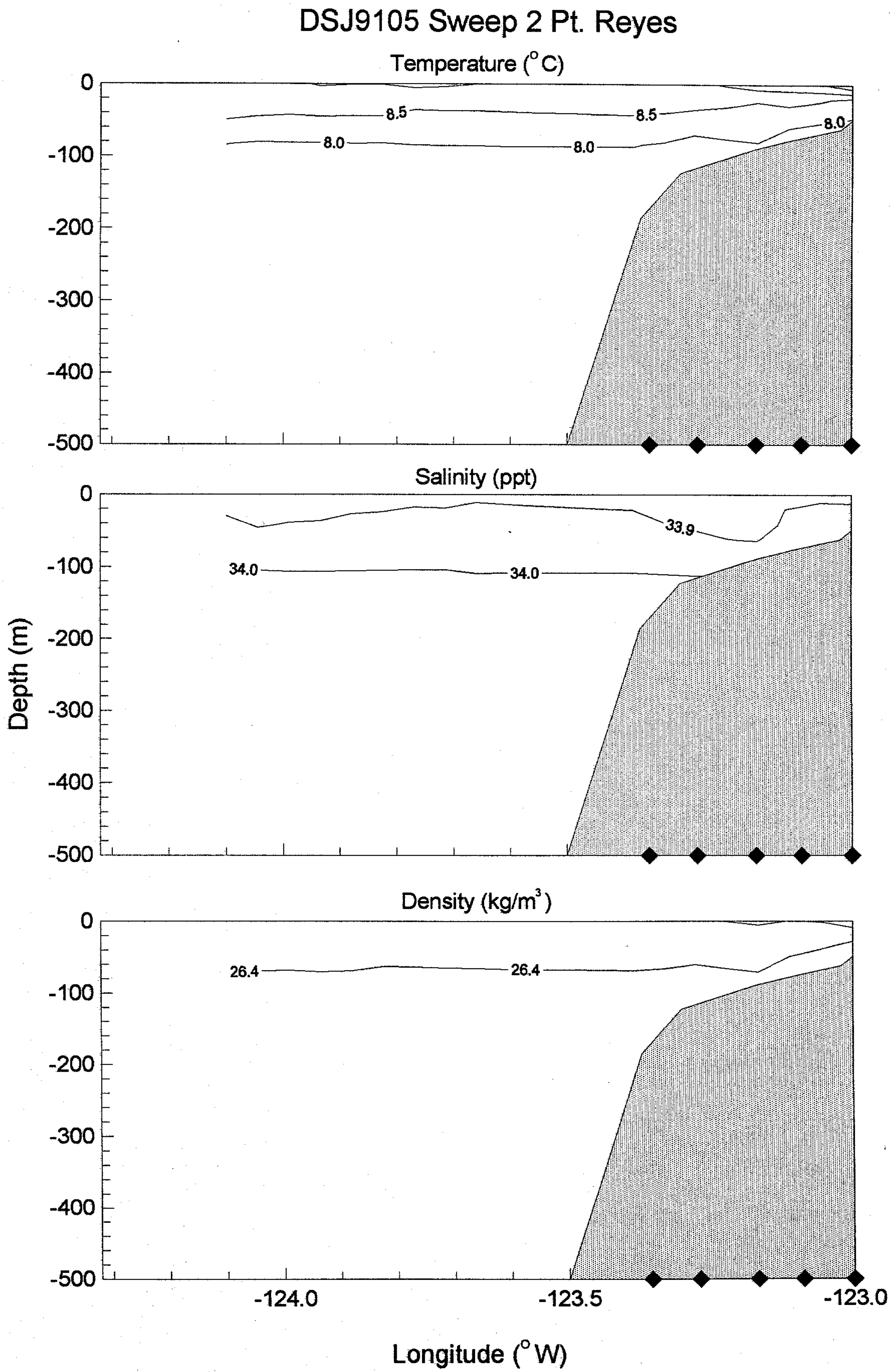


DSJ9105 Sweep 2 Davenport
Temperature (°C)
Salinity (ppt)
Density (kg/m³)
Depth (m)
Longitude (° W)
0
-100
-200
-300
-400
-500
9
8
7
6
33.8
34.0
34.2
26.2
26.6
-123.0
-122.5
-122.0

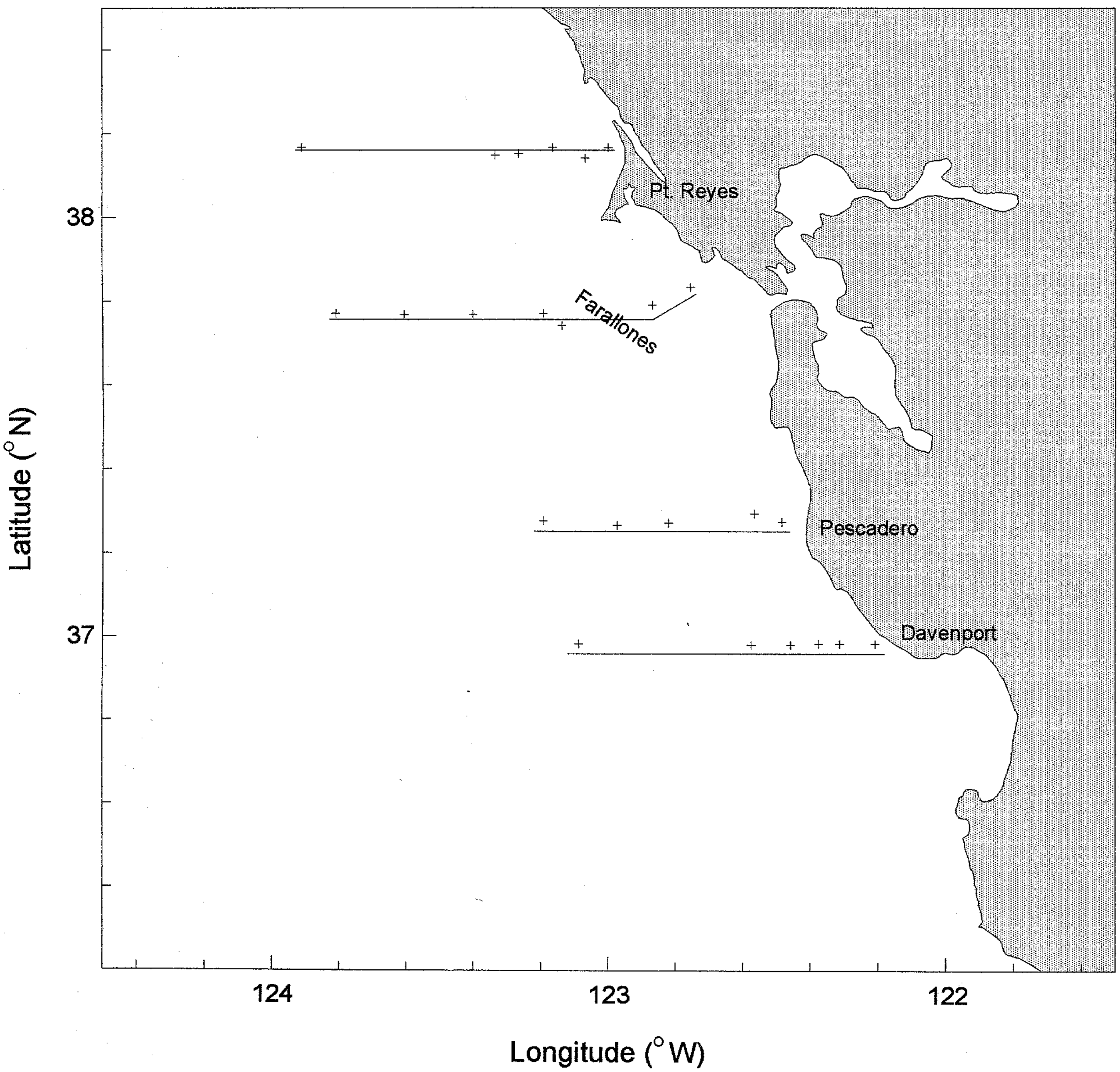

DSJ9105 Sweep 2 Pescadero
Temperature (°C)
9
9
8
7
Salinity (ppt)
33.4
33.6
33.8
34.0
34.2
Density (kg/m³)
25.8
26.2
26.2
26.6
Depth (m)
0
-100
-200
-300
-400
-500
-123.0
-122.5
-122.0
Longitude (°W)

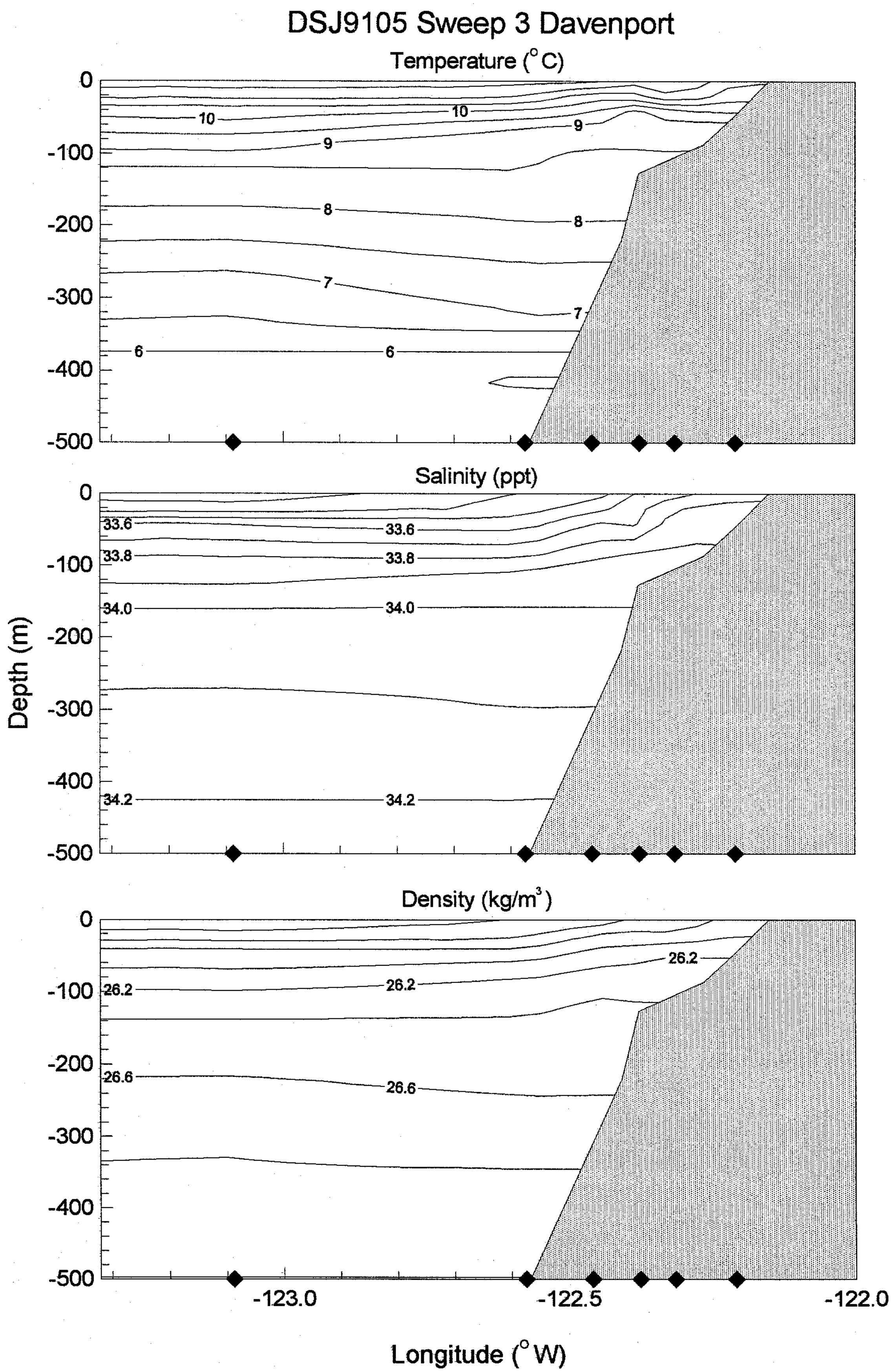
DSJ9105 Sweep 2 Farallones



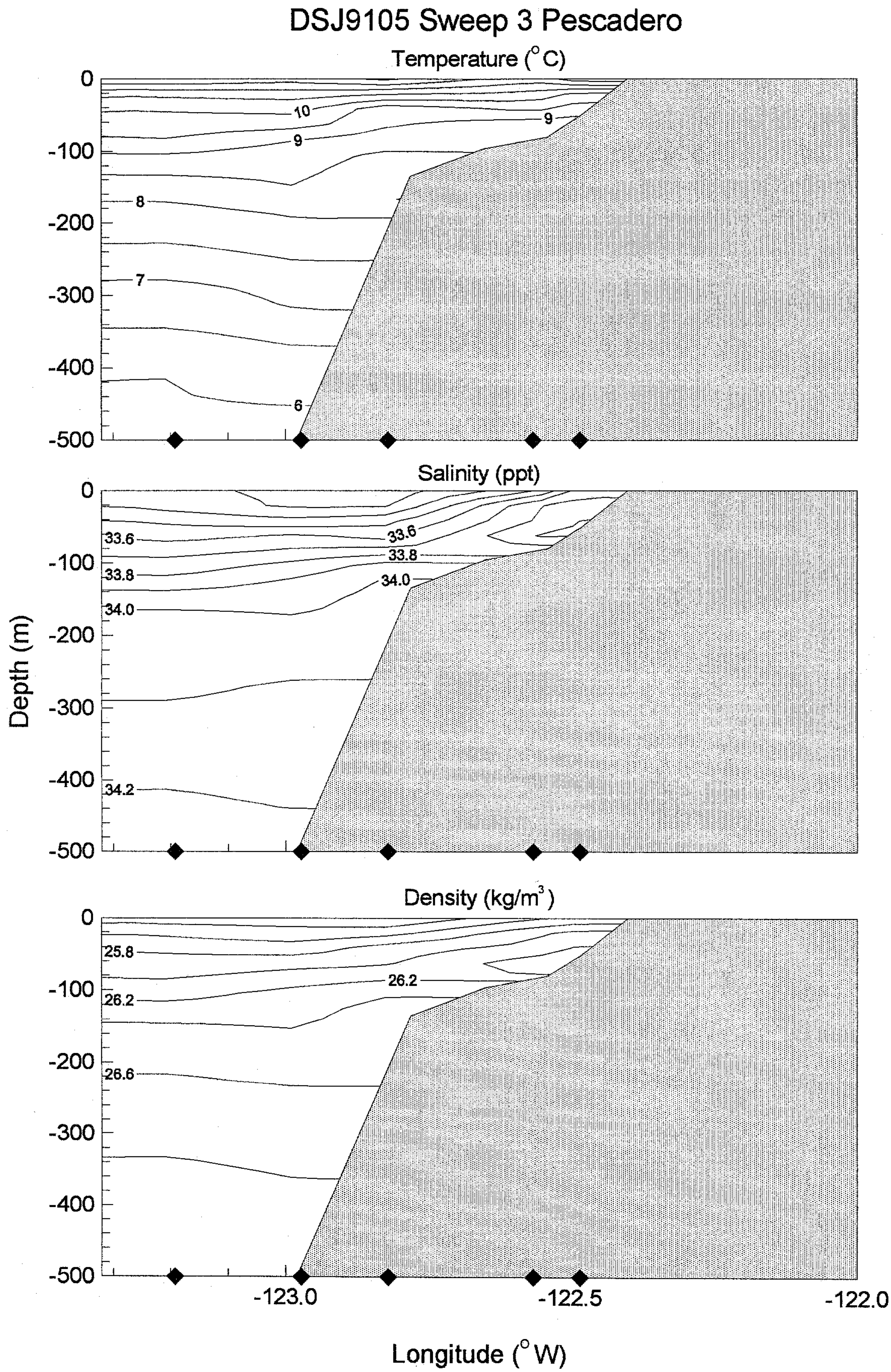

DSJ9105 Sweep 2 Pt. Reyes
Temperature (°C)
8.5
8.5
8.0
8.0
8.0
Salinity (ppt)
33.9
34.0
34.0
Density (kg/m³)
26.4
26.4
Depth (m)
0
-100
-200
-300
-400
-500
-124.0
-123.5
-123.0
Longitude (°W)

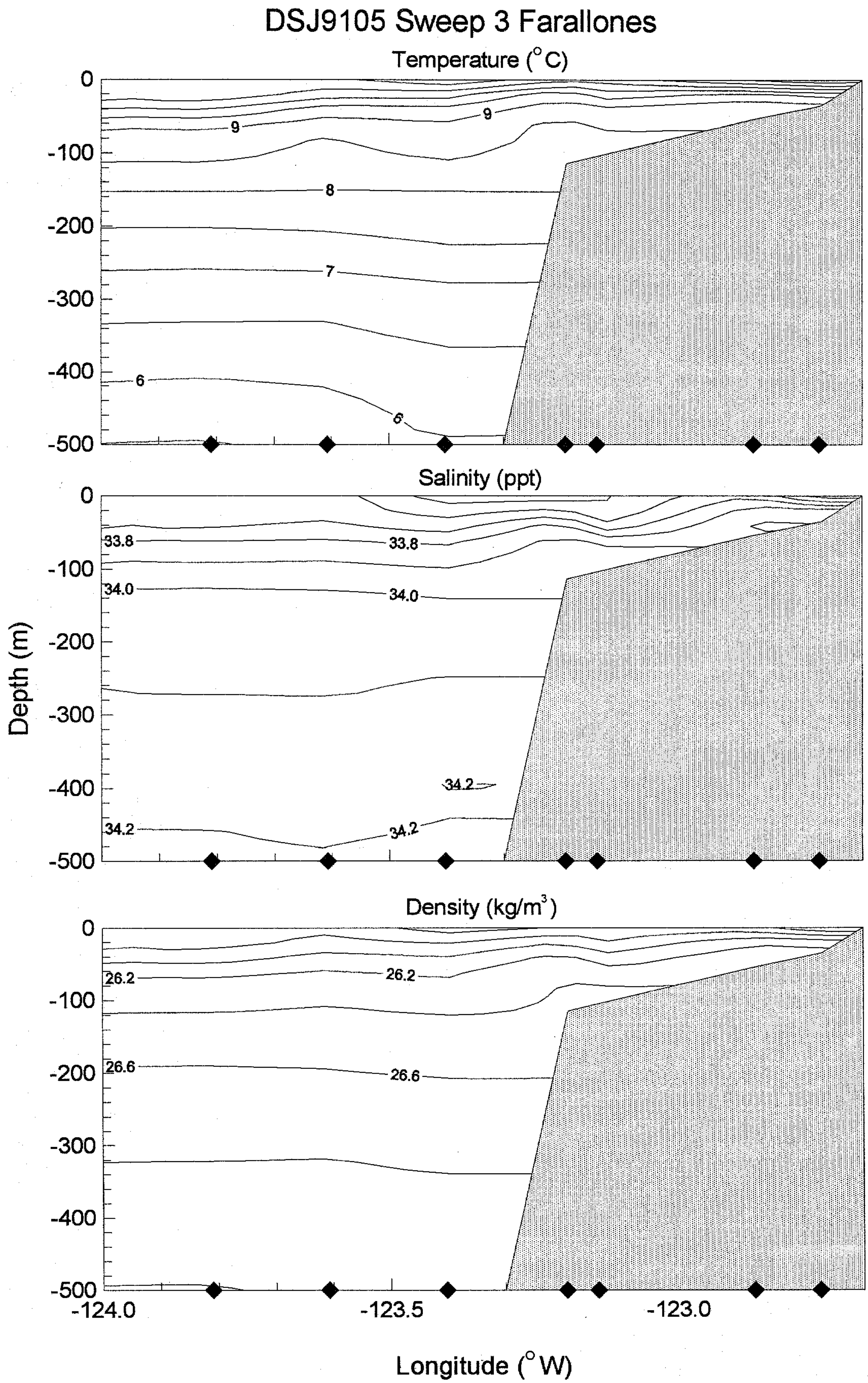
DSJ9105 Sweep 3 Vertical Transect Stations





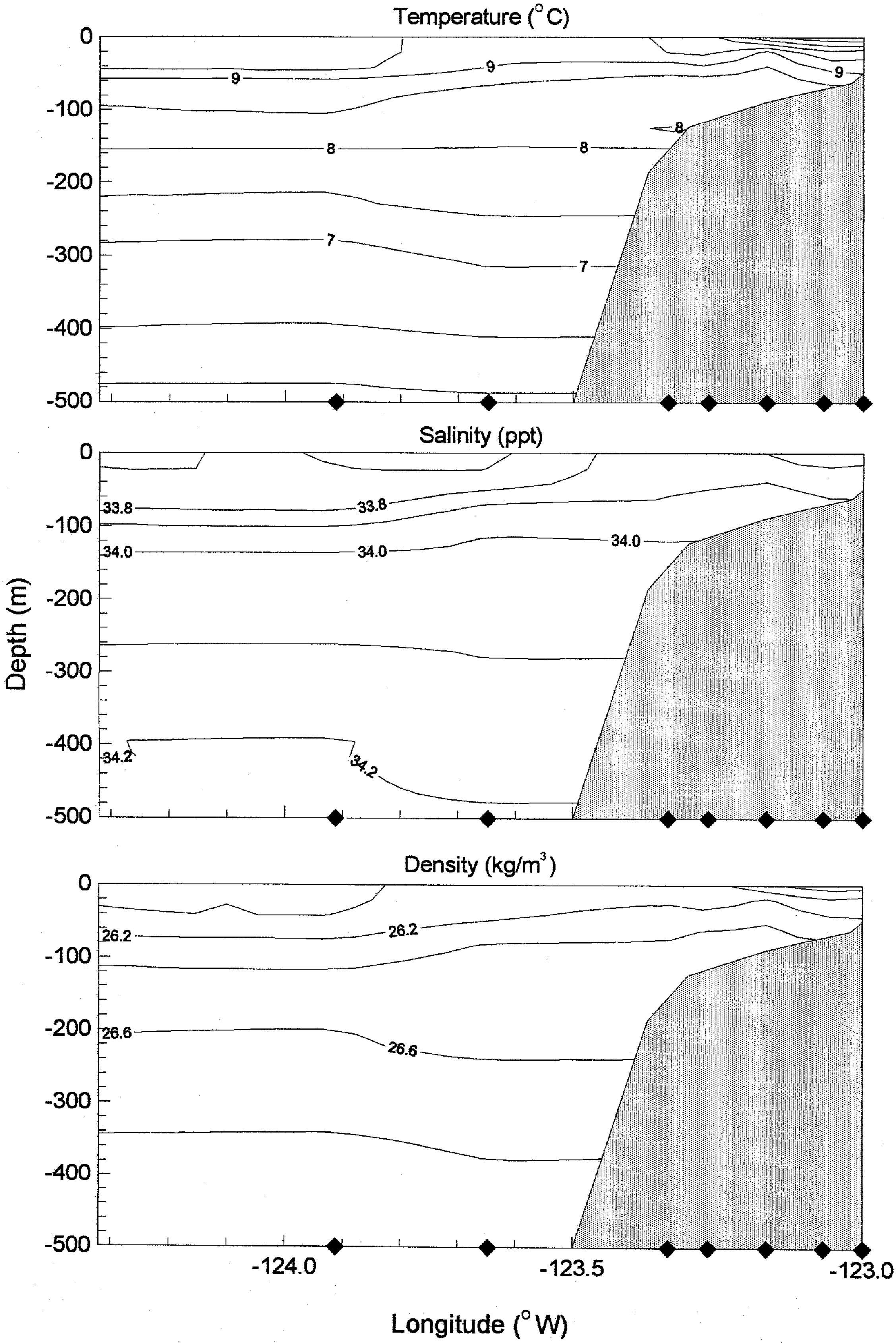
DSJ9105 Sweep 3 Davenport
Temperature (°C)
10
10
9
9
8
8
7
7
6
6
Salinity (ppt)
33.6
33.6
33.8
33.8
34.0
34.0
34.2
34.2
Density (kg/m³)
26.2
26.2
26.2
26.6
26.6
Depth (m)
0
-100
-200
-300
-400
-500
-123.0
-122.5
-122.0
Longitude (°W)


DSJ9105 Sweep 3 Pescadero
Temperature (°C)
10
9
9
8
7
6
Salinity (ppt)
33.6
33.6
33.8
33.8
34.0
34.0
34.2
Density (kg/m³)
25.8
26.2
26.2
26.6
Depth (m)
0
-100
-200
-300
-400
-500
-123.0
-122.5
-122.0
Longitude (°W)



DSJ9105 Sweep 3 Farallones
Temperature (°C)
9
9
8
7
6
6
Salinity (ppt)
33.8
33.8
34.0
34.0
34.2
34.2
34.2
Density (kg/m³)
26.2
26.2
26.6
26.6
Depth (m)
0
-100
-200
-300
-400
-500
-124.0
-123.5
-123.0
Longitude (°W)

DSJ9105 Sweep 3 Pt. Reyes



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